Africa Biogas Partnership Program: A Review of Clean Cooking Implementation through Market Development in East Africa

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Abstract

This paper analyses the Africa Biogas Partnership Program (ABPP) in Kenya, Tanzania and Uganda. ABPP was established in 2009 to promote adoption of biodigesters by rural households in sub-Saharan Africa. We use the RE-AIM framework (Reach, Effectiveness, Implementation, Adoption, Maintenance) with information from literature, internal documents, primary data from user surveys and interviews with sector stakeholders.

ABPP was implemented with the primary objective of establishing viable biodigester markets. By 2017, Kenya made most progress toward commercial viability, evidenced by market entry of companies offering prefabricated digesters and establishment of 22 marketing hubs, which link rural organizations with local construction enterprises and finance institutions. In Uganda 5 marketing hubs were established and in Tanzania 7. Between 2009 and 2017 over 27,000 households installed a biodigester, half of them in Kenya. Additional objectives include improving agricultural productivity by using bioslurry, improving health, reducing deforestation, and improving livelihoods.

Households perceive higher crop yields (84%-91% of users), reduced fuel consumption (84%-94% of users), reduced eye problems and respiratory symptoms (45%-91% of users). Benefits most appreciated are "easy cooking" and "saving time and money". Fuel consumption tests show households with biodigesters use 2.1 to 3.3 fewer tons of wood per year than similar households without biodigesters.

The ABPP case study suggests that the program has created a nascent biodigester market in East Africa. The country programs have been dynamic and adaptive, moving along the cycle of market development; however, many challenges remain. For example, while half of the adopters in Kenya exclusively use biogas for cooking, in Uganda and Tanzania fuel stacking is more prevalent, making it more difficult to achieve health and environmental objectives. In addition, high upfront cost, limited access to credit, and lack of maintenance present challenges. In 2016, 27% of biodigesters constructed between 2009 and 2013 were not working. In response, ABPP implemented call centers and launched campaigns to repair non-functioning plants. To ensure
long-term viability and increase the likelihood of achieving environmental and health goals, we suggest deeper engagement with governmental and non-governmental stakeholders and a targeted campaign promoting exclusive use.

Keywords
Biogas; Cooking fuel; Biodigesters; Adoption; Sustained use; Rural energy access

1. Introduction
Throughout East Africa, households rely heavily on solid biomass for cooking. This is particularly true in rural areas, where over 95% of households report using solid fuels as primary source of energy (ICF International, 2015). Biogas is an alternative option for households for households that have access to sufficient suitable organic feedstock (IRENA, 2017). Globally, roughly 50 million biogas systems have been installed to produce gas for cooking. The majority of these systems are in Asia, particularly China (Chen, Zhao, Ren, & Wang, 2012; Putti, Tsan, Mehta, & Kammila, 2015; Wang et al., 2016; Zuzhang, 2013) and India (IRENA, 2017; Putti et al., 2015). Approximately 300,000 biodigesters are installed in Nepal (Bajgain & Shakya, 2005; Saroj, 2012) and another 300,000 in Vietnam, Bangladesh, Cambodia, Indonesia and Pakistan (IRENA, 2017). Dissemination in Africa is still very limited. Most of the literature about use of biogas in Africa discusses its potential contribution to the well-being of its population, economic development and environmental protection, or the challenges for large-scale uptake of the technology (Amigun, Parawira, Musango, Aboyade, & S. Badmos, 2012; Lwiza, Mugisha, Walekhwa, Smith, & Balana, 2017; Mulinda, Hu, & Pan, 2013; Mwirigi et al., 2014; Nhete & Kellner, 2007; Roopnarain & Adeleke, 2017; Smith et al, 2011). This study describes the implementation of national biogas programs in three East African countries (Kenya, Tanzania and Uganda) and reviews its effectiveness and adoption and sustained use of biogas over a period of eight years (2009-2017).

1.1. Household energy in East Africa
Throughout East Africa, biomass dominates residential energy supply; large majorities use wood and charcoal as their primary cooking fuel (ICF International, 2015).¹ Fuels like LPG, ethanol, biogas, and pellet fuels burned in advanced stoves emit less pollution than unprocessed wood or charcoal.² Some of these fuels are gradually becoming more accessible in East Africa, particularly in urban settings. Access to electricity is increasing in East Africa: rapidly in Kenya and more gradually in Uganda and Tanzania. In all three countries, urban electrification rates have exceeded 50%; however, rural access remains quite low (ICF International, 2015). In some African countries, electricity is popular for cooking. For example, in Namibia and Zimbabwe over 50% of urban households cook mainly with electricity (ICF International, 2015). However, it is rare in East Africa, where

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¹ Many households use multiple fuels, but most nationally representative surveys only collect information about primary fuels.
² The WHO discourages the use of kerosene as a household fuel because pollution emissions lead to potentially harmful exposures. Therefore we omit kerosene from this list of “modern” fuels (World Health Organization, 2014).
fewer than 1% of urban households use electricity as primary source for cooking. Clean fuels like ethanol, pellets coupled with advanced gasifier stoves, and solar cookers are even less common. All have all been introduced in Kenya, Tanzania and Uganda; however, they have limited distribution and very low adoption.

1.2. Domestic biogas in Africa

According to a study in 2007 conducted by SNV-the 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 (Heegde & Sonder, 2007). The three countries we assess here showed some of the highest potentials: Tanzania - 1.8 million households, Uganda - 1.3 million households; and Kenya - 1.3 million households. Actual dissemination and use of biodigesters in Africa contrast with number of systems disseminated in Asia and high technical potential for use in Africa. By 2005, Tanzania was the only country with more than 1,000 biogas plants installed (Laramee & Davis, 2013; Nhete & Kellner, 2007).

Initial investment is a constraint for biodigester dissemination in Africa. The most common design in East Africa is based on the Chinese fixed dome digester (Mulinda et al., 2013). Because of high upfront cost, some argue that flexible balloon models should be promoted instead of fixed-dome digesters (Richter, 2014; Rota & Sehgal, 2015; Smith et al., 2011). Others argue that adoption depends on the program strategy. Household level adoption can be enhanced by an integrated program approach, including technology standardization, quality control, and integrated farming using biogas and bio-slurry (Mwirigi et al., 2014).

The “sector development” model developed by SNV in Nepal and replicated in Asia was introduced in Africa (SNV, 2009). The model’s core principle is that large-scale dissemination is driven by user- satisfaction, and product credibility, which create a feedback loop: "service-quality - user satisfaction - promotion - sector development". To create a new market, coordinated effort is needed to build supply, demand, and an enabling policy environment. The model pursues a balance between market forces and program-enforced quality management (Ghimire, 2013; SNV, 2009). Functions should be undertaken by multiple rather than single stakeholders allowing competition on the supply side, which benefits users. Additionally, successful programs quickly grow too large and complex to be run efficiently by a single actor. Lastly, coordination is needed through proper institutional arrangements.

The aforementioned studies about biogas potential in Africa and contrasting low numbers of actual dissemination and use (Heegde & Sonder, 2007; Nhete & Kellner, 2007) were discussed at the “Biogas for Better Life An African Initiative” Conference in 2007. The Initiative also discussed a number of guidelines aimed at sector development respecting market principles (Nes & Nhete, 2007). Within each country, national governments are expected to provide policy, legal and institutional frameworks while NGOs and private sector players would act as implementing agencies. A business plan presented by the Initiative concluded that with the right approach and sufficient funding, two million African households could access biogas for cooking and lighting in 10-14 years (Biogas Team,
They estimated USD 1,050 million would be needed to complement farmer investments and microcredit (assuming each unit requires USD 130-330 in subsidies and USD 200 for marketing and management). Notably, the Investment cost is nearly double the average cost in Asia (USD 530 compared with USD 300) due to higher cost of labor, raw materials, and appliances (Biogas Team, 2007).

The first national program in Africa following guidelines discussed at the Conference was launched in Rwanda. Through this program over 2,400 digesters were installed between 2007 and 2011 (Bedi et al., 2015; Landi et al., 2013), increasing to 9,850 by March 2018 (personal communication). Subsequently, in 2009, the Netherlands’ Directorate-General for International Cooperation (DGIS), part of the Ministry of Foreign Affairs, approved funding for national programs in 6 countries coordinated by the Africa Biogas Partnership Program (ABPP).

The national biogas programs in Kenya, Tanzania and Uganda function under the umbrella of the ABPP. “The overall objective of the ABPP is to contribute to the achievement of the Millennium Development Goals through the dissemination of domestic biodigesters as a local, sustainable energy source aiming at the development of a commercial, market oriented sector in selected African countries” (DGIS, Hivos, & SNV, 2008). It was established by the Ministry of Foreign Affairs of the Netherlands, providing funding, and two Dutch NGOs: the Netherlands Development Organization, SNV, providing technical assistance, and Hivos, taking care of fund management and coordination. The first phase of ABPP ran from 2009-2013; a second phase began in 2014 and will run through 2019.

This study describes the implementation of ABPP in the countries mentioned and reviews its effectiveness and adoption and sustained use of biogas using the REAIM framework (Glasgow, Vogt, & Boles, 1999) (+ Overview article in this issue). Section 2 describe research methods. Sections 3 and 4 analyze the program implementation strategy, program effectiveness and describe household adoption and sustained use of biogas in the three case-study countries, using parameters from the RE-AIM framework. Section 5 and 6 present some lessons learnt.

2. Methods, Sources and Approach

We used the RE-AIM framework tailored by the United States National Institutes of Health Implementation Science Network (NIH-ISN) to evaluate clean cooking interventions (See Appendix A), which integrates five factors i.e. Reach, Effectiveness, Implementation, Adoption, Maintenance, to analyze the implementation of ABPP in Kenya, Tanzania and Uganda (CITE INTRO PAPER). In summary, reach refers to the proportion and characteristics of the individuals participating in the intervention; effectiveness refers to the success rate of the intervention if implemented as planned; adoption is the percentage and representativeness of settings that adopt the intervention; implementation refers to the consistency and costs of delivering the intervention; and maintenance refers to the long-term sustainability at both the setting and individual levels.

3data provided by Anaclet Ndahimana, SNV Rwanda RE Sector Leader on 25 April 2018
The data collection comprised of secondary data through desk review of literature on dissemination of domestic biodigesters in Africa, extraction and analysis of household energy and livestock data in Demographic and Health Surveys and internal documents such as feasibility reports, annual reports and mid-term review reports. The internal documents were availed to the research team as two of the four authors are affiliated with Hivos an international NGO and one of the partners with SNV and the Dutch Government in the ABPP in Kenya, Uganda, Tanzania, Ethiopia and Burkina Faso. Documents provided input to assess 28 of 37 parameters from the RE-AIM framework. The secondary data were complemented with primary data from user surveys carried out by Eco-Frontier in Kenya and Uganda and by University of Dar es Salaam in Tanzania. The surveys were carried out on random samples of participants, and collected data about socioeconomic background, livestock ownership, biodigester status, fuel consumption, and user perceptions (Appendix B describes the surveys used in this analysis). User and fuel consumption surveys were carried out in compliance with the monitoring requirements set forth in the methodology for small scale household energy projects (Gold Standard, 2015), as the program has been registered by the Gold Standard to allow ABPP to earn carbon credits. Survey data are key to evaluate adoption and maintenance factors. Finally, semi-structured interviews with sector stakeholders were undertaken in November 2017 by independent researchers who are authors in the article to verify the information gathered from the desk study (see Appendix C). The interviews focused on 17 of 37 parameters from the RE-AIM framework (see Appendix A).

3. Africa Biogas Partnership Program: biogas sector development in East Africa, from market creation to market facilitation

The national biogas programs in Kenya, Tanzania and Uganda function under the umbrella of the ABPP with a common approach and funding structure. Implementation in each country is coordinated by a National Implementing Agency (NIA). In Kenya, the Federation of Agricultural Producers (KENFAP) was NIA during Phase I and the Kenya Biogas Program (KBP) is NIA for Phase II. In Tanzania, the Centre for Agricultural Mechanization and Technology (CAMARTEC), and in Uganda, Heifer International was NIA during Phase I and Biogas Solutions Uganda Ltd (BSUL) during Phase II. Technical assistance is provided by SNV. In each country a Steering Committee has been founded under leadership of the Ministry of Energy.

The program was implemented with a primary objective of establishing a sustainable and commercially viable biodigester market in each country. The in-country programs were defined by a series of specific objectives under this overarching goal, including:

- Strengthening institutions for sustainable development of the biodigester sector
- Achieving a specific number of biogas installations
- Ensure that most/all of the installed plants are operated properly in the long-term

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4. Africa Clean Energy Switch Biogas (ACES Biogas) Program of Activities was registered by the Clean Development Mechanism (CDM) in December 2012. Africa Biogas Carbon (ABC) Program of Activities was registered under the voluntary track of Gold Standard in 2016.
• Promote the use of bio-slurry
• Maximize additional benefits including improved health and living conditions in rural households, particularly of women and children; reduced deforestation and greenhouse gas emissions; rural employment opportunities

The target population consists of all rural families within the three countries that own 2 or more stabled cows. This population is part of households with technical potential, as economic factors are taken into consideration and possession of crossbreed and stabled cows. Feasibility studies suggest that roughly 500,000 households satisfy these criteria: 172,000 in Kenya, 50,000 in Uganda and 276,000 in Tanzania (ETC Group, 2007; GTZ, 2007; Winrock, 2007). Project documents set specific targets to install reliable, high quality biogas plants at 32,000 households during Phase I (2009-2013) and 54,600 households during Phase II (2014-2019) (DGIS et al., 2008; Hivos & SNV, 2013). By end of 2017, a little over 5% of the overall target population was reached. Table 1 shows targets and achievements by country.

3.1 Regulation and government policies

None of the ABPP countries in East Africa have policies in place supporting biogas except the investment subsidy in Phase I and reinstated in Tanzania in 2015 (see below). In Kenya, stoves, other appliances and prefabricated digesters may be imported tax exempt. However, interviews with biogas entrepreneurs indicated that the exemption only applies to entire shipping containers of appliances and do not benefit small enterprises. Moreover, the process to obtain duty-free status is unclear to entrepreneurs. In Tanzania and Uganda, there are no tax exemptions. Uganda’s Ministry of Energy noted that tax exemptions would unduly favor imports over national production. Through a consultation for this research, one international biodigester producer admitted that high import duties factored into their decision not to enter the Ugandan market.

3.2 Supply chain

The biodigester supply chain involves two distinct material streams. The first consists of construction materials, construction services, biogas appliances (stoves, piping, valves etc), spare parts and other information and services that are critical in the functioning and sustained use of the system. Some households also purchase biogas lamps and desulphurizers5. In the three countries, households purchasing fixed dome biodigesters are responsible for sourcing the construction materials as instructed by mason. For the prefabricated biodigesters, installers bring all the needed materials. Double burner stoves are imported from manufacturers in China (e.g Puxin, Lanneng, Wusi), although local production of Lotus III stoves is also undertaken at small scale.

The main challenge reported during our interviews with BCEs and local suppliers was that appliances (e.g. lamps and desulphurizers) are not readily available. System owners prefer the imported appliances over locally fabricated ones, but imports are in scarce supply.

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5Biogas can include a small amount of hydrogen sulphide (H2S). Removal of H2S is often required for reasons of health, safety and corrosion of equipment, including gas stoves. One supplier who imports appliances from China explained demand for desulphurizers is high.
Biogas lamps are particularly troublesome. The mantle and chimney are fragile, and when they break, they are difficult to replace. Over time, some households have opted to buy solar lamps rather than continue to use biogas lamps. Program staff no longer recommend use of biogas lamps.

The second supply chain consists of the feedstock material that must be fed into the biodigesters, which is equally critical to the success of any installation. In Kenya, Tanzania and Uganda, feedstock is mainly obtained from dairy cattle, local cattle, market swine and breeding swine. The program primarily targets households with stabled animals for easy collection of manure. Before installing a biodigester the most common manure handling methods was daily spread (ranging from 27% in Uganda to 54% in Tanzania) or storage in dry lot (34% in Kenya and 38% in Uganda). Some farmers stored manure in uncovered lagoon (17% in Uganda). In each country a minor percentage of farmers used manure for composting: 7% in Uganda, 12% in Tanzania and 16% in Kenya.

Use of bioslurry on crop fields is much more productive (except when manure was used for compost) (Bonten, Zwart, Rietra, Postma, & Haas, 2014; Groot & Bogdanski, 2013). Table 2 shows the most common feedstock used in each country. As can be seen, households fed different portions of the manure to the biodigester while the rest was used for other purposes or left as waste. Users did not report problems regarding feedstock in user surveys and interviews.

3.3. Evolution in program implementation

Phase I focused on market creation. SNV’s model (SNV, 2009) formed the base of activities in each country. During the first two years, each national program emphasized local engagement, training masons, and creating Biogas Construction Enterprises (BCEs). To promote early adoption, households initially received subsidies of about 30% of construction cost along with extensive training for use and maintenance of the biodigester and stove and the application of bioslurry. Systems included a 1-2 year guarantee on hardware. Community members received small cash incentives to bring in new clients. Quality control was enforced by making subsidy payments conditional on meeting certain standards, with compliance measured by biogas engineers employed by the national program.

As the programs matured, they have undergone several modifications. In 2011/2013 several national level functions were decentralized to subnational implementing partners and, in 2013, a results-based finance system was introduced to make payments more conditional on performance. The policy aimed to transfer marketing and supervision closer to customers to maximize the benefits of having a biodigester and speed up dissemination and market development. With the transition to Phase II in 2014, subsidies were phased out except when provided by government funding. The phase out was motivated by donor requirements as well as a belief that ABPP was ready to transition from market creation to establishment.7

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6Data from household surveys contracted by ABPP in 2014 (Kenya and Tanzania) and 2017 (Uganda).
7The term "market establishment" was used by the consultant conducting a Mid Term Evaluation Phase II in 2016 (ICCT Ltd, 2016), taken from a framework to analyze Lighting Africa.
During Phase II, ABPP shifted its focus from ‘program push’ to ‘market pull’. New incentives were introduced targeting producers and other upstream actors instead of consumers. For example, BCEs received extra motivation to provide after sales service, with payouts conditional upon confirmation of system functionality both 3 months and 12 months after completion of construction.

ABPP established Customer Support Centres (CSCs), which call new and old users to check whether they are encountering any problems. Any issues are recorded and sent to the NIA and forwarded to the relevant BCE. A quality control manager follows up to ensure that the problem is addressed. Users have also been provided with a tollfree line managed by the NIA to report any problems, which are also forwarded to the relevant BCE.

To further support adoption, ABPP introduced marketing hubs to link community based and rural organizations like dairy and coffee cooperatives with BCEs and local finance institutions. The hubs allow BCEs to identify high potential market areas and target consumers who have regular income and/or easy access to loans. This lowers marketing costs and increases efficiency. At the time fieldwork was conducted in late 2017, there were hubs 5 in Uganda, 22 in Kenya, and 7 in Tanzania.

As Phase II progressed, ABPP continued to adapt its implementation strategy in order to address persistent challenges. In particular, with subsidies removed, affordability remains a major barrier. In addition, to build a ‘market pull’ for the technology, ABPP focused more attention on the business case both for farmers and for actors in the supply chain.

3.4. Business case for households

The business case for households is determined by fuel and time savings and income generated by bioslurry. A majority of biogas users report money and time savings as a major benefit of the technology (See section 4). Benefits of bioslurry may often be more important in financial terms by generating income or reducing the cost of farm inputs (SNV, 2015; Warnars & Oppenoorth, 2014). Uses of bioslurry are discussed further in Section 4. ABPP estimate households can recover investment cost in 2-3 years. The payback period is shorter for the larger sizes, but an estimate for a 6 m3 digester in East Africa is 2.3 years, for a typical household: investment cost USD 700, annual maintenance cost USD 30, annual cost reductions USD 220 (fuel USD 120, fertilizer USD 40, food USD 60) and annual additional revenue from increased agricultural production USD 120 (Hivos, 2015).

The upfront cost of a biodigester is mentioned in project reports and interviews as a main barrier for adoption, especially after withdrawing the investment subsidy. To increase affordability, ABPP developed modified designs of fixed dome biodigester and also encouraged other models to compete with the fixed-dome. The modified design minimized the construction materials needed. For example, BSUL introduced design changes that reduced the amount of cement by 4 bags and bricks by 200, which saved approximately USD 83 (UGSh 300,000) (about 17% of the original installation cost). Similarly, the modified designs reduced construction cost in Kenya and Tanzania by near 25%. In Kenya, there are now 7 companies offering different types of ready made tubular plug flow models and fixed dome models made from heavy-duty plastic. These are all eligible for ABPP’s
“results-based” incentives. ABPP intends for this competition to benefit consumers by reducing prices.

ABPP also intends to support affordability by increasing access to finance. Three of the new entrants (Simgas, Takamoto and Biobolsa) offer in-house credit, while agreements were signed with finance institutions to help buyers acquire loans. However, financial institutions have not prioritized biodigesters and high interest rates lead to low rates of loan uptake. For example, in Kenya, just 18% of households surveyed used some type of loan to acquire their biodigester. In Tanzania and Uganda, fewer than 10% financed the biodigester with a loan.

More recently, additional measures have been taken to improve access to credit for biodigesters. For example, BSUL has made arrangements with several Savings and Credit Cooperatives (SACCOs) to provide them with funds so that the SACCOs can create finance packages specifically for biodigesters with two to four months grace period and below-market interest rates (1.5% monthly flat rate instead of 3%). Similarly, KBP has worked with dairy SACCOs to create a favorable loan package for coop members. The effects of these measures are still incipient. Many stakeholders interviewed consider that lack of access to affordable long-term finance remains a key barrier.

3.5. Business case for constructors and service providers

The creation of rural employment opportunities is one of the additional benefits pursued by the national programs. The programs primarily focus on capacity building to support local construction and maintenance of biodigesters. Masons are trained to construct biodigester and Biogas Construction Enterprises (BCEs) are formed or strengthened. At the time this research was conducted, 1,832 masons had been trained (Kenya 646, Tanzania 756 and Uganda 430). However, attrition is high and only 10 to 20% are actively engaged in constructing household biodigesters. It is difficult to make a living constructing domestic biodigesters alone. However, there are part time employment opportunities; during construction one or two unskilled workers are hired to assist each trained mason. The programs report 350 jobs in three countries in 2016-2017 (Kenya 115, Tanzania 126, Uganda 109), although not all jobs e.g. masonry may provide full time employment, plus part-time unskilled labor.

ABPP estimates that to be viable, a BCE needs to construct 10 biodigesters per month with additional cash incentives (20 without). In 2017, few BCEs met this target; however, interviews indicate that many BCEs have other businesses. In Uganda, one BCE owner mentioned that his reputation for building high quality biodigesters created other job opportunities in construction. Others tap into related markets. For example, Ecosafe in Central Uganda does about 55% of its business installing septic tanks and latrines and 45% constructing biodigesters. Other BCEs combine biogas with other energy technologies like solar installations or cookstoves (e.g. KENBI Enterprises and SCODE Ltd in Kenya).

In Phase II building a business case for credit institutions is also part of program strategy, but this does not seem to be successful. Few users receive loans for their systems because

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8Oloo Laston, MREC, Mbale; interview 15 November 2017
most micro-finance institutions and SACCOs do not perceive biodigesters as attractive investment. They have concerns about payment capacity and, because fixed-dome digesters cannot be repossessed, they have no collateral value. However, portable digesters may be more attractive to lenders.

### 3.6. The role of subsidies and incentives

ABPP has received official development assistance from the Dutch Government through DGIS and SNV during both Phase I and II, with additional co-financing from Energising Development (EnDev) during Phase II\(^9\). Donor finance and subsidies were justified by many public benefits of biogas (including health improvements, reduced deforestation and greenhouse gas emissions) and the absence of private market (DGIS et al., 2008). Subsidies were gradually withdrawn and incentives changed to transition ‘from program push to market pull’ (as mentioned before).

Staffing of NIAs and implementing partners was roughly 50 personnel per country during Phase I and 10 in Phase II. Donor commitments run through 2019. A carbon credit mechanism\(^10\) has been set up to sustain after sales services (including CSC). Beyond 2019, NIAs will likely request additional support to continue building the market for biodigesters in their respective countries. Program management sources\(^11\) justify program subsidies for activities associated with market facilitation i.e. quality control, standards, policy support, access to finance and market information (including a grading system for BCEs).

### 4. Adoption and Sustained Use of Biodigesters

#### 4.1. Adoption of biodigesters

People decide to adopt a biodigester for many different reasons. While one of the goals of ABPP is to improve health and living conditions in rural households, particularly of women and children, these indicators are difficult and costly to quantify. ABPP relies largely on self-reported data. “My wife no longer cries in morning as she prepares for us breakfast” said Mr Salongo from Uganda during our field visit. The main reason for installing the biodigester was so to reduce the use of firewood, which was hectic for his wife to use due to the smoke it produced. He also wanted to use the bioslurry as fertilizer for his fodder. ABPP collects data via periodic user-surveys including questions about saving and/or cost on fuel and other perceived benefits of biodigesters, with responses listed in Table 3.

The user survey implemented in Tanzania was more extensive than the other programs and asked users about additional benefits of biodigesters systems. Over three quarters of respondents note that their kitchens and utensils are cleaner and that they’ve experienced

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\(^9\)Total investment was USD 26 million during Phase I and USD 15 million during Phase II, including program cost, technical assistance, subsidies and incentives to BCEs and finance institutions. Since 2016, incentives in Tanzania have been provided by the Tanzania Renewable Energy Agency with support from Norway. On average, during a period of 10 years, annual cost has been USD 1.1 million in Kenya, USD 1.0 million in Tanzania, USD 0.7 million in Uganda and USD 1.2 million for international technical assistance and program management.

\(^10\)Under the African Biogas Carbon Program, emission reductions are verified by the Gold Standard (“African Biogas Carbon Programme (ABC),” n.d.). Under this program the first carbon credits were issued in 2016 for Tanzania (32,190 tCO2eq) and in 2017 for Kenya (93,583 tCO2eq). A first request for issuance for Uganda will be submitted in 2018 (approx. 38,000 tCO2eq).

\(^11\)Interview Kevin Kinusu, 17 November 2017
either cost-savings or increased income. 84% say that their biodigesters facilitated either started or improving a business activity such as sales of vegetables, grains, dairy products, fruits, or even bioslurry. Finally, the Tanzania survey also asks about the benefits that users most appreciate. Here, 73% of respondents cited “easy cooking” a key benefit. Over 50% note that they appreciate saving time and money. Apparently, health improvements were not valued much. While 82% note that they experience cleaner kitchens and utensils, just 13% note that they value cleaner kitchens. Similarly, 45% noted lower incidence of eye irritation and/or respiratory symptoms (Table 3), but only 5% appreciated that reduction.

To better understand the decision process, the user surveys in Kenya and Uganda include a question why people would recommend biogas, and in Tanzania, what they most appreciated about their biodigester system. Families in the three case-study countries most often listed reasons that were economic in nature like saving time and/or money.12 Convenience and cleanliness also featured prominently in people’s responses. Taken together economic and aesthetic factors appear to have a stronger role than health or environmental concerns (Table 4).

4.2. Use of bioslurry

Bioslurry is a useful co-product of biodigester systems and country programs have put substantial effort into sensitizing users about the benefits of utilizing it as fertilizer or in other applications. These efforts include trainings, demonstrations, and information campaigns. The efforts appear to have paid off. User surveys indicate that nearly all respondents report using bioslurry in some way. Most apply slurry to crops either directly in liquid form, dried, or composted with other organic matter. A small fraction of respondents use slurry in other ways, such as applying in fishponds, selling to neighboring farmers or giving it away. Table 5 shows the percentages of each application in each country. Of those using slurry as fertilizer on their crops, 84-91% indicate that crop yields have improved. In addition, many hadn’t used any form of fertilizer prior to using bioslurry and many of those who did use fertilizer reported reduction in fertilizer expenditure.

Households often use bioslurry to start new farming activities such as vegetable growing, which is likely to improve food security. For a selected group of farms and crops, improvement in yields have been documented in project documents (SNV, 2015; Warnars & Oppenoorth, 2014) supported by findings published elsewhere (Bonten et al., 2014; Groot & Bogdanski, 2013).

4.3. Sustained use of biogas

Initial acquisition is only part of the adoption process. Biodigester cooking benefits only accrue if the families sustain use of the systems over time and minimize stove stacking – i.e. reduce the use of wood or charcoal that they used prior to installing their system. These outcomes depend on a combination of factors within the household such as behavioral

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12The questionnaires used differed per country. In Kenya and Uganda, respondents were asked whether they would recommend a biodigester to others and why. Enumerators recorded open-ended responses, which were coded into the categories listed in Table 4. In Tanzania, respondents were asked about the three things they appreciated most about their biogas plant, and respond Yes or No to a predetermined list. The list correlated closely, but not exactly, to the codes assigned to the open-ended responses from Kenya and Uganda.
change, reliable supply of feedstock, and system maintenance as well as external factors such as after-sales and repair services.

4.3.1. Operation and maintenance of biogas plants—In each country, ABPP has implemented several measures to promote proper operation and maintenance of installed biodigesters. First, masons are trained to build biodigesters to strict specifications. Second, users are trained to manage the system for adequate biogas production. Third, quality control mechanisms are put into place; and, finally, measures are implemented to repair systems that malfunction. Some components have evolved over time. For example, initially biogas engineers from the national programs trained by SNV were responsible for quality control (QC), but Phase II introduced new QC mechanisms such as third-party quality service providers to monitor functionality of installed units the ground. In addition, the programs introduced incentives for BCEs in form of staged payments made three and twelve months after completing each biodigester on the condition that plants are demonstrably operational at those times. Programs also introduced CSCs, which call users directly to inquire about problems with their systems. Any problems are reported back to the national programs, which provide maintenance advice and/or schedule repairs.

Households surveys and program evaluations revealed that a significant percentage of biodigesters constructed in Phase I were not operational. In response, ABPP increased attention to sustained use in Phase II. In 2016 abandonment rates were found ranging from 23% of installations in Kenya to 31 and 33% in Uganda and Tanzania\(^\text{16}\) (i.e. 27% in the three countries). Most of the non-operational digesters were constructed in Phase I. A small number of units in each country never functioned properly, but on average, abandoned systems were in use for about three years. Some users abandon systems because of improper feeding or for non-technical reasons such as sale or death of livestock or lack of water to mix in the digester. However, a substantial fraction stopped using their systems because of technical problems such as broken fixtures, blocked inlets, or malfunctioning stoves. Of these, most have sought assistance to solve the problem. Until 2015, problems were not adequately addressed e.g. because masons did not show up to make repairs. In 2016 campaigns were launched to repair plants. Between 2016 and 2017, 55 units were repaired in Kenya, 232 in Tanzania, and 294 in Uganda (project statistics).

4.3.2. Stove and fuel stacking—ABPP monitors stove stacking through user surveys and detailed fuel consumption surveys. Fuel consumption surveys are conducted on a random sample of “baseline” households, who do not have a biodigester, and “project” households, who have installed biodigesters. Average annual household savings range from 2.1 to 3.3 tons of wood, either used directly as fuelwood or converted to charcoal (Figure 1).\(^\text{17}\)

\(^{16}\text{Research on dis-adoption of biodigesters in Central Uganda has been published by (Lwiza, Mugisha, Walekhwa, Smith, & Balana, 2017). The study was conducted in two districts: one with digesters installed before 2009 and one with digesters installed during ABPP Phase I.}\)

\(^{17}\text{Charcoal was converted to wood equivalent units assuming 10% conversion efficiency in Kenya and Uganda (van Dam, 2017) and 12% in Tanzania (Peter & Sander, 2009).}\)
The tests show that households with biodigesters use significantly less fuelwood and charcoal than households without biodigesters. There is some variation in fuelwood savings between the three countries, which correlates well with the degree of stove stacking among test households in each country ($R^2 = 0.72$). When more households retain the use of their previous stove, overall reductions in baseline fuel consumption decline.

The rates of stacking biogas with fuelwood and/or charcoal vary. In Kenya 54% of households with digesters use exclusively biogas for cooking, while 46% stack. In Tanzania and Uganda stacking rates are 71% and 89% respectively. Data collected during fuel consumption surveys indicate that fuelwood and charcoal consumption are significantly lower among biodigester users, despite high rates of stacking.

For this case study, households from the fuel consumption surveys were called by phone and asked about preparation of dishes and fuel use during the last week. Although not all households could be reached by phone, a global picture emerges. In Kenya and Tanzania, biogas is an exclusive fuel at breakfast, mostly for tea. Most households use biogas to prepare lunch and dinner, but some use firewood or charcoal to prepare ugali and vegetables or maize and beans, either for lunch or for dinner, because the biodigester does not produce sufficient gas. A few respondents explain they prefer to cook heavy foods with firewood or charcoal because of taste. In Uganda, firewood is the dominant cooking fuel of biodigester owners. Most respondents in Uganda argue that biogas cannot cook for long hours and prepare matoke (steamed bananas), posho (ugali) and beans with firewood. They use biogas mainly for breakfast (tea, boil water or milk) and light dishes at lunch or dinner (e.g. rice or potatoes). Some noted that they have limited dung to feed the biodigester, and thus a limited supply of biogas with which to cook. Across the three countries we conclude that biodigesters are widely used, but not all cooking needs are met.

## 5. Discussion

### 5.1. Can the sector development model developed in Asia be replicated in Africa?

The SNV model for sector development, focusing on supply, demand and ecosystem, was used to create markets. The model was adapted from successful programs in Asia. However, the conditions for its implementation in Africa are less favorable: construction costs are higher, incomes are lower, and cattle are less often stabled (a condition necessary to facilitate manure collection). Furthermore, in East African countries there are fewer small and medium enterprises in rural areas, and access to financial services for smallholders is scarce.

For these reasons, progress is slower. In eight years of market development, a little over 5% of the overall target population has been reached. But markets have been created, masons have been trained, small biogas construction enterprises have been formed and other private companies are entering the market, especially in Kenya. The sector development concept

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18The description is based on responses from 97 households reached from a sample of 142 households (Project Fuel Test, see Appendix B), 64 of them explained in detail the use of cooking fuels.
introduced by ABPP in East Africa has demonstrated proof of principle. While investment cost is high and credit access is poor, there are a significant number of adopters.

5.2. Commercially viable markets and targeted installations

Fieldwork carried out in late 2017 revealed that the Kenyan program has made modest progress toward commercial viability. Kenya achieved its Phase I installation target, established 22 marketing hubs, and 28 active BCEs. MoUs have also been signed with 9 lending institutions; however, the number of loans they provide is still limited. There is somewhat less progress toward commercial viability in Uganda and Tanzania, where only 8 marketing hubs had been established (5 in Uganda and 3 in Tanzania).

Progress toward the targeted number of installations also varies between the three countries. Kenya exceeded its Phase I target, installing nearly 10,000 units by the end of 2013 (Table 1). In contrast, both Tanzania and Uganda fell short of their Phase I targets. During Phase II of the Kenyan program, ABPP intended to add 20,000 units. By late 2017, approximately 3,500 had been installed, a pace that is insufficient to reach the target.

5.3. Evolution of program implementation and market development

The programs have been dynamic and adaptive (see Section 4.1). It may be argued that program policy changes have been too rapid; e.g. the abolishment of subsidies and insufficient user training by BCEs has caused a slow-down in adoption in Phase II. Although the 'program push' to 'demand pull' may have helped to transfer responsibilities to private sector partners, and in the case of Kenya companies offering new biodigester models entered the market, the expansion has not materialized. In 2014 to 2017 construction numbers decreased in all three countries. Actions to support affordability were partly successful: construction cost was reduced with 17-25% which is nearly equal to the subsidies in Phase I. However, access to credit is still very limited. Regarding quality and reputation it was found that functionality of biodigesters constructed in Phase I was less than anticipated (23 to 33 percent of plants not working, against a target of 10 percent). During the field visit to Uganda it was found that biogas constructors pay little attention to explain the use of bioslurry and proper feeding of the biodigesters. In 2016 campaigns were launched to repair plants to enhance reputation which is vital to market expansion. This may, however, be insufficient to address lack of knowledge to properly operate and maintain biodigesters. Finally, we have seen that the business case for farmers is viable, provided they have access to (long term) finance, the business case for constructors varies with scale and complementary businesses, while the business case for finance institutions is doubtful. Overall it looks like immature financial markets are the most important barrier for scaling up biodigester dissemination in the three countries, while reputation is another key factor. Market development takes more time than anticipated in program design.

5.4. Success and challenges of program implementation

Our case study shows that implementation strategy and practices matter for adoption and sustained use. Nes & Nhete (2007) assessed in 2007 that, while former programmes to disseminate biodigesters in Africa were largely unable to achieve adoption at scale and sustained use of biogas, a more systematic approach could change the nature of adoption and
sustained use. This has been confirmed by ABPP experience. After-sales services and quality control are essential in a systematic approach. The quality control mechanism of ABPP has evolved over time and is projected to evolve further. In Phase I compliance with protocols and inspections was emphasized, while Phase II focused on incentive systems and establishing Customer Support Centres. It is envisioned that in future product standards and a BCE grading system can assure product quality within a market setting.

However, each phase shows trade-offs and structural challenges. In Phase I ambitious construction targets and decentralization led to increase of biodigester installation but also less than sufficient quality control and after sales service. It was found in 2016 that abandonment due to technical failures occurred. In Phase II, training needs were not sufficiently addressed by market players (BCEs). This also affects proper functioning of biodigesters, e.g. causing problems by improper feeding of the digester. Or, in other cases, lack of productive use of the bioslurry, which in turn affects the financial attractiveness of the investment. Looking ahead, beyond Phase II, governments need to take up an active regulatory and enabling role. As shown by other clean cooking interventions upscaling ultimately depends on an enabling environment. In the case of biogas in East Africa, this requires a more proactive government compared to Phase I and II.

5.5. Willingness to invest but persistent stacking with woodfuels

The relatively high rate of adoption, compared to experience in the past and considering high investment cost, can be explained by the aspirational nature of biogas. Survey respondents indicate that biogas is highly appreciated as a fast and convenient cooking fuel. Half of the users surveyed in Kenya exclusively use biogas for cooking. Among households stacking biogas with other fuels, any meal cooked with biogas saves time or money. For example, even in Uganda where only 11% of households surveyed use biogas exclusively, 94% still benefit from reduced fuel consumption and/or expenditure. In other words, a large majority of users reduced their fuel consumption and/or expenditures, while biogas only covers part of their cooking fuel needs. Another factor stimulating investment in the three countries is the use of bioslurry, which reduces expenditure on commercial fertilizer and improves crop yields.

5.6. Health improvements

Results from household surveys show that a majority of ABPP participants perceive health improvements. While self-reported data are not completely reliable indications of people’s health status, they are useful because they reflect the respondents’ quality of life and potential demand for health services (Díaz et al., 2008). A large percentage of ABPP participants report reduced eye irritation and respiratory problems, which indicates some degree of success toward ABPP’s health improvement goals. However, significant reductions in major diseases like respiratory infections, chronic lung disease, and heart disease associated with exposure to household air pollution (HAP) are unlikely to occur without major reductions because of the non-linear nature of exposure-response relationships (Burnett et al., 2014; Smith & Sagar, 2014). ABPP has not measured HAP exposures directly. Results from HAP studies in Cambodia found significan reductions in exposure by biogas users (Hyman and Bailis in this issue), but stacking rates are lower in...
Cambodia. In Kenya, the proportion of ABPP participants dis-adopting firewood and charcoal makes it likely to achieve a reduction in diseases. In Uganda and Tanzania this likelihood is lower.

6. Conclusion

Before 2007, dissemination of biodigesters in Africa was very limited. Compared to Asia, economic and financial conditions in Sub-Saharan Africa are less favorable. The Africa Biogas Partnership Program, established in 2009, suggests a proof of principle for the creation of biodigester markets in East Africa. Demand for biodigesters has been demonstrated and new enterprises are entering the market, especially in Kenya. The country programs implemented in Kenya, Tanzania and Uganda have been dynamic and adaptive, moving along the cycle of market development. Notwithstanding high upfront cost and limited access to credit, over 27,000 households adopted biogas (half of them in Kenya), while before 2009 only Tanzania had more than 1,000 functioning biodigesters.

Households perceive direct benefits such as higher crop yields, reduced fuel consumption or expenditure, and convenience and cleanliness of cooking. Fuel consumption tests show households with biodigesters use 2.1 to 3.3 tons less wood per year than households without biodigesters.

Abandonment rates observed in 2016 due to technical problems or lack of feedstock, led to several adaptations including customer service centres and repair campaigns. Looking ahead, ABPP will encourage governments to take a more active regulatory and enabling role. Half of adopting households in Kenya make exclusive use of biogas for cooking, but exclusive cooking rates are lower in Uganda and Tanzania. To maximize the health benefits of biodigester systems, ABPP will need to collaborate with governments and non-governmental stakeholders to promote behavioural change and increase dis-adoption of traditional stoves and fuels.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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HIGHLIGHTS

• This case study suggests a proof of principle for the creation of biodigester markets in East Africa

• ABPP has installed over 27,000 households biodigesters in Kenya, Tanzania and Uganda

• Fuelwood savings of 2.1-3.3 tons per household-year are inversely correlated with stove stacking; stacking is highest in Uganda

• 27% of biodigesters constructed in 2009-2013 were not working in 2016; in response call centers and repair campaigns were launched
Figure 1:
Average household savings of fuelwood and charcoal (in wood equivalent units) based on fuel consumption surveys carried out in each country (error bars show 95% confidence intervals)
Table 1:
ABPP East Africa: target population and number of biodigesters installed, program target and realized until December 2017

| Country | Target population | Phase I: 2009-2013 | Phase II: 2014-2019 | Reached 2009-2017 |
|---------|-------------------|--------------------|--------------------|-------------------|
|         | Target population| Construction target| Reached            | Construction target| Reached 2014-2017 |
|         |                   |                    |                    |                   | Reached 2009-2017 |
| Kenya   | 172,000           | 8,000              | 9,803              | 20,000            | 3,457             | 13,260             |
| Tanzania| 276,000           | 12,000             | 4,181              | 21,000            | 2,260             | 6,441              |
| Uganda  | 50,000            | 12,000             | 5,168              | 13,600            | 2,420             | 7,588              |
| Total East Africa | 498,000       | 32,000             | 19,152             | 54,600            | 8,137             | 27,289             |

Source: ABPP by email, 31 January 2018
Table 2

Percentage of manure available at household level fed into the biodigester, reported in user surveys

| Country  | Dairy cattle (%) | Local cattle (%) | Market swine (%) | Breeding swine (%) |
|----------|------------------|------------------|------------------|-------------------|
| Kenya    | 95.4             | 59.5             | 50.0             | 75.0              |
| Uganda   | 97.5             | 88.0             | 47.4             | 18.5              |
| Tanzania | 81.9             | 21.5             | 3.6              | 0.6               |
Table 3:
Perceived benefits of biodigesters: by percentage of users surveyed experiencing the following positive impacts, reported in user surveys

| Impact                                      | Kenya | Tanzania | Uganda |
|---------------------------------------------|-------|----------|--------|
| Reduced eye problems and respiratory symptoms | 80%   | 45%      | 91%    |
| Reduced fuel consumption or expenditure     | 84%   | 85%      | 94%    |
| Reduced time/effort compared to obtaining woodfuel | 56%   | 64%      | 78%    |
Table 4:
Reasons to recommend biogas (KE and UG) or things most appreciated (TZ) about their biogas plant, reported in user surveys

| Reason                                                                 | KE   | UG   | TZ   |
|------------------------------------------------------------------------|------|------|------|
| Economic - saves time and/or money                                      | 61%  | 69%  | 86%13|
| System is convenient or easy to use                                    | 14%  | 31%  | 73%  |
| System results in cleaner kitchen and/or household                     | 19%  | 30%  | 13%  |
| Reduces wood use or other environmental benefit                         | 14%  | 2%   | 14%  |
| Use of bioslurry for fertilizer14                                       | 4%   | 17%  | 8%   |
| Good way to dispose of animal waste                                    | 1%   | 4%   | 5%   |
| Good source of lighting                                                | 0%   | 6%   | 15%  |
| Health benefits                                                        | 1%   | 0%   | 5%   |

13Responses in Tanzania, separated by Economic – saves time: 77% and Economic – saves money: 59%
14The word ‘biogas’ was used in the question and not biodigester, which may have led to less number of respondents mention use of bioslurry for fertilizer
Table 5:
Use and impacts of bioslurry reported in user surveys

|                                | Kenya | Tanzania | Uganda |
|--------------------------------|-------|----------|--------|
| No. surveyed                   | 135   | 184      | 130    |
| Use directly as fertilizer (wet or dried) | 83%   | 66%      | 81%    |
| Make compost, then use as fertilizer | 4%    | 32%      | 11%    |
| Give away for free             | --    | 11%      | --     |
| Do not use                     | 4%    | 5%       | 6%     |
| Sell as fertilizer             | 1%    | 3%       | --     |
| Use in fish pond               | 1%    | 2%       | --     |
| No response                    | 7%    | 3%       | 2%     |
| Report improvements in crop yield | 84%   | 86%      | 91%    |
| Purchased fertilizer before installing biodigester | 66%   | --       | 17%    |
| Percent of those who purchased fertilizer reporting savings | 79%   | --       | 92%    |

15Responses with “--” are not shown in responses in Tanzania survey

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