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## Assessment of the Cambodian National Biodigester Program

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### Abstract

The National Biodigester Program (NBP) was established in 2006 to build and maintain household biodigesters in Cambodia. In its first six years, the program installed almost 20,000 biodigesters and established an in-country network of local financiers, construction companies, skilled masons, bioslurry specialists and after-care technicians accessible to rural users in 14 of 24 Cambodian provinces. Since its initial success, the program's adoption rates have stalled despite increasing government support and high rates of user satisfaction. Building on an initial evaluation of the NBP in 2013, this updated assessment identifies multiple changes in its second implementation phase that have undermined the initial momentum of the program. Abrupt interruptions in institutional support, deteriorating supply side services (access to construction agents, masons, repair services) and reduced access to credit for farmers have eroded the service network that the first implementation phase established. Structural changes in the rural economy may also contribute to declining demand. Government support to another biodigester program which offers a lower investment price, but does not provide after-sales services has also undercut the long-term implementation strategy of the NBP. The paper finds that despite these programmatic changes, the installed biodigesters continue to perform according to expectation and to be maintained and valued by their users, but the future viability of the program remains uncertain.

### Keywords

Biodigesters; RE-AIM framework; Carbon finance; Energy subsidies

### 1. Introduction

The National Biodigester Program (NBP) was established in 2006 with the aspiration of building and maintaining household biodigesters throughout the Kingdom of Cambodia. The program was originally a joint endeavor by the Dutch Development Organization (SNV) and the Cambodian Ministry of Agriculture, Forestry and Fisheries (MAFF). It has been operating as an independent Cambodian initiative since 2015 (S. Lam, 2017a).

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The key feature of the NBP is an integrated approach to biodigester adoption and maintenance. The program builds upon the agricultural extension services already established within Cambodia to add training and incentives for biodigester masons, bioslurry experts and program promoters. Buyers receive warranties and access to local technical support. Biodigester financing is facilitated through a special agreement with local banks and credit unions, thus representing an integrated approach to technology dissemination and adoption. In 2013, the program was evaluated by independent consultants, who concluded that while NBP had successfully introduced domestic biodigesters into Cambodia, it would be difficult to fully remove subsidies (Buysman & Mol, 2013a). They also noted that NBP's reliance on carbon finance to fund subsidies was unsustainable because carbon markets had been struggling, and that sustained external assistance was needed. Five years later, this paper provides an update on the status of the NBP and finds that despite increased government support and a stable source of carbon finance, the project has been undermined by other factors. We argue that sustained development assistance is necessary, but insufficient for the long-term provision of domestic biogas within the country. Further, we note that supply-side services (construction services, technical after-care, and access to finance) are crucial to the success of the NBP.

Arguments for the promotion of biodigester programs usually point to their associated co-benefits. Decreased dependence on conventional rural cooking fuels is expected to reduce financial expenditure and/or alleviate the burden of women's work, which usually includes wood collection and transportation (Schlag & Zuzarte, 2008). Biogas is said to particularly benefit women and children who spend the most time at the hearth (Katuwal & Bohara, 2009). Other expected benefits associated with domestic biogas include the convenience of lighting a burner rather than starting a fire, the status symbol of possessing a modernized stove top, and expanded hours for work and study enabled by the introduction of biogas-lit lamps (NBP, 2011). Biogas combustion has been demonstrated to significantly reduce HAP when compared with traditional wood and charcoal stoves (Berkeley Air Monitoring Group & SNV World, 2015) and users, predominantly women, report high levels of satisfaction with the level of convenience and associated time savings (Kooijman, 2015).

However, the durability of social, economic and environmental co-benefits is uncertain (Karhunmaa, Pitka nen, & Tuominen, 2015). A review of biodigester usage in Africa identifies financial constraints, lack of livestock, water constraints, educational barriers and construction difficulties as limiting the ability of rural populations to access and utilize the technology. In addition, aftercare services (warranties and local repair services) are needed to support a biodigester program (Mwirigi et al., 2014). A qualitative study on the potential social and economic benefits of biogas in Ghana demonstrates that improvements in health, agricultural productivity, financial savings and environmental sustainability are achievable provided that financial support systems and subsidies are available (Arthur, Baidoo, & Antwi, 2011).

## 2. Contextual Background

The Royal Kingdom of Cambodia is a tropical country in southeast Asia. The climate is dominated by an annual monsoon cycle. Cambodia has a population of over 15 million

increasing at roughly 1.6% per year. The country is organized into 24 provinces plus its capital city, Phnom Penh, which is administered as a 25<sup>th</sup> province.

Cambodia was classified as a Least Developed Country at the start of the NBP implementation period, although it graduated to lower middle-income status in 2015 (World Bank, 2018). Poverty is declining, but it persists, particularly in rural areas. For example, in 2014, the poverty rate was 14%, down from 48% in 2007. About 90% of the poor live in the countryside and 4.5 million people remain “near-poor”, with incomes slightly above the poverty line (World Bank, 2016).

Despite substantial progress in the past decade, Cambodia remains far behind in human development. Undernourishment is prevalent and stunting remains widespread, affecting 32% of children under five years old in 2014 (National Institute of Statistics/Cambodia, Directorate General for Health/Cambodia, & ICF International, 2015). 18% of the total population has access to piped water and 66% of the rural population practices open air defecation (UNICEF & World Health Organization, 2014).

## 2.1. Energy use

Cambodia relies heavily on fuelwood and charcoal, particularly in the residential sector, where it constitutes 90% of energy consumed (IEA, 2017). However, LPG is gaining popularity and access to electricity has expanded rapidly, reaching near universal access in urban areas and nearly 50% of rural households by 2014, though few households cook with electricity (Figure 1).

## 2.2. Background on the NPB

Feasibility studies for the NBP began in 2004, and it has been operational since 2006. SNV, a Dutch non-governmental organization (NGO), signed a Memorandum of Understanding with the Cambodian Ministry of Agriculture, Forestry and Fisheries (MAFF) to establish the NBP. Hivos, also a Dutch NGO, joined the consortium in 2007, providing carbon finance. Hivos and SNV have worked together on eight national biodigester programs in Africa and Asia. The programs all follow a similar model involving close collaboration with a national partner. SNV representatives are given fixed terms to start the initiative, with an “expiration date” built into their tenure in order to ensure the local organization takes ownership (J. Lam, 2011).

The NBP supports and monitors the creation of an in-country network of masons, trained to build the “Farmer’s Friend”, which is closely modeled after the Chinese “fixed-dome” biodigester (Bond & Templeton, 2011). The digester requires skilled, local, labor to construct on-site and lacks moveable parts. The digester is installed below ground level and varies from 4 m<sup>3</sup> to 12 m<sup>3</sup> or larger. A 4 m<sup>3</sup> digester can accommodate waste from 2–3 cows or 4–6 pigs. Farmers keep the animals in stalls for the majority of the day, shoveling the dung for use in the biodigester. They mix the animal waste into the biodigester inlet with water, the waste collects at the bottom of the dome where anaerobic digestion creates a methane-rich gas and a bio-slurry that can be used as a soil amendment. As the gas forms, it creates pressure within the dome that both pushes the gas through a pipeline to the farmer’s home and pushes the effluent into a storage trough outside the biodigester (NBP, 2011).

The NBP's original goals were to create a self-financing biodigester market in Cambodia that would achieve the following: 1) install 20,000 biodigesters over the first project implementation period (2006–2012) and double that number by 2018; 2) ensure that installed biodigesters are well-maintained and continue to be used over the long-term; 3) ensure that the “co-benefits” associated with the biodigester, i.e. the bio-slurry fertilizer and household lighting functionality, are maximized and 4) build national capacity to technically and to financially carry forward the project in the absence of SNV (Buysman & Mol, 2013a; J. Lam, 2011). Policy emphasis on financial sustainability and national capacity building drew its origins from the 2004 feasibility study, which acknowledged a history of unsuccessful biodigester implementation in the past (J. Lam & Boers, 2005).

The original Memorandum of Understanding between MAFF and SNV included an implementation plan for the first phase of the program (2006 – 2012) which helped to ensure cooperation with national authorities (J. Lam, 2011). Under the agreement, SNV provided a Senior Advisor for a five-year term who planned for his departure from the start by hiring a Cambodian counterpart. Figure 1 shows the program's structure.

In order to ensure program commitment at the highest levels of government, the NBP is governed by a Steering Committee with representatives from MAFF and SNV. Under the MoU, MAFF provided agricultural extension workers who would market the biodigester to farmers in six provinces (later expanded to ten) and hosted the NBP within its Department of Animal Health and Production (DAPH). DAPH also served as co-advisors to NBPO alongside SNV. Extension services were based from MAFF's field centers throughout rural Cambodia. A national non-governmental organization, The Cambodian Center for Study and Development in Agriculture (CEDAC) hosts four additional provincial offices, creating 14 NBP “Provincial Biodigester Program Offices” (PBPO) nationwide (Buysman & Mol, 2013a; J. Lam, 2011; S. Lam, 2017a). At the provincial level, the PBPO is responsible for training “Biodigester Construction Agents” (BCAs) and the skilled masons who work for them. The PBPOs also engage with microfinance institutions and banks to ensure that farmers can access loans.

In addition to securing donors, the NBP also spent three years working toward certification of its greenhouse gas emission reduction stream to qualify for Gold Standard Verified Emission Reductions (GS VERs).<sup>4</sup> Hivos International was an early partner in this effort and signed an Emissions Reduction Purchase Agreement that has been active since 2010, in which Hivos agrees to pre-purchase the GS VERs at a set rate (Clemens, 2012; MAFF & Hivos, 2008). As of 2016, 486, 605 VERs have been generated over the lifetime of the program (The Gold Standard Foundation, 2018). According to Hivos' Climate Finance offer, all of the credits have been sold and NBP is guaranteed 80% of the credit value for its program funding (Clemens, 2016). While overall VER prices have fallen from 2010–2018, the Emissions Reduction Purchase Agreement with Hivos has shielded NBP from global pricing trends (Vivid Economics, 2016).

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<sup>4</sup>The NBP monetizes the greenhouse gas emissions reductions associated with the project, based on the baseline assumption that 5.9 tons of carbon dioxide equivalent would otherwise be emitted into the atmosphere from the livestock manure per year (Tüv Nord, 2014). The calculation is based on the equivalencies published by the UNFCCC (i.e. a ton of methane is equivalent to 21 tons of carbon dioxide).

### 2.3. Biogas, Livestock and Manure Management

Livestock ownership is a pre-requisite for participation in the NBP. In the past, livestock also served as a source of wealth, savings, and animate labor for rural households. However, in recent years, Cambodia has shifted away from a predominantly agrarian economy, with rapid growth in textile jobs pulling young people away from farm labor. In addition, two-wheeled walking tractors have become more available (Kooijman, 2015). These factors have led to a decline in livestock ownership over the past decade (Figure 3).

Feasibility studies conducted in 2004 estimated that 0.5 million farms could be eligible for household biodigesters, i.e. farms that own at least two cows or five pigs to produce sufficient manure to fuel the biodigestion process (McIntosh 2004, Lam and Boers 2005). Manure management is also an important factor. An assessment of NBP's potential carbon emission reductions found that livestock owners in targeted regions valued manure from pigs and cows and utilized much of what was available either in solid form or as bio-slurry, which indicated that handling manure for biodigesters would not require a large change in their standard practices (NBP, 2011). Declining livestock ownership could reduce NBP's market; however, a smaller biodigester that requires fewer animals can be introduced and is being developed. One updated assessment finds the same number of potential consumers (Lamberet, 2015).

## 3. Sources, Methods and Approach

We analyzed the implementation of Cambodia's NBP using the RE-AIM framework (Reach, Effectiveness, Implementation, Adoption, and Maintenance), which was originally developed for estimating the effectiveness of public health interventions (Glasgow, Vogt, & Boles, 1999). This case study also builds from a doctoral dissertation on the NBP (Hyman, 2017). Data are based on field visits by the authors in September 2017, which updated information from field work that one author conducted in May-June 2011 and May-July 2012. Primary data were derived from 62 semi-structured interviews with biodigester users, as well as NBP employees, funders, and other key stakeholders spread across ten of the fourteen provinces covered by NBP. Interviews were usually conducted with a translator, and followed a basic template designed to quantify gains (and losses) from project participation in terms of income, time, and opportunity costs, while also covering qualitative questions on the participants' assessment of their quality of life in general terms, and the impact of the project on their livelihoods and choices. These data were supplemented by internal NBP documents including biannual Biodigester User Surveys (BUS), Annual Reports highlighting project finances and installations, program design documents, and carbon offset verification reports submitted to the Gold Standard.

## 4. Applying the RE-AIM framework

### 4.1. Reach—scale and coverage of intervention

Within the RE-AIM framework, "Reach" refers to the absolute number and proportion of the individuals who participate in the NBP. We have also interpreted this category to include the policy strategy through which "reach" occurs. By October 2017, NBP installed over 26,000

biodigesters in 14 of the 24 Cambodian provinces (Figure 4) (NBP, 2017). User surveys covering systems of different ages indicate a 90% usage rate. Based on the average family size among participating households, the NBP conservatively estimates that at least 140,000 people directly benefit as users.

The BUS provides basic demographic information on NBP participants. The 2015 report indicates 54% of users live in wooden houses, and 27% live in homes made from both concrete and wood (concrete reflects a more affluent household). Two-thirds of the families characterized themselves as “not-rich, not-poor.” The average family owns 1.9 hectares and 90% of them cultivate rice.

The average size of NBP’s biodigesters has declined over time. During the first four years of the program, the 6 m<sup>3</sup> model was most popular, indicating that the average user was not the smallest farm-holder eligible (Kooijman 2015). However, more recently, the 4 m<sup>3</sup> model has been the most popular size (NBP, 2017). This shift may reflect NBPs’ efforts to reach out to smaller less well-off households, but may also reflect the overall trend of declining livestock ownership and increasing farm mechanization mentioned above (NBP 2015).

Families surveyed in the BUS 2015 own, on average, 4.05 cows or buffalo and 3.28 pigs. They reported feeding the biodigester with 92% of their available dung, which indicates that the families which own biodigesters have significant manure to keep them operating (Kooijman, 2015).

By the end of 2012, NBP nearly achieved its goal of 20,000 installations. However, during the second phase of the program in 2013, the NBP underwent two significant changes. The program dropped the Farmer’s Friend subsidy from \$150 to \$100 USD for six months, in an effort to phase out the subsidy over the long run. the NBP as a financially self-sustaining initiative. At the same time, the Dutch director left the program. Following these changes, biodigester installations dropped by 73% (NBP, 2017).

User responses are mixed about the degree to which the subsidy is needed to support a viable biogas market within Cambodia or whether the subsidy should be further strengthened to reach an even poorer population (BUS 2015). The \$150 USD subsidy was reinstated in the second half of 2013 and installation rates began to rebound. However, while the subsidy remains in place, NBP has not recovered the momentum it had during the first phase and, at the time of writing, annual installations are declining once again (Figure 5). Following the Dutch director’s transfer in 2012, SNV and NBP were unable to find a suitable replacement given the particular strengths and challenges associated with the program. Since mid 2015, the NBP has been independently managed without SNV guidance, though the Dutch agency did provide some program support through 2015. Factors related to Cambodia’s changing rural economy might also be affecting annual installations. We return to these issues in more detail in the analysis section of the case.

The second implementation phase from 2013–2016 was characterized by a range of different funding streams, resulting in different marketing priorities as designated by a multitude of donors,<sup>5</sup> such as a focus on distributing the least-cost biodigester for the poorest user population, or promoting industrial biodigester for the heaviest polluters (NBP, 2016).

For the third project phase, which runs from 2017–2020 (and has now been amended to include program funding through 2025), NBP benefits from complete integration into MAFF’s regular program of work. The “Policy on Biodigester Development in Cambodia 2016–2025” establishes a government-supported National Advisory Committee to facilitate increased support and expansion of the NBP through 2025 (MAFF, 2016). Key goals for the NBP expansion are summarized in Table 1 below:

In order to support this growth, the Cambodian government plans to increase the financial resources allocated to the Animal Production and Animal Health budget within MAFF by least 10% from 2015 levels by 2025. In addition, MAFF acknowledges the utility of a financial subsidy to make the biodigester more affordable and reports that it will retain the US\$150 subsidy cost over the term of the program (MAFF, 2016). The costs of different sized plants are shown in Table 2.

#### 4.2. Effectiveness—ability of scale and technology to achieve desired goals

The goals of NBP include broad objectives like reducing forest degradation and improving quality of life for rural families, as well as these specific goals: installation of 33,000 units by 2020, long-term adoption and maintenance of installed units, the widespread utilization of bio-slurry fertilizer and biogas for lighting, and ultimately, to build sufficient capacity to deploy biodigesters throughout the county. In this section, we examine the extent to which the program is effectively meeting the broad objectives of forest degradation and quality of life improvements, as well the specific goals of slurry utilization and lighting.

**4.2.1. Impact on forest degradation**—Impacts on forest degradation are difficult to demonstrate because it is driven by multiple factors (Masera et al., 2015). The available data does not allow us to draw conclusions about NBP’s impact on forest degradation, but it does provide insight into whether households adopting biodigesters have decreased fuelwood or charcoal consumption, which would contribute to reduced forest degradation under certain conditions (Masera et al., 2015). Consumption can be quantified in several ways; households may be surveyed about their consumption over a given period of time (e.g. wood bundles per week or cartloads per month); cooking simulations can be conducted to quantify the fuel needed to cook typical meals with different types of stoves; or fuel consumption can be physically measured by visiting households repeatedly over several days and directly weighing the fuel that is used (Bailis, Smith, & Edwards, 2007).

If it is implemented properly using statistically sound sampling methods and sufficient sample sizes, the latter approach is the most accurate. NBP/SNV implemented several variations of this approach to quantify reductions in wood consumption. The results are summarized in Table 3 below.

Stove “stacking” among NBP participants is an additional factor that impacts effectiveness.<sup>7</sup>

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<sup>5</sup>Donors as of September 2017 include Dutch Non-Profit SNV; International Fund for Agricultural Development; People in Need International, People in Need Czechoslovakia; Hivos International (carbon credit buyer); EnDev; CCA, Climate Change Cambodia NGO, Energizing Development (EnDev) through GIZ; Cambodia Youth’s Capacity Assessment Organization (CCA).

<sup>7</sup>“Stacking” indicates the use of multiple stoves and fuels.

The data presented in Table 3 was drawn from a sub-sample of households that still use fuelwood or charcoal. However, three studies report that the majority of NBP participants have stopped using fuelwood or charcoal altogether Table 4.

While the sample sizes are quite small, these assessments indicate that NBP participants appear to use significantly less fuelwood or charcoal than non-participants to meet their energy needs. Coupled with minimal stacking and dropout rates (discussed in Section 4.3 on “Maintenance”) we can conclude that the program is effective at reducing forest degradation.

**4.2.2. Improved quality of life for rural families**—The BUS 2015, which surveyed 165 biodigester users, shows that 96% were satisfied with their biodigester and 100% use the biogas for cooking. This echoes findings from previous years (Kooijman, 2015). The study also found that technical precision and quality control in the craftsmanship is reliable; the majority of biodigesters (76%) have always worked properly and 82% of users who reported malfunctions noted that the problem had been temporary and had only decreased the amount of biogas but did not shut down the plant completely (idem).

In addition to general satisfaction with the biodigesters, quality of life can be directly affected by reductions in HAP exposure. As studies of household cooking interventions proliferate, it has become apparent that significant reductions in HAP exposure are not easily achieved, either because the stoves are not sufficiently clean-burning or users continue to use high emitting stoves alongside clean ones (Clark et al., 2013; Pilishvili et al., 2016; Quansah et al., 2017). Others have noted that sources of pollution from outside users kitchens such as stoves from neighboring households, burning refuse piles, and seasonal agricultural burning also affect exposures (Das, Jagger, & Yeatts, 2017; Piedrahita et al., 2017).

Berkeley Air Monitoring Group and SNV commissioned a study to quantify exposure reductions achieved by the NBP during the dry season, as did Hivos in the same year during the rainy season (Berkeley Air Monitoring Group & SNV World, 2015; Buysman, 2015). The two separate studies both measured kitchen concentrations and personal HAP exposure. Both measured PM<sub>2.5</sub> and one also measured CO. The studies had relatively small sample sizes (18–25), but found significant HAP reductions ranging from 36%–96. Interestingly, the relationship between kitchen concentrations and personal exposures for PM<sub>2.5</sub> vary between the two studies. In one study, kitchen concentrations are significantly lower than personal exposures for both control and intervention households, indicating that test subjects experienced substantial exposure outside the kitchen (possibly from burning of trash or agricultural waste). In the second study, kitchen concentrations are significantly higher than personal exposures for both control and intervention households, indicating that kitchens are more polluted than other microenvironments in the community. In addition, in that study, personal exposures among interventions in the second study fall significantly below 35 µg/m<sup>3</sup>, the WHO’s interim target for PM<sub>2.5</sub> (Figure 6).

The studies used these HAP measurements to estimate NBP’s health benefits.

HIVOS study:



The HAPIT tool was used to convert the improvement in household air quality (HAQ) to aDALYs and averted deaths.<sup>8</sup> The cumulative benefits accrued by 2014 stand at 29.5 averted deaths and 1,442 aDALYs. With the continued implementation of NBP, this is projected to increase to a total of 51 averted deaths and 2,519 aDALYs by 2020 (p. 2).

NBP, as an HAP health intervention, costs around \$4,266 to \$5,548 per averted DALY and \$208,523 to \$271,186 per averted death depending on the evaluation period (p. 44)

SNV/Berkeley Air Monitoring Group study:

Biodigesters having a 5- or 10- year lifetime result in a central estimate of the annual cost per aDALY of \$3,160 and \$1,810, respectively. The 5-year biodigester would place this in the “cost-effective” category and the 10-year would be considered “very cost-effective”.

Reported economic co-benefits include improved agricultural productivity and financial savings. The effluent or bio-slurry co-produced with biogas can be a substitute for chemical fertilizer. 92% of biodigester users report that they use bioslurry in this way, which reduces their use of commercial fertilizers (saving an average of \$26 per year) and increases crop yields by an estimated 25%, which the BUS 2015 survey estimates is worth \$156 in additional income for each household. Conservatively, considering only the direct cost savings from reduced fertilizer use (i.e. US\$26), the savings are still significant.

In addition, there are other less tangible benefits that users report. For example, the 2015 BUS elicited the responses shown in Figure 7.

The overall satisfaction rates reported by the biodigester user surveys (Kooijman, 2015), independent verification reports (Tüv Nord, 2014) and independent research (Karhunmaa et al., 2015) reports range from 94–98% satisfaction rates, an exceptionally high level for a development intervention.

### 4.3. Adoption

“Adoption” refers to factors supporting the population that are willing to install, utilize, and maintain a household biodigester. It is notable that the NBP is, from the outset, a program that can reach the poor, but not the indigent. For example, the majority of biodigester users live in wooden houses with tiled roofs, average landholding is 1.9 hectares, and 66% of families surveyed identify their economic status as “not rich but not poor”(van Mansvelt, 2010). Nevertheless, these families are still at risk of malnutrition, childhood stunting, reduced lifespan, and water-borne disease, and many lack formal education.

The most commonly cited adoption barrier is cost (Barnhart, 2014; Bond & Templeton, 2011; Buysman & Mol, 2013a; Garfí, Ferrer-Martí, Velo, & Ferrer, 2012; Mwirigi et al., 2014). The investment required to purchase the 4m<sup>3</sup> biodigester is equivalent to several months’ income in target communities. Micro-finance does help reduce upfront costs, but is

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<sup>8</sup>aDALYs are “averted Disability Adjusted Life-Years”, which are used to quantify the health benefits of an intervention.

not accessible for all and mistrusted by some potential consumers (Lamberet, 2015). In addition, other options to change traditional cookstoves for more efficient devices are far cheaper. The New Lao Stove, a popular charcoal stove, sells for just five US dollars (Nexus, 2015).

**4.3.1. Subsidies and micro-finance**—The NBP is cognizant of its target communities' cash constraints and designed a subsidy and loan system to enable households with sufficient livestock to access the biodigester. From 2006–2012, SNV offered a fixed subsidy of \$150. This initially allowed for a simple and progressive intervention: poorer families buying smaller systems received proportionally larger benefit than wealthier farmers who opted for larger biodigesters (J. Lam, 2011). Subsequently, the subsidy was phased out for plants 8 m<sup>3</sup> and larger. 2 and 3m<sup>3</sup> units became available in 2016. Seeking to demonstrate that biodigesters could be commercialized, NBP reduced the subsidy by one third in 2012, the end of Phase I.

NBP restored the full subsidy in the second half of 2013, supported by a profitable carbon finance stream and support from several new donors such as Energizing Development (EnDev) and People in Need (PIN) (a Czech NGO).

In addition to the subsidy, the NBP forged partnerships with national banks and micro-finance institutions. From 2007–2012 the loans were pre-approved and pre-guaranteed by the NBP. Once the local representative of the NBP confirmed that a farmer met the minimum livestock requirement, a loan query note -- signed with a thumb print to account for high rates of illiteracy in the Cambodian countryside -- could be taken to any of the participating banks for a guaranteed loan.<sup>9</sup> In 2017, the mean loan size was 646 USD, indicating that farmers utilize the lending channel to finance not just for the biodigester but also other agricultural needs (NBP, 2017).

More recently, the percentage of installations receiving loans has declined. This can be partially explained by external policy changes. During Phase I, NBP had the authority to pre-approve loans for certain lenders. However, in 2013 a national policy was implemented prohibiting microfinance institutions (MFIs) from giving more than two loans to the same recipient in order to reduce excessive debt in rural communities. This affected eligibility for NBP loans and, while MFIs can request exceptions in some cases (Ry, 2017) micro-lending for biodigesters has clearly declined (Figure 8).

However, in 2015, a village-level initiative (ESRET) from the Food and Agriculture Organization and the Asian Development Bank began to gain popularity. ESRET allows farmers to access a community bank at 2% monthly interest without needing to put down collateral. Data on the use of ESRET-based loans is currently unavailable due to its recent implementation, thus it is unclear if this new program is making up for some of the decline in micro-loan use among new NBP customers observed since 2015. The default rate for those loans underwritten by the partner banks remains close to zero, with only one farm defaulting on the loan in 2016 (the farmer moved to Vietnam for work) and the rest of the

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<sup>9</sup>Acleda and Praesec banks have been NBP participants since 2006; HKL bank joined the NBP loan program in 2015.

13,841 borrowers from Jan 2007-June 2016 paying back their loan on schedule (NBP, 2017; Ry, 2017).

#### 4.4. Implementation

The NBP implementation strategy is led by the principle of local ownership and local expertise. The NBP office in Phnom Penh oversees administration, financing and marketing of the program and also supervises the technical and bio-slurry units which are directly responsible for field implementation. Evaluation is predominantly managed by two Dutch consultants, who implement periodic user surveys and carbon monitoring reports.

The implementation structure of the NBP supports the participation and/or the creation of other ancillary organizations that help implement and maintain the biodigester. The provincial (PBPO) offices provide training to masons in order to support the creation of “Biodigester Construction Agents” (BCAs), which serve their village populations.

Management of the biodigester construction itself is standardized by the NBP. The masons and BCAs are paid a fixed commission of US\$90 per biodigester, a task that usually requires one skilled and two unskilled workers and can take up to 10 days for construction. The prices are fixed by the NBP in order to ensure consistency within the program, though the Program Director readily agreed that such regulation was not in line with a pure market model: “We decided to prioritize reliability, and we wanted to make sure that the BCAs competed on quality, not on price. It’s not a pure market in that sense, but I think the standardization is necessary for the project to succeed,” (J. Lam, 2011). Even with the fixed price scheme, the majority of BCAs, masons and supervisors (9 of 11) acknowledged that payment from biodigester installations was not enough money to be a sole source of income. When demand for installations decreases, BCAs turn to other forms of labor and are less likely to invest in promoting the NBP, leading to a downward cycle (Ment, 2017).

According to the NBP Annual Reports, the total number of established BCAs from 2006–2017 is 99, of which 55 are still operating. Of the 55 active BCAs, 21 of them were trained in 2016–2017. Multiple informants mentioned the high BCA dropout rate as a key vulnerability of the program.

##### 4.4.1. Technical Coordinators and Supervisors—NGOs versus Extension

**Agents**—The Technical Coordinators and Supervisors are employed by the PBPOs, which are either overseen by MAFF or a national NGO (CEDAC) depending on the province. In the first phase, CEDAC achieved 135% of its installation targets for its four administered provinces, as compared to MAFF meeting 81% of its targets in eight provinces (Tong, 2012). By Phase II the MAFF-administered provinces were outperforming CEDAC. The program manager suggested that CEDAC’s initial implementation costs were higher than MAFF, due to MAFF’s ability to build biodigester promotion and technical supervision into its regular agricultural extension program and CEDAC’s total reliance on NBP financial support. It follows that the MAFF personnel, who were salaried workers that added in the NBP considerations to their regular workstream, learned how to promote the NBP more slowly than CEDAC, but were also better able to sustain engagement over time (S. Lam, 2017a). In 2012 at the end of Phase I, CEDAC estimated that it had lost US\$ 20,000 in

unpaid labor costs. Losses were attributed to the amount of hours required to locate and educate willing households, and to implement and maintain the biodigesters in heterogeneous implementation environments (Tong, 2012).

**4.4.2. Bioslurry Experts and Capacity Building**—Bio-slurry is co-produced with biogas and has multiple uses. Bioslurry Experts (BSE) are employed by the PBPO to teach farmers how to store and utilize slurry as a nutrient spray for their vegetables, a substitute for chemical fertilizer, and as fish, pig, and duck feed. The BSEs approach the farmer during the construction process and follow up with monthly trainings, which often serve as promotional/marketing events for new users. However, as installation rates have declined, BSEs are doing other types of work in addition to their support to the NBP (Monoram, 2017).

**4.4.3. Promotion and Marketing**—NBP relies on formal and informal marketing strategies. BUS results indicate biodigester users learned about NBP equally by word-of-mouth from friends, relatives and neighbors, PBPO representatives, and masons who tend to live nearby (Kooijman, 2015; van Mansvelt, 2010). The importance of social networks in the diffusion of new technologies (Ramirez, Dwivedi, Ghilardi, & Bailis, 2014; Rogers, 2010) is recognized by NBP management. The PBPO pays 5 dollars for referrals from “promoters”, who are usually housewives who already own a biodigester and spread the word among friends and neighbors (Khin, 2012; Laihea, 2012).

**4.4.4. Implementation Budget**—The NBP implementation budget has varied considerably from 2007–2016, with its highest budget expenditures corresponding to the end of Phase I at 1.5–1.6 million dollars per annum from 2010–2012, when installations were at their peak and the carbon finance registration process was at its most intensive. A cumulative breakdown of NBP implementation costs shows comparative expenditure on program operating costs (salaried staff, equipment, office space) and Farmer’s Friend subsidy payments. The subsidy budget increases in years when the programs is more successful, as it is only paid out upon installation. Low installation rates correspond with years where the subsidy did not dominate the budget.

Following the division between SNV and NBP, the program sought budgetary assistance from a range of donors with varying priorities. As such, some budget items such as research into the provision of micro-scale biodigesters, are temporary whilst other program areas remain constant such as training, PBPO operations and carbon finance.

#### **4.5. Maintenance at the programmatic level**

The NBP has undergone significant administrative changes over time, including variations in the subsidy, supply-side incentives, and shifting partnerships affecting access to technical expertise, core funding, capacity building and annual goals. However, the goal of the program has always been to create a permanent biogas market in Cambodia and therefore experimentation with reducing and/or phasing out the subsidy for large-scale users and with transitioning the NBP towards national autonomy was planned into the earliest phases of the NBP’s execution (J. Lam, 2011).

The majority of NBP field staff suggest that the absence of a Senior Biogas Advisor places more pressure on the Program Coordinator and reduces resources for field office support, coordination and technical backstopping (Hyman, 2017). Despite the relatively short period of time that the Senior Advisor spent building the program,<sup>11</sup> the NBP delivered a technically sound product with timely and effective aftercare services, including a two-year warranty on the dome and a 3-year warranty on the biogas lamps (Kooijman, 2015; J. Lam, 2011). However, the loss of the external advisor appears to have reduced capacity building workshops and PBPO-led marketing activities, which are critical for program implementation. Further research is required to establish whether there is a negative feedback cycle at play, whereby reduced capacity from the NBP headquarters leads to less momentum in the field, and therefore a higher rate of attrition amongst the skilled masons and BCAs who work for commission and turn to other livelihood options faced with declining income from biodigester installations.

## 5. Outlook and analysis

Applying the RE-AIM framework to the NBP intervention makes clear that the program is focused on the creation of a biogas market that supports the adoption and maintenance of an aspirational technology for small-holder farms. This ambition is reflected in four features of the program:

1. Partnership arrangements with local government, and delegation of implementation and maintenance to local actors. Fixed term, non-renewable, contracts for international program advisors.
2. Emphasis on the training and regulation of skilled BCAs employing local masons and laborers and transferring skills to the local economy.
3. A stated goal to build a self-sustaining biogas sector in Cambodia, which attempted to phase out subsidies, and utilizes carbon finance to capitalize on public goods the program generates.
4. Emphasis on aftercare service and technical backstopping for biodigesters and use of bioslurry.

This section briefly reviews the key variables identified in the case for clues as to the external and internal drivers that are undermining the NBP's household-level successes.

### 5.1. External factors

The NBP is only accessible to farmers that can meet a threshold level of livestock ownership and can afford at least 250 USD, the cost of the smallest biodigester after applying the subsidy. Three external factors have constrained this already limited demographic's ability to acquire a Farmer's Friend.

First, as has been previously described, the government imposed a limit on micro-loans, which led to a decline in loan usage rates. While the NBPO and MFIs confirm that

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<sup>11</sup>Other SNV programs received advisory services and support beyond the single seven-year term that NBP received; e.g. Vietnam's program received 14+ years.

exceptions are possible, the process now requires additional steps, more collateral, and lacks transparency. Secondly, the Department of Animal Production and Health (the MAFF department hosting NBP) entered an agreement with the Chinese government in 2016 to promote a limited number of pre-fabricated Chinese household biodigesters and distribute them free of charge.<sup>12</sup> Total free installations are capped at 1800 units for the program lifespan, limiting the absolute impact of this agreement (S. Lam, 2017b). Based on five household visits in 2017, including two adopters of the Chinese model, there appeared to be a demonstrable difference in performance, quality, and reliability between the programs -- the Chinese biodigesters were in disrepair and not in use, just months after installation. However, the price differential is significant and the NBP estimates that the marketing drive had some impact on their installation rate in 2016 (*idem*). The PBPO in Takeo also noted that the Chinese biodigesters were usually installed by BCAs and masons who had been trained by NBP, so that NBP was effectively subsidizing their competitor (Phae, 2017).

In addition to direct competition with the fully subsidized Chinese model, several other models have been introduced in the past three years. Subsidies and incentives to adopt these units range from 400 to 1500 USD, many times larger than the subsidy USD 150 offered by NBP (*idem*). The NBP is the only biodigester initiative with a full capacity building model, warranty system, and after-sales service. NBP is currently lobbying MAFF and its donors for support creating a standard for biodigester technologies and programs that would ensure innovative technical designs lead to healthy competition within the biogas market.

Third, many households and NBP staff interviewed mentioned labor migration, reduced numbers of livestock, and electrification as factors undermining demand for the Farmer's Friend. These assertions are supported by observations by BCAs (who perform the warranty and repair work), who noted that some biodigesters are abandoned because families sell their livestock and/or leave the village, not because the technology fails. Since 2007, only 352 biodigesters have been recorded as abandoned: further research is required to understand disuse rates and their cause.

## 5.2. Internal Factors

In addition to the external pressures limiting the reach and adoption rates of the NBP, internal policy changes may also be significant. The contemporaneous departure of the SNV Senior Advisor and the 30% reduction in subsidy corresponds with the first drop in biodigester installations. It is reasonable to believe that the NBP would have benefited from longer-term engagement with SNV advisory services. For example, the SNV advisory services in Vietnam were originally planned to last for 15 years, and this time-frame has now been extended to include a longer tenure for advisory services to support the nearly 160,000 biodigesters installed (World Bank, 2018; Zwebbe, 2017). In contrast, SNV supported the NBP for only ten years, with a single term of service from a Senior Advisor (van Waveren, 2017). Further research is required to determine whether fixed-term contracts for expatriated program administrators is more beneficial for program autonomy than it is disruptive.

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<sup>12</sup>These digesters, which originate in China, are not the fixed-dome design on which the Farmer's Friend is based, but a pre-fabricated plastic model that was recently introduced in Cambodia. There are reports that they are less durable than the fixed-dome design, but it is too early to draw conclusions about their long-term performance.

Beyond key personnel changes and the temporary subsidy disruption, a continued pattern of BCA attrition is problematic for the NBP's durability, particularly given the crucial role that the BCA plays in identifying new users and fulfilling the terms of the warranty. They report that it is unlikely that they would operate in the absence of the PBPO's facilitating efforts to run farmer field trainings, compensate the promotion of the biodigester through the promoters and the efforts that the NBP undergoes to provide quality control and technical backstopping. At the same time, BCA efforts have been successful in that the quality of the biodigesters is standardized and the knowledge regarding their construction has been transferred and integrated into the local context. Thus it is imperative that the provincial offices remain actively engaged in promoting the program. Similarly, research on how to incentivize (and perhaps encourage healthy competition) amongst the PBPOs may also prove fruitful. Given that the PBPO staff are usually employed through MAFF, it is likely that there is a compound effect now that MAFF has also agreed to promote the Chinese biodigester program.

## 6. Conclusion

The NBP case demonstrates the potential of training and deploying national skills and entrepreneurialism to support adoption of biogas stoves. Annual monitoring and external carbon verification reports present credible evidence that the technology is utilized and maintained in the Cambodian rural household. A zero-default rate on the MFI loans for the Farmer's Friend implies that the investment is viable and that the financial sector could take on more risk on the biodigester technology.

Yet despite these successes, the rate of growth of biodigester installations is declining. Building on the prior evaluation (Buysman & Mol, 2013b), our updated analysis finds that contrary to their concern that carbon finance was unreliable, the revenues from carbon finance have been stable. In addition, the Cambodian government has demonstrated increasing interest in the NBP and in biodigesters in general. However, prior progress in biodigester implementation is being undermined by new challenges.

First, as new actors enter the biodigester market and offer new models and dissemination methods, there is a need for biodigester protocols and performance standards. At present, multiple programs receive government support and engagement, yet the NBP is the only program that trains masons, offers a full-service warranty, and establishes quality control mechanisms to build trust on the demand-side. It is recommended that efforts to disseminate free or highly subsidized biodigesters with the support of the national government be required to include some degree of post-installation service, given the cost of the initial investment. So too, MAFF's support for the NBP would benefit from full integration within national policy.

In addition, supply side incentives must not be overlooked. The issue of attrition within the BCAs and skilled masons indicates that without stable demand at adequate volume, prior efforts in capacity building and technical training will be wasted as the skilled masons seek other forms of work. The current commission-based payment system is unreliable for both

the laborers paid under its system and the NBP that invests in their trade. Further thinking is required on how to incentivize and maintain commitment to the NBP on the supply side.

Finally, the lack of default on the farmer's loans indicates that the financial mechanism is working and the credit mechanism can continue to be offered to new users. Past experience with phasing out the subsidy was likely impacted by the major changes in personnel and project governance that simultaneously occurred, resulting in less support for biodigester construction agents, masons and promoters. Over ten years in the NBP experience, it appears that biodigester demand is not the predominant bottleneck. Project developers wishing to build a domestic biogas market can take the example of the NBP and learn from its current struggles by focusing on providing adequate incentives and quality assurances along the supply side of their biodigester program.

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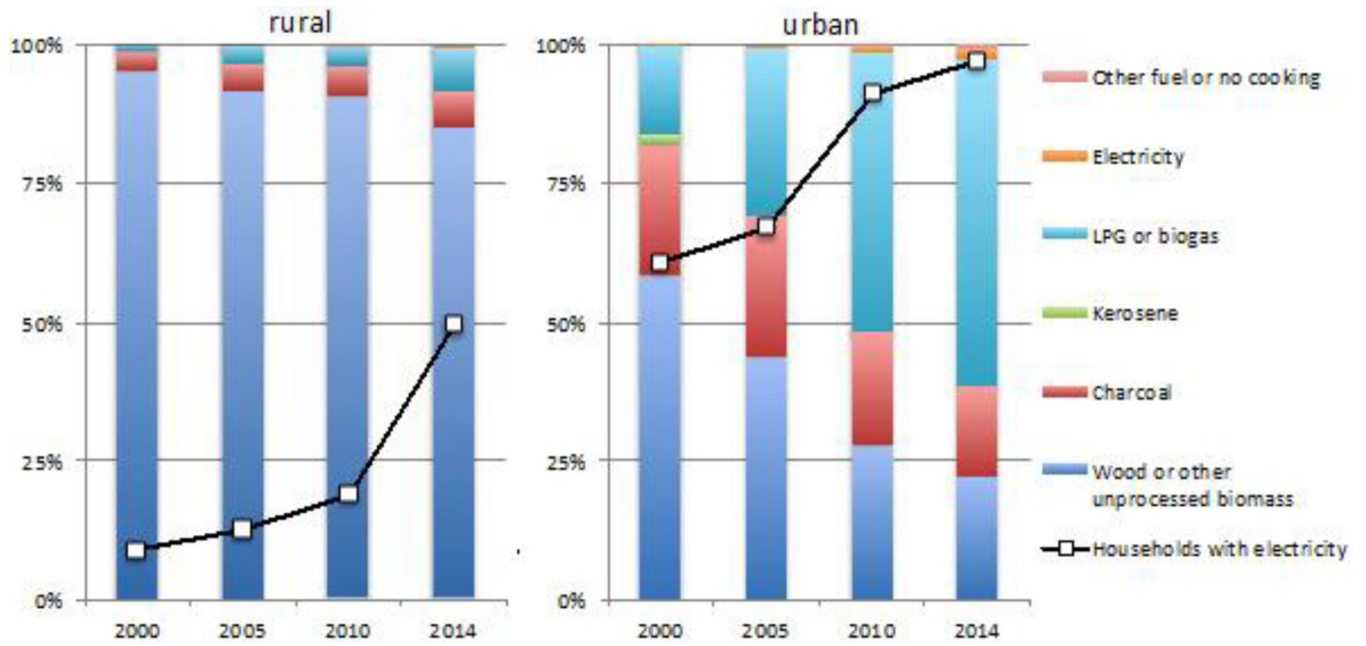


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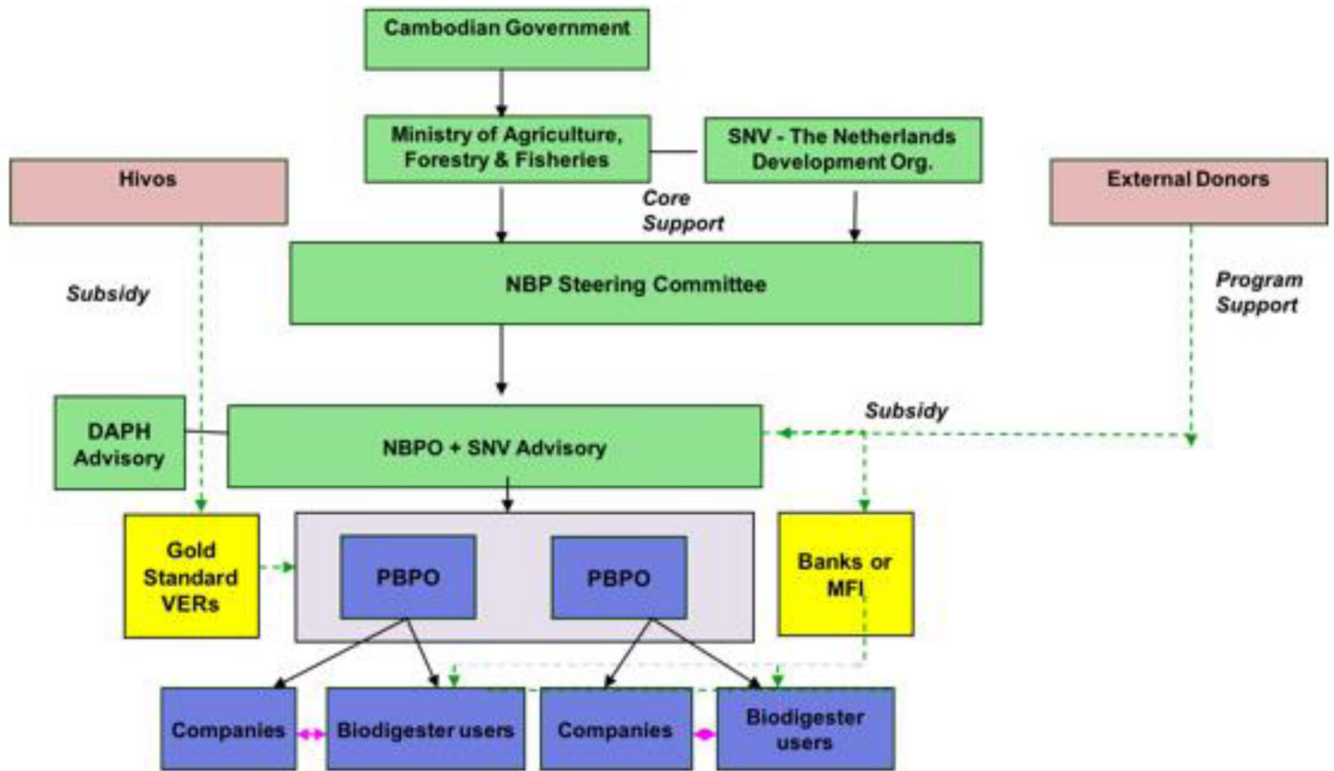
**HIGHLIGHTS**

- Despite high satisfaction rates, NBP biodigester installations are declining.
- Supply side services are critical to sustained adoption and use of the digesters.
- The NBP has been undermined by a giveaway program lacking after-sales support.
- There is a zero-default rate on the NBP loan; the private sector can expand its role.
- Multiple biodigester models in Cambodia push the need for technology and implementation standards.



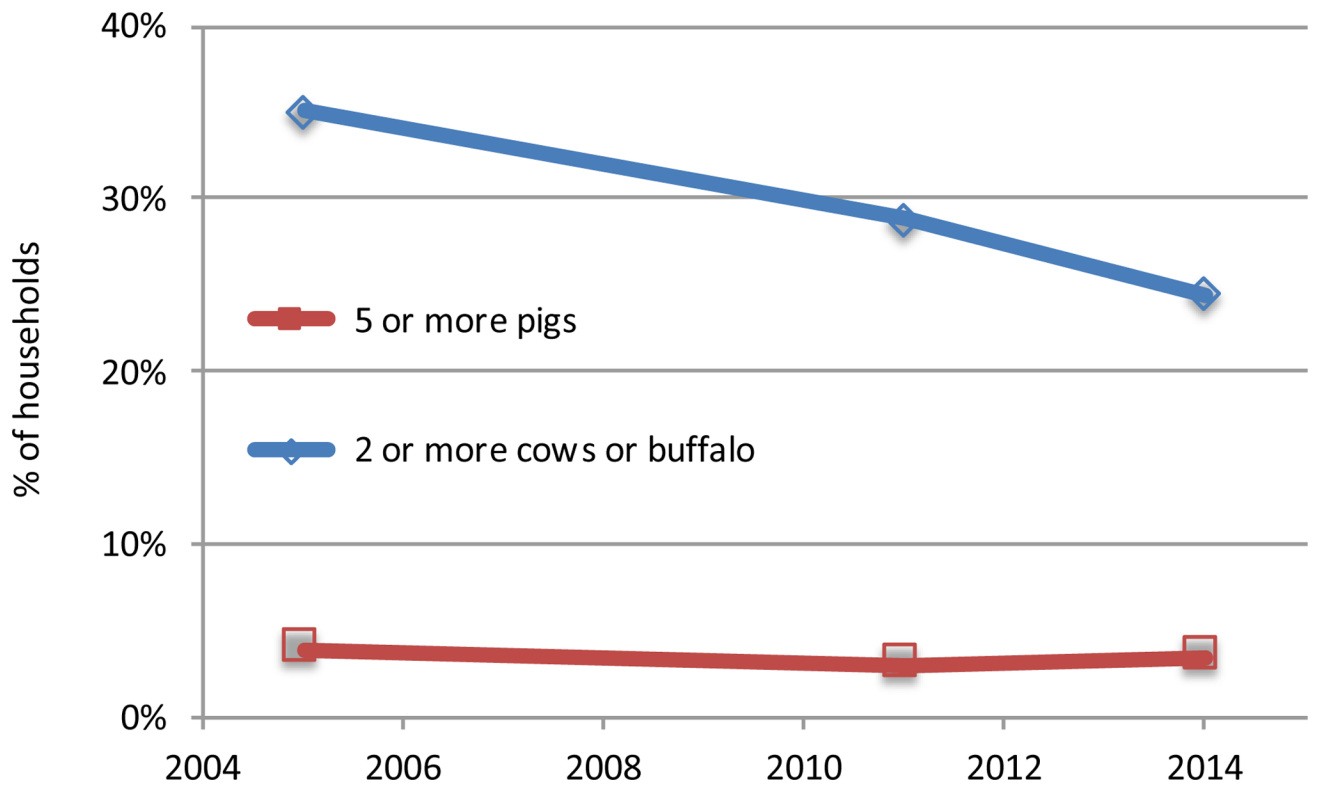
**Figure 1:** Primary household cooking fuel and electricity access nationwide (NIPH, NIS, & ORC Macro, 2006; NIS, DGH, & ICF International, 2011, 2015; NIS, DGH, & ORC Macro, 2001)<sup>2</sup>

<sup>2</sup>The original data combines LPG and biogas; however, the majority of households use LPG.

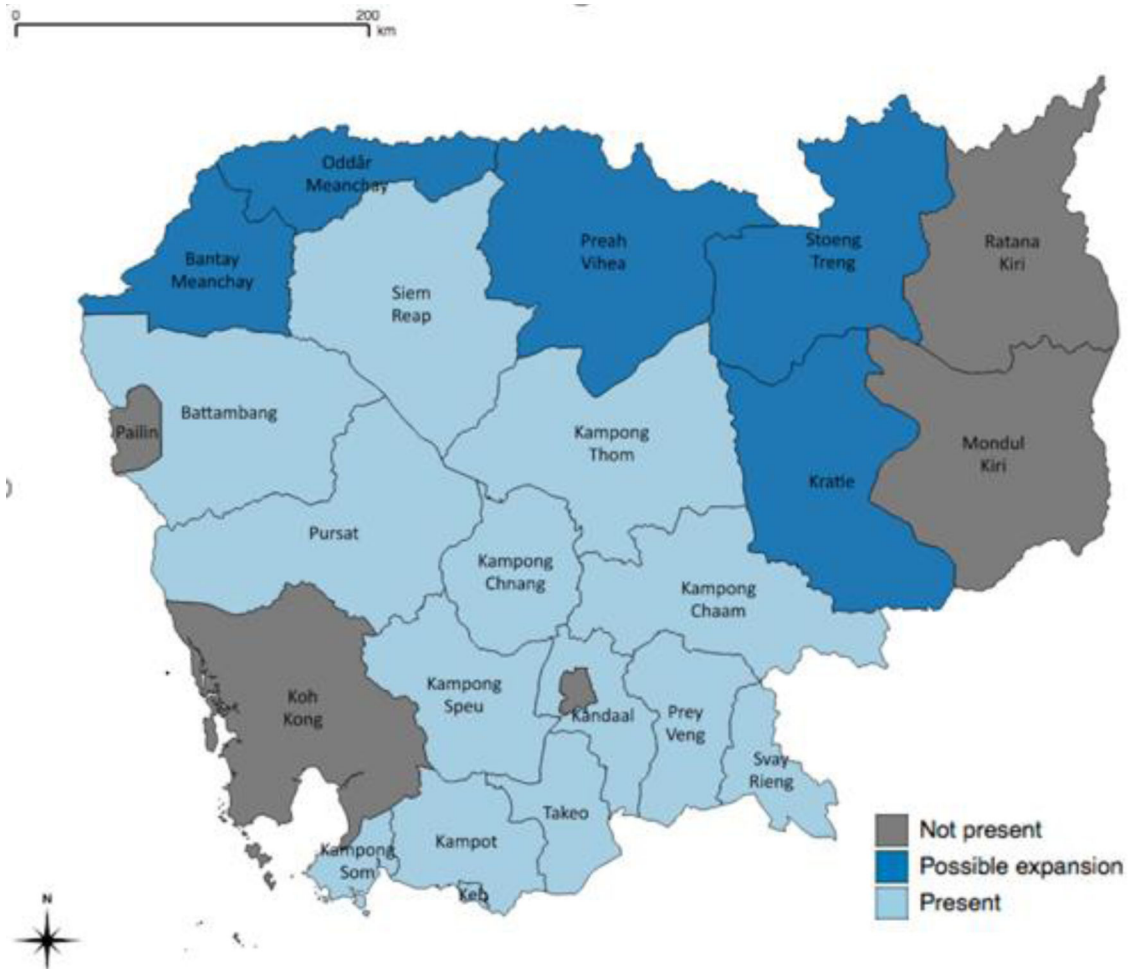


**Figure 2:**  
NBP Governance Structure During Phase I<sup>3</sup>

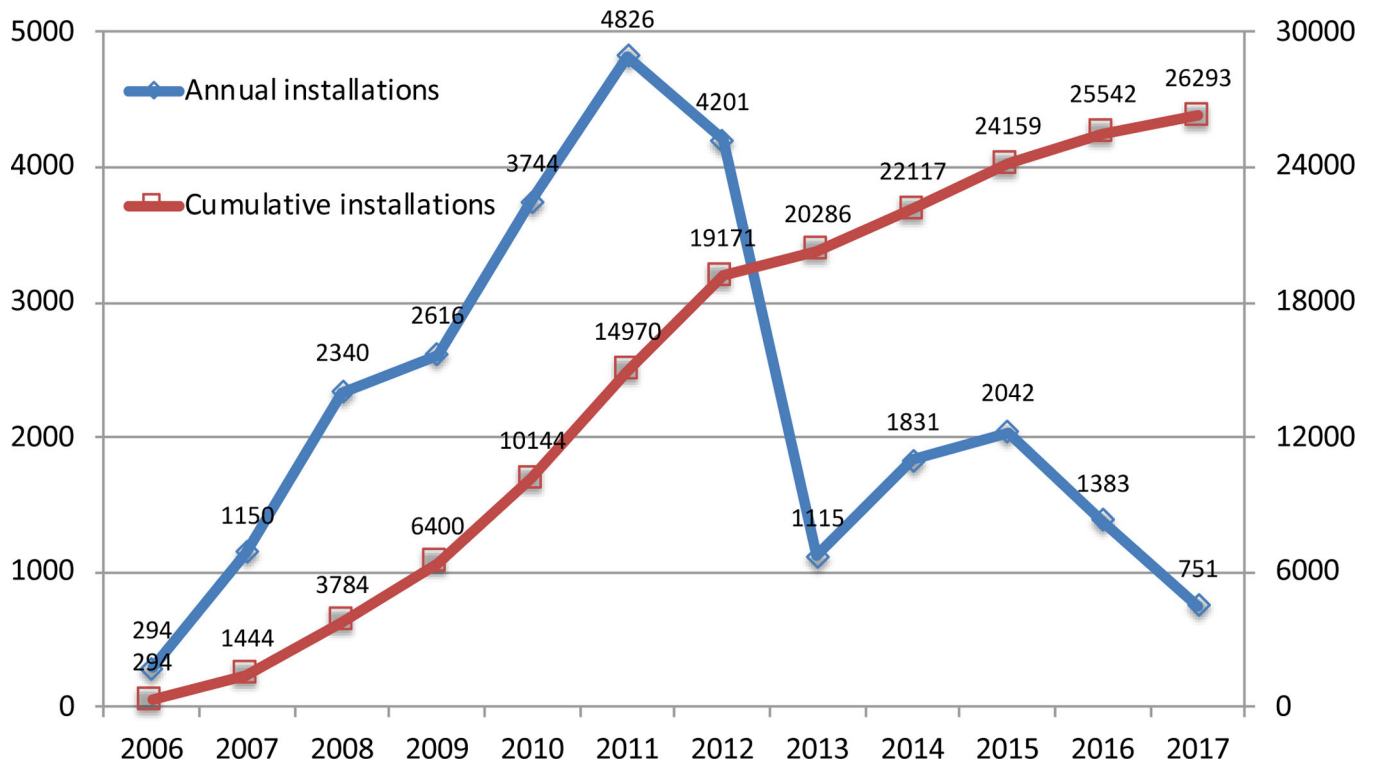
<sup>3</sup>This organizational chart was conceptualized by the NBP and adapted to include carbon finance and named donors by the authors.



**Figure 3:** Fraction of households owning sufficient livestock to feed a small biodigester (NIPH et al., 2006; NIS et al., 2011, 2015)



**Figure 4:**  
NBP Program Coverage and Possibility for Expansion in 2016 (NBP, 2016)



**Figure 5:**  
Annual and cumulative biodigester installations from 2006 to August 2017 (NBP, 2017)

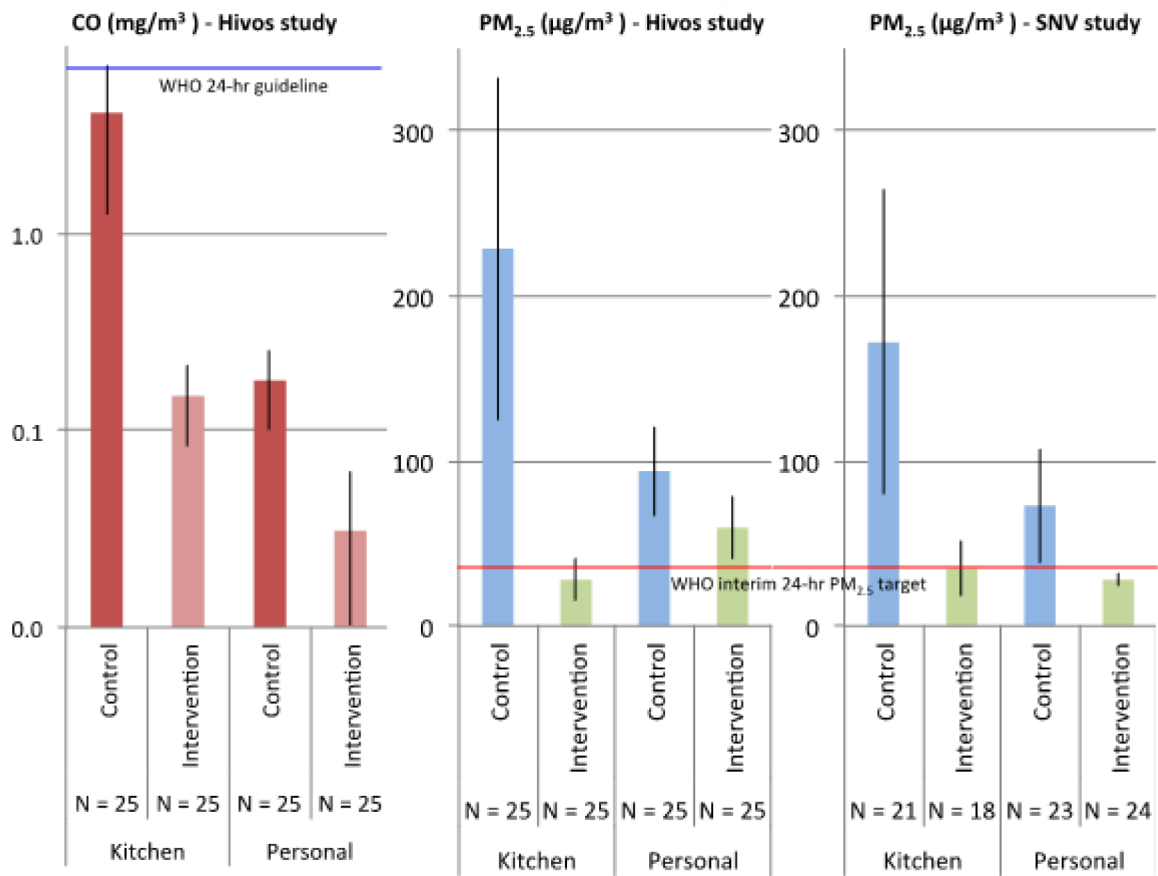
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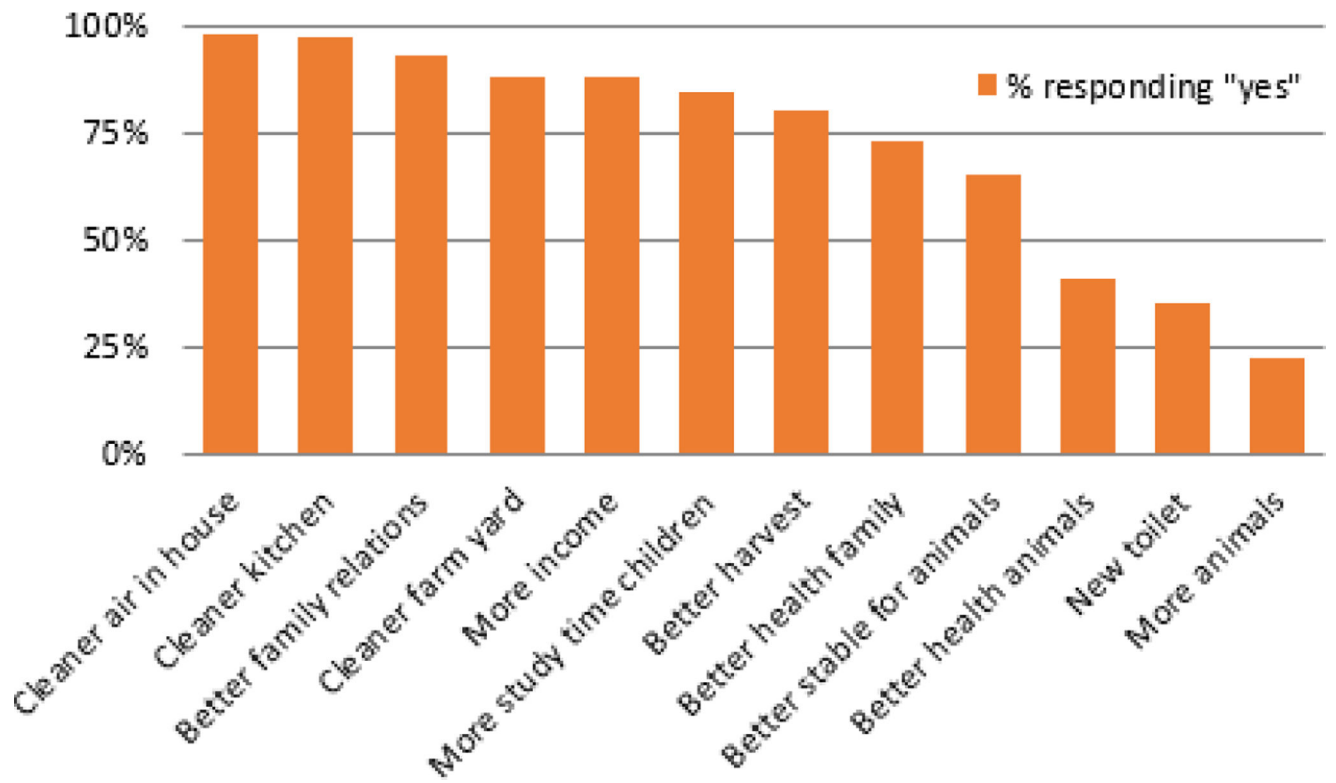
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**Figure 6:** HAP measurements in NBP households from two studies (Berkeley Air Monitoring Group & SNV World, 2015; Buysman, 2015)



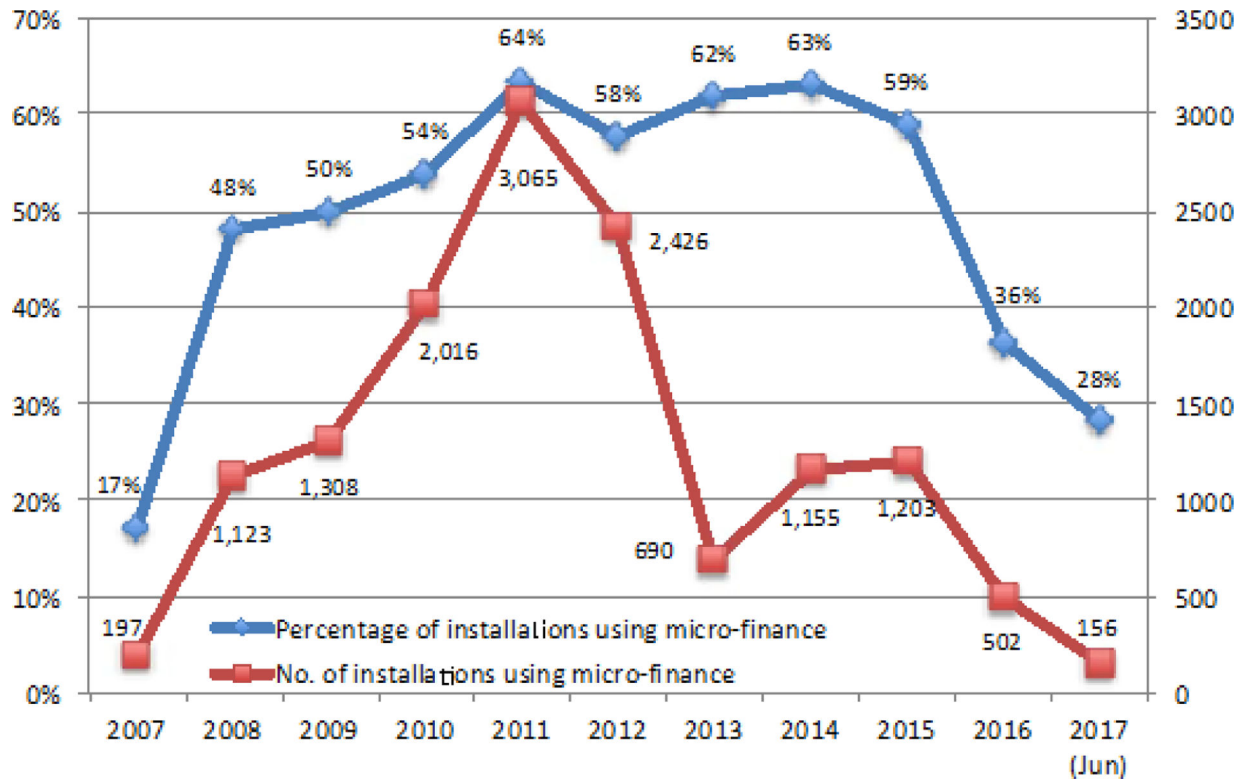
**Figure 7:** Self-reported benefits of biodigesters experienced by adopting households (Kooijman, 2015)

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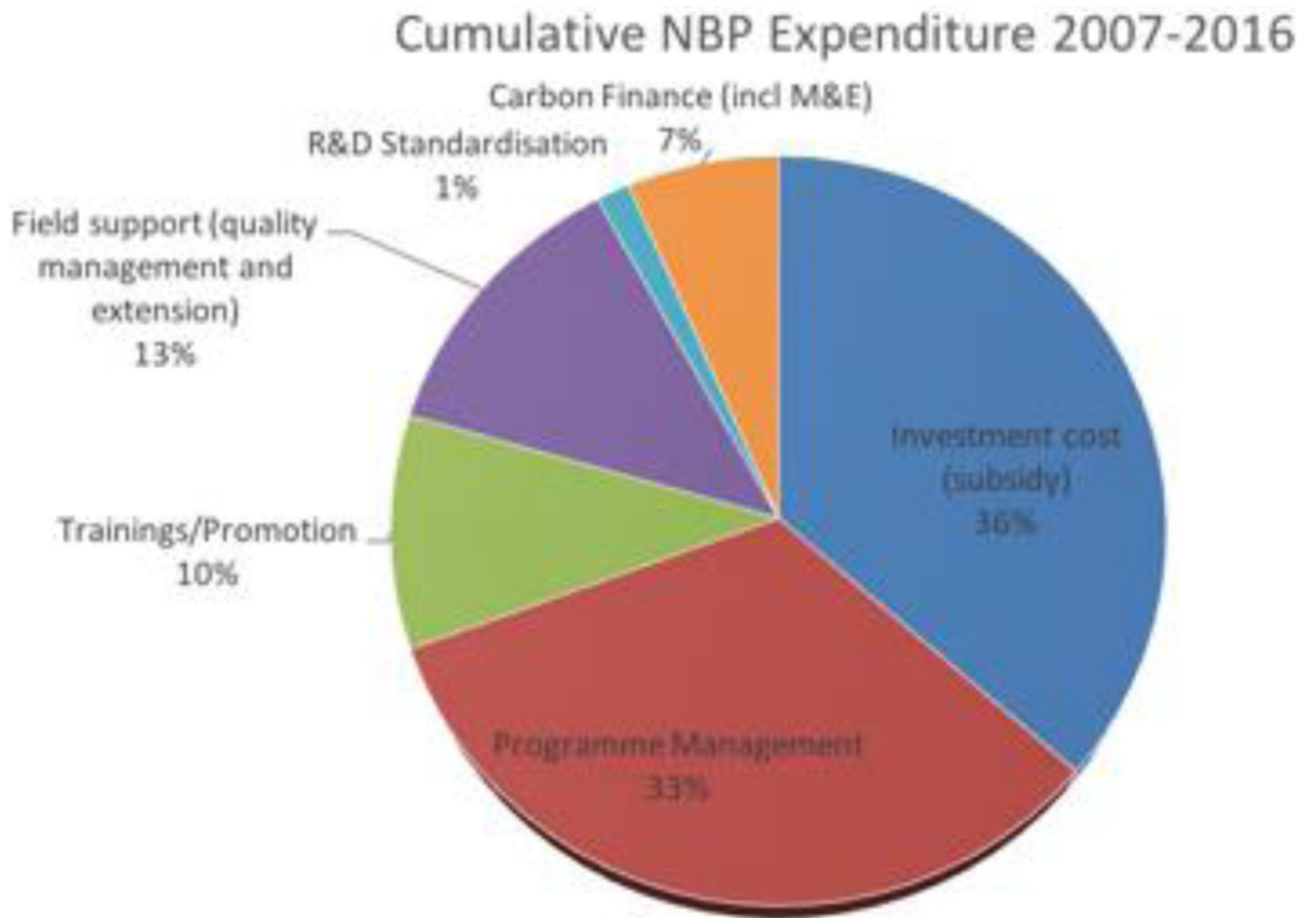
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**Figure 8:**  
 Number and percentage of biodigesters using micro-finance through June 2017 (NBP, 2017)



**Figure 9:**  
Cumulative NBP expenditure 2007–2016<sup>10</sup>

<sup>10</sup>Budgetary analysis is based on NBP's internal budget records from 2006-present. The carbon monetization process includes a requirement for annual third-party monitoring and verification of the digester usage and bioslurry utilization. The cost of the monitoring and evaluation includes payment to the third-party, UN-accredited verifier and The Gold Standard's issuance fee (which is bundled together with its fee for reviewing the documentation).

**Table 1:**

Recent and projected NBP indicators 2016–2025 (MAFF, 2016)

Indicators	2016	2020	2025
Cumulative household biodigesters installed (up to 100 kg dung daily)	25,000	33,000	43,000
Cumulative medium-scale biodigesters constructed (1,500–12,000 kg dung daily)	100	200	500
Cumulative slaughter house and other large- scale biodigesters (over 12,000 kg dung daily)	6	30	60
Cumulative GHGs reductions (in thousand tons of CO <sub>2</sub> equivalent) <sup>6</sup>	470	951	1689
Cumulative firewood consumption reduced (thousand tons)	276	489	818
Natural fertilizer produced from effluent (thousand tons)	207	367	613

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<sup>6</sup>NBP estimates emission reductions using Gold Standard methodology for biodigesters. Reductions are achieved by a combination of reduced firewood consumption and reduced methane emissions, which are explained in detail in the project design document (NBP, 2011).

**Table 2:**

Summary of Plant Costs (NBP, 2017)

Plant size (m3)	Farmers investment (US\$)	Subsidy (US\$)	Plant cost
4	250	150	400
6	350	150	500
8	400	150	550
10	500	150	650
15	750	150	900

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**Table 3:**

Reductions in wood consumption measured or estimated in recent NBP studies

Study	Grouping	Number of household surveys conducted (n)	Average wood consumption (kg/HH-day)	Standard deviation	Comments
BAMG <sup>a</sup>	Control	24	2.8	1.2	Results are based on weights of woodpiles participants were asked to set aside estimating their consumption on a typical day rather than wood used for actual cooking.
	Biogas	24	1.3	2	
	<b>Difference</b>		<b>-54%</b>		
2015 BUS <sup>b</sup>	Before biogas installation	288	6.5	NA	Estimated monthly wood use from NBP's 2006 Baseline study (unknown sample size), converted to daily consumption.
	After biogas installation	15	1.8	NA	Average wood use in 15 households during a 24-hour period
	<b>Difference</b>		<b>-72%</b>		
HIVOS <sup>c</sup>	Control	25	3.6	NA	Reflects cooking and water boiling in 25 HHs and fodder preparation in 4 HHs
	Biogas	5	0.8	NA	Reflects cooking and water boiling in 4 HHs and fodder preparation in 5 HHs
	<b>Difference</b>		<b>-78%</b>		

<sup>a</sup>From Berkeley Air Monitoring Group's 2015 study on air quality and health impacts<sup>b</sup>From the 2015 Biodigester User Survey<sup>c</sup>From HIVOS' 2015 study on air quality and health impacts

**Table 4:**

Three-study comparison of fuelwood or charcoal usage

Study	Number of household surveys conducted (n)	% of HHs using fuelwood or charcoal	Comment
BAMG <sup>a</sup>	24	50%	Stove-use monitors indicate that 12/24 HHs used wood during the monitoring period
2015 BUS <sup>b</sup>	165	28%	29% of surveyed biodigesters users “regularly used other sources of fuel”, including collected wood (86%), purchased wood (6%), charcoal (6%), and LPG (3%). Dropping LPG users leaves 28% of the total.
HIVOS <sup>c</sup>	25	48%	Around 36% of the biogas households use a wood-fired stove on a daily basis and 48% use a wood-fired stove on a weekly basis.

<sup>a</sup>From Berkeley Air Monitoring Group’s 2015 study on air quality and health impacts

<sup>b</sup>From the 2015 Biodigester User Survey

<sup>c</sup>From HIVOS’ 2015 study on air quality and health impacts



**Table 5:**

Breakdown of biodigester size and capacity (subsidy remains fixed) (NBP, 2011)

<b>Plant size</b>	<b>4 m<sup>3</sup></b>	<b>6 m<sup>3</sup></b>	<b>8 m<sup>3</sup></b>	<b>10 m<sup>3</sup></b>	<b>15 m<sup>3</sup></b>
Estimated cost (USD)	400	470	550	625	890
Dung requirements	20–40	40–60	60–80	80–100	100–150
[kg/day]					
Estimated gas production (m <sup>3</sup> /day)	0.8–1.6	1.6–2.4	2.4–3.2	3.2–4.0	4.0–6.0
Estimated fuel wood saving (kg/day)	4–8	8–12	12–16	16–20	20–30

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