THE POWER OF DUNG

Lessons learned from on-farm biodigester programs in Africa

ESMAP
Energy Sector Management Assistance Program

WORLD BANK GROUP
Agriculture

Address: 1818 H Street NW
Washington DC 20433
Telephone: 202-473-1000
Internet: www.worldbank.org

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ACRONYMS AND ABBREVIATIONS

ABPP	Africa Biogas Partnership Programme
BCE	Biogas Construction Enterprise
CDM	Clean Development Mechanism
CME	Coordinating and Managing Entity
CSC	Customer Support Centre
CPA	(CDM-POA) Component Project Activity
ETB	Ethiopian birr
EUR	Euro
FCFA	West African CFA franc
GDP	Gross domestic product
GHG	Greenhouse gas
Ha	Hectare
Hivos	Humanist Institute for Cooperation with Developing Countries
KBP	Kenya Biogas Program
Kg	Kilogram
KSh	Kenyan shilling
MFI	Microfinance institution
MoWIE	Ministry of Water, Irrigation and Electricity (Ethiopia)
NBPCU	National Biodigester Program Coordination Unit (Ethiopia)
NBPE	National Biogas Program of Ethiopia
NBPE+	National Dissemination Scale-Up Program of Ethiopia
NGO	Nongovernmental organization
PMO	Partenaires de Mise en Œuvre (Implementing partners) (Burkina Faso)
PNB-BF	Programme National de Biodigesteurs du Burkina Faso
POA	(CDM) Programme of Activities
RBPCU	Regional Biodigester Program Coordination Unit (Ethiopia)
SACCO	Savings and Credit Cooperative Organization
SNV	Netherlands Development Organization
US$	United States dollar

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SUMMARY AND KEY MESSAGES

The share of households that cook primarily with wood, charcoal, coal, crop waste, or dung accounts for over one-half of the developing world's population. This share is currently increasing or stagnant in most regions. Dependence on solid fuels, potentially harmful modern fuels such as kerosene, and inefficient and polluting cookstoves is one of the world's major public health challenges, causing more premature deaths than HIV/AIDS, malaria, and tuberculosis combined. The use of solid fuels and stoves also imposes significant economic costs on societies that can least afford them and contributes to adverse environmental and climate change effects (ESMAP 2015).

While in past years the Global Alliance for Clean Cookstoves and partners increased efforts to invest in improved cookstove technologies, growing evidence acknowledges that many of even the "improved" cookstoves on the market have little effect on improving health outcomes (Lambe and Ochieng 2015). Recent evidence shows that truly clean stoves provide both reduction of fuelwood used (less deforestation) and improved health impacts (reduction of indoor air pollution), and these stoves are primarily those that use gas or electricity.

Because many of the world's poor live in rural areas and engage in farming as their primary activity, a large opportunity exists to work with farmers to transition to cleaner stoves and fuels for cooking. Biogas is an important fuel to consider in this regard. In addition, farmers producing agricultural waste or animal manure have ready sources of feedstock that can be converted from wastes to clean cooking energy.

Biodigesters (biodigesters) have been used for decades across the world to generate energy from organic material (animal manure or agricultural waste). In essence, a biodigester is a closed, airtight vessel in which organic material is deposited to support anaerobic digestion, a process that leads to degradation of the material by bacteria in the absence of oxygen, converting it into a methane and carbon dioxide mixture. Biodigesters also produce liquid fertilizers, which further offset costs for farmers and greenhouse gas (GHG) emissions resulting from the use of chemical fertilizers. The digestate or slurry from the digester is rich in organic matter, ammonium, and other nutrients. The slurry can be used directly or as compost and is a potent organic fertilizer contributing to sustainable land management. Biodigester technology ranges from simple plastic bags on beds of straw to produce small amounts of gas for cooking, to complex systems such as Up-flow Anaerobic Sludge Blanket (UASB) digesters used in farming installations capable of producing several megawatts of electricity. Biodigesters have multiple co-benefits, including: waste disposal of organic material so that animal waste, human waste, or other organic materials (from agricultural waste, slaughterhouses, etc.) do not contaminate groundwater; emissions reductions from digestion of manure and offsetting methane[1]; and emissions reduction by substituting renewable energy for fossil fuels.

1 "Methane destruction": Extracting methane from organic matter to subsequently oxidize the methane to carbon dioxide. GHG beneficial as methane has a 20-times higher global warming potential (GWP) than carbon dioxide. As feedstock is organic matter, carbon dioxide production can be considered "carbon neutral."

Several types of biodigesters are available. Traditional brick dome digesters have been promoted for several decades and have seen incremental improvements. They are generally reliable but require specific skills in their construction to avoid defects such as cracking over time. Depending on the country, these fixed biodigesters may also carry a higher cost than other, more temporary digesters. A good example of a low-cost solution is the "Plastic Bag Digester," an inexpensive, prefabricated plastic biodigester designed for farmers in developing countries. The device, which is UV-resistant and composed of recycled plastic, can be manufactured locally and installed in one day[2]. Throughout 2018 another model was distributed throughout Tanzania and Kenya by company SimGas, which introduced small-scale, environmentally sustainable, manure-fed biodigesters and stove systems custom-designed for the East African farmer. Another model based on a system designed for Mexico, is prefabricated, made of high-quality polyethylene membrane, comes as a turn-key system and can be installed in a few hours. Other examples of portable modular biodigesters are in development and technology advancements may lead to significant price reductions in the upfront cost of biodigester systems, with comparable levels of field performance.

Despite the significant reported benefits of small-scale biodigesters, biodigesters have relatively low penetration in Sub-Saharan Africa. Cultural aversions arise to using manure linked to cooking (Energypedia)[3] and logistical challenges with transporting manure as feedstock. However, with agriculture employing one-half of the labor force in Africa (IMF 2012) and specifically small farms employing 175 million people directly (AGRA 2014), biodigesters create a good option for cleaner cooking within targeted farming demographics across Sub-Saharan Africa.

Biodigesters in the World Bank context

According to a 2007 study conducted by SNV (Netherlands Development Organization) and the International Institute of Tropical Agriculture,[4] cooking with biogas is technically feasible for 18.5 million households, benefiting an estimated 150 million people. Yet small-scale biodigesters are not that well established in the World Bank as a tool for delivering development outcomes. In the World Bank, biodigesters have mainly been supported under carbon finance, with several attempts over 2009–2011 to create programs in China following a model where a biodigester component was added under a World Bank lending project.[5] More recently, biodigesters resurfaced as part of a portfolio of Clean Development Mechanism (CDM) Program of Activities (PoA) promoting energy access by the Carbon Initiative for Development (Ci-Dev) Trust Fund (www.ci-dev.org). Household-scale biodigester programs are part of Ci-Dev's portfolio in Burkina Faso,[6] Ethiopia,[7] and Kenya.[8]

2 However, recent longitudinal examinations have shown that the lifespan for some of these models is limited. Some PVC models use a chemical formula that makes them vulnerable to sun exposure, limiting lifespan.

3 https://energypedia.info/wiki/Cooking_with_Dung

4 Ter Heegde & Sonder (2007) Biogas for a better life -- An African Initiative.

5 Eco-Farming Project (P096556); Hubei Eco-Farming Biogas Project (P105046); CFF Hubei Household Biogas Project (P119123)

6 BF – Support to the National Biodigester Program (P156413)

7 ET Clean Cooking Energy Program (P153425)

8 Promoting Biogas as Sustainable Clean Cooking Fuel for Rural Households in Kenya (P153493)

From these more recent experiences, it is evident that (i) for a biodigester program to be successful, biodigesters cannot appear out of nowhere, and (ii) the emergence of the sector (demand in terms of outreach and advocacy and supply in terms of masons with access to training and capital) needs to be planned and included in national strategies. In a country with no preexisting biodigester sector, a project focusing on agricultural productivity may identify the biodigester technology as a solution but may or may not accept to invest in a five- to seven-year plan to create a sustainable biodigester sector. A Community Driven Development project interested in quick impact on poverty may prefer to import prefabricated biodigesters. If the focus of the task team is more on household development (part of a community program, or a social compensation), then the constructed biodigester is also a solution, but the implications for project design are different. Same story if the objective is to promote climate-smart agriculture, GHG reductions, food security, health or waste treatment outcomes, all additional reasons to support the sector.

This study examines the current use and potential for expanding the penetration of small-scale biodigesters in farming households, with a specific focus on Sub-Saharan Africa. Combining a literature review and evidence from three country case studies, this report makes a case for why World Bank task teams should investigate incorporating biodigesters into the design of agriculture, climate, environment, and health projects. Biodigesters might be considered a relevant instrument for several types of projects: increasing productivity, improving community livelihoods, improving on-farm waste management and adapting agricultural practices to climate change. This report presents recommendations for how to tailor biodigester programs specifically for farming communities and agriculture programs, with the aim of promoting widescale uptake. Use of biodigesters as a source of biogas for cooking applications is also examined. However, from the analysis, it is clear that perhaps the most compelling reason to promote biodigesters is because it they are a source of biofertilizer that is (i) of high quality, (ii) with high market value, (iii) cheap to produce, and (iv) locally produced (no need for import and distribution infrastructure).

Four key findings from this analysis are that:

Functionality of biodigesters is a key challenge. The lack of well-trained and motivated technical staff for the reliable construction of fixed dome digesters, farmer training, after-sale services, and quality assurance are barriers for achieving a sustainable, market-oriented sector. Furthermore, the type of digester promoted should be carefully considered. Capacity building and training should be provided for farmers, masons, biogas companies, and agricultural extension staff.

High costs of installation and maintenance can deter interest in biodigesters. A clear value proposition must be presented to farmers for the technology to be attractive. Agriculture programs could address this through strong rural extension programs to provide training and awareness and to facilitate access to finance and provision of capacity building to (micro-) finance institutions and farmers. Innovative financing mechanisms need to be supported, such as the use of existing agriculture structures (cooperatives, Savings and Credit Cooperative Organizations (SACCOs)) for the provision of microfinance or lease-to-own facilities.

A general lack of demand and of awareness of the existence and benefits of biodigesters is a key barrier. The two key products of biodigesters – biogas (gas for clean cooking and lighting) and slurry (fertilizer) – need to be highlighted when communicating with farmers and other stakeholders. These products bring a variety of benefits, including agricultural yield increases, reduction of cost for agricultural inputs, workload reduction (primarily for women), improved health due to cleaner cooking fuel, increased rural employment, and decreased deforestation, among others.

Insufficient government support can hinder private biogas sector development. The absence of guiding policies and a supportive regulatory framework creates uncertainties and can discourage private investment in the biogas sector. Government support can contribute to awareness about biodigesters and the benefits for crop cultivation, while regulation, enforcement of standards, and provision of licenses can support sector development and create the trust needed among end users for stable demand growth.

1. INTRODUCTION

About 1.5 billion people, representing more than 20 percent of the world's population, do not have access to electricity, and approximately 3 billion people (some 45 percent of the world's population) rely on firewood, crop residues, cattle dung, or coal to meet their cooking needs (Surendra et al. 2014). With rapid population growth, energy demand is expected to continue to increase by 28 percent between 2015 and 2040, mostly in Africa, the Middle East, and Asia (IEA 2017).

Biomass, which comprises 10–14 percent of the total global energy demand, accounts for over 90 percent of household energy consumption in many developing countries, where most communities are disconnected from the grid (IEA 2010; Ramachandra and Shruthi 2007, cited in Surendra et al. 2014). Dependence on solid fuels and inefficient, polluting cookstoves is one of the world's major public health challenges, imposing significant economic costs on societies that can least afford them, while negatively impacting the environment and climate (ESMAP 2015). For households with suitable access to organic feedstock, one promising alternative is the use of biogas as an energy source (Subedi et al. 2014).

Biodigesters are closed, airtight vessels in which organic material (e.g., kitchen waste, cow dung, crop residues) is deposited to ferment and produce biogas (a mixture of methane, carbon dioxide, and other trace gases) for energy use (Figure 1). A co-benefit is the production of biofertilizer (bioslurry, a liquid that can be applied directly or indirectly as organic fertilizer) (FAO 2013). Researched benefits from biodigesters include: reduction of (women's) labor time and exposure to wood smoke, avoided deforestation, reduction in traditional energy and chemical fertilizer expenditures for rural households, and improved management of livestock waste.

Figure 1. Schematic representation of a biogas digester

Source: Graphicsbuzz 2017.

Globally, roughly 50 million biogas systems have been installed to produce gas for cooking. The majority of these systems are in Asia, with concentrations in China, India, Nepal, Vietnam, Bangladesh, and Cambodia (Clemens et al. 2018). To date, dissemination in Sub-Saharan Africa has been more limited, although East Africa has made good progress – Ethiopia and Kenya have nearly 21,000 units each – and Burkina Faso in West Africa has over 12,000 units (Hivos-ABPP 2018 production data).

According to a 2007 study conducted by SNV (Netherlands Development Organization) and the International Institute of Tropical Agriculture, cooking with biogas is technically feasible for 18.5 million households in 24 African countries, based on livestock ownership, water availability, fuelwood scarcity, population density, and climate (Surendra et al. 2018; Heegde and Sonder 2007). However, various barriers prevent the scale-up of biodigester programs across the continent.

This study examines the use of small-scale biodigesters for farming households, with a specific focus on Sub-Saharan Africa. Specifically, the study was tasked to:

- Identify how small-scale biodigesters have been successful with farming households to meet their cooking needs, and;
- Develop recommendations for how to tailor biodigester programs specifically for farming communities and agriculture programs to help promote widescale uptake.

The study entailed a desk review of literature and evidence collected from visits to three countries – Burkina Faso, Ethiopia, and Kenya – and the development of country case studies. Based on the findings of this set of studies, this report presents recommendations for how to tailor biodigester programs to achieve a wider uptake among the farming communities and users of traditional cooking fuels.

Chapter 2 summarizes the literature review findings and provides answers to how small-scale biodigesters have been successful with farming households to meet their cooking needs. Chapter 3 describes the three country case studies with a focus on lessons learned. Chapter 4 summarizes and presents recommendations for agriculture programs with the aim to promote biodigesters. Annex 1 provides a detailed description of the research methodology. Annex 2 give a list of stakeholders interviewed. Annex 3 provides the questionnaires used. Annex 4 shows potential demand for biogas in Ethiopia and Annex 5 briefly describes the National Dissemination Scale-Up Program of Ethiopia (NBPE+) and finally Annex 6 shows the Kenya Biogas Program's Code of Conduct.

2. BIODIGESTER TECHNOLOGY AND BENEFITS

2.1. BIODIGESTERS FOR FERTILIZER AND AS A SUSTAINABLE ENERGY SOURCE

This chapter analyzes the potential role of biodigesters in meeting the demand in Sub-Saharan Africa for energy, clean cooking, and organic fertilizer, and describes the multiple economic, social, and environmental co-benefits of biogas. Barriers to the successful adoption of biodigesters by farming households as well as respective lessons learned (interventions, program design) are presented. The use of biogas in cooking is analyzed in more depth in a separate chapter.

Digesters differ by size, purpose, and feedstock required, with three main types. Household digesters are mainly fed with cow dung to supply energy for cooking, targeted heating (like water heating) lighting, or sanitation. Larger-scale biodigesters, with the aid of a generator or turbine, can also be used to generate electricity. Community or institutional digesters use crop residues and the organic fraction of municipal solid waste for waste management and cooking. Commercial digesters are fed with wastes from agro-processing and food production industries for gas and electricity purposes (Rupf et al. 2017).

Biogas technology has a high potential for addressing energy access in Sub-Saharan Africa, particularly in rural areas. About 70 percent of Africa's population is smallholder farmers (AGRA 2017), the majority of whom have no or minimal access to electricity (Roopnarain and Adeleke 2017). Despite longstanding efforts to address energy poverty, 792 million people still rely on traditional biomass (firewood, charcoal, crop residues, or cow dung) as their primary energy source for cooking (Morrissey 2017). Based on two main technical indicators for biodigester project feasibility – the number of households with access to water and the number of domestic cattle per household – the technical potential for biogas in Africa is estimated at 18.5 million households (ter Heegde and Sonder 2007).

The produced energy can be used as a clean renewable energy source for cooking and for generating heat and electricity. The use of traditional biomass, including firewood and charcoal for cooking, is a source of indoor air pollution, posing significant health risks to women and children. Smoke-induced health effects such as respiratory infections, chronic obstructive pulmonary disease (COPD), lung cancer, tuberculosis (Sumpter and Chandramohan 2013), pneumonia (Mortimer et al. 2016), and stroke are responsible for the death of almost 4 million people every year (World Health Organization 2018). Biogas can be used in a variety of different appliances, including simple gas stoves for cooking, lamps for basic lighting, hot water boilers, small refrigerators, poultry/egg incubators, and milk chillers. With medium or larger biodigesters, small electricity generators also become possible. Biodigesters are thus considered to be an excellent tool for improving health and livelihoods in the developing world.

Biodigesters can play an important role in supporting soil fertility management in Sub-Saharan Africa. As clearly identified by the Soil Atlas of Africa (Jones et al. 2013), soil degradation, mainly due to the decline of soil fertility through nutrient and organic matter losses under continuous cropping, is a serious threat to approximately 25 percent of the productive land in Sub-Saharan Africa. Digestate (also referred to as bioslurry) is a byproduct of the anaerobic digestion process that can be used as soil amendment (when composted with crop residues) and fertilizer. Digestate mainly consists of converted nutrient content of the organic feedstock, indigestible material and microorganisms. The digestate volume produced by a biogas plant is usually around 90–95 percent of the digester total input material, as only 5–10 percent total digester input is transformed into biogas. Pathogens possibly present in the manure are reduced in bioslurry when compared to raw manure and even further if the bioslurry is composted (FAO 2013). Nutrients in digestate, especially nitrogen, are more readily available for plants to absorb (Bonten et al. 2014). From the perspective of climate-smart agriculture, a replenishment of organic matter might be the most important benefit of bioslurry, particularly for many Sub-Saharan African soils.

Converting cow dung into digestate results in a valuable and possibly marketable organic fertilizer, with positive impacts on soil quality (structure, water retention capacity) and a proven positive effect on productivity (CRI 2015; SNV 2015a). Examples of the profitability of digestate use were summarized for the Tanzania Domestic Biogas Program. A single application of digestate on fodder crops contributed to improved nutrition and thereby a 50 percent increase in milk yields, while the application of digestate (instead of untreated cow dung) increased maize yields from 1.5 tons to 2.5 tons. (Warnars and Oppenoorth 2014) even reports increased maize yields by 92 percent, tomato yields between 33 percent and 103 percent, and potato yields by 34 percent. Other reported benefits include savings of US$140 per year on a smallholder farm by replacing synthetic fertilizer (SNV 2015a).

Results from the Burkina Faso case study demonstrate that farmers are able to significantly reduce synthetic fertilizer use and increase productivity. Farmers found that using digestate from the biodigester enabled them to increase their maize harvest from 0.89 tons/hectare (ha) to 2.54 tons/ha, rice outputs from 0.78 tons/ha to 4.00 tons/ha, and sorghum from 0.81 tons/ha to 1.44 tons/ha. Many farmers from this program also reported selling the digestate for an average price of US$75 per ton of compost.

A number of conditions are critical for large-scale dissemination of biodigesters among farming communities. For example, to provide a minimum of 0.8–1.1 m3 of biogas, an estimated 20–30 kilograms (kg) of fresh cow dung, or three to four cows per household, are required.[9] Although biogas can be generated with other organic material as well, cow dung is considered best suited as feedstock for household digesters (ter Heegde and Sonder 2007). Table 1 provides an overview of criteria for large-scale dissemination of biodigesters.

9 In East Asia and in Latin America, the technology is often used with pigs, requiring a minimum of between 5-10 pigs.

Table 1. Criteria for the feasibility of large-scale dissemination of biogas digesters among farming communities

Criteria	
Technical	Even daily temperature >20°C throughout the year
	Minimum of 20 kg fresh animal dung available per digester per day
	Minimum of 20 liters of water available to mix with fresh dung in a 1:1 ratio.[10] If not available in the homestead, then a maximum walking distance of 20–30 minutes
	Sufficient space for biogas digester in the homestead
	History of functioning biogas digesters in the country and region
Financial	Traditional practice of using organic fertilizer; use of dung as energy source
	Scarcity of traditional energy sources such as firewood or charcoal
	Availability of access to credit
	Livestock farming as key farming activity and household source of income
Social	Role and potential for women in investment decision making
	Potential to integrate biogas digester operation into normal farm working routine
	Awareness of biogas technology and potential (farm) benefits
Institutional	Political will of the government to support biogas technology
	Interest of stakeholders to get engaged in biogas
	Access of organizations to potential users; e.g., the availability of an agricultural extension network

Source: Adapted from ter Heegde and Sonder 2007.

Co-benefits of biodigesters

Biodigesters produce economic, social, and environmental co-benefits. Digestate can be sold as high-quality fertilizer and/or compost, creating market opportunities within the agriculture sector. Moreover, economic benefits include potential reduced expenditures (financial resources, time savings) on firewood, kerosene, and other sources of energy (Kabir, Yegbemey, and Bauer 2013; Mengistu et al. 2016). Biogas technology can also provide significant employment opportunities for masons, plumbers, civil engineers, and agronomists (Mengistu et al. 2015).

Social benefits include reduced labor burden, especially for women, due to the reduced and/or prevented need for firewood collection.[11] Health benefits include reduced exposure to indoor smoke (and thus a reduction in smoke-induced health impacts), improved air quality, improvement in household sanitation, and the absence of soot and ashes in the kitchen (Ghimire 2013; Mengistu et al. 2015).

10 The water:dung ratio of bag digesters is 2:1. A bigger bag digester is needed to produce the same volume of gas as a fixed dome digester. A bag digester needs twice as much water, which may be a challenge

11 Biogas digesters need to be fed daily with a mixture of feedstock (dung) and water. Feedstock collection and preparation thus requires labor inputs as well. Slurry is collected in on-farm slurry basins and applied on the land, comparable with untreated cow dung. The liquid bioslurry is fed to the soil through gravity systems or mixed in compost pits to produce (good-quality) compost. Both of these require some effort, but due mostly to the offset of fuelwood collection, most user surveys indicate substantial time savings by households with a digester compared to those without.

Environmental benefits include improved soil fertility and crop productivity both by reducing the removal of woody biomass, dung, and crop residue for fuel and by supplying nutrient-rich digestate, a reduction of methane emissions from manure management, and reductions in synthetic fertilizer use (Mengistu et al. 2016). Further environmental benefits include reduced fuelwood demand, contributing to reduced deforestation and forest degradation, and reduced greenhouse gas (GHG) emissions through substitution of fuelwood or charcoal with biogas. Finally, aerobic pathogens are reduced through treatment in the digester (Smith et al. 2013, cited in Rupf et al. 2016; Mengistu et al. 2015, 2016).

2.2. POTENTIAL FOR BIOGAS AS COOKING FUEL IN SUB-SAHARAN AFRICA

Biogas has the potential to be a multifaceted solution for agriculture, climate, energy, and solid waste management. The dissemination and adoption of the technology has been hampered by several technical and financial challenges, however, limiting achievement of the positive portended outcomes. A large body of knowledge on small-scale biodigesters focuses on their feasibility, the financial, technical, and operational requirements, as well as adoption and operational challenges. But most of the analyses stop at the operational level of the biodigester, without analyzing the energy end-usage. Some critical questions remain unanswered: Is the gas supplied by digesters adequate to fulfill the daily cooking demands? Is the technology used suitable for the local cooking needs? Do all available biogas technologies meet the globally set efficiency and emission targets?

Experience with other household cooking interventions have shown the risk of attributing benefits to a technology based on the degree of penetration and number of units installed. For example, owning a cookstove does not necessarily mean using it, and not every stove is a clean cookstove that can yield the positive health, climate, and other development goals that underpin their promotion. For instance, a study in Malawi found no evidence that an intervention comprising cleaner burning biomass-fueled cookstoves reduced the risk of pneumonia in young children (Mortimer et al. 2016). Understanding the challenges at end use is important to incorporate measures to overcome the challenges at early phases of the program, thereby maximizing the benefits.

2.2.1. Biogas cooking projects in Africa

Africa has both the need and the physical conditions to make biogas thrive. The technical potential is estimated at 18.5 million households (ter Heegde and Sonder 2007). This potential has not substantially translated into cookstoves in households, however, despite decades of investment in biogas.

Domestic biogas was introduced in Africa some four decades ago but did not pick up until 2007. Between 2007 and 2009, SNV installed 735 biogas plants in Africa, with the primary end-use application of cooking. Rwanda accounted for 59 percent of the plants, while Ethiopia and Tanzania accounted for 17 percent and 14 percent, respectively. By 2012, the total number of biogas plants had risen to nearly 23,000, and by the end of 2018, to 75,561 with the involvement of other agencies under the umbrella of the Africa Biogas Partnership Programme (ABPP). The adoption rates are considered encouraging, although still far below the expected targets of the ABPP initiative.

Biogas projects are usually targeted at populations that own at least three to four cows (to provide a minimum of 0.8–1.1 m3 of biogas), often in rural areas. This segment forms a significant portion of the hundreds of millions of people who will continue to cook with biomass in an inefficient and hazardous way in 2040 (IEA 2014). As mentioned above, approximately 18.5 million households in Sub Saharan Africa fall under the target segment, based on indicators of access to water and number of domestic cattle. However, 2018/2019 calculations done by SNV (report expected in May 2019) estimate that more than 30 million households fall into the target segment, with the increase from 2007 due to population growth and increased cattle holdings by household. In addition to access to water and cattle holdings, important household-level variables should be considered in biogas promotion to ensure success. These include household education and income level, which have been shown to correlate with adoption. The effect of individuals' income is their ability to afford to install a digester system and to keep it operational.

Another consideration is family size. Biodigesters' size should be based on: (i) the (daily) amount of available feeding material; and (ii) the biogas requirement of the family. The smallest biodigester promoted in Africa has a capacity of 4 m3, which produces from 800–1,600 liters of biogas per day depending upon the loading rate. This is considered sufficient to fulfil the basic cooking needs of a small family of four to five members (Ghimere 2013). However, large average household sizes of greater than five persons per household are often observed across much of Africa (UN DESA 2017). Bigger biodigester units are required to satisfy larger families' relatively greater needs for cooking gas (Mulinda, Hu, and Pan 2013). This also implies bigger upfront investment costs and higher demand for feedstock for more animals.

Local diets and cooking preferences also matter. The baseline fuels used by households, how the fuel is sourced (purchased or gathered for free), labor, demand, and acceptability of the end-use appliance are other important considerations. Because these factors are key to success for any cooking fuel and technology, they are tackled separately in subsequent sections.

2.2.2. Biogas cooking technologies in Sub-Saharan Africa

Changing the way people cook is a complex process. A newly introduced technology must meet multiple criteria, such as ease of use and adaptability to local cooking needs. For programs that aim to introduce clean fuels such as biogas, it is a lot more challenging to fulfill the necessary criteria that underlie adoption. Lessons on how past cookstove programs have surmounted the challenges can be transferred to the biogas sector.

Challenges relating to digester installation, operation, and maintenance are important, such as the need to couple the technologies with loan facilities, and these lessons have influenced subsequent programs' designs. For families that have functioning biodigesters, what types of technologies are used to burn the biogas, and what are users' perception of these technologies? Ultimately, it is end users' satisfaction that will determine the success of biogas cooking projects.

Gregory (2010) offers some insight into the historical development of the technology, which started in China and India in the 1950s. According to Moulik (1985), "the official policy encouraged initiative, experimentation, creativity in locally available construction materials and feedstocks, as well as designs suited to local conditions." In 1976, the Development and Consulting Services (DCS) of the United Mission to Nepal developed its own biogas burner design, which was cheaper than those commercially available from India or China. In 1993, SNV took over the Nepal biogas program and developed its own design for a biogas burner. As SNV extended its biogas program to other countries in Asia, this stove design was copied, improved, made by other manufacturers, and transported to other regions. A recent study reported that the double-burner stoves are imported from manufacturers in China, but that small-scale production of single burners exist at small artisanal scales (ScienceDirect 2019). The end-use technology is a critical part of the cooking system, along with the fuel, and therefore warrants attention in any assessment of biogas potential.

A biogas cookstove comprises two distinctive parts: the burner, which should be made to standard specifications; and the frame, which holds the burner and supports the pot. The frame should be adaptable to local conditions (e.g., pot sizes used in cooking).

The past decade witnessed significant developments in the cookstove technology sector. In 2010, the Global Alliance for Clean Cookstoves (now the Clean Cooking Alliance), a public–private initiative under the UN Foundation, was established with the goal of fostering the adoption of clean cookstoves and fuels in 100 million households by 2020. The period also saw a change in the definition from "improved cookstove" (which assumed anything is better than the traditional cooking stove) to "clean cookstove" (reflecting the goals of the development community). In parallel, efforts were made to develop international guidelines for evaluating cookstove performance. The ISO International Workshop Agreement developed by the Clean Cooking Alliance and partners provides a framework for rating cookstoves against tiers of performance (1 to 5) for a series of performance indicators, including fuel use (efficiency), emissions (carbon monoxide and particulate matter 2.5), indoor emissions (carbon monoxide and particulate matter 2.5), and safety. ESMAP (Energy Sector Management Assistance Program), under the SE4All initiative, in turn developed the Multi-tier Framework to monitor and evaluate energy access by following a multidimensional approach (ESMAP 2019a). Energy access goes beyond having a clean source of energy to "the ability to avail energy that is adequate, available when needed, reliable, of good quality, convenient, affordable, legal, healthy and safe for all required energy services."

Biogas fuel by its nature is clean. It is therefore expected to have very low emissions, which is largely stove-independent. Thus, evaluation of the appliances used to burn the gas has not been given priority, as it has been for woodburning stoves. This review found very few studies that measured the performance of biogas stoves against the standard set of criteria applied in cookstove testing.

SNV commissioned tests on biogas burners obtained from eight countries (Bangladesh, Cambodia, Ethiopia, India, Lesotho, Nepal, Rwanda, and Vietnam) and lamps from four countries (Cambodia, Ethiopia, India, and Nepal). None of the stoves met the quality certification criteria under both the Chinese and Indian standard specifications. The stoves from Bangladesh and Cambodia only met the prescribed minimum thermal efficiency of 55 percent. Carbon monoxide concentration in smoke was found to be too high in all tested appliances (Khandelwal and Gupta 2008). Another study subjected eight locally available biogas stoves in Uganda to Approvecho stove test protocols, which have been applied to other cookstoves (Tumwesige et al. 2014). The stoves were found to have extremely poor performance. They were not made according to basic gas stove theory and had lower efficiencies than were acceptable. Their average efficiency was 22 percent, while the Chinese and Indian standards define 55 percent as the minimum efficiency level. Poor gas combustion usually generates carbon monoxide and carbon particles (which show as red flashes in the flame). For seven out of the eight stoves, the carbon monoxide emissions were above the set standards. Poor heat transfer was also observed, attributed to the frame's height (too short) and diameter (too narrow) for the pot sizes in use, leading to heat loss.

A recent study in Vietnam on biogas appliances similarly reported poor performance of biogas stoves (Roubík and Mazancová 2019). High concentrations of carbon monoxide in its diluted and undiluted forms were detected in biogas flue gas. This was attributed to insufficient burning, the use of inappropriate biogas cookstoves, and inappropriate maintenance. According to the authors, biogas cook stoves of Chinese origin are often produced from low-quality material that is not suitable for achieving operational temperatures and burner loads based on the weight of the cooking mass and cooking hours. This results in deformation and burner cracks, leading to low performance. The authors report similar observations from a study carried out in Sri Lanka (Roubík and Mazancová 2016).

Poor performance of end-use appliances has also been observed with biogas lamps. Clemens et al. (2018) report that the ABPP program staff no longer recommend biogas lamps to their clients, most of whom had already switched to solar lamps due to dissatisfaction with the product. This mirrors findings in Vietnam, where 77 percent of interviewed households did not plan on purchasing biogas lamps at all due to high rate of problems with the devices (Roubik and Mazancova 2019). In the SNV -commissioned tests, none of the tested lamps qualified under the Chinese standard specification (Khandelwal and Gupta 2008).

These results point to the need for performance testing of biogas cookstoves, as done with other cooking technologies, before widescale dissemination. The reported low efficiencies in the stove tests would translate into a stove not cooking as fast as expected, but also in depleting the supply more quickly. A high level of stacking (use of multiple stoves and fuels) was reported in a recent evaluation of the ABPP program (Clemens et al. 2018), attributed to the stoves' very low power, which does not suit preparation of main household meals. Aside from low power, the gas is reported to not last long enough to meet the time requirements for preparation of the staple meals of matoke (steamed bananas), posho (ugali), and beans. Insufficient biogas production was reported as a concern in other settings as well (Ferrer et al. 2011).

The cookstove sector has already learned lessons about making assumptions on fuel and stove performance. For instance, kerosene was for a long time considered a clean fuel until research proved otherwise. While biogas itself is a clean source of energy, the conversion processes of the gas can render it unclean. Attention is thus required, as certain variables can render it unclean and even harmful if not identified and addressed at the design and usage phase.

2.2.3. Reassessing end users' benefits

Based on the above findings, this section reassesses the potential of biogas, focusing on the end points for which the technology is being promoted.

Health

The health benefits of biogas will depend in part on: (i) the baseline fuel type: (ii) the degree of displacement of this fuel; and (iii) the emissions associated with the technology use.

Very few rigorous analyses exist of biogas stove performance against the three criteria. A study on the perceived benefits of digesters showed that over three-quarters of respondents in Tanzania reported clean kitchens and utensils, which implies a reduction in harmful smoke and soot (Clemens et al. 2018). Over 80 percent reported reduced eye problems and respiratory symptoms. Similar results were reported in Uganda and Kenya, although some variation arose in the degree of perception of health benefits. In another study in Kenya, female biogas adopters reported fewer breathing problems compared to female nonadopters (43 percent versus 71 percent), less shortness of breath, less difficulty in breathing, and less chest pain while breathing (Hamlin 2012). Self-reported back pain has also been shown to be lower for women cooking with biogas in comparison to those relying on wood (Dohoo et al. 2013).

In the same evaluations, however, stove stacking is reported. To achieve health benefits, the new stove should displace the traditional stove and account for most of the cooking needs. The ABPP evaluation reveals that in Kenya more than one-half of households cook exclusively with biogas (Clemens et al. 2018). In Tanzania and Uganda only 29 percent and 11 percent of respondents, respectively, use biogas exclusively. These findings could imply a public health gain for the households that made the switch, if the biogas displaced the use of fuelwood. If the baseline fuel was electricity or liquid propane gas, then a switch from these energy sources to biogas would not be associated with positive health benefits.

Several studies have shown that biogas is more likely to be adopted by households with higher socioeconomic status. In some settings, high socioeconomic status is also associated with use of higher-end fuels such as liquid propane gas and electricity (Othieno, H. & Awange, J.2016). In other settings (Kenya, for example), even middle- and high-income households rely on biomass as their primary cooking fuel (Clemens et al. 2018). Many rural households targeted by biogas projects are not connected to the grid, so cooking with electricity is not an option. In such situations, it is safe to assume that introduction of biogas would displace to some extent the use of biomass fuels. Projecting this to health benefits, however, would go against evidence-based practice recommended for public health. Rigorous evaluations are required, more so in the light of findings that some biogas stoves exhibit poor performance.

Fuel savings

Unlike health benefits, which are uncertain, a lot of literature supports the claim of fuel savings following adoption of biogas (Mwiringi et al. 2009; Rupf et al. 2016). ABPP surveys indicate that fuelwood and charcoal consumption are significantly lower among biodigester users, despite the high rates of stacking. Furthermore, these surveys show that fuel savings are among the most appreciated benefits of the program, and the reason why beneficiaries would recommend biogas to others. As with health, it would be important to account for baseline fuel usage in these analyses. The surveys should also be accompanied by some quantitative measurements. The evidence to date is based on self-reported fuel savings.

Climate benefits

The incomplete combustion of biomass fuels leads to emission of black carbon (soot), a climate-forcing pollutant. In addition, the use of biomass fuel for cooking in arid/semi-arid regions leads to deforestation and forest degradation, releasing the carbon in the biomass into the atmosphere with little to no sequestration back into living biomass. Such fuel is referred to as “nonrenewable biomass.” Replacement of traditional biomass stoves with biogas cookstoves therefore has the potential of mitigating climate change. Unlike health outcomes, for which stove stacking significantly minimizes the benefits, climate benefits would be realized even with partial displacement of biomass fuels. Replacement of liquid propane gas with biogas stoves would also lead to climate benefits, which is not the case with health. The field data on adoption of biogas stoves are therefore supportive of the claim that biogas has positive climate benefits. When coupled with other benefit pathways (such as manure management, which reduces methane emissions, and bioslurry, which reduces dependence on chemical fertilizers), the benefits seem substantial. This would explain why many biogas programs have been registered for the Clean Development Mechanism.

Time savings

Time savings are reported in many surveys of biogas users. In one survey, biogas users are reported to spend about 65 percent less time (57 minutes per week) than nonadopters (166 minutes per week) on fuelwood collection (Wilkes and van Dijk 2017). The ABPP evaluation also reported time savings from biomass installations in East Africa (Clemens et al. 2018). In Nepal biogas users are reported to save 96 minutes per day for cooking compared with traditional stove users. The time savings arise from wood collection, but also from convenience and higher speed of cooking, and from washing cooking utensils.

The time saved in fuelwood collection should be weighed carefully against the labor demands of biodigesters. The routine operation and maintenance of digester systems requires much physical work, which is usually laborious and messy. When the biogas plant is in use, feeding should be done daily to ensure the gas is produced consistently. Not all digester types have facilities for mixing the slurry or for maintaining a certain temperature in the digester and controlling it, activities that must be done manually. SNV recommends that the mixing be done daily. Most plants also lack facilities for removal of sand, stones, and other nondigestible materials. Accumulation of these materials over the years decreases the digester's volume and its efficiency. It should be noted, however, that some level of effort is required to manage the dung from stabled/semi-stabled cattle even without a biodigester.

To accurately attribute time savings to biogas cookstoves, this additional time demand needs to be weighed against the time it takes to source fuelwood. A study in Uganda found that households would only save time using their biodigester if the distance travelled for fuelwood was more than twice the distance travelled for water (Smith et al. 2013). The time measurement should also take into account that women often combine fuelwood fetching with other activities, such as going to the market or fetching water. The time savings are therefore uncertain without detailed measurements.

Gender aspects

From a gender perspective, the motivation for promoting biogas remains strong. Most of the benefits linked to biogas have gender dimensions. The health burden of household air pollution falls more on women than men due to their domestic roles. As the task of fuelwood collection also falls on women, they are the primary beneficiaries of interventions that reduce the need to collect wood. Most evaluations report time savings, in spite of the labor demands that a biodigester presents. It could be that men are more involved in the operation and maintenance of digesters. If so, this would suggest a tacit shift of some cooking-related responsibilities away from women to men, which is a positive outcome.

Gender is also relevant for the promotion of biogas as a cooking fuel. Many studies have shown that men control the budget for investments in cooking energy. Because men are not directly affected by the smoke and the burden of fuelwood collection is on women, men do not prioritize investments in cooking (although the situation may be different if fuels are purchased). In settings where fuelwood is the predominant fuel, the agricultural and financial benefits of biodigesters need to be clear and also realized to gain and retain men's interest. For instance, the ABPP survey reports that one reason for failed projects was lack of men's support in contacting program staff to perform the repairs.

Finally, as long-term investments, availability of land with secure tenure is a determinant of biogas adoption. Land tenure issues are often under the control of men. As such, promotion efforts that do not target men would have minimal success.

Financial savings

The financial savings form the business case for biogas and underlie its sustainability. The financial feasibility of the biodigester depends largely on (i) whether outputs in the form of gas and slurry can substitute for costly inputs that were previously purchased, and (ii) the efficiencies with which the fuel is used. In evaluating financial savings, one should also take into account the savings that would arise from replacing chemical fertilizers with bioslurry.

Winrock International carried out a financial and a holistic cost-benefit analysis of biogas technology, considering benefits such as provision of cooking and lighting energy, production of organic fertilizer, improved health and sanitation, reduced labor requirements, reduction in GHG emissions, and improvements to the local environment (Mohammed et al. 2017). Savings per household from cooking with biogas (wood purchase and time spent collecting fuel) are reported as US$3.15 in Uganda, US$7.20 in Tanzania, US$5.20 in Ethiopia, and US$5.10 for Sub-Saharan Africa as a whole. The value of time savings is much higher for cooking and cleaning, estimated at 96 minutes and 37 minutes per household per day, respectively. This results in an annual economic value of savings per household of US$84.50 in Uganda, US$97.50 in Rwanda, US$71.40 in Ethiopia, and US$84.40 in Sub-Saharan Africa. When projected to country level, the economic benefits range from US$30 million to US$58 million for national programs and exceed US$5.6 billion for Sub-Saharan Africa as a whole.

In comparison to cooking, fertilizer use benefits were much higher: US$148,076,310 for Uganda, US$83,292,924 for Rwanda, US$29,947,200 for Ethiopia, and US$9,413,455,900 for Sub-Saharan Africa. Other studies report that the benefits of bioslurry are more important in financial terms by generating income or reducing the cost of farm inputs (Mohammed et al. 2017; SNV 2015a).

The high upfront costs of biodigesters present a major barrier for adoption. One measure currently being employed to overcome the high initial investment costs is increased access to finance. Under the ABPP, some entities now offer in-house credit, while agreements have been signed with finance institutions and Savings and Credit Cooperatives (SACCOs) to help buyers acquire loans. These measures can only work and be sustained if the plants are able to repay themselves. Some estimates show that households can recover their total investment cost in two to three years, based on an initial investment cost of US$700, an annual maintenance cost of US$30, annual cost reductions of US$220 (one-half of it from reduced fuel use), and annual additional revenue from increased agricultural production of US$120 (Clemens et al. 2018).

Safety

Biogas may consist of 55–75 percent methane and 30–45 percent carbon dioxide. When the level of methane exceeds 45 percent the biogas is flammable, and proper care and precautions must be taken when using biogas. Usually, the biodigester is situated outside with good ventilation and the gas is stored and handled under relatively low pressure (1–3 bars), which reduces the risk of uncontrolled combustion. However, it must be noted that cooking inherently involves high temperatures and the danger of accidents arising from contact with any heat source. The most important impurity in biogas is hydrogen sulfide. Hydrogen sulfide is very toxic for humans and aquatic organisms but is only present in small amounts (Praet 2010). Hydrogen sulfide typically has a smell of rotten eggs, which can indicate a gas leak if enough hydrogen sulfide is in the gas (around 0.7 parts per million). Long exposure to small concentrations can be irritating to eyes and the respiratory system and can eventually result in pulmonary edema (Praet 2010). When the storage tank is placed in a well-ventilated spot (e.g., outside), the risk is reduced. Hydrogen sulfide is not usually removed in small household biodigesters. It is often falsely believed that the anaerobic digestion process inevitably kills all pathogens present in animal manure. The scientific literature clearly shows that both temperature and retention time are crucial parameters to determine whether the resulting effluent can be used without causing health risks (FAO 2013). Finally, a risk of asphyxia can occur if one enters into a biodigester to clean it while it is still in operation and has not been ventilated.

2.3. BIOGAS TECHNOLOGY PROMOTION IN SUB-SAHARAN AFRICA

Since being introduced in Sub-Saharan Africa during the 1950s, the uptake of biogas has been sporadic (Rupf et al. 2015; Kebede, Gan, and Kagochi 2016). In 2007 "Biogas for Better Life – An African Initiative" was launched, aiming to establish 20 million biodigester installations by 2020. It provided a platform for biogas dissemination programs in Sub-Saharan Africa by establishing the ABPP, which started its operations in 2009 (Box 1).

The ABPP – a public–private partnership between two Dutch nonprofit organizations (Humanist Institute for Cooperation with Developing Countries, or Hivos, and SNV) and the national governments of the host countries – originally aimed to install 70,550 biodigesters in four years, later downscaled to 54,000 digesters in five and a half years. At the end of Phase I in August 2013, 32,000[12] digesters had been installed. Sector development and market creation proved more difficult than expected (Hivos and SNV 2013).[13] A second phase began in 2014 and will run through 2019, with plans to incorporate 54,600 additional households. By early 2019, combining Phases I and II, 68,000 digesters had been installed (SNV databases).

A 2018 review of the ABPP in Kenya, Tanzania, and Uganda showed progress in the creation of biodigester markets (Clemens et al. 2018). By 2017, Kenya had made the most progress toward establishing viable biodigester markets, including hosting companies with prefabricated digesters and establishing 22 marketing hubs, linking rural institutions to local enterprises and finance (Clemens et al. 2018). Between

12 The 32,000 digesters installed represent the equivalent of nearly 88 MW (megawatts), with a gross energy production of over 314,000 MWh (megawatt-hours) and reduced GHG emissions of 275,000 tons carbon dioxide-equivalents (Hivos and SNV 2013).

13 The second phase of the program (2014–2017) set an ambitious aim of 100,000 digesters. The second phase was extended until March 2019 and is currently in its final stage of implementation, supporting domestic biogas in five Sub-Saharan Africa countries: Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda (https://www.africabiogas.org/).

2009 and 2017, over 61,000 households installed a biodigester, 18,560 (31 percent) of which were in Kenya. Results from this 2018 study showed that households using biodigesters perceived higher crop yields, reduced fuel consumption, and reduced eye problems and respiratory symptoms, and most households appreciated the easy cooking and reduced time and money saved.

Other African countries have attempted to jumpstart biodigester markets. The ABPP is currently running domestic biogas programs in Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda. Several other Sub-Saharan Africa countries have experience with biogas technology, including Benin, Botswana, Cameroon, Guinee Conakry, Lesotho, Madagascar, Nigeria, Rwanda, Senegal, South Africa, Zambia, and Zimbabwe (Rabezandrina 1990; Akinbami et al. 2001; Austin and Morris 2012; Kranert et al. 2012, all cited in Rupf et al. 2015; and SNV own data). International development institutions active in the region include the Global Network on Energy for Sustainable Development and the World Bank, which put forward an Action Plan for Energy Access in Africa based on the Investment Framework for Clean Energy and Development. Moreover, the New Partnership for Africa's Development put forward a strategic development vision with clear objectives for meeting the region's energy needs.

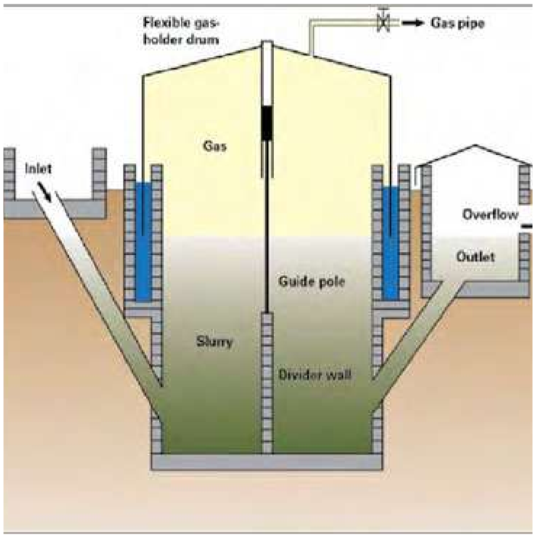
Type of biodigesters promoted in Sub-Saharan Africa

Different biodigesters are used across Sub-Saharan Africa. Depending on how the biodigesters are fed, they are classified into two broad groups: batch type and continuous flow type. In the batch system, all the raw material is added at once, and emptied after three to four weeks of decomposition. This type is less common in Sub-Saharan Africa. More common is the continuous flow model, where raw material is added on a daily basis, replacing an equivalent amount of digested residue (digestate) that is discharged from the system (Berglund 2016, cited in Mengistu et al. 2015). An overview of the main common household biodigesters is provided below (Rupf et al. 2016; Mutungwazi, Mukumba, and Makaka 2018; Wilkes and van Dijk 2017). Table 2 summarizes their main characteristics and lists the advantages and disadvantages of each digester.

Research from the case studies undertaken for this report revealed that refabricated plastic (tubular, molded, or bag-type) digesters were preferred by farming communities considering ease of construction, affordability, easy operation, emptying, and maintenance, and suitability for all soil types. However, this may easily change with the introduction of different improved digesters.

The **fixed dome model** has a main digester made of brick and cement in which organic input is collected and anaerobically converted into methane. Connected to the digester is a tank in which the feedstock gets mixed with water prior to feeding into the digester, and a compensation tank where the co-product (bioslurry) gradually accumulates until it overflows to a composting pit.

The floating drum model has an underground well-shaped digester with inlet and outlet connections through pipes at its bottom on either side of a partition wall. An inverted drum (gas holder) is placed in the digester, and rests on the wedge-shaped support and guide frame at the level of a partition wall. This drum can move up and down along a guide pipe with the accumulation and disposal of gas. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use.



Prefabricated plastic tubular models have recently been introduced. The tube is constructed of interlocking segments that allow a modular design such that digesters can be anywhere from 2 m3 to 20 m3 in size.

Source: SimGas 2018. (www.simgas.com).

The prefabricated plastic molded model is a portable and very simple system: it consists of a round- or square-shaped plastic digester tank with an inlet, a displacement tank with an outlet for bioslurry, and a gas pipe connected to the cooker. The digester is filled halfway and refilled with smaller amounts of feedstock every two weeks.

Source: BiogasSA 2018. (http://www.biogassa.co.za).

In the **flexible bag model**, the substrate flows through a tubular polyethylene or PVC (polyvinyl chloride) bag (the reactor) from the inlet to the outlet. The gas is collected by means of a gas pipe connected to a reservoir.

Source: Biogas International 2018. (https://biogas.co.ke).

In higher-end polyethylene models, the membrane comes as tightly packaged kit in sizes ranging from 6 m3 to over 600 m3. It includes an inlet feeding tank, bioslurry storage and a full range of thermal, mechanical and electrical biogas appliances.

Source: Sistema.bio 2019 (https:// http://sistema.bio/).

Box 1. The Africa Biogas Promotion Programme (Phase I 2009–2013, Phase II 2014–2019)

The overall objective of the Africa Biogas Promotion Programme (Phase I) is to "improve the living conditions of households in five African countries (Burkina Faso, Ethiopia, Kenya, Tanzania and Uganda) through the multiple benefits of the construction of domestic biogas digesters and lay the foundations for the emergence and development of a market oriented domestic biogas sector." It aims to contribute to the achievement of the Millennium Development Goals through the dissemination of domestic biodigesters as a local, sustainable energy source.

Key objectives include to: (i) strengthen and increase demand for and supply of the biogas digester market in the five ABPP countries; (ii) improve biogas digester operation and maintenance; and (iii) create a supportive institutional environment for biogas digester dissemination.

To achieve these objectives, key activities include:

- Awareness creation at national and regional level
- Improved affordability and provision of credit to rural households (farmers)
- Maximization of benefits for biogas users, among others by training users in digestate use and composting
- Training and capacity building of masons and Biogas Construction Enterprises (BCEs)
- Support for the development of biogas digester appliances
- Implementation of a quality assurance and customer protection system
- Provision of training in biogas digester operation and maintenance
- Support for country governments in policy development, subsidy provision, and standardization and regulation of the biogas sector
- Strengthening of the position and role of farmers' organizations and development of biogas sector associations

Phase I focused on market creation. SNV's model formed the base of activities in each country (SNV 2009). During the first two years, each national program emphasized local engagement, training of masons, and creation of BCEs. To promote early adoption, households initially received subsidies of about 30 percent of the construction cost along with extensive training for use and maintenance of the biodigester and stove and the application of bioslurry. In 2013, a results-based finance system was introduced to make payments more conditional on performance.

During Phase II, subsidies from donor funds were phased out and new incentives were introduced targeting producers and other upstream actors. The ABPP established Customer Support Centres (CSCs)-to troubleshoot problems and ensure quality, and marketing hubs to link community-based and rural organizations with biogas digester companies and local finance institutions.

Phase II is financially supported by the Directorate General for International Cooperation (DGIS) of the Dutch Ministry of Foreign Affairs. The financial contribution of DGIS amounts to EUR 20 million, which will leverage about EUR 40 million of household investments representing approximately one-third of the total program costs. Funds are channeled through Hivos, which carries out the role of fund and program manager, operating from Nairobi.

Source: Hivos and SNV 2013.

Table 2. Characteristics of main household biogas digesters

	Fixed dome	Floating drum	Prefabricated plastic tubular model	Prefabricated plastic molded model	Flexible (“bio”) bag
Investment (US$)	700–900	900–1,200	700–900	600–800	410–810
Lifetime (years)[11]	15–20	10–15	5–10	30[3]	15
Construction time (days)	10	20–25	Installation time: 1	Installation time: 1	Installation time: 1
Materials	Masonry	Masonry, steel gas holder	Plastic	Plastic	Plastic, PVC (polyvinyl chloride)
Portability	Fixed	Fixed	Mobile	Mobile	Mobile
Manure required as feedstock	Depends on size: 6 m3 40 kg/day	Depends on size: 6 m3 40 kg/day	Depends on size: 9 m3 40 kg/day	Depends on size: 6 m3 40 kg/day	Depends on size: 9 m3 40 kg/day
Advantages	Relatively low construction costs Long lifespan (if well-constructed) Underground construction saves space and provides protection Construction provides opportunities for local employment Stable temperature No expensive imports and loss of hard currency A “Solid State” version of the fixed dome now on the market reduces water requirements by 75% Stable pressure	Relatively easy construction Directly visible stored gas volume Ease of use Risk of construction errors for operation and gas volume (yield) is low Stable pressure	Easy installation High digester temperatures in warm climates; lower temperatures at night with associated lower performance Easy emptying and maintenance Shallow installation depth or aboveground installation, suitable for areas with high groundwater, hard bedrock, or instable soil types (e.g., black cotton) Easy to repair if damaged	Easily mass-produced Not easily damaged Possibility of modular installation Precise volumes to guarantee biogas pressure No risk of construction error	Suitable for all soil types Completely movable Easily transported Possibility to reduce prices by scale purchases Easy emptying and maintenance Easy to repair

Disadvantages	Depending on volume of stored gas, fluctuating gas pressure, but much more stable than tubular and bag digesters Acrylic emulsion paint is required for inside plastering of the gasholder Not suitable for all soil types High risk of gas leaks when constructed by inexperienced masons High labor input required for site preparation and construction Difficult to repair once constructed	High material costs for steel Shorter lifespan due to susceptibility of steel to corrosion Higher maintenance costs if drum is made of steel, as regular painting is required to protect against corrosion Less suitable for fibrous feedstock Takes considerable space	Relatively short lifespan Material usually not locally produced Temperature can easily become too high (> 37°C) Declining pressure when gas is used, needs weights on the bag Needs fencing (included in price?) Needs twice as much water as other models Takes considerable space	Potentially high transportation costs Construction does not provide many opportunities for local employment New technology not tested on a large scale and for longer periods Not clear if technical challenges solved now Production monopoly linked to only one company Takes considerable space	Potentially shorter lifespan as plastic is very sensitive to sun radiation Prone to damage by external factors Might incur import taxation Minor installation errors could lead to damage Biogas pipe to biogas digester link a possible weak point Sensitive to external temperature; less suitable for colder areas Needs fencing and roof/tent (included in price?) Made abroad, hence will cost hard currency to import Declining pressure when gas is used, needs weights on the bag Needs twice as much water as other models Takes considerable space

Source: Adapted from Wilkes and van Dijk 2017, based on Sovacool, Kryman, and Smith 2015; Vögeli et al. 2014.

14 The lifetimes reported here are as claimed by the manufacturers of the biodigesters. Practice has observed considerably shorter lifespans.

15 Expected lifetime reported by Kentainers (2017); see http://www.kentainers.co.ke/product-category/energy/blue-flame/

2.4. BARRIERS TO SUCCESSFUL ADOPTION OF BIODIGESTERS BY FARMING HOUSEHOLDS

Numerous financial, political, sociocultural, informational, institutional, training, and technical factors contribute to low adoption rates of biodigesters. Table 3 provides a comprehensive list of barriers to adoption of household biodigesters. For farmers, one of the major barriers is the high investment cost – often in combination with a lack of access to credit – for the construction of a biodigester. Other constraints include daily labor inputs for operation and maintenance, and the lack of available cow dung (mainly when livestock are sustained in free-ranging and semi-zero-grazing systems) and water to maintain the biogas system (Roopnarian and Adeleke 2017). For farmers who do not have water directly available, a distance of up to 1 kilometer for water collection or a 20- to 30-minute walk is considered the maximum (Austin and Morris 2012, cited in Rupf et al. 2016; ter Heegde and Sonder 2007). Improved digesters also improve a situation with little water – "Solid State" digesters function with only 25 percent of the normally required process water.

Education level of the household head, farm income, land size, and number of cattle positively influence the adoption of biodigesters (Kabir, Yegbemey, and Bauer 2013; Mwirigi, Makenzi, and Ochola 2009; Walekhwa et al. 2009, all cited in Lwiza et al. 2017). Furthermore, scarcity of fuelwood can increase the likelihood of farmers adopting biodigesters (Rupf et al. 2016).

Important to emphasize is that although farmers may decide to adopt biodigesters, this does not guarantee long-term utilization of biogas. A study in Uganda revealed that in 80 percent of disadoption cases, households abandoned their biodigester within four years after installation (Lwiza et al. 2017). Factors contributing to disadoption included failure to sustain cattle and pig production (thus a lack of dung as feedstock supply), reduced availability of family labor, and the inability to repair the biodigester after it malfunctioned.

Table 3. Main barriers to adoption of household biodigesters

	Main barriers	Description
Technical	Poor technical expertise and inadequate training and follow-up	Lack of expertise for construction, operation, and maintenance, especially in rural regions, and lack of availability and/or access to technicians and masons for repairs
Technical	Lack of water or feedstock (dung, crop residues)	Lack of access to sufficient water. Manure is the most important feedstock for digesters; farmers with low numbers of cattle are less willing and/or able to adopt digesters. Furthermore, rearing of cattle and other livestock in grazing systems makes dung collection for biogas unfeasible. In some cases, competition with traditional/other uses of cow dung is very high.

Technical cont.	Lack of suitability and availability of the material used	Reliance on expensive imported construction materials and spare parts; unable to access shops for replacement of broken or stolen components.
	Low rate of functional installed biogas systems/short lifespans	Problems such as broken parts, gas leaks, and cracking[16] in biodigesters.
	Poor design and construction: unsuitable for local conditions and/or users	Local conditions are not fully considered: e.g., local demand, access to maintenance/knowledge, spare parts, etc. Land tenure: the majority of digesters are immobile, so are not feasible if the land is not owned or if households tend to migrate.
Economic	High biodigester investment, installation, and maintenance costs	Depending on the region and type, the cost of a typical household-level digester varies from US$435–1,667. Studies show that farmers are more likely to adopt the technology if their income is medium or high.
	Reduced supply of family labor	Reduced supply of household labor as a result of progress with education and in search of paid employment off-farm can hinder biodigester operation and maintenance.
	High competition with firewood	In places where wood collection is free and available, adoption of biodigesters is low.
	Not seen as a productive investment	Business case is not clear, particularly the bioslurry part.
Socio cultural	Lack of interest/ motivation	Low interest to feed the digester or undertake repairs, e.g., as a result of inadequate gas production.
	Lack of knowledge	Lack of knowledge, lack of awareness about the technology and its benefits, and low literacy levels make adoption of the technology more difficult. Level of education plays an important role.
	Tastes and traditions	Preferences for cooking the traditional way, with a firewood stove, hinder uptake.
	Gender issues	Women and children of a household are more likely to use the biogas system,[17] while men are more likely to make investment decisions.
	Social/cultural/ religious objections	Using human waste is not common in all cultures. Most use is expected to be with animal waste.
Institutional	Absence of policies, regulatory frameworks, and standards	Regulatory vacuum creates uncertainty among consumers and discourages private investment in high-quality digesters.
	Absence of explicit organization to promote biogas	In the absence of an organization at the national level, biogas cannot play an important role in national programs.
	Absence of information	In most countries, up-to-date information, knowledge sharing, and translational biogas research is lacking at national, continental, and international level.

SSource: Lwiza et al. 2017; Mengistu et al. 2015; Mulinda, Hu, and Pan 2013; Mutungwazi, Mukumba, and Makaka 2018; Mwirigi, Makenzi, and Ochola 2009; Mwirigi et al. 2014; Roopnarain and Adeleke 2017; Rupf et al. 2015, 2016, 2017; Shane, Gheewala, and Kasali 2015; Surendra et al. 2014.

16 Cracking risk relative to quality of construction and time digester is allowed to remain empty.

17 However, bioslurry will also benefit men, who are more likely to work the fields.

2.5. POSSIBLE INTERVENTIONS AND LESSONS LEARNED FOR PROGRAM DESIGN

A number of successful mechanisms exist to address barriers to adoption of biodigesters. Table 4 provides an overview of interventions reported in the literature, with particular relevance to agriculture programs and applicability to farming households.

Table 4. Possible interventions for successful adoption of biodigesters among farming households

	Interventions
Technical	Enforce a solid biodigester design and high-quality and after-sale services that ensure digesters' long-term functioning Provide training and capacity building among masons and biogas companies to increase supply and ensure high-quality biodigesters Collect baseline data, providing information on farmers' resources such as land, labor, livestock, dung, and water, and potential risks affecting sustainable adoption/ disadoption Identify who in the household will be responsible for biogas operation and maintenance; target end user training and after-sale services to this person to ensure functionality Organize bioslurry application extension
Economic	Highlight profitability for fertilizer production and soil fertility management, reduced labor costs, and other co-benefits important to farmers Show business cases Most farmers are very price-sensitive, so develop a cost-effective design for the product; the cost of digesters can be reduced by constructing them from cheaper, locally produced material Target better-off farmers who have access to financial services –i.e., microfinance and credit; identify financial and risk management incentives needed to stimulate the market and attract qualified buyers Secure commitment and support of financial institutions Design and apply financial/credit incentives in a uniform, transparent, and easy-to-administer manner to ensure that financial incentives reach target groups
Sociocultural	Provide information, training, and capacity building and after-sale services by biogas service providers to farmers Consider gender issues within farming households
Institutional	Use existing structures in the agriculture sector: target farmers' organizations (e.g., associations, cooperatives) for information provision, awareness creation, training and capacity building, as well as provision of credit (e.g., by the use of check-off systems) Start in areas with a well-resourced extension system Identify key institutional players, strengthen their capacity to effectively carry out their roles, and provide technical and management support to all key players Build a platform at national and regional levels for information exchange and promotion of regional cooperation Governments should standardize proven technologies or formulate minimum requirements to make quality control easier and allow a large number of competing companies to enter the market; this will bring an end to experimentation on farmers and reduce the number of failed biodigesters

Source: Lwiza et al. 2017; Roopnarian and Adeleke 2017; Wilkes and van Dijk 2017.

3. RESULTS: LESSONS LEARNED FROM BIOGAS PROGRAMS

3.1. OVERVIEW OF COUNTRY CASE STUDIES

In addition to the literature review, three case studies were undertaken to generate more specific insights. The country programs were selected based on their treatment of key barriers to adoption, as well as their specific relevance for agriculture. Using these criteria, national biogas programs in Burkina Faso, Ethiopia, and Kenya were selected for detailed review. Table 5 provides an overview of key characteristics of these programs.

Table 5. Country selection for detailed review

		Burkina Faso	Ethiopia	Kenya
Technical aspects	Country experience and relevance of digestate use and promotion for the agriculture sector	Since 2010; digestate is a key driver of successful digester adoption, especially in the Sahelian zone	Since 2009	Since 2009
	Number of targeted/installed biodigesters[15]	Target: 17,905 Installed: 12,009 (67%)	Target: 30,100 Installed: 20,480 (68%)	Target: 38,500 Installed: 20,699 (54%)
	Agro-ecological region	Semi-arid/arid	Semi-arid/arid	Medium- to high-potential areas
	Cattle population[16]	9,396,466	59,486,667	20,529,190
	Water availability[17]	43.2%	29.9%	49.8%
	Type of digester promoted (fixed dome; prefabricated plastic digester)	Fixed dome	Fixed dome	Fixed dome and prefabricated plastic digesters
Economic aspects	Financial incentives/ mechanisms for farmers	Subsidy for digester construction (50% of total investment cost, but flat-rate subsidy; fixed amount for each digester means smaller farmers receive a higher subsidy percentage-wise.	Subsidy for digester construction (30% of total investment cost)	Subsidy for digester construction until 2013 (20–30%), now credit using the hub model
Sociocultural aspects	Farmers' awareness of biodigesters and the potential use and benefits of digestate	High awareness	Awareness	Awareness

Institutional aspects	Key implementing partner; involvement of the Ministry of Agriculture/Livestock	Led by the Ministry of Animal and Fisheries Resources (MRAH, or Ministère des Ressources Animales et Halieutiques)	Led by the Ministry of Water, Irrigation and Electricity (MoWIE); Ministry of Agriculture in Steering Committee	Led by the Ministry of Energy and Petroleum; Ministry of Agriculture in Steering Committee
	Existence and status of private sector	Critical role for the private sector. Private sector actors (construction companies and mason coops) are responsible for marketing, construction, after-sale service, client support	Critical role for the private sector	Diverse and active private sector, with numerous biogas companies

3.2. BURKINA FASO

3.2.1. Country context and potential for biogas

Burkina Faso is a poor landlocked country in the West African Sahel region. With a rank of 185, the country is listed at the bottom of the UN's Human Development Index and is one of the smallest economies in the world. Its gross domestic product (GDP) is growing at a rate of approximately 6 percent annually though (CIA World Fact Book 2018). According to the World Population Review (2018), the country is growing rapidly, with an estimated current population of 19.75 million. The largest share of the population is located in the center and south of Burkina Faso, with approximately 85 percent of the population living in rural areas.

Agriculture represents 32 percent of its GDP and occupies 90 percent of the working population (CIA World Fact Book 2018). Burkina Faso is strongly vulnerable to climate change; it suffers from increasing soil degradation, and desertification and food insecurity prevail. Therefore, a dry climate, water shortages, and significant soil degradation are core challenges for the Burkinabe agriculture sector. The country is strongly dependent on firewood – 86 percent of the national energy consumption is covered by the use of firewood.

Assessments of the potential for biogas vary significantly. According to a report by SNV, the potential market was assessed to be up to 880,000 biodigester units based on availability of water and ownership of three or more cows (ter Haagde and Sonder 2007). Yet other studies (e.g., GTZ 2007) put the potential at 200,000 units.

18 Reference is made to the targets for the original first and second phases of the country programs (2009/2010–2017); installed digesters are numbers reported until September 2017.

19 In 2016 (FAOSTAT 2018, http://www.fao.org/faostat/en/#home).

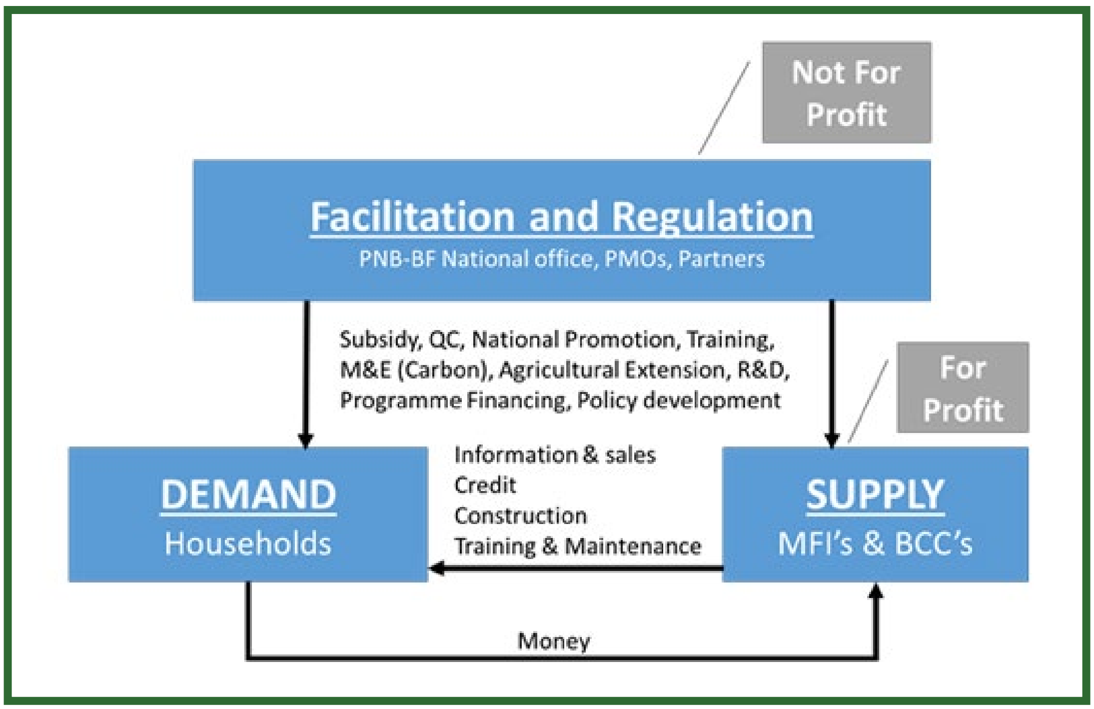
20 Defined as percentage of rural households with access to basic drinking water resources (World Bank data 2018).

3.2.2. Programme National de Biodigesteurs du Burkina Faso

The overall objective of the Programme National de Biodigesteurs du Burkina Faso (PNB-BF) is "to create a permanently viable and market-oriented sector including multi stakeholders in the construction of biodigesters to improve the living conditions of rural and peri-urban households" (SNV project presentation 2018). The program promotes the installation of fixed dome cement digesters with a volume in the range of 4–10 m3. The PNB-BF was able to significantly reduce the costs of a digester through better construction quality. Since the introduction of an improved model, adoption of a biodigester has cost around FCFA 320,000 (US$600) (Verbist and Kaboré 2015). Lasting from 2010 until 2013, the first phase of the PNB-BF aimed at supporting the construction of 6,000 biodigesters. The second phase (2014–2018) aims for 11,905 units (SNV project presentation 2018).

Even though the success of the program is measured in the number of installed and operating biodigesters, project staff consider it most important to develop a well-functioning private sector to ensure the long-term sustainability of program activities. Due to this, the program is structured in a "Not for profit section," including the PNB-BF and implementation partners, and a "For profit section," including households on the demand side and BCEs and microfinance institutions (MFIs) on the supply side (Figure 2). In the long run, the for-profit section is meant to be self-operational.

Figure 2. PNB-BF setup



Source: SNV project communication 2018. Note: BCC (Biogas Construction Company) = BCE (Biogas Construction Enterprise).

To achieve the objective, the national program focused on three priority activities in 2018 (PNB-BF program documentation 2017):

- **Private sector and credit development**: Improvement of the supply side by providing technical and financial support to BCEs and promoting cooperation with MFIs. The overall objective is to enable BCEs to independently conduct marketing and sales, and to provide construction and maintenance services.
- **Agricultural extension and training**: The approach of promoting digestate/compost value chains for agriculture is planned to be intensified, with BCEs to play an active role. According to the PNB-BF, trials to market compost have been very successful and show significant potential in improving financial accessibility and increasing farmers' crop yields.
- **Monitoring and evaluation and quality management**: Before 2016, 75 percent of biodigesters were functional (mainly plants constructed before 2015). To keep all biodigesters operational, the PNB-BF will focus on improving BCEs' customer service and developing internal monitoring of them. After a large restoration scheme, the program was able to increase the functionality level to 95 percent of all constructed digesters (UNFCCC 2018).

A continuation of the current phase into a third phase in the present form, supported by DGIS (Netherlands Development Cooperation)/ABPP is under review. The PNB-BF registered a Programme of Activities (PoA) and a Component Project Activity (CPA) in June 2014 to the Clean Development Mechanism (CDM) through the "West African biodigester program of activities." A sales-purchase agreement for carbon credits was entered into between SNV and the World Bank. Carbon finance via the World Bank-managed Carbon Initiative for Development (Ci-Dev) program is intended to supplement the financing and cover part of the program costs from 2018 until end 2024. The first carbon credits for GHG emissions reductions were issued in February 2018. With the objective to make the biogas sector permanent and demand-driven, SNV technical assistance will continue until 2020 and it anticipates continuing its partnership with Hivos for implementation of the proposed AB20-24, successor of the ABPP. SNV will continue its role of Coordinating and Monitoring Entity (CME) within the carbon project at least until 2024 (Project documentation 2018).

Institutional setup

The biogas program has full government support. The Government of Burkina Faso recognizes the serious threats that climate change and increasing land degradation pose to the country. The adoption of renewable energy sources is very high on the political agenda. By 2020, the country wants to cover 30 percent of its energy consumption with renewable energy sources. On top of these resources are solar power and biogas. The Prime Ministry adopted the PNB-BF as a priority program and the president committed to provide subsidies for the adoption of biodigesters until 2025.

The government takes an integrated approach to support the PNB-BF. The Ministry of Animal and Fisheries Resources (MRAH – Ministère des Ressources Animales et Halieutiques) leads the program, while the Office of the Prime Ministry, the Ministry of Energy, the Ministry of Environment, the Ministry of Finance and Economy, and the Ministry of Agriculture are active members of the Steering Committee. Against this background it must be emphasized that the PNB-BF is not considered an ABPP-driven program, but a program of the Government of Burkina Faso. SNV is responsible for technical assistance. At local level, the PNB-BF cooperates with implementing partners (Partenaires de Mise en Œuvre, or PMOs) based in different regions of Burkina Faso. PMOs manage masons and conduct a large share of the promotional work. The program channels its funds for training, promotion, contracting of masons, and quality control through these PMOs. The cooperation with PMOs has been increasingly phased out, and the PNB-BF instead now promotes direct cooperation with BCEs (Project documentation and interviews 2018)..

Financial flow mechanism

The program's budget forecast for 2018 was US$1,106,930. This budget includes incentive measures for PMOs of about US$31,705 and of about US$29,070 for BCEs, paid directly to them as operative support. This includes company office costs (rent, energy, communications) and activities like marketing, internal quality control, and training. The rest of the budget is channeled through program activities (e.g., promotion, training, development of monitoring systems, and agricultural extension).

In addition to this budget, the government contribution is FCFA 516,166,195, of which FCFA 494,995,000 is for construction subsidies, FCFA 9,240,000 is for rental expenses of program offices, and FCFA 11,931,195 is for the management of electricity and water consumption. The government subsidy for each digester is FCFA 160,000, regardless of its volume.

3.2.3. Effectiveness and sustainability: Status of biogas in Burkina Faso

While the first phase of the program did not achieve installation targets, it did establish a market-based sector, and the second phase is likely to achieve its targets. The PNB-BF is the only institution in the country promoting biodigesters. Thus the status of the biodigester sector strongly depends on the success of the program's activities. During Phase I, 4,013 biodigesters were installed, failing to achieve its objective of 6,000 digesters. Under Phase II, 10,620 biodigesters were constructed by February 2018. Consequently, the program expects that the target of 11,905 will be achieved by the end of Phase II. As mentioned above, 95 percent of the installed digesters are functional (PNB-BF 2017). However, the digesters may not be used everywhere year-round due to water scarcity during the dry season (as indicated during the stakeholder interviews).

The program has made good progress in setting up a commercial biogas sector. At the start of the program, there was no market for biodigesters and thus no BCEs existed. The PNB-BF started by cooperating with 15 PMOs. The program promoted the commercialization of these tasks, such that BCEs were established and slowly took them over. To date, only four PMOs are left. Instead the project works with twelve BCEs, including four masons' cooperatives and eight private construction companies. These BCEs finance their work through funds that households spend on the construction of their digesters, government subsidies provided for each digester constructed, and the above-mentioned incentive payments provided by the PNB-BF. The PNB-BF is looking at ways to phase out the incentives while BCEs have the means to expand (stakeholder interviews 2018).

The PNB-BF initially focused on promoting the production of biogas for clean cooking, but the digestate turned out to be the more important output of the digester. Based on this experience, the program started to partner with farmers' unions in many parts of the country to link digestate production to major value chains (rice, sorghum, sesame, fish, etc.). This cooperation was used to demonstrate the productivity gains, savings on (inorganic) fertilizer, and the financial gains from digestate. Moreover, the program promoted the establishment of compost markets (PNB-BF 2016).

Although the main reason for biogas adoption is the production of digestate, biogas itself is regarded as a valuable output. Most farmers who adopt a biodigester also make use of the gas for cooking and lighting. Farmers interviewed as part of this study pointed out that they spent significantly less time and money on the provision of firewood. Moreover, biogas is regarded as a much cleaner source for cooking than traditional cookstoves.

Many farmers were able to significantly reduce, or even completely substitute for, the use of synthetic fertilizer and to increase their farming outputs. Moreover, a large number of households did not use fertilizer at all. Based on a survey of the program, a farming household using compost is able to increase its maize harvest from 0.89 tons/ha to 2.54 tons/ha (Table 6). Due to the use of digestate, farmers were able to improve soil health and water sequestration ability, and to increase the share of arable lands. An average-sized biodigester (4–6 m^3), the size typically promoted by the program, produces about 15–25 tons of compost (or even more if optimally used), enough to cover the fertilization needs of an average household (PNB-BF 2016).

Furthermore, a number of farming households that adopted a digester did not use all of the compost for own farming, but instead sold the surplus compost, which turned out to be quite a lucrative market. For instance, in 2016 the PNB-BF promoted two compost collection and sale operations in the Sahel region in Burkina Faso. The first operation sold 22 tons of compost provided by seven producers, earning FCFA 880,000. The second marketing operation allowed 14 producers to sell about 19 tons of compost for FCFA 760,000. This yields an average price of FCFA 40,000 (US$75) per ton of compost. In 2016, more than 116 tons were commercialized and provided extra income to many biogas households (PNB-BF 2016).

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Table 6. Yields compared (i) without use of fertilizers, (ii) with use of chemical fertilizers, and (iii) with the application of compost from digestate at a rate of 5 tons/ha

		Maize	Sorghum	Rice	Cotton
Yield	Farmers' practice without fertilizer (yield in tons/ha)	0.89	0.81	0.78	0.50
	Farmers' practice with chemical fertilizer (yield in tons/ha)	1.54	1.01	3.00	0.90
	Application of 5 tons/ha of compost from the biodigester (yield in tons/ha)	2.54	1.44	4.00	1.17

Source: PNB-BF 2016.

3.2.4. Lessons learned

Development of a biodigester market must be integrated into livestock and agriculture sector development. At least three actors are important: (i) farmers as entrepreneurs investing in their business; (ii) stable MFIs to provide the financial means for such investments; and (iii) commercial BCEs providing their services and expertise according to predefined quality standards.

Furthermore, the PNB-BF learned to promote digestate not as co-benefit, but rather as a key output that can help farmers ensure a return on investment. This also means that farmers have to be regarded as entrepreneurs who invest in their farms, rather than as "beneficiaries" of a subsidy program. This approach could also help MFIs to gain more trust in the biodigester market.

Finally, a key lesson learned is that biodigester technology can be scaled up even in the dry climate of the Sahelian zone. Despite the lack of water and a difficult physical environment, the biodigester is positioned as a potential solution for food safety, access to clean energy, and resilience to the effects of climate change (Table 7). The Sahel region in Burkina Faso is where the greatest amount of compost is produced, and it has the highest level of functionality of installed units (as communicated during stakeholder interviews).

3.2.5. Barriers to and recommendations for adoption of household biodigesters

Table 7 summarizes specific barriers to the adoption of household biodigesters, as identified during stakeholder interviews, and recommendations for how to address them.

Table 7. Barriers and recommendations for the Burkina Faso biogas program (Programme National de Biodigesteurs du Burkina Faso)

	Main barriers	Explanation	Recommendations
Technical	Lack of water	In Burkina Faso, an increasingly dry climate, water shortages, and significant soil degradation are core challenges for the agriculture sector. Water shortage is a main barrier for the functionality of biodigesters and thus to their adoption. However, a dry climate and water availability problems do not necessarily lead to a rejection of biodigesters. PNB-BF experience shows that the population in the country's dry regions (Sahel zone) were among the best clients of the program; due to the digestate, soil water sequestration capacity is improved, leading to higher crop yields. Moreover, the program was able to develop a technically optimized (solid state) biodigester model that needs less water input than the original model (1:4 water:dung ratio; previously 1:1). This model was piloted in Tanzania but is not yet in Burkina Faso or other countries except Zambia. Presently the program is promoting the Faso Bio 2015 model, which is 30% cheaper than the model promoted up to 2015.	1.- Conduct a detailed feasibility study toward development Conduct a detailed feasibility study toward development of an integrated (technological, financial, economical) package with the biodigester as a central element. Look at availability of water and feedstock as important criteria. Target households with semi- or zero-grazing systems and year-round availability of cattle (e.g., dairy farmers). 2.- Target "low-hanging fruits," i.e., households that have sufficient number of cattle, and access to credit, or who can afford a biodigester. 3.- Develop initiatives to compensate for the lack of dung due to water shortage in dry seasons, for instance by installing storage facilities for dung.
	Lack of feedstock (dung)	The availability of dung is a natural limitation to adoption of biodigesters. Many households do not have sufficient number of cattle and are thus unable to adopt a digester.	
Economic	Absence of market for biogas digesters	The PNB-BF trained and supported 12 BCEs. The core barriers for these BCEs are financial resources and a not yet fully functioning private demand. Households must cover approximately 50% of the investment costs for a digester; government subsidies cover the other 50%. On the farmers' side, the contribution to a digester includes a large share of in-kind contributions (e.g., buying cement, excavation work for the collection of sand and gravel, making bricks, unskilled labor, etc.). Hence, the 50% of biodigester installation costs are not fully borne by paying BCEs for services, but by taking over some of their tasks. A BCE has to construct approximately 120 digesters per year to get into a profitable range (project communication). The price for biodigester installation, but especially for maintenance services, does not yet sufficiently compensate BCEs for their work. This is a serious barrier to establishment of a sustainable private sector.	1.- Enable masons and BCEs to develop a profitable business and provide all services including the promotion, construction, and maintenance of biodigesters. 2.- Provide masons and BCEs with capacity building on business model development, including the use of new technology for customer relations and digester functionality.

Economic cont.	Lack of available credit for biogas sector stakeholders	MFIs are generally limited in their liquidity. Furthermore, MFIs are hesitant to finance digesters, and rather provide credit for investments that they traditionally know (e.g., in agriculture). Investment in biodigesters is perceived as risky as MFIs do not have much experience with them. Though exceptions exist,[21] MFIs do not yet believe biodigesters will provide a secure return on investment.	1.- To increase the availability of (micro) finance for both farmers and BCEs, provide a credit line to MFIs to increase their liquidity and gain more working capital. This would also decrease MFIs' reliance on their clients' savings and thus reduce the risk put on financial stocks. 2.- Provide capacity building for MFIs on the functioning of the biogas sector and development of appropriate microfinance solutions. 3.- Support farming households in the development and implementation of business plans, which can also serve as a bank assurance to apply for (micro) finance and to plan sufficiently for maintenance costs. 4.- To improve BCEs' promotional work and after-sale services, the PNB-BF promoted the installation of call centers to decrease BCEs' logistical burden. Clients can request operational support or general information. The initiative started recently, and reception was generally positive. It should be further explored if this is an adequate tool to decrease coordination costs for BCEs.
	Lack of economic means among BCEs	A key barrier to the construction/supply of good-quality digesters and maintenance services is not so much the lack of capacity, but rather BCEs' lack of economic means to provide adequate services. BCEs do not yet have adequate financial resources to finance promotional work and invest in their own enterprises (e.g., insufficient means of transport to reach scattered farms for maintenance and after-sale services on a demand-driven basis).	
Socio cultural	Lack of knowledge	A general lack of knowledge and literacy often causes misunderstanding of biogas and its benefits among rural households. Examples include underestimation of the advantages of using biogas for cooking (e.g., reduced workload and costs, clean air) or the belief that compost cannot be used as fertilizer because the digester "takes the energy" from the manure.	Conduct promotional work and training to increase users' knowledge about the functioning and benefits of biodigesters. Ensure high functionality of biodigesters (e.g., by user training, after-sale services) to contribute to positive word-of-mouth promotion. Satisfied adopters of biodigesters often share positive experiences with neighboring farmers.
	Roles and responsibilities within the household	To keep the digester operational, it is important that responsibilities are clearly sorted out and adhered to. In many farming households, responsibilities are often not clearly settled. For instance, if the person who operates the digester leaves the farm for a certain time, it is not always clear who will take over that task. In addition, the person who uses the biogas is not necessarily the one who tends to the biodigester.	Addressing the right person and managing responsibilities within households will remain an ongoing task when promoting biodigesters.

Institutional	Working toward improved regulatory system and standards: *Currently all BCEs must have an internal controller, but their control will be validated by the PNB-BF either by its own technicians or by external service providers*		IIn the long run, monitoring and quality enforcement are to be taken over by BCEs. Clear quality standards introduced by the PNB-BF must be enforced in combination with a self-sustaining supply market that has the financial and technical means to conduct these control measures. These include: • A quality charter is available • The program has put in place a franchise system for BCEs • The household subsidy regulates the intervention of BCEs in the sector by subjecting them to compliance with specifications • The commitment of the program to the carbon market reinforces the oversight on quality of services and customer satisfaction
Project	Proof of concept and promotion of different biogas technologies	During Phase I, the program faced significant problems with the quality of the installed biodigesters and maintenance. This did not help to improve the reputation of biodigesters generally. Even today the program suffers from these reputational deficits.	Conduct promotional work and training to increase users' knowledge about the functioning and benefits of biodigesters. Ensure high functionality of biodigesters (e.g., by user training, after-sale services) to contribute to positive word-of-mouth promotion. Satisfied adopters of biodigesters often share positive experiences with neighboring farmers.

21 A pilot experiment conducted in the Sahel region by SNV resulted in all granted households repaying in full.

3.3. ETHIOPIA

3.3.1. Country context and potential for biogas

In Ethiopia, 85 percent of the population lives in rural areas, mostly in small and scattered settlements (Eshete, Sonder, and ter Heegde 2006). With a total land size of 1.1 million km2, Ethiopia is the tenth largest country in Africa. In 2017 the country was home to a population of 105 million people, with an annual population growth rate of 2.5 percent (World Bank 2019). From 2005 to 2015, the country experienced strong economic growth rates of 10.5 percent each year on average. Both the expansion of services as well as the agriculture sector contributed to these high growth rates (World Bank 2019). Despite its contribution to GDP growth and relevance for export (e.g., coffee), the agriculture sector is still dominated by subsistence farming. Smallholder farmers, the majority of the rural population in Ethiopia, produce approximately 90 percent of the agricultural output on 95 percent of the cropped land (Hanjra et al. 2009, cited in Boere et al. 2016). Of the 112 million hectares of land, 16.4 million hectares (~15 percent) are considered arable (Croppenstedt and Demeke 1997, cited in Boere et al. 2016). The average farm size is small; about one hectare per farm, often insufficient to sustain the household (Eshete, Sonder, and ter Heegde 2006).

An estimated 88 percent of the energy used by Ethiopian households is provided by biomass, mainly fuelwood and agricultural residues. Considering the country's rapid population growth, an increasing pressure on natural resources exists, and degradation of the environment in large areas of the country can be observed. In 2006, Eshete, Sonder, and ter Heegde researched the potential for domestic biogas in Ethiopia. Based on technical, financial, social, and institutional criteria (Annex 4) applied to Amhara, Oromia, Tigray, and SNNPR regions, the technical potential for domestic biogas was estimated at 3.5 million households. These households fulfilled the two main criteria: (i) having more than four head of cattle, and (ii) living within 20 to 30 minutes walking distance to a water source (Eshete, Sonder, and ter Heegde 2006). Taking into account that approximately 23 percent of households have access to safe water, the "low potential" was estimated at 1.1 million households (Eshete, Sonder, and ter Heegde 2006).

3.3.2. The National Biogas Program of Ethiopia (NBPE)

The National Biogas Program of Ethiopia (NBPE), part of the five-country ABPP, started in 2009. The second phase of the program, NPBE-II, ends in March 2019, while the new NBPE+ program started on April 11, 2017, and runs until mid-2022 (see Annex 4 for a detailed description).

The overall objective of the program is *"to develop a commercially viable domestic biogas sector, providing access to clean energy at household level through the implementation of biodigesters while substituting the use of firewood, increasing agricultural production through the application of bio-slurry (the liquid effluent from the digesters), improving living conditions by reducing the workload and improving health and sanitation for mostly women and children, while increasing employment and income and contributing to the reduction of greenhouse gas (GHG) emissions"* (NBPE-II Program Implementation Document 2014).

The specific aim for the second phase included to "support the market-driven dissemination of 20,000 high-quality biogas installations to provide households with access to clean energy for cooking and lighting and promote the use of digestate as organic fertilizer in a scientific way" (NBPE-II Program Implementation Document 2014).

To achieve this aim, the main program activities included (NBPE-II Program Implementation Document 2014):

To achieve this aim, the main program activities included (NBPE-II Program Implementation Document 2014):

- **Private sector development**: Training and capacity building of masons and BCEs on fixed dome biodigester construction and maintenance, and business model development.
- **Quality management**: Internal and external quality control, gradually shifting quality control from woredas (districts) to Alternative Implementing Partners[22] and (regional and national) BCE associations; data collection and verification.
- **Training** of masons, supervisors, technicians, and end users.
- **Extension services for appropriate use and application of digestate**: Forging relations with the extension department of the bureaus of agriculture as well as extension networks of nongovernmental organizations (NGOs) and universities.
- **Research and development and innovation**: Dissemination of research and development results of NBPE-I and streamlining of procurement of imported parts.

Institutional setup

The main implementers are the Ministry of Water, Irrigation and Electricity (MoWIE) at national and regional level and SNV. The key implementers and their roles and responsibilities as laid out in the NBPE-II Program Implementation Document (2014) are summarized below.

- The Ministry is responsible for program management, policy alignment, hosting, and coordination.
- SNV is responsible for technical assistance (management leadership at national level, private sector development and engagement in the biogas sector, mainstreaming of digestate use, and short-term technical assistance on, e.g., credit provision).
- SNV and MoWIE are supported by the Steering Committee. The Steering Committee ensures guidance for and alignment with national policies and strategies, provides advocacy and lobbying support to the program, and has overall oversight for the program and its monitoring and evaluation. This includes the endorsement of annual plans, budgets, and progress reports.

22 Alternative Implementing Partners (e.g., NGOs) are involved in the program to take over a number of responsibilities for a temporary period of time, until the private sector has the capacity to do so.

- The National Biodigester Program Coordination Unit (NBPCU) is responsible for overall coordination, day-to-day program implementation management, and strengthening of regional units.
- A similar structure exists at regional level; the program is aligned with regional policies and strategies as well as managed by the Bureau of Water, Irrigation and Electricity (BoWIE). Furthermore, a regional Steering Committee provides directives and guidance for aligning the program with regional policies and strategies and supports stakeholder coordination.

Fund flow mechanism

The total budget for the second phase of the program is EUR 15.4 million. The Government of Ethiopia contributes EUR 4.5 million to partially finance the investment subsidy for end users, while end users are assumed to cover EUR 6 million for investment costs in construction materials, appliances, and labor fees. The ABPP contribution is EUR 4.9 million.

Of the total budget, approximately 29 percent is used for the investment subsidy for end users (ETB 5,000 per digester). General program support takes up 21.5 percent, while 7.8 percent is used for international technical assistance. Table 8 provides an overview of the program budget (NBPE-II Program Implementation Document 2014).

Funds flow from Hivos to the Ministry of Finance and Economic Development, which is responsible for then channeling them to the regional Bureau of Finance and Economic Development (BoFED), which in turn channels funds to the respective Regional Biodigester Program Coordination Unit . The BoFED is also responsible for (i) integration of the NBPE within its regular planning; (ii) impact monitoring; and (iii) timely disbursement of project funds (NBPE-II Program Implementation Document 2014).

In addition to the NBPE-II, a World Bank credit line for Renewable Energy Market Development (US$40 million) exists for two purposes: (i) end user funding; and (ii) private sector (e.g., BCE) funding for business development in rural energy products. The aim is to introduce clean energy and improve the living standards of rural households, while reducing GHG emissions. Biogas is a key component of this fund. Funding for end users flows through MFIs, which provide end users with credit. Funding for the private sector flows directly to the Development Bank of Ethiopia to provide loans, including a limited Forex facility (US$1 million) for import of solar systems or biogas system components. Until now, little use has been made of this private sector fund (World Bank and Development Bank of Ethiopia, personal communication 2018).

Table 8. Summary of the NPBE-II budget

Budget category	Total budget (EUR)	Relative budget (%)
Household investment share	6,000,000	38.8
Investment subsidy	4,500,000	29.1
Program support activities	3,319,692	21.5
NIA/IP service fee Government of Ethiopia	423,700	2.7
Technical assistance	1,206,362	7.8
Grand total	15,449,754	100

Source: NBPE-II Program Implementation Document 2014.

3.3.3. Effectiveness and sustainability: Status of biogas in Ethiopia

The Ethiopian program has not reached its ambitious production targets and the functionality of the digesters is relatively low. By October 2017, roughly 18,000 biodigesters had been installed in Ethiopia (Figure 3). Targets were ambitious: the first phase of the NBPE set a target of 14,000 digesters, of which 8,031 were installed, while NBPE-II set a target of 20,000 digesters (NBPE Phase I report from 2009–2013, 2014).

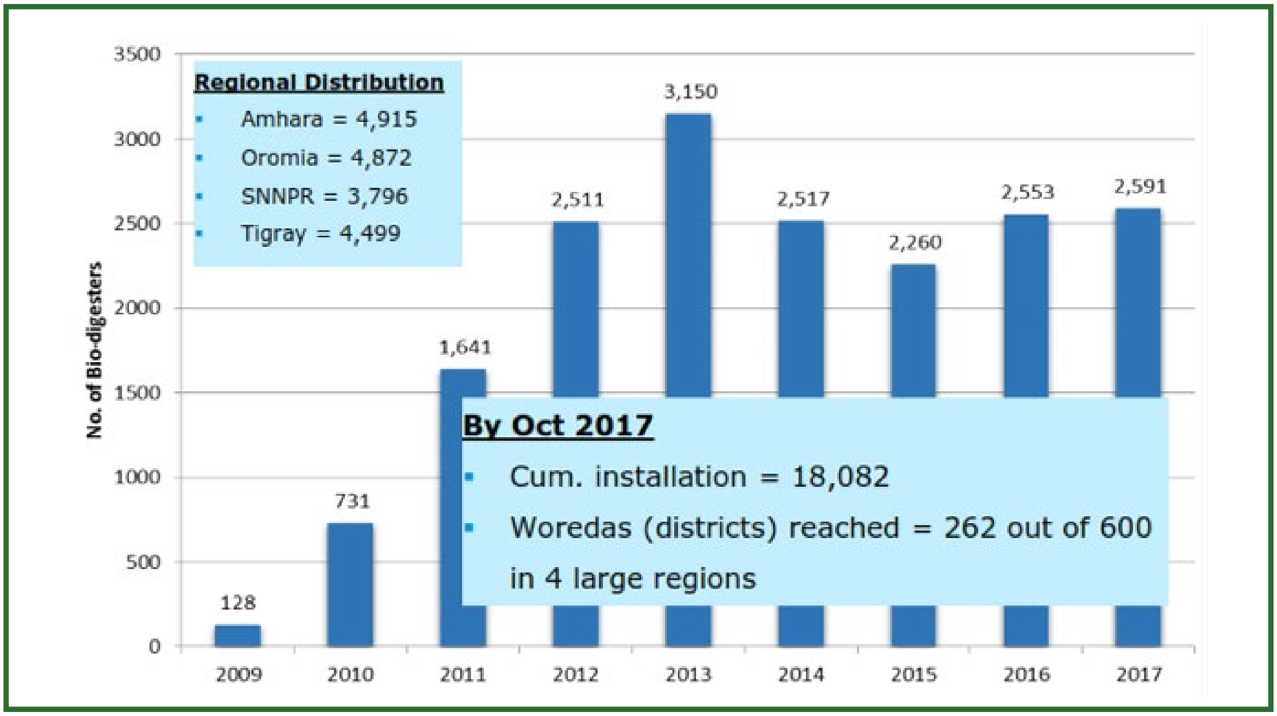
Digesters' functionality varies between and within regions. Preliminary results of field verification indicate that overall functionality of all digesters constructed since 2009 may just exceed 60 percent (SNV personal communication 2018). According to several implementing partners interviewed, explanations for the low functionality rate include: (i) poor feeding of digesters (due to a lack of knowledge among end users, and/or lack of water or dung); (ii) technical problems (lack of spare parts, after-sale services, cracks and leaking of the system, design unsuitable for local conditions); and (iii) migration (abandoned digesters). Low functionality is addressed by the program through a two-pronged approach: (i) one-time rehabilitation of all nonfunctional digesters (curative approach); and (ii) a strategy for reduction of non-functionality (preventive approach).

The main purpose of digesters, as reported by end users (farmers), is the use of digestate as fertilizer, followed by the use of gas for lighting and clean cooking purposes. The use of digestate varies across regions and between farmers. In a survey among biogas users implemented in 2015, most users indicated using a significant amount of energy from biogas for lighting (SNV 2015a). Of the users who participated in the survey, 95 percent indicated to sometimes or even always continue to use firewood, dung, or charcoal for cooking. The key explanation mentioned is the inability of cookstoves to be used for traditional injera making. Furthermore, insufficient gas due to inconsistent biodigester feeding contributed to the continued use of traditional biomass for cooking.

Although the program aims to contribute to a viable biogas sector, private sector development is lagging, and a fully functioning (effective and efficient) private sector supply chain is still far from being achieved. Approximately 30 BCEs exist in the country, of which 24 have business plans and 5 have an office. Numerous masons were trained over the course of (earlier phases of) the program, of whom an estimated 200 masons are still (part- and fulltime) active in the biogas sector (SNV personal communication 2018). Similar work (e.g., construction work) with higher daily rates is an important barrier for masons to remain active in the biogas sector.

Figure 3. Annual trend and total biodigesters installed during NBPE-I and NBPE-II

Source: SNV personal communication 2018.



3.3.4. Lessons learned

Government support for the biogas program is considered strong at national and regional level, which is positive but also raises some challenges. The government is a key supporter of biogas technology in Ethiopia, in terms of staffing as well as provision of financial resources. However, the intensive role of the government as key implementer of the program also raises challenges: government procedures are bureaucratic; a large number of personnel are involved; coordination between national and regional level is limited; and decision-making processes are slow.

The Ministry of Agriculture, though involved in the Steering Committee, has had a limited role in program implementation. As the main purpose of biodigesters, reported by end users, is the use of digestate as fertilizer, active involvement of the Ministry of Agriculture seemed more relevant than that of the Ministry of Energy. During implementation of NPBE-II, more emphasis was placed on promotion and awareness creation of the benefits of digestate, and training and capacity building on the right use (application) of digestate for crop cultivation.

The Ministry of Agriculture finally agreed to include digestate use in its agricultural extension services. For future programs, the involvement of the Ministry of Agriculture and the promotion of the use and benefits of digestate will be of key importance.

A number of lessons learned in Phase I were used for the design of Phase II (Table 9). Further lessons learned, as identified during stakeholder interviews, are elaborated below.

Key lessons learned are as follows:

1. **The importance of quality assurance and after-sale services (user training)**: In numerous households, non-functionality is high although it varies across regions. The high non-functionality reflects the need for quality assurance, user training, and after-sale services. If the private sector (masons, BCEs) is not (yet) capable of taking over these services, other project implementers (e.g., SNV) should do so.
2. **Limited promotion of digestate**: Biogas is often promoted as a clean energy source, replacing fuelwood, charcoal, and other unsustainable energy sources for cooking and lighting. However, for many households, not only in Ethiopia but also in other countries, digestate appears to be the main benefit of biogas. Not only can digestate contribute to sustainable farm management and increase farm yields, it can also substitute synthetic fertilizer and can be sold as compost, generating additional income.
3. **Conflicting aims of lead implementer**: During the course of program implementation, the ABPP and the MoWIE discovered they had different aims and approaches. Whereas the ABPP prefers a market-based approach, selecting those regions and households with the highest potential for biogas (i.e., "low-hanging fruits," or households with access to credit/those that can afford a biodigester), the government prefers a poverty reduction and equity approach. Therefore a compromise had to be sought for the geographical focus of the program. The ABPP wanted to focus activities on a smaller number of woredas, while the government wanted to increase the geographical focus to enable all rural households to benefit from biogas. However, funds, infrastructure, and resources remained the same. This turned into a large challenge for effective and efficient program implementation.
4. **Scale of interventions**: The size of the country and dispersion of households make "on-the-ground" implementation of the ambitious targets a challenge. Proportionally more resources should be spent on local-level implementation (e.g., for infrastructure, vehicles, etc.).

Table 9. Lessons learned from NBPE-I

Issue	Lesson
Institutional setup: At national level, NBPE coordination is housed in the MoWIE and is accountable to the State Minister for Energy. At regional level, it is under the Mines and Energy Agencies (MEAs) (Amhara, SNNPR, and Tigray) or BoWME (Oromiya).	Streamlining of bureaucratic procedures is required to procure services and actively involve stakeholders to respond swiftly to sector dynamics by working closely with relevant government ministries and other implementing partners.
Investment incentive: About 40% of biodigesters' total costs are covered by donor and government funding.	Farmers need to seek available credit facilities, through Development Bank of Ethiopia (DBE) and MFIs. Incentives, or subsidies, need to be reduced in maturing markets.
Carbon revenue: Carbon revenue was not included in the design and implementation of NBPE-I.	Monetize reductions in GHG emissions by generating carbon credits that contribute to (i) the financial sustainability of the program, and (ii) rewarding farmers for functioning digesters.
Private sector involvement: Most digesters were constructed by individual masons. However, in the last two years masons have increasingly formed BCEs.	Enhance the pace of implementation in terms of construction progress as well as the commercial viability of the program by facilitating proactive private sector engagement.
Implementing partners: Almost all implementing partners are government institutions.	Engage an increased number and variety of stakeholders (e.g., private sector and NGOs) to establish a vibrant biogas sector.
Technology development: Technical innovations will enhance program uptake; e.g., the lack of injera-baking devices and a model suitable for semi-arid areas.	Introduce a biogas-fueled injera stove as well as a modified biodigester, allowing farmers living in (semi-) arid conditions with limited water availability to benefit.
Maturity of the program: With technical support from SNV, the program has now reached a degree of maturity where most staff, resources, and procedures are in place at woreda, regional, and national level.	Focus technical assistance on the four priority areas of Phase II: management support; credit and innovative financing mechanisms (carbon and results-based financing); private sector development; and digestate development and promotion for food security. SNV will bring in expertise as required.

Source: NBPE-II Program Implementation Document 2014.

3.3.5. Barriers to and recommendations for adoption of biodigesters

Based on the lessons learned, Table 10 provides an overview of the key barriers to adoption identified during stakeholder interviews, as well as suggestions on how to overcome each of them.

Table 10. Barriers to and recommendations for Ethiopia's National Biogas Promotion Program

	Main barriers	Explanation	Recommendations
Technical	Poor technical expertise; inadequate training of end users and follow-up	Poor expertise and lack of long-term experience with biogas among masons and BCEs for construction, farmer training, maintenance, and after-sale services hinder the construction, functionality, and thereby sustainability of high-quality fixed dome digesters.	1.- Let masons or BCEs build up a profitable business and take over all aspects related to site preparation and construction of digesters. Let them determine the price for digesters. This price should include the provision of high-quality materials and after-sale services. 2.- Provide masons and BCEs with capacity building on business model development and quality assurance measures to enhance quality and accountability. 3.- Introduce national biodigester standards by the respective government entity, in collaboration with private sector representatives.
	Limited or slow availability of the material used	A slow pace in supply of materials (e.g., cement), appliances, and accessories hinders the timely construction of fixed dome digesters. According to one mason interviewed, having to organize provision of cement is a large barrier for farmers. The other challenge is continued public procurement of appliances and accessories that, as per the approved Private Sector Development Framework, should have been completely privatized.	
	Variable rate of functional installed biogas systems	Digesters have a variable rate of functionality due to the lack of proper feeding, low-quality construction, lack of after-sale services, gas leaks in the digester, drought, and migration. Varying functionality can have a negative influence on promotion of biodigesters.	
	Need to further improve design and construction: sometimes unsuitable for local conditions and/or users	For many years the lack of a biogas injera stove, high labor input requirements for site preparation and construction, and the materials required (e.g., cement) made the fixed dome digester unattractive to farmers and masons. However, since late 2018 when an injera stove was first promoted, the challenge has been to accelerate production. Current capacity is grossly insufficient to meet the emerging market demand. Furthermore, the variance in conditions (e.g., the existence of black cotton soil types in certain regions of Ethiopia) requires production of a variety of models.	1.- Diversify the types of biodigesters promoted: include plastic tubular or molded biodigesters and flexible bags for ease of construction, product diversification, and improvement of functionality, and to enable private sector development, turning biogas into a profitable business. 2.- Speed up the introduction of biogas injera stoves countrywide.

Economic	Public procurement system and low payment for biodigester construction for masons and/or BCEs	Although the investment subsidy and microfinance increase affordability and may thus be attractive to farmers, the public procurement system and low fee for digester construction and after-sale service makes the biogas sector very unattractive to masons and BCEs. The public procurement system is complex and slows down the process. Agreements have to be made, and it often takes a long time between agreement, construction, and payment to masons. The low fee paid for construction (irrespective of the size of the digester) and comparative sectors with higher daily rates (e.g., construction) make biogas construction unattractive and often a second choice.	1.- Review the subsidy scheme and payment model, making it market-based and periodically reviewed. 2.- Diversify the financial model (e.g., with “pay-as-you-go” schemes with vendor financing through financial institutions, or by cooperation with agriculture sector stakeholders [e.g., dairy cooperatives and SACCOs, which could also play a role in biogas promotion, user information, and training).
	Limited experience with and awareness of biogas among MFIs; low microfinance repayment rates	Limited awareness of and experience with biogas exists among MFI staff. Furthermore, due to the long time required for biodigester construction, and limited after-sale/construction services, many digesters are not fully functioning. Farmers are then reluctant to pay back their microfinance credit. Repayment rates are currently approximately 62–64% (Oromiya Credit and Savings Share Company (OCSSCO), personal communication 2018).	1.- Devote capacity building, training, and awareness creation to finance institutions. 2.- Ensure high-functioning biodigesters, provide after-sale services on their correct use, and create awareness on the financial benefits of digestate use for crop cultivation.
Sociocultural	Lack of knowledge and awareness	Lack of knowledge and awareness about biogas and its benefits (digestate for crop cultivation) and low literacy levels make adoption more difficult. The lack of knowledge on biogas use (feeding) and maintenance hinders the functionality of biodigesters.	Pay more explicit attention to awareness creation and differentiate promotion among male and female household heads. Refer to digestate as the main benefit for male household heads, and to the use of biogas for cooking and lighting for female household heads.
	Taste and tradition	For many Ethiopian households, a strong preference still exists for cooking the traditional way with a firewood stove. The traditional Ethiopian dish, injera, is a key element of Ethiopian culture. The current lack (slow development and dissemination) of a biogas injera stove is considered an important barrier to biogas adoption.	The development of two designs for biogas injera stoves was supported. Continue support by provision of technical advice and capacity building on business model development to create a sustainable and profitable business for biogas injera stoves.

Institutional	Insufficient government support and lack of biogas/renewable energy policy	Though government support for and involvement in the biogas program is high, having the government as the lead implementer not only consumes a large share of resources, but also slows down decision-making processes and implementation, and presents a barrier to private sector development. Furthermore, a risk of corruption exists. Commitment of woreda- (district-) level government employees is quite poor and capacity development is less sustainable, due to fast turnover/transfers. Technical capacity is generally low, mobility of biogas experts high, and resources (vehicles, infrastructure) insufficient. Examples include the required approval of the private sector by Regional Bureaus (BoWIEs), or the long time required from agreement (end users, Bureau, and masons) to actual construction and payment to the mason. A draft Energy Policy has been available since 2011 but has not yet been endorsed.	1.- Make the program “leaner” by reducing government involvement and creating an enabling environment for private sector involvement with appropriate supporting policy and regulation. 2.- Provide capacity building on private sector development to all government staff, and increase infrastructure and resources (e.g., vehicles) at lower levels active in actual (“on-the-ground”) program implementation. 3.- Endorse the Energy Policy.
	Limited private sector involvement	To make the biogas sector commercially sustainable, the private sector has a key role to play. Currently, private sector development is just starting, delaying sustainable biogas sector development. A “Private Sector Development Framework for the Biogas Sector” was developed and approved by the government through a long and participatory process, but implementation has been extremely slow.	Create an enabling environment for private sector development, e.g., by capacity building on business model development and provision of foreign currency for import of spare parts and/or prefabricated plastic biodigesters. A fully functioning private sector should incorporate promotion, user training, after-sale services, and maintenance. Quality control and assurance should be part of the private sector’s responsibility and in its own interest.
	Absence of explicit organization to promote biogas	Currently, the government (MoWIE) and SNV are active biogas promoters. However, no specific organization exists for biogas promotion. Furthermore, the role of the Ministry of Agriculture in the biogas program and promotion of biodigesters should be considered. Its engagement is limited to participation in Steering Committee meetings.	Strengthen the involvement of the Ministry of Agriculture to take up bioslurry extension activities and involve in biogas promotion activities in high-potential zones. Show importance of digestate and compost manure management and avoidance of burning dung cake for cooking, which deprives farmers of the fertilizing value of dung.
	Absence of information	Up-to-date information, knowledge sharing, and translational biogas research are lacking at national and continental level.	Increase up-to-date information; create a forum to enable learning from biogas technology; include scholars and ensure frequent exchange and update of information within the country as well as between countries.

3.4. KENYA

3.4.1. Country context and potential for biogas

Kenya has a population of over 45 million and is the largest economy in East and Central Africa, with significant industrial manufacturing, agro-processing, and service development compared. Situated on the eastern coast of Africa, Kenya has a total area of 582,650 km2, including 11,230 km2 of water. The country has a GDP per capita of US$1,143.1 and a Human Development Index of 0.555 in 2015 (UNDP 2016). The economic growth rate increased from 5.7 percent in 2015 to 5.8 percent in 2016. The major sources of GDP growth in 2016 include agriculture, forestry, and fishing (15.2 percent), manufacturing (6.3 percent), transport and storage (9.7 percent), information and communications (6.1 percent), construction (8.2 percent), real estate (12.3 percent), and financial services (7.3 percent) (World Bank 2017).

Over the years, the agriculture sector has continued to play a significant role in Kenya's economy as well as in the livelihoods of the majority of Kenyans. Smallholder farmers with an average of 0.2–3.0 hectares are the major driver of Kenya's agriculture, accounting for over 75 percent of total agricultural output and 70 percent of total marketed agricultural produce (Government of Kenya 2009). The sector directly and indirectly employs about 80 percent of the rural-based population in Kenya (Thurlow, Kiringai, and Gautam 2007).

Biomass fuels (firewood, charcoal, crop residue, and grass) are the most important source of primary energy in Kenya, accounting for over 70 percent of total primary energy consumption (KIPPRA 2010). According to the 2014 Demographic and Health Survey, 95.4 percent of Kenya's rural population used biomass fuels for cooking, compared to 45.5 percent of the urban population (https://www.knbs.or.ke/). The potential for biogas in Kenya is estimated at 500,000 digesters (Kenya Biogas Program personal communication 2018).

3.4.2. Kenya Biogas Program

The Kenya Biogas Program (KBP) is a component of the ABPP and is a public–private partnership formed by the Government of Kenya, the Government of Netherlands, and two NGOs (Hivos and SNV). The overall aim of the program is to "develop a commercially viable, market-oriented biogas sector that supports the use of domestic biogas plants as a local, sustainable energy source." Key activities of the program include: increasing the number of good-quality and operational household biogas plants; strengthening the institutions enabling the sustainable development of the biogas sector; ensuring the continued operations of all biogas plants installed under the program; and optimizing the benefits, which are currently underdeveloped in the Kenyan biogas sector (KBP, personal communication 2018).

Institutional setup

The program is led by a national Steering Committee chaired by the Ministry of Energy and Petroleum, and comprises representatives from key stakeholders – e.g., financial institutions, contract partners (BCEs and biogas companies), training institutions, and research institutions. The program is supported by the Directorate General for International Cooperation (DGIS) under the Netherlands Ministry of Foreign Affairs. Support is channeled through Hivos as the fund manager and partnership facilitator and SNV as the technical advisor. The national stakeholder-appointed implementing entity is the KBP. However, in Phase I the implementing agency was the Kenya National Federation of Agricultural Producers (KENFAP) (Porras, Vorley, and Amrein 2015); ABPP Annual Plan 2017).

One key aspect of the KBP's institutional setup is the targeted promotion of biodigesters working with the hub model (Box 2). Existing structures in the agriculture sector such as (dairy) cooperatives are used for dissemination of information, provision of training, and marketing aspects.

Digester-supported and financial incentives

Phase I of the program, the Kenya National Domestic Biogas Program (KENDBIP), started in July 2009, with the aim to facilitate the provision of energy for cooking and lighting through dissemination and construction of biodigesters in Kenya. Stakeholders chose the Kenya Biodigester Model (KENBIM)[23] as the most appropriate. Phase II introduced a modified version of the KENBIM model, reducing the excessive material used and thereby increasing affordability to end users. The second phase also incorporated plastic/prefabricated digesters (KBP project presentation 2018).

In its first phase (2009 to June 2013), farmers could receive a subsidy (with funding from the DGIS of the Netherlands' Ministry of Foreign Affairs). The subsidy covered approximately 30 percent of installation costs for a biodigester (KSh 25,000, or roughly US$250). The subsidy was reduced from June to December 2013 to cover approximately 20 percent of installation costs (KSh 18,500, or roughly US$185).

The aim of the subsidy was to reduce the labor-related cost of constructing the biodigesters: farmers were expected to buy locally available construction materials, while the subsidy was used to pay BCEs to cover the costs of construction. The subsidy was mainly used as a catalyst to promote awareness, create interest, conduct trials, and enhance adoption. The subsidy was withdrawn at the end of 2013 to enable the sector to be more demand-driven and for the private sector to play a more prominent role in the biogas sector's development.

During Phase I, 11,529 biogas plants were constructed against a target of 11,000, and 200 BCEs were trained on construction of biogas plants. In Phase II (2014–2019) the target was to install 27,500 digesters, without household subsidies, while deepening the working relationship with BCEs from Phase I and incorporating plastic/prefabricated biogas companies.

23 This model is a hybrid version of the CAMARTEC and AKUT models; fixed dome digester.

During implementation of Phase II, new incentives were introduced to BCEs, masons, and the biogas marketing hubs (MFIs and cooperatives). The incentives were intended to ensure after-sale services were offered to farmers and to de-risk the financial institutions and cooperatives for lending for biogas construction. The main aim of introducing the incentive was to strengthen the business case for biogas for all sector actors. Table 11 lists the incentives offered to different categories of stakeholder to promote biodigester adoption in Phase I and Phase II.

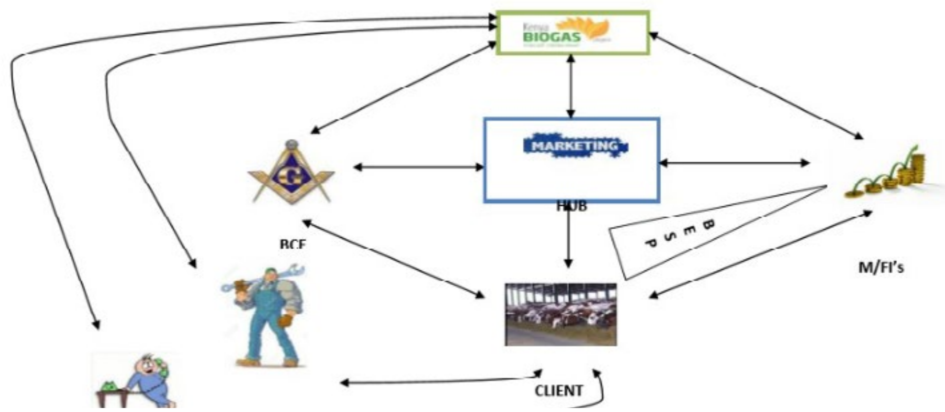
Table 11. Financial incentives provided in the Kenya Biogas Program

Type of incentive	Duration	KSh	US$
Farmer subsidy	July 2009–May 2013	25,000	250
	June 2013–December 2013	18,500	185
	January 2014	0	0
BCE/Masons/Biogas companies – Biogas commissioning	2015–2017	2,000	20
BCE/Masons/Biogas companies – After-sale service	2015–December 2017	3570*2	71.4
BCE/Masons/Biogas companies – New after-sale service	February 2018 to date	9,700	97
MFI and Cooperatives – For credit advanced to facilitate biogas construction	2015–December 2017	6,000	60
MFI and Cooperatives – Sales incentives for marketing hubs, BCEs, sales agents	February 2018 to date	6,000	60

Source: KBP personal communication 2018.

The hub marketing model was adopted in Phase II to increase the uptake of biodigesters in the country. With extension support, the hubs are expected to be the point of sale by providing credit facilities and other technical support services. The biogas extension support team provides technical training and marketing of biodigesters among farmers and provides linkages to BCEs and financial institutions. To date, KBP has signed MOUs (Memoranda of Understanding) with 22 hubs, including nine lending institutions (MFIs and SACCOs), six coffee cooperatives, and seven dairy cooperatives (Box 2). During 2017, 50 percent of installed/commissioned digesters were sold via hubs, and 38 percent of installed/commissioned digesters were premanufactured.

Box 2. The hub model for promotion and marketing of biogas in Kenya



The biogas marketing hub model aims at building an effective marketing and business development structure for the biogas sector. The model concentrates biogas digester information, training, sales, extension, and marketing efforts around organized target markets that already have a common interest or service for farming households (e.g., MFIs and cooperatives, which are more advanced in terms of farmer cooperation). The hubs are supported by Biogas Extension Service Providers (BESPs) that are responsible for training and extension and provide the necessary linkage between MFIs and cooperatives to BCEs and the company. Once a biogas unit has been installed, the system is reported and registered with the KBP. The program has a Call Service Centre (CSC) to follow up on the functionality of the systems and evaluate user satisfaction. Quality Service Providers (QSPs) are hired consultants who work closely with BCEs and biogas companies to ensure the biogas systems installed meet the required quality standards.

Source: KBP personal communication 2018.

3.4.3. Effectiveness and sustainability: Status of biogas in Kenya

Though an active private sector exists, the ambitious target of 38,500 digesters has not been achieved. Since 2009 over 18,000 fixed dome and prefabricated plastic biodigesters have been installed. Phase I set a target of 11,000 digesters, while Phase II defined 27,500 digesters as the target.

Currently, 72 percent of the digesters constructed in Phase I are functional. The program initiated a process of physical verification of all digesters identified by the CSC as having technical problems. More than 90 percent of the digesters constructed in Phase II are functional. A detailed database was developed for all biodigesters installed in Phase II to follow up on their functionality (KBP personal communication 2018).

The use of digesters for clean cooking purposes led to a reported decrease in expenditures for firewood, charcoal, and other energy sources. In a user survey implemented in 2016, 91 percent of respondents indicated to have reduced their energy expenditures by more than 50 percent (Ogara, Ayieko, and Odindo 2017). Further benefits reported include a reduced workload due to less time required for firewood collection, reduced incidences of eye problems and respiratory illnesses, and decreased expenditures for synthetic fertilizer.

The private sector is the main driver of growth and development of Kenya's biogas sector. The program works with over 70 active BCEs and masons to construct fixed dome digesters across the country and developed a partnership with seven medium- and large-scale companies providing prefabricated plastic designs in Kenya: HomeBioGas, Rehau, Kentainers,SimGasBiogas International, Systema Biobolsa, and Takamoto (Box 3).

Box 3. Private sector development in delivering domestic biogas in Kenya

The involvement of the private sector evolved over the years through the support of various partners. Phase I of the KBP focused on private sector development by training masons to install fixed dome digesters. Subsidies were used to incentivize users. Masons were later retrained on new technologies and entrepreneurship and graduated to BCEs. At the same time investors in plastic/prefabricated biogas digester systems started emerging and promoting their systems. Phase II included these digester companies within the program.

Collaboration between the private sector and the KBP is the cornerstone of biogas development in Kenya. The private sector (comprising BCEs, companies, and MFIs) is involved in the promotion and installation of biogas digesters across the country. The program aims to develop the capacity of BCEs and biogas companies to increase installation from 3,000 biogas digesters in 2018 to 12,000 per year by 2021. The private sector is also developing its own unique business models (e.g., by adopting the lease-to-own credit facility, and collaborating with MFIs and hubs). Furthermore, innovative appliances such as the use of milk chilling plants running on biogas provide opportunities for collaboration with dairy processors. The milk chilling is only prototyped, but not yet taken into production by the developers.

Development of the private sector has not been without challenges: most are unable to sustainably develop their businesses due to lack of access to finance and the lack of technical skills to grow their businesses. To address the financial challenges, the KBP is collaborating with Innovare Advisors LCC to establish Biogas Digester Finance Africa Ltd.; it is rolling out a variety of long-term financing instruments, including risk capital finance and long-term loans to support initiatives like lease-to-own facilities. The KBP and the ABPP (SNV and Hivos) are facilitating technical assistance to develop the sector in a broad sense with inclusion of financial investment solutions.

Source: Sistema.bio 2019

3.4.4. Lessons learned

Close collaboration among key private sector players and the KBP makes hubs a viable option to deliver quality biogas units and finance to users. A strong collaboration exists between partners, working together with the national implementing agency to achieve the KBP's objectives. The program has further developed the hub model, which is expected to be an instrument to overcome challenges in financing and biodigester quality control, and to provide follow-up on systems constructed or supplied to guarantee quality.

Lack of regulation within the sector is a major challenge in providing and monitoring delivery of quality biodigesters in Kenya. The KBP adopted a system of social accountability among stakeholders to address quality. For example, all BCEs and biogas companies signed a code of conduct and provide at least a one-year warranty for all systems installed. Furthermore, customer support/CSC services are provided to measure client satisfaction and plant functionality. However, this still does not provide the much-needed safeguard to protect users from unscrupulous masons and suppliers who deliver poor-quality biodigesters.

Access to finance and affordability of the biogas system were identified as two of the most significant challenges to the dissemination of biogas technology. The effects of limited financing options are felt by all stakeholders, from BCEs, importers of accessories, and biogas companies to end users. BCEs and biogas companies lack the capital required to scale and market biogas to a wider range of potential users to enhance adoption of the technology. Thus strategies to reduce cost and expand financing options for all stakeholders are necessary to ensure widescale dissemination of the technology in Kenya.

End users' access to technical support services must increase. The existence of technicians who are well-versed with the repair and maintenance of biogas systems would provide much-needed trust among users and increase adoption rates. Technical support to BCEs and biogas companies is needed for development of reliable technical support services for end users.

3.4.5. Barriers to and recommendations for adoption of biodigesters

Table 12 provides the barriers to and recommendations for the successful adoption of biodigesters in Kenya, as identified by various stakeholders during the interviews.

Box 4. Creating Market Conditions for the Private Sector: A Case Study

The KBP was instrumental in creating the groundwork necessary for private companies to enter the market, including improving import conditions of biogas units to Kenya and providing early support with technology trails and farmer outreach. In 2017, with these conditions established, the largest biogas producer in Latin America, Sistema.bio, set up operations in Kenya. Since then, Sistema.bio has sold over 2000 biogas units under the program, with projections of over 3000 units in 2019. With technology that serves farmers with anywhere between 2-200 cows, the company has invested in expanding market coverage and developed a lease-to-own model that has made the units available for a wide range of farmers.

Source: Sistema.bio 2019

Table 12. Barriers to and recommendations for the Kenya Biogas Program

	Main barriers	Explanation	Recommendations
Technical	Poor technical expertise; inadequate training of end users and follow-up	A number of masons/BCEs were trained by the KBP over the years. During the same period many either left the business or were blacklisted for nonconformity to the code of conduct. Most counties and rural households are not able to get masons and technicians to construct or repair biodigesters. Likewise, biogas companies do not have enough technicians to reach many rural households. Currently, BCEs and companies do not have the technical capacity to offer the required services to their clients.	Capacity development is needed at different levels and among different categories of stakeholders. BCEs' and biogas companies' capacities need to be enhanced to enable them to provide quality products and offer after-sale services to their clients. Entrepreneurial capacity is also required to ensure that BCEs and companies can operate profitable enterprises and scale up biogas in the country. The KBP has already made finances available to upgrade masons to entrepreneurs through the Biogas Entrepreneurs Accelerator Facility (BEAF).
	Low-quality and expensive materials	Most materials used for construction of biodigesters are available locally. However, other accessories like gas meters/gauges are imported and are usually expensive and often of low quality. The high costs of accessories also increase the cost of biogas plants and costs incurred in repairs and maintenance.	Companies offering equipment and accessories should be identified and actively involved in the program. These companies should also receive business development support to be able to make bulk purchases of quality equipment. This will enable BCEs and companies to have quality accessories and reduce costs.
	Variable rate of functionality of installed biogas systems	BCEs and biogas companies identify operational problems as the major contributor to challenges experienced by most users, while users believe their challenges are a result of poor workmanship and BCEs' and companies' lack of experience in construction of biodigesters. The operational problems are usually not complex to solve but require regular visits to and training of households.	A strategy is required to ensure that all suppliers (BCEs and companies) adhere to strict quality standards. The program should consider preparation of quality standard guidelines on the design, construction materials, and after-sale service delivery and quality information to end users prior to making investment decisions. Linking investment return with quality provides programs with the necessary leverage on service quality. Training on functionality of the plant should also be done regularly.
	Poor design	The design for the fixed dome biodigester was modified to reduce the cost and make it more affordable to users. Based on the evaluation of BCEs, the new design has several challenges and the unit has a short lifespan. Biodigesters' most common problem is cracking.	Commercialization and development of technology requires a lot of support for the technology to grow and gain trust among users. New types of systems developed in the recent past have experienced challenges. Systems are being introduced to the market and need financing to test their suitability for different categories of users. Future interventions should consider technology development as a core component of program design to make it possible to test and validate new designs and technologies.

Economic	High initial investment cost	The initial investment required ranges from KSh 55,000–85,000 for a 6 m3 biodigester regardless of the technology. Given current prices, biogas technology seems to be for those at the top of the pyramid. This type of client is rare in rural areas, where the technology is more applicable.	1.- To enhance adoption of the technology, a financing mechanism that can reach many farmers is required; efforts already exist by biogas companies to offer credit through lease-to-own facilities and by SACCOs and cooperatives to offer credit facilities to their members, but only a few farmers have access to these credit facilities. The conditions set to get financing for biogas are still prohibitive for many farmers and offering credit financing for biogas installation is not a priority credit line for SACCOs and cooperatives. 2.- A dedicated financing mechanism to support biogas installation and the capital requirements of companies and BCEs will go far in increasing adoption and scale-up of the technology. The KBP is already collaborating with Biogas Finance Africa Ltd. (BFA) to provide much-needed financing through private sector investment. BFA is currently setting up and will provide dedicated financing for users, BCEs, and companies through MFIs. A pilot phase has shown great promise. Suitable financing option to enhance biogas adoption must be developed and promoted.
	Lack of credit for biogas stakeholders	Farmers' financing options are MFIs, SACCOs, and cooperatives. Only a few financiers have targeted lending for biogas. BCEs and biogas companies also require funding for capital investments and business development, but financing from the available financial institution is a challenge. Companies like Systema Biobolsa and Taka-moto have an initiative to sell biogas on a lease-to-own basis but face challenges in raising sufficient capital to fund it.	
Socio cultural	Lack of knowledge and awareness	Awareness about the technology and its benefits is still low, especially among rural communities. Farmers visited during the survey reported that many potential clients who visited their farms to learn about biogas did not have information of the technology nor it benefits beyond energy production. A majority of visitors interacted with the technology for the first time during a farm visit. Without knowledge of the technology and its benefits, it is difficult for farmers to adopt biogas and scale up the use of the technology.	Increased consumer education is needed, particularly in rural areas where biogas technology is required. Awareness about biogas as a viable energy option and its potential benefits needs to be increased. A two-pronged promotional approach that involves promoting biogas by the KBP and by suppliers (BCEs and companies) should be adopted. This will make it possible for the KBP to promote the technology while suppliers are at liberty to promote their specific technologies and market them to clients. Marketing of biogas technology to users is currently limited.

Institutional	Insufficient government support and lack of a biogas/renewable energy policy	The Ministry of Energy chairs the national Steering Committee that promotes biogas in the country. However, limited direct financial involvement to support the sector exists. At the moment the government has a budget of KSh 20 million to construct fixed dome biodigesters for demonstration purposes only. Currently, the government gives no technical or financial support to specifically target end users, BCEs, and biogas companies. An explicit policy on biogas is also lacking.	1.- One way to address some of the key challenges highlighted is through development of policies and a regulatory framework that encourage the wider adoption and use of biogas technologies, thereby enhancing their role in economic development. Policies and regulation will improve management of the system and enhance awareness to gain wider acceptance and adoption of the technology and increase the level of government support to research and development. Initiatives to develop regulations for the biogas sector should be supported by key stakeholders. 2.- National and county governments' capacities should be strengthened to facilitate and promote biodigester adoption (e.g., by provision of technical assistance to the government on awareness and promotion of digestate use for crop cultivation, and other key benefits of biodigesters).
	Lack of a regulatory framework for sector stakeholders	The KBP has spearheaded efforts to develop a regulation for the biogas sector, but progress has been slow due to a lack of finances to support the technical working group and facilitate a beneficiary assessment study. The Ministry of Energy developed a curriculum to train masons and artisans on biogas construction, the main objective of which is to develop a training program that can accredit them. The curriculum was forwarded to the National Industrial Training Institute (NITA) for review and approval.	
Project	Proof of concept and promotion of different biogas technologies	Phase I focused on promotion of fixed dome biogas units, despite the existence of other technologies like plastic/ prefabricated biodigesters. This projected fixed dome digesters as the only viable biogas technology, limiting dissemination and adoption of prefabricated biogas systems.	In Phase II, all biogas systems are included, and an incentive introduced for both BCEs and biogas companies. Future programs should engage all biogas sector stakeholders from the onset to increase the potential for impact and scale.

4. RECOMMENDATIONS

4.1. SPECIFIC RECOMMENDATIONS

Based on the experiences of each country, as well as lessons learned from the case studies and recommendations reported in literature, a number of recommendations on how to tailor biodigester components for World Bank agriculture lending operations are presented below. The objective is to help promote widescale uptake of biodigesters among farming communities.

Recognize that the biogas technology for clean cooking and agriculture is still fairly young. This technology will likely go through further development stages, affecting both design and functionality. Case studies have shown that it is possible to adapt the technology to local conditions within the lifetime of a project. Programs should be flexible enough to react to and take advantage of this process.

Carefully consider the type of digester(s) to be promoted. Local conditions and farmer characteristics differ and have an impact on the most suitable type of digester. Fixed dome digesters can be produced with local materials and labor and have a long lifespan, but they take much longer to construct and have potentially higher investment costs. However, for countries that do not waive/exempt the import/customs duties and taxes on imported prefabricated digesters and appliances, brick dome digesters are often the cheapest household solution. Although plastic and prefabricated biodigesters might have a shorter lifespan, their use may be preferred in certain areas. The import of prefabricated, mass-produced digesters can increase affordability for farmers and reduce installation time. They are also easier to construct and operate. It is possible to pilot a diverse set of biodigester technologies and to provide farmers with a range of options.

Target areas with a high density of medium-scale farmers (e.g., western Kenya, with its high density of small- and medium-size dairy farmers). Feedstock should be conveniently available on a daily basis throughout the year (target livestock farmers with semi- or zero-grazing systems, such as dairy farmers). The walking distance to water should not exceed 20 to 30 minutes, although preferably water should be directly available at the homestead. A lack of dung and water during the dry season can be compensated for by dung and rainwater storage facilities.

Accelerate awareness creation and communication among all key stakeholders such as ministries, (micro-) finance institutions, extension officers, and farmers. SNV and other key stakeholders have laid the foundation for awareness. However, this capacity building needs to be done better and smarter, and the two main products of biodigesters – energy and fertilizer – need to be highlighted via communication campaigns and through agricultural extension networks. Gender dynamics should be taken into consideration: the key benefits of energy for clean cooking should be targeted to women, while the key benefits of digestate could be communicated to both sexes. Though farmers are interested in both benefits, they may not be aware of the latter. It will be interesting for them to learn more about this new agricultural technology, capable of producing a high-quality digestate that allows them to increase their yields while providing renewable energy for clean cooking, as well as clean heating and chilling.

Budget for a generous capacity-development component. The biogas technology as such is not extremely complicated, but the development and dissemination processes require a certain level of technical skills and literacy among stakeholders. The lack of highly qualified and motivated technicians for the construction of digesters and masons with business skills has been an obstacle to the supply of high-quality digesters. At the farm level, the best way to ensure high functionality is to clearly explain to farmers how to use biodigesters. Provision of after-sale services is key for long-term functionality. Call centers or a dedicated helpline are instruments to provide customer service in areas with large distances between scattered farm households.

The integration of South-South cooperation schemes is recommended. Considering the extensive experience of the ABPP with biogas promotion and dissemination, as well as in-depth country knowledge, it is recommended to build on this experience for future programs incorporating biogas technology.

Farmers' meetings and field visits to other rural areas/countries usually provide a good platform for exchange of information on biodigester use in a similar context and help the adoption of the technology at farm level. A similar cooperation and exchange can be fruitful for biogas companies of different countries, allowing them to share experiences and technology and possibly to cooperate. Equally important is the training of agricultural extension staff on the functioning, requirements, costs, and benefits of biodigesters with respect to soil fertility management.

Ensure affordability of digesters and facilitate access to finance. Affordability of biodigesters is an important prerequisite for adoption by farmers. Awareness creation on the existence, use, and benefits of biogas is the first step to ensure finance institutions increase their loan products for biodigesters. Further instruments could include: (i) a credit line to MFIs to increase their liquidity, gain more working capital, and increase the availability of microfinance to farmers; (ii) capacity building for MFIs on the functioning of biogas technology and the agriculture sector, and development of appropriate microfinance solutions; and (iii) capacity building of farmers on business plan development to serve as a bank assurance for microfinance and to plan sufficiently for maintenance costs. By working with local lending entities to tailor financing products for the biodigester market and to broaden the types of assets that are accepted as collateral, MFIs could be convinced to offer loan products for biodigesters.

Given the increasing need for public resources to be used to mobilize and leverage private finance for development, innovative solutions should be pursued. Innovative financing mechanisms that could be supported include the use of existing agriculture structures (cooperatives, SACCOs) for the provision of microfinance, use of the check-off system, lease-to-own facilities, or the possibility to use livestock as collateral. A lease scheme could be an attractive option for those farmers who cannot afford to pay high installation costs. It is further recommended to review existing subsidy schemes in agriculture (i.e., fertilizer subsidies) in view of their effect on the promotion of biodigesters, particularly for fertilizer production.

Review the policy and regulatory environment. The absence of guiding policies and a supportive regulatory framework as well as insufficient involvement of the Ministry of Agriculture create uncertainties and can discourage private investment in the biogas sector. Not only can government support contribute to awareness about biodigesters and the benefits of clean cooking and crop cultivation, but the regulation and enforcement of standards and the provision of licenses supports development of the sector and creates the trust needed among end users for stable demand growth. For a targeted group of poor consumers, public support in terms of a subsidy may be justified. Impact evaluations of subsidy schemes from countries such as Burkina Faso would be useful to determine the effectiveness and efficiency of such support.

Encourage and facilitate private sector coordination along the value chain. Close collaboration among key private sector players can bring down the cost of construction as well as customer service for the sector. It is also beneficial for the monitoring and evaluation of ongoing technology innovations and process developments. Tools to be used are: (i) a code of conduct among producers as a way of self-regulating the market at an early stage and in the absence of government involvement; or (ii) geographical hubs that bring together masons constructing fixed dome digesters, importers of critical spare parts, companies providing prefabricated designs, and service centers. Public support to value chain development could be provided in the form of the establishment and operation of a Value Chain Facility for the purpose of extending technical and financial services to businesses, including: the provision of (i) technical assistance to establish and monitor a code of conduct; (ii) advisory services and implementation support to biogas businesses; and (iii) cross-sectoral collaboration to improve basic infrastructure, such as electricity, a potable water supply, and road access as needed for geographical hubs.

Install risk management mechanisms. Due to the early stage of the technology, biogas promotion is prone to certain risks that can have a fatal impact on the speed of adoption. Cultural biases, tastes, and traditions may severely slow down the acceptance of the technology. Poor-quality suppliers and word of mouth can also represent key barriers. Early anticipation and flexible response mechanisms coupled with targeted and well-tailored communication efforts are essential to mitigate these risks.

In summary, this report suggests that interventions to promote biodigesters could be integrated into various components of World Bank investment operations. Modules to create awareness about the benefits of digestate for soil fertility could be integrated into components on sustainable land management. Components on rural financial services and access to finance could include capacity-building activities for MFIs on biogas technology and training for biogas businesses. Projects to promote agribusiness value chains would be a perfect vehicle for interventions to encourage and facilitate closer coordination among key actors along the biodigester value chain. Vocational training of masons to gain specialization in biodigester construction could be considered as part of initiatives and programs focused on job creation.

4.2. SUSTAINABILITY AND FUTURE OUTLOOK

The potential of biogas as a clean energy source that can reduce the high dependence on biomass fuels and their associated impacts is not questionable. The full menu of energy resources available in Africa must be tapped into if the ambitious energy targets set by African nations and the international community are to be achieved. Of all the renewable energy sources that can be applied in cooking, biogas is superior in terms of being renewable, familiar, having a positive association to liquid petroleum gas and it does not compete for land use with agriculture. The future prospect is therefore positive.

To realize the full potential of biogas, the efficiency of end-use appliances must be improved, and they must be adapted to local cooking conditions, as has been done with other cooking technologies. The technology should also be targeted to suitable populations, considering socioeconomic status, family size, and baseline fuels. In the current scenario in which several challenges relate to end use of the product (such as inadequate heat supply), biogas is unlikely to substitute for biomass fuel use and realize its full benefits. Surmounting these challenges should be a priority.

Despite significant strides in the cookstove sector development in Africa, the biogas subsector is lagging in technology development, marketing, and distribution. The agriculture sector has a long-established rapport with households and a higher capacity to penetrate and supply them with products than the energy sector. On the other hand, the energy sector has knowledge of stove designs and standards that can ensure that products do not just meet international performance requirements but are also adapted to local cooking needs. The stoves tested in Uganda, for instance, were provided by Heifer International, which does not traditionally work with energy. The team that tested the stoves was able to identify very simple modifications that would considerably enhance their performance. Thus, a strong motivation exists for the two sectors to work together in the design and promotion of biogas systems.

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6. ANNEXES

6.1. ANNEX 1 RESEARCH METHODOLOGY

This review used a three-phased research methodology:

1. A desk study for a review of biodigester programs globally, with a specific focus on Sub-Saharan Africa (reflected in Chapter 2);
2. A detailed review of three selected biogas programs
    - Program design: Review of program documentation
    - Effectiveness and sustainability of biogas programs: Stakeholder interviews
3. Data analysis: Clustering of stakeholder responses, consolidation of lessons learned, and development of recommendations.

Throughout the review, methodological triangulation was employed. This technique involves using more than one method to gather data and information, such as primary and secondary data, program documents and stakeholder interviews, scientific and grey literature, and nonpublished research. Particular attention was paid to interviewing public and private entities in Sub-Saharan Africa directly involved in the planning and construction of biodigesters in rural households, to gather extracts from their direct experience. The research also took into account the national and regional diversity in the area of study, to clarify which particular aspects would favor and which ones would oppose a biodigester program.

Country case studies were determined on the basis of their treatment of key barriers to adoption, as well as their specific relevance for agriculture. Using these criteria, the national biogas programs of Burkina Faso, Ethiopia, and Kenya were selected for detailed review. An overview of the criteria and their relevance in each of the countries was provided in Table 5 in Chapter 3. Given the small number of case studies, it was not possible to be regionally representative or to cover every aspect of biodigester programs.

Detailed review of three biogas programs

The desk study identified a range of potential barriers for adoption of biogas (Table 3 in Chapter 2). These barriers are used as an underlying framework for the detailed review of selected biogas programs (case studies).

Review of program documentation

As a first step, the design of each biogas program was assessed, with particular focus on relevant elements for agriculture programs. Available program documentation was reviewed. Questions included the extent to which the project design considered:

1. Technical aspects
    - Availability of feedstock (dung) and water; characterization and suitability of livestock production systems (grazing, semi-zero, or zero-grazing) for biodigesters
    - Suitability and local availability of construction materials and spare parts
    - Use of technically sound biodigesters with a long lifespan, suitable for local conditions
    - Provision of technical expertise and training for digestate use and promotion
2. Economic aspects at farmer level
    - Installation and maintenance costs
    - Availability of family labor for digester operation
3. Sociocultural aspects
    - Awareness, interest, or motivation for biogas investment or operation, specifically for the use of digestate
    - Inertia toward change and new technology
    - Gender aspects
4. Institutional aspects
    - Role and responsibility of the Ministry of Agriculture and/or Livestock; integration of biodigesters in agriculture programs and/or extension services
    - Government support; renewable energy/biogas policies
    - Involvement of private sector
    - Availability of (micro-)credit
    - Availability of information on biogas technology, including the benefits of digestate for crop cultivation/the agriculture sector
5. Operationally relevant project interventions
    - Technical assistance
    - Investments (considering best ways to avoid overpricing of biodigesters); provision of credit or subsidies; innovative financing mechanisms (e.g., pay-as-you-go schemes)
    - Aimed at developing a biodigester market in the targeted area

The abovementioned elements were used as an overarching framework for the detailed description of the design of each biogas program.

Stakeholder interviews

To evaluate the effectiveness and sustainability of the biogas programs, as well as identify lessons learned, a range of key stakeholders was interviewed (Annex 2):

1. Biogas program implementers (e.g., SimGas, SNV, Agronomes et Vétérinaires Sans Frontières)
2. Funding agencies (e.g., Hivos, World Bank, International Fund for Agricultural Development, African Development Bank), MFIs, and banks
3. Biogas companies, including technical staff
4. Beneficiaries (farmers, disaggregated by gender and youth)
5. Policy makers (from the Ministries of Agriculture, Environment, and Energy)

Stakeholders were interviewed to discuss the program design, barriers to adoption (reflecting on technical, economic, sociocultural, and institutional aspects and project interventions as reported in literature), effectiveness and sustainability of the biogas program, and lessons learned. Indicative criteria included:

1. Effectiveness
    - To what extent were the objectives achieved/likely to be achieved?
    - What were the major factors influencing the achievement or nonachievement of objectives? How did the agriculture sector play a role?
2. Sustainability
    - To what extent did the benefits of the program continue after donor funding ceased?
    - What were the major factors that influenced the program's sustainability?
3. Lessons learned
    - How could the achievement or nonachievement of objectives be improved/overcome?
    - What impact/effect could the integration of biodigesters in agriculture programs/extension services have?
    - How could the program achieve a more sustainable impact?

Questionnaires for the semi-structured interviews are provided in Annex 3.

Data analysis

The design of each biogas program is described in detail using the elements elaborated in section 3.1.

Results of the stakeholder interviews were analyzed using thematic content analysis: results were coded and clustered according to themes. Adoption barriers as reported in literature were used to categorize stakeholder responses.

Triangulation was employed to compare clustered responses with adoption barriers, success factors, and lessons learned as reported in the literature. Data analysis was also used to verify if certain issues were not of relevance to the selected biogas programs and why, in order to identify and evaluate their relative importance.

Development of recommendations

The consolidation of lessons learned and recommendations for integrating biodigesters into agriculture programs constituted the key element of this assignment. Specific attention was thus paid to lessons learned in implementation of biogas programs. Furthermore, criteria that could stimulate the creation of a biodigester market were taken into consideration.

Identification of lessons learned was based on phase 1 and 2 of the three-phase methodology. As an additional activity, the identified lessons learned were discussed with biogas program implementers (as a feedback loop) as well as with the World Bank team.

It is expected that the findings and recommendations will also be of interest to other development banks, development partners, and private investors. An explicit differentiation was made whether proposed investments have a public or private good character.

6.2. ANNEX 2 STAKEHOLDERS INTERVIEWED

Burkina Faso

Name	Organization	Role
Mr. Xavier Bambara	PNB-BF	Program Coordinator
Mr. Jan Lam	SNV Burkina Faso	Senior Advisor Biogas
Mr. Serge Somda	PNB-BF	Extension Officer
Ms. Dothié Soma	PNB-BF	Private Sector Development and Microfinance Officer
Mr. Moussa Ouedraogo	PNB-BF	Extension Assistant
Mr. Martin van Dam	SNV Burkina Faso	Country Sector Lead Renewable Energy
Ouattara Fousseni	SNV Burkina Faso	Agricultural Extension
Mr. Sylvain Thiombiano	Farmer in Bouassa	Client farmer
Mr. Adama Traore	UCEC/Sahel – Union des caisses d'epargne et de credit du sahel Rencontre GRAINE	Microfinance institute
Ms. Eléonore Gyebre	GRAINE SARL	Microfinance institute
Ms. Assétou Koutou-Kafando	Farmer in Boucle de Mouhoun	Client farmer who sells compost from digester
Mr. Lamine Quedraogo	Ministry of Environment	Director General of Green Economy and CC
Mr. Batiene Pohcarfe	Ministry of Environment	Director General of Business Development and Green Investments
Mr. Etienne	Farmer in Leo, Sissili	Client farmer
Mr. Rosmane	Farmer in Leo, Sissili	Client farmer
Mr. Mamadou	Ministry of Energy	Director Renewable Energy
Ms. Zemde Zalissa	Leo BCE	Call Center Agent
Ms. Aschlet Niangao	Chargée de Mission Sociale, Nununa Shea Butter	PMO
N/A	Biodigester Construction Enterprise (Cooperative)	Mason
Group of farmers	Farmers in Village	Four neighbors who jointly decided to adopt biodigesters on their farms
N/A	Biodigester Construction Enterprise	Owner of a BCE
Mr. Adama Savadogo	Ministry of Agriculture	General Director of Vegetable Productions

Mr. Abdoulaye Sereme	Prime Ministry	Chef du Département de l'Agriculture
Mr. Bamory Ouattara	Prime Ministry	Secrétaire Général

Ethiopia

Name	Organization	Role
Saroj Rai	SNV	Team Leader Biogas Program
Aster Haile	SNV	Senior Expert Implementation
Melis Teka	SNV	Senior Institutional Development Expert, Deputy Team Leader
Mekonnen Mekuria	SNV	Bioslurry (digestate) Value Chain Advisor
Melkamu Dame	SNV	Credit/MFI expert
Asresie Hassen Seydu	SNV	Biogas technology expert
Temesgen Tefera	NBPE	Manager NBPE
Eyob Aguma Ayana	World Bank Ethiopia	Operations Officer Energy Practice
Ob. Tefera Tesfaye	Oromia Credit & Saving SC (OCSSCO)	Deputy Executive, Managing Director, Operation
Elias Asfaw	Development Bank of Ethiopia	Energy Coordination Team Manager
Fantaye Kassahun Bayou	RBPCU	Program Manager Amhara Program Coordination Unit
Kassahun Emagnew		Farmer in Amhara region
Temesgen Chalachew		Farmer in Amhara region
Adebabay Yitaieh		Mason in Amhara region (Bahir Dar)
Ashebire Alemie		Woreda Energy Expert
Getu Alemayehu	GM Clean Energy and Fuel Efficient Technology Developer and Disseminator Plc.	Chief Engineer and General Manager
Abrham Mengesha Birkie	Amhara Water Irrigation & Energy Development Bureau	Deputy Head

Kenya

Name	Organization	Role
Bert van Nieuwenhuizen	SNV	Chief Technical Advisor – Africa Biogas Partnership Programme
Jean Marc Sika	Hivos	ABPP Fund / Sustainable Food / Renewable Energy Programme Development Manager in East Africa
Kevin Kinusu	Kenya Biogas Program	Program Manager
John Maina	Ministry of Energy	Senior Assistant Director
Dan Githinji Ndiragu	Ministry of Energy	Director – Bioenergy
Paul Kiama	Taifa SACCO	Research and Development Manager
Jane Macharia	Taifa SACCO	Credit Officer – Nyeri
Catherine Faragu	Taifa SACCO	Credit Officer – Ndaragua
David Mwangi	Taifa SACCO	Credit officer
Musungu Wycliffe	Biogas Stakeholder Network	Vice Chair
Andrew Wamanya	Biogas Stakeholder Network	Member
Lydia Omwenga	Biogas Stakeholder Network	Member
Dominic Wanjihia	Biogas International Ltd	CEO, supplier of the Flexi Biogas system
Joseph Kuria	Centre for Innovation Development Solution	BCE
Charles Ngure Mwangi	Kubi Enterprises	BCE
Amos Nguru	Afrisol Ltd	BCE
Eng. David Kuria Njoroge	Green Action Network Ltd	BCE
Carlette Chepgeno	Sistema.Bio	Marketing Manager
Cerdic Todwell	Sistema.Bio	Technical Head
Francis Githinji Mwangi		Farmer
Ron Yariv	Amiran Kenya Ltd (Home Biogas)	Business Development Manager
Roger Frank	Biogas Finance Africa Ltd	Board Member/Consultant
James Mugo	KBP	BESP (Biogas Extension Service Provider)
Paul Kiama	Independent	Mason

6.3. ANNEX 3 QUESTIONNAIRES

Questionnaire for biogas program implementer and funding agencies

Nr	Category
1	Name, institution, contact details
2	Role in the biogas program
Biogas program design	
3	What were/are the objectives of the biogas program? Include e.g., number of technicians trained or business proposals developed
4	Have the objectives during the implementation of the biogas program changed and if so, why and how?
5	What was/is the definition of 'biogas adoption' for the program? (number of digesters installed/constructed, daily feeding, daily use biogas for cooking, use of digestate as fertilizer, measure of daily biogas production)
6	How is the program setup, and how does it consider the following aspects: • Technical • Economic • Socio-cultural • Institutional aspect • Operationally relevant project interventions
7	Has the program setup changed over the course of implementation of the program? If so, why and how?
Effectiveness	
8	Have you implemented a biogas program before? (E.g., were you involved in a previous phase of the biogas program?)
9	Has the previous (phase of the) program achieved its objectives e.g., with respect to: • Number of biogas digesters adopted • Reduced usage of fuelwood and harmful modern fuels • Increased household incomes
10	What factors contributed to achieving the objectives?
11	What were the adoption barriers? *Differentiate barriers according to categories mentioned in literature* • Technical • Economic • Socio-cultural • Institutional aspects • Project interventions

12	Looking at the list of adoption barriers as reported in literature, what additional barriers may have played a role in the adoption of biogas digesters? *Go through the list of barriers mentioned in literature* • Technical • Economic • Socio-cultural • Institutional aspects • Project interventions
13	Will the current program achieve its objectives and why? What lessons from the previous phase have been incorporated in the current program?
Sustainability	
14	How is sustainability defined?
15	To what extent are biogas digester still being used for gas production (even after external funding stopped)?
16	How many households stopped using the biogas digesters (after initial adoption) and what were the major reasons?
	How sustainable are the biogas digester (maintenance, spare parts, repairs)?
17	Are there service provider that have developed as a result of the program, and do they still continue provision of their services?
18	Has an independent biogas digester market resulted from the program? Was there a spread of the biogas digester technology due to the project?
Lessons learned and recommendations	
19	How could the achievement of program objectives be improved?
20	How could the sustainability of the program be improved?
21	How could the program ensure that households who require biogas, can get access to biogas? E.g., biogas promotion, linkage to companies, financial services, etc.
22	How could the program favor the establishment of biogas digester companies, support business proposal development and contribute to an independent biogas market/sector?
23	What interventions are possible to address the above mentioned adoption barriers?
24	What recommendations would you give for future biogas programs (Program design, targeting…)

Questionnaire for finance institutions

Nr	Category
1	Name, institution, contact details
2	Role in the biogas program
3	As a finance institution, what are your objectives in the biogas program?
4	How long have you been involved in the biogas program?

5	What is your experience in financing biogas digester?
6	Profile: what does the finance institution do?
7	How many biogas digester have you financed in the last year?
8	What can be done to increase the number biogas units financed by your institution?
9	Does the institution have the capacity to promote and increase uptake of biogas finance without the intervention of the program?
10	What can be done by other partner to increase uptake of finance for biogas?
Biogas program	
11	What are the objectives of the biogas program?
12	Have the objectives been achieved during earlier phases of the program?
13	Have the objectives during the implementation of the biogas program changed and if so, why and how?
14	What factors positively contribute to achieving the program objectives?
15	What were and/or are barriers to adoption?
16	What additional barriers may play a role? (refer to list of barriers as mentioned in literature)
17	Will the current programs achieve ist objectives?
18	How could the success of the program be improved (in terms of objectives and sustainability (functionality))?
19	What is needed to promote biogas digester in Ethiopia?
20	What role do you see for public and private sector in the promotion of biogas digester?
21	What can you as financial institution do to contribute to biogas digester promotion?
22	What recommendations could you give for future biogas programs?

Questionnaire for private biogas companies

Nr	Category
1	Name, institution, contact details
2	Since when did you start working with biogas digester? Why, what interests you in biogas?
3	What is your aim?
4	How many biogas units have you installed during the last year?

5	With your current capacity, what is the number of biogas digester that you can deliver per month?
6	Would you like to scale up your operations?
7	What does your company/do you need to be able to scale up operations and reach more clients?
8	What potential/opportunities do you see for biogas in your country?
Adoption	
9	What factors contribute to the wide-scale adoption of biogas digesters? Technical • Economic • Socio-cultural • Institutional aspects • Project interventions
10	What are barriers to the wide-scale adoption of biogdigesters? Differentiate barriers according to categories mentioned in literature • Technical • Economic • Socio-cultural • Institutional aspects • Project interventions
Sustainability	
11	To what extent are biogas digester still being used for gas production?
12	How sustainable are biogas digester (maintenance, spare parts, repairs)?
Lessons learned and recommendations	
13	What interventions are possible to address the above mentioned adoption barriers?
14	What is needed to promote biogas digester?
15	What role do you see for the public and private sector in the promotion of biogas digester?
16	What can you do to contribute to the promotion of biogas digester/renewable energy?
17	What recommendations would you give for future biogas programs? (Program design, targeting…)

Questionnaire for end users (“beneficiaries”)

Nr	Category
1	Name, contact details
2	How/by whom was biogas first introduced to you?
3	What type and size of biogas digester do you own?

4	When was the biogas digester installed?
5	How long have you been actively using biogas?
6	What were the major reasons for adopting the biogas technology?
7	Who in the household decided to adopt a biogas digester?
8	Are you still engaged in biogas production? If no, why not?
9	Who in the household operates and maintains the digester?
10	What do you use the biogas for?
11	What was the source of initial capital for construction of the biogas plant? (own savings, NGO support/subsidy, government support, cost sharing with NGO or government, “pay as you go”)
12	If credit, then what type of credit do you have?
13	Do you have access to technical services (repair and maintenance) for your biogas unit?
14	If yes, who provides these services? And how does it work? (e.g., who calls the service provider, how quickly are services delivered, who pays, etc)
15	Are there any challenges you face in operating the biogas plant?
16	What were your initial expectations, before the biogas digester was installed? Have these expectations been met?
17	What are the main benefits of biogas for you and your family? (e.g., the gas, slurry…)
18	Would you recommend biogas digester to others e.g., your neighbours or relatives?
19	What can be improved on biogas digester? E.g., technology, applicability of biogas…
20	In your view, how can biogas adoption and utilization be promoted in your area and country?
SNV program involvement	
21	How long have you been involved in the SNV program?
22	What contribution has the program made to your biogas digester?
23	What can/should the program do differently to enhance adoption of biogas in your area?

Questionnaire for policy makers

Nr	Category
1	Name, institution, contact details
2	Role in the biogas sector

3	What is your experience in/with biogas?
4	What potential do you see for biogas in your country?
5	What policies exist that are of relevance/support biogas or renewable energy?
6	If there are no current policies existing for biogas, are there efforts being undertaken for policy development?
7	How does or can agriculture and energy policy support development of the biogas sector?
8	Is there a regulatory framework for the biogas sector? E.g., to ensure quality biogas digester?
Adoption	
9	What factors contribute to the wide-scale adoption of biogas digesters? • Technical • Economic • Socio-cultural • Institutional aspects • Project interventions
10	What are barriers to the wide-scale adoption of biogdigesters? *Differentiate barriers according to categories mentioned in literature* • Technical • Economic • Socio-cultural • Institutional aspects • Project interventions
Sustainability	
11	To what extent are biogas digester still being used for gas production?
12	How sustainable are biogas digester (maintenance, spare parts, repairs)?
Lessons learned and recommendations	
13	What interventions are possible to address the above mentioned adoption barriers?
14	What is needed to promote biogas digester?
15	What role do you see for the public and private sector in the promotion of biogas digester?
16	What can you do to contribute to the promotion of biogas digester/renewable energy?
17	What recommendations would you give for future biogas programs? (*Program design, targeting…*)

6.4. ANNEX 4 POTENTIAL DEMAND FOR BIOGAS IN ETHIOPIA

Table A4 1. Criteria used and results of the feasibility study in Amhara, Oromia, Tigray, and SNPPR regions

	Condition	Score	*Conditions for large-scale dissemination of domestic biogas in Ethiopia* Remark
Technical	Even daily temperatures over 20°C throughout the year	++	Average maximum temperatures range in the 20s throughout the year. On the plateau, however, night temperatures may drop to 10°C or slightly lower during the rainy season
	At least 20kg of fresh animal dung available per plant per day	++	As argued earlier, under the current holding regime sedentary farmers would need at least 4 cattle. Large parts of the plateau have an average cattle holding of 4 or more per household.
	Availability of water required to mix with fresh dung in a 1:1 ratio	+/-	Water availability is very area dependent, and in most parts of Ethiopia recurrent droughts have to be taken in consideration.
	Sufficient space for biogas plant in the compound of potential users	++	Compound space is not an issue in rural areas; farmers have yards of reasonable size.
	History of proper performing biogas installations	+/-	60% non-functioning is not a good track record, but up to 750 plants nation wide is not a large amount either.
Financial	Traditional practice of using of organic fertilizer	+	Traditionally, dung is used as fertilizer. Unfortunately, energy shortage increasingly force households to use dung as energy source instead
	Scarcity of traditional cooking fuels like firewood	++	Fuelwood is scarce to the extent that its use is considered a luxury in large parts of the country
	Potential users have access to credit	+	All visited regions have good, albeit recent, micro credit facilities. There is, however, no experience yet with biogas credit
	Livestock farming is the main source of income for potential households	++	Farming integrates cropping and livestock. Hence, livestock may not be the main source of income, but it is an indispensable part of it
Social	Role of women in domestic decision-making process and life	– –	Traditionally, domestic decision making is male skewed. The decision for an investment in a biogas installation would definitely be within the male domain.
	Biogas plant can be integrated into normal working routine at the farm	++	In view of the integrated farming system, biogas will fit seamlessly in most situations in the highlands, where cattle are night-stabled.
	Awareness of effects of biogas technology among potential users	-	In view of the low penetration of new technologies in general and biogas in particular, many farmers may not be very aware
	Willingness among potential users to attach a toilet to the plant	+/-	Handling (products of) night soil definitely is a sensitive issue. However, there are some good examples.
Institutional	Political will of the Government to support a national biogas programme	+	At REDPC and BoE level, the political will is certainly there. The MoFED and BoFEDs, however, have not been consulted in this detail yet
	Willingness of (potential) stakeholders to get engaged in biogas programme	++	Both from government side (REPDC, BoEs, BoAs) as well as NGO side (UNDP-GEF, Selam, RNE, SNV-Ethiopia) the team met with considerable enthusiasm.
	Availability of organizations having access to potential users	+	The government's agricultural extension network reaches down to kebele level, but habitats are much dispersed.

Score	*Condition*
++	*Fully met*
+	*Met*
+/-	*Doubtful*
-	*Not yet met*
--	*Falls short*

Source: Eshete, Sonder, and ter Heegde 2006.

6.5. ANNEX 5 DESCRIPTION OF THE NBPE+

Specific objectives of the National Dissemination Scale-Up Program of Ethiopia (NBPE+) include to:

1. 1Provide 180,000 rural people with biogas as a clean energy for cooking and bioslurry as a high-value fertilizer from biodigesters with investment incentives;
2. Improve affordability of biodigesters and provide a pro-poor orientation toward female-headed and other disadvantaged families;
3. Expedite sector capacity development for a sustainable domestic biodigester sector with private sector development and engagement of other partners to fill in the capacity gap;
4. Further improve the products, quality, and product options, including introduction of a new biodigester for domestic and nondomestic purposes and appliances or accessories;
5. Further develop the institutional and policy framework for the domestic biogas sector.

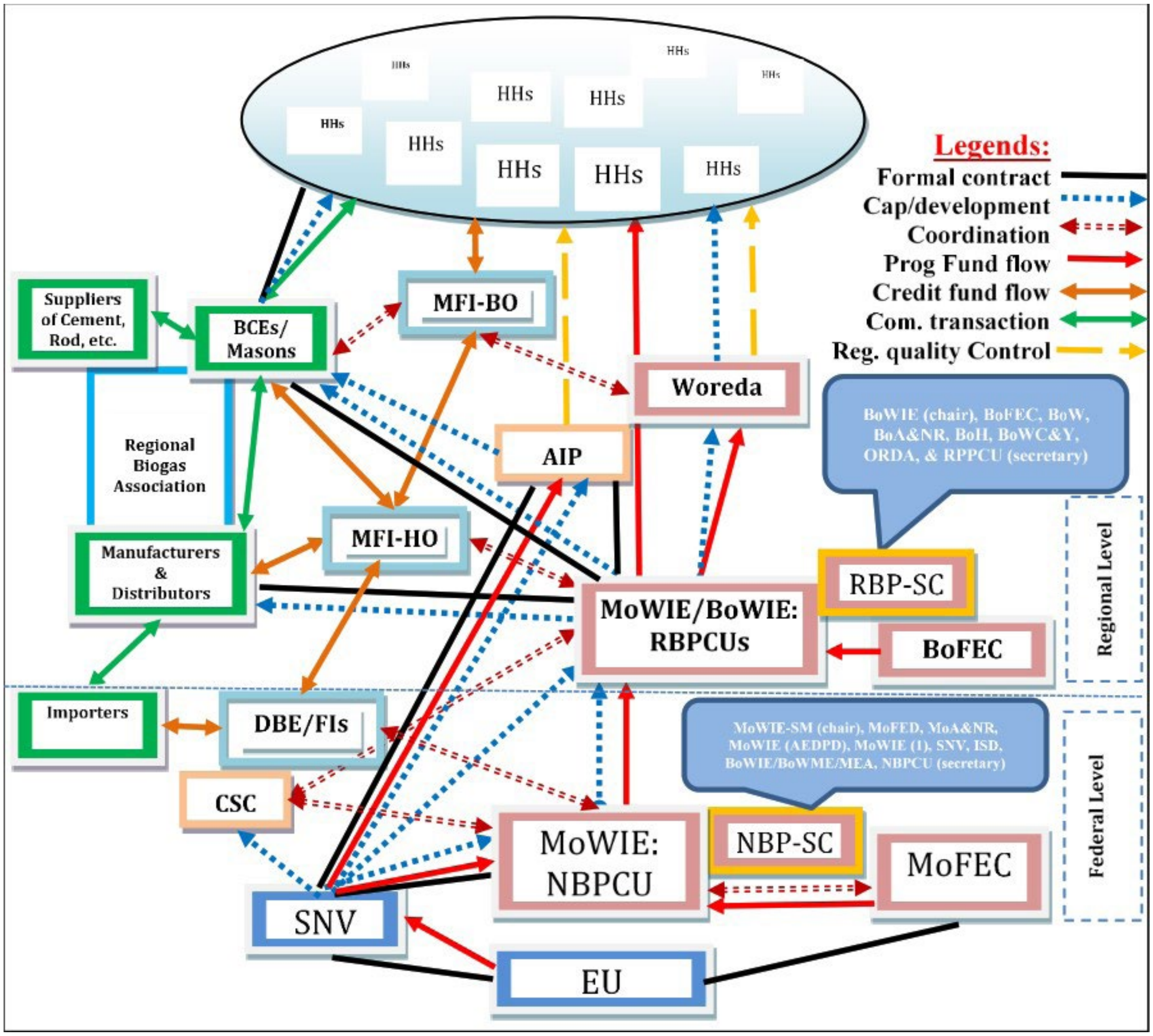
To achieve these objectives, the main program activities include:

1. Promotion of biodigesters and multiple benefits (including digestate) among rural farmers; provision of investment subsidies for end users (ETB 7,000 ≈ 30 percent of total investment), after-sale service, quality control, and monitoring;
2. Improvement of access to credit for biogas users; development and implementation of strategies for improved gender balance; and pro-poor orientation of the program;
3. Private sector development: training and capacity building, licensing of biogas construction enterprises (BCEs), and introduction of Alternative Implementing Partners (AIP) to take up responsibilities on quality management (until private sector is capable of doing so);
4. Introduction, testing (piloting), and standardization of biodigester designs (including prefabricated ones), appliances (e.g., injera stoves), and accessories;
5. Support for a national institutional framework, outlining roles and responsibilities of different institutions and at different levels, and support for a policy dialogue mechanism.

Institutional setup

Similar to the NBPE-I and NBPE-II, NBPE+ is set up as a public–private partnership at all levels (Figure A5.1). An overview of key implementing partners and their roles and responsibilities is provided in Table A5.1.

Figure A5 1. Institutional setup of the NBPE+



Source: SNV personal communication 2018.

Table A5 1. Implementing partners of the NBPE+ and their key roles and responsibilities

Implementing partner	Roles and responsibilities
SNV	Overall program management • Regular program management functions, including preparatory and closure-related activities • Planning, budgeting, monitoring and evaluation, reporting, and reviews • Fund management (European Union fund part) and Government of Ethiopia/donor compliance • Procurement of infrastructure for SNV and services (studies and surveys) • Compliance-related activities Quality assurance • Development and enforcement of quality assurance systems and tools • Quality/functionality monitoring directly/indirectly, including through Biogas Users' Survey Technical assistance • Capacity-development support in areas of program management, institutional and policy matters, private sector, access to credit, and bioslurry promotion • Direct implementation of pilot activities on new products and systems development through piloting Implementation support • Closely working with RBPCUs and others for implementation support • Advisory services for capacity and system improvement/enforcement • Facilitation in areas of partnership, innovations, etc.
Ministry of Water, Irrigation and Electricity (MoWIE)	Program alignment, hosting, and coordination • Aligns the program with national policies/strategies • Hosts the program at national level with enabling environment • Establishes and chairs program Steering Committee (SC) • Coordinates at national level and with regions, through SC and other channels Management oversight and support • Regular management oversight and support to NBPCU through the NBPE Manager • Resource (financial, human, etc.) management oversight and support • Periodic performance and program progress monitoring and review

National Steering Committee	Policy and strategic direction • Provides directives, guidance, and policy/strategic discussion for aligning the program with national policies and strategies High-level coordination • Helps coordination through the members or other channels for resolving issues at the highest level • Helps in coordination between federal and regional levels for consistency/efficiency/effectiveness of implementation Overall oversight, monitoring, and supervision • Endorses the annual plan and budget and progress reports • Approves principles or premises on matters that have direct or wider financial and/or administrative implications
National Biogas Program Coordination Unit (NBPCU)	Regular program management on behalf of the Government of Ethiopia • Planning, budgeting, monitoring and evaluation, reporting, and reviews • Financial management and channeling to regions • Developing and enforcing national program frameworks, guidelines, and tools • Coordination at national level and with regions Other program management functions • Aligning with policies/strategies and handling policy issues • Secretariat of Steering Committee and follow-up decisions • Secretariat or hosting Technical Committee and other committees • Procurement of vehicles and computers for NBPCU and regions Quality assurance and database management • Product standardization, and development and enforcement of quality control systems and tools • Collection and maintenance of national database on biodigester programs • Quality and functionality monitoring, including through the Customer Support Centre (CSC) Capacity development and backstopping • Capacity backstopping in areas of program management, technical training, creating institutional linkages for access to credit or bioslurry promotion, etc. • Promoting learning/sharing among regions and from outside
Bureau of Water, Irrigation and Electricity (BoWIE)	Program alignment, hosting, and coordination • Aligns the program with region's policies/strategies • Hosts the program at regional level with enabling environment • Establishes and chairs regional Steering Committee • Coordinates with MoWIE and regional government agencies through the Steering Committee and other channels Management oversight and support • Regular management oversight and support to RBPCU through the RBPCU Manager/Coordinator • Resource management oversight and support in areas of financial, human resources, etc. • Periodic performance and program progress monitoring and review

Regional steering committee	Policy and strategic direction • Provides directives and guidance for aligning the program with regional policies and strategies • Discusses to resolve any policy or strategy alignment issues at regional/federal level and resolves them or raises to right level High-level coordination • Helps in coordination between the regional level government and other stakeholders (e.g., MFIs and NGOs) for improved cooperation and collaboration in implementation • Helps in coordination through the members or other channels for resolving issues at the regional level • Helps in coordination between federal and regional levels for consistency/efficiency/effectiveness of implementation
Regional Biogas Program Coordination Unit (RBPCU)	Program management functions • Planning, budgeting, monitoring and evaluation, reporting, and reviews • Woreda selection and target setting • Coordination/facilitation with NBPCU and SNV and at regional level • Enforcement of program frameworks, guidelines, and tools • Secretariat of regional Steering Committee and follow-up decisions • Aligning with policies/strategies and handling policy issues Quality assurance and database management • Quality control/monitoring through quality control systems/tools • Accreditation of BCEs/masons and appliance/accessory manufacturers/suppliers using the Policy and Strategic Direction framework • Quality/functionality monitoring, directly and through woredas • Documentation for investment incentive and reporting to NBPCU Capacity and partnership development • Training/capacity development for Woreda Energy Offices • Private sector (masons, BCEs, and others) • Partnership development with other relevant stakeholders like Bureau of Agriculture and Natural Resources and MFIs Actual implementation • Awareness creation/promotion among communities/institutions • Piloting/demonstration of promotional/extension services for mainstreaming to partners’ activities or systems • Payment investment incentive to end users through BCEs or woredas with proper verification and documentation of installation
Woreda (district)	Partnership development • Partnership development with government and others, working in areas like agriculture or livestock and with MFIs • Actual implementation • Support BCEs/masons in awareness creation/promotion among end users/institutions • Support to BCEs/masons in demand generation, site selection, sales agreement, and end user training • Quality control with use of guidelines and tools and verification of quality and digester system completeness • Data collection, including through use of mobile phone apps • Documentation for investment incentive and reporting to RBPCU

Biogas Construction Enterprises/Masons	Partnership development • Partnership development with government and others working in areas like agriculture or livestock and with MFIs • Actual implementation • Promotion, demand collection, site selection, sales agreement, and end user preconstruction training • Construction/installation, commissioning, and user training • Warranty card and after-sale service • Internal quality control with use of guidelines and tools and verification of quality and digester system completeness • Also, if not now, then in future: data collection, including through use of mobile phone apps; and documentation for investment incentives and reporting to RBPCU
Alternative Implementation Partner (AIP)	Capacity development support to RBPCU • Developing capacities of BCEs and woredas • Orientation of relevant MFI staff for credit provision Actual implementation support to RBPCU • Support woredas and masons/BCEs in promotional activities, particularly in new woredas • Regular quality control and monitoring in the field, based on random samples from NBPCU • Collection, quality control, and compilation of documents received from BCEs regarding new constructions and after-sale service • Data entry and report generation on behalf of RBPCU

Source: SNV personal communication 2018.

Fund flow mechanism and financial incentives

The total EU (European Union) grant budget for the program is EUR 22.9 million. The Government of Ethiopia contributes EUR 2 million to partially finance the investment subsidy for end users. Of the total budget, approximately 35 percent is used for the investment subsidy for end users. General program support takes up 20 percent, while 23 percent is used for human resources. Table A5.2 provides an overview of the program budget.

The EU budget flows through SNV to the Ministry (MoWIE) and regional bureaus (BoWIEs). The investment subsidy is provided by the Woreda Energy Office and/or directly to BCEs or masons.

Financial incentives

The subsidy is used to finance masons for biodigester (fixed dome) construction. Irrespective of the size of the digester, the mason receives a lump-sum payment. A small fee is deducted from the payment to the mason to enforce quality control, act as a guarantee, and thereby ensure functionality up to two years after construction. Materials for construction of the digester (e.g., cement) are organized by end users themselves to enable a low-cost digester.

Table A5 2. Summary of the NPBE+ total budget

Items	Total budget (EUR)	Relative budget (%)
1. Human resources	5,377,157	23.5
2. Travel	83,274	0.4
3. Equipment and supplies	261,703	1.1
4. Local office	932,775	4.1
5. Other costs, services	515,804	2.3
6. Others		0.0
7. Investment incentives	8,052,628	35.2
8. Program support (general)[24]	4,696,354	20.6
9. Program support for access to credit	566,230	0.2
10. Subtotal, direct eligible costs	20,485,924	89.7
11. Indirect costs (SNV overhead)	1,434,015	6.3

12. Subtotal	21,919,939	95.9
13. Contingency 4.54% of 7 (maximum 5%)	930,061	4.1
14. Total eligible costs	22,850,000	100
15. Taxes and in-kind contribution	-	
16. Total accepted costs (= total eligible costs)	22,850,000	100

Source: NBPE+ Description of the Action 2017.

24 Sizable and "results-based financing" budget for program support activities like promotion, training, and quality control that are directly related to the installation (quantity) and quality.

6.6. ANNEX 6 KBP'S CODE OF CONDUCT

Glossary:

a). Kenya Biogas Program-(KBP)

b). Biogas Masons- (BMs),

c). Biogas Construction Enterprises -(BCEs)

d). Service Providers- (SPs)

e). Contractor –BMs/BCEs/Companies/Appliance dealers f) Code of Conduct -(CoC)

f). Customer Service Centre-CSC

Purpose

The purpose of the Code of Conduct (CoC) is to promote and protect the interests of all Biogas stakeholdersincluding Kenya Biogas Program by providing guidelines of good, ethical conduct in provision of services and practice. The CoC also outlines the obligations of parties to this agreement.

Our Vision

Green kitchens and organic farms for all

Our Mission

To facilitate economic viability and sustainability of bio-digester sector in Kenya

Core Values

1. Professionalism
2. Excellence
3. Accountability
4. Knowledge

Obligations under the Code

All sector partners have responsibilities under the CoC. For the CoC to be mutually beneficial, all partners must take their respective duties seriously, and communicate with the other party constructively and on a consistent basis.

BMs, BCEs, appliance dealers or SPs found in violation of the CoC will be subject to the disciplinary procedures which include, but are not limited to, charges being filed and the possibility of repair surcharges, suspension, and/or expulsion from the KBP programme. Every BM, BCE and appliance dealer working under the KBP programme in Kenya shall obtain a copy of the code and sign an agreement to strictly adhere to it.

Kenya Biogas Program shall;

a). KBP shall equip contractors with necessary knowledge and skills in construction, operation, maintenance of bio-digesters plants as well as bio-slurry use

b). Train and certify Contractors on new biogas technologies in the market

c). Train Contractors on Taroworks reporting procedures as well as actual data collection

d). Share leads and market linkages from CSC and hubs.

e). Facilitate contractors through results-based commission to conduct After Sales Services within the stipulated service timelines.

f). Share feedback gathered from CSC/Clients and also complaints documented in grievance mechanism tool

g). Participate in and support policy formulation and development in the biogas sector through lobbying, resource mobilization, and advocacy

h). Facilitate market linkages for contractors to showcase their products and services

i). Provide technical support on organizational development.

Contractors shall:

a). Apply knowledge, skills and expertise in offering services to biogas clients

b). Train all clients on operation and maintenance, bio-slurry use and management.

c). Conduct after Sales Services to all plants as prescribed by the program. Failure to comply with terms and conditions of After Sales Services procedure will result in forfeiture of the respective commission

d). Submit timely, complete, accurate and consistent reports through the use of the Mobile App (TARO) to KBP in line with the agreed upon targets/ deliverables e). Ensure supply of quality appliances and put in place a product warranty scheme.

f). Provide adequate product information to stakeholders

g). Ensure fair pricing policies are adhered to improve affordability

h). Respond to customer's complaints promptly as prescribed in operations processes and procedure manual

i). Support KBP agents/partners during plant quality verification visits and other program activities as may be required from time to time

Principles governing the conduct of parties

For the biogas sector to continue to thrive and be of value to all stakeholders, all parties in the sector must act in utmost good faith with each other and in the best interest of the contract. Therefore all sector players shall;

1. Behave equitably, honestly, and transparently
2. Discharge duties and obligations in a timely manner and with a high degree of integrity
3. Comply with all applicable laws, legislation, and associated regulations
4. Avoid conflict of interest
5. Not maliciously or recklessly injure or attempt to injure the reputation of another party

Conduct of the KBP staff

The Kenya biogas programme staffs are responsible for communicating the KBP-Kenya CoC to all BMs, BCEs, SPs and other sector partners, ensuring they are fully compliant.

To achieve the goals of the CoC, the KBP-Ken programme staff shall ensure that:

a). BMs, BCEs, Appliance dealers and SPs shall apply their knowledge, skills, and experience diligently on the job.

b). BMs, BCEs, Appliance dealers and SPs shall make every effort to upgrade their skills on a regular basis.

c). BMs, BCEs, Appliance dealers and SPs, especially those with extensive experience in the field, shall convey their knowledge and skills of the biogas trade to their colleagues to strengthen the overall value of workmanship under the KBP programme as well as to encourage teamwork.

d). BMs, BCEs, Appliance dealers and SPs abide by the zero tolerance policy for legal, commercial or technical malpractice.

e). BMs, BCEs, Appliance dealers and SPs perform consistently productive work, keep idle time to a minimum, and make every effort to eliminate unnecessary disruptions on the job.

f). BMs, BCEs, Appliance dealers and SPs respect the biogas plants as a property of the client, and are fully aware that any forms of destruction are not tolerated.

The KBP-Kenya programme team will approach BMs, BCEs, Appliance and/or SPs who demonstrate bad work habits, advise them of their responsibilities as partners in the KBP, and provide guidance and direction.

Conduct of the Contractor

The contractor or his employees should;

a). Act professionally

b). Undertake the contract with focus on customer satisfaction by complying with and meeting their requirements

c). Aim to observe all statutory and contractual obligations fully and timeously e.g., conditions of employment, occupational health and safety, training, fiscal matters etc.

d). Not attempt to influence the judgement, or actions, of partners in the sector by inducement of any nature

e). Appoint subcontractors in a fair, unbiased manner, and using written contracts

f). Not engage in unfair or unethical practices

g). Not make spurious claims for additional payment or time extensions to the contract

h). Not undermine the construction objectives of the Client through pursuit of selfish interests

i). Not engage in collusive practices that have direct or indirect adverse impacts on the cost of the client

j). Not entertain slowdowns or other methods to extend jobs or give rise to labour overcharges;

k). Ensuring that the proper types and quantities of tools and materials are available on the site to facilitate speedy progress;

l). Not engage in any activities that cast KBP programme partners in a negative light;

m). Not to subject another BM, BCE, appliance dealer or KBP-Kenya staff, or any other group of persons to inappropriate behaviour, harassment, or discrimination

n). Strictly adhere to the contractual obligations including siting, construction, piping, and after sales service for a period not less than one year from the date of plant commissioning.

o). Never solicit payment on any plant over and above the amount indicated in the contractual form and such amounts shall not exceed 30% of the bill of quantities excluding labour charge.

p). Ensuring that their agents take responsibility for mistakes created by management and rectify them expeditiously

q). Charge fair prices for the appliances to address affordability.

It shall be the employer's responsibility whenever their mason/agent has violated the Code of Conduct to deal with or report such violations immediately by providing KBP-Kenya with a letter detailing the alleged violation(s) and the surrounding circumstances.

Right of Association

Under the KBP programme, BMs, BCEs, appliance dealers and SPs are encouraged to associate and/or affiliate to any registered professional body in Kenya, to attend meetings and to hold any leadership offices in such associations.

Dispute Resolution Mechanism

KBP-Kenya staffs, BMs, BCEs, Appliance dealers and SPs all have obligations to respect the resolution of disputes. In the early stages of a dispute, KBP-Kenya staff will actively facilitate dialogue between parties. Similarly, BCEs, Appliance dealers should promptly address any and all problems and issues of concern as they arise. If these initial remedial actions of KBP-Kenya and/or BCEs/Appliance dealers fail to resolve the matter, the parties will pursue their respective remedies guided by applicable laws of Kenya.

Compliance

Every member will be expected to sign a compliance agreement to this code of conduct.

KBP-Kenya Code of Conduct Agreement

Hereby read and acknowledged the KBP code of conduct and agreed to abide by its stipulations as it states including any future alterations or additions to it.

For BM / BCE / Appliance Dealer/SP:	For KBP:
Name	Name
Full address	Full address
ID no	ID no
Position	Position
Tel no	Tel no
Email	Email
Signature	Signature
Date	Date

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