

Carbon Markets and Biogas Strategy in Indonesia

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Executive Summary

In Indonesia, the world's 4th most populated country, over 40% of the population continue to lack access to reliable energy sources. These ca. 28 million households then rely on the harvest and combustion of firewood to meet their daily cooking needs, contributing to deforestation, eutrophication, and respiratory diseases from breathing smoke in poorly ventilated households, one of the nation's leading causes of premature death. One promising energy alternative to address these issues is biogas. Produced by the anaerobic digestion of organic matter (kitchen/farm waste, livestock dung) in a digestion chamber, biogas is a clean and renewable energy that can be produced at no cost by the households. Several programs have been initiated to disseminate this technology in Indonesia, however they have continuously failed to meet their distribution and compliance goals. Two national biogas programs initiated by the clients Su-re.co (Bali) and Hivos (Jakarta) using different digester models were investigated to determine the flaws and successes of each through water boiling tests, household air quality measurements, financial analyses, and conversations with end users. Recommendations were made to increase success through design changes, monitoring enhancements, and tailored sizing/model selection and financing strategies. A final recommendation for the most scalable and sustainable programs and digester designs was delivered to the Indonesia Domestic Biogas Program (IDBP) to allow a fully market-based solution to scale Indonesia's biogas strategy.

The following key recommendations were delivered to the clients and IDBP:

1. Applications from potential biogas users should include the number of livestock and number of hours spent cooking per day so that the gas production model can be used to select the appropriate size digester for the family.
2. Digester recipients should complete the baseline survey designed for biogas here, and the user surveys should be completed on follow up visits within one year of installation. These data should be stored in a shared database
3. Su-re.co should focus on finalizing and installing a 2 m³ PVC bag-style design instead of the current 1 m³ capacity in order to have the desired impacts on deforestation, health from indoor air pollution, and ERs from firewood
4. Hivos should bridge the financial gap between cost and subsidy + WTP by focusing on a 3.5 m³ PE tank digester design

5. The two recommended designs should be incorporated into Hivos' Gold Standard registration under VPA-3, together representing 90% of the market
6. Traditional monitoring should be modernized through the use of remote flow rate meters and gas consumption ER models, such as the one presented here

Introduction

Approximately 40% of the global population continues to use solid-state fuels (firewood, charcoal, dung, agricultural residues) for their daily cooking and water boiling needs. In some developing countries, chopping down trees for firewood can account for up to 54% of deforestation. Additionally, households using solid fuels typically cook over open fires and have little to no air ventilation. The combustion of solid fuels releases fine particulate matter (PM_{2.5/10}) and carbon monoxide (CO) into the household, which are then inhaled by its inhabitants. Fine particulate matter (hereby PM_{2.5}) is small and light enough to float in the air and bypass the nose and throat directly to the lungs when inhaled. These fine particles lodge themselves in the lungs causing health impacts ranging from coughing, wheezing, and shortness of breath to more serious conditions like heart disease and lung cancer. Carbon monoxide is an odorless, tasteless gas that can cause headaches, dizziness, vomiting, and nausea (CDC). More research is needed looking at the long-term health effects of exposure to low levels of CO, though exposure to moderate and high CO levels has been shown to increase the risk of heart disease (CDC).

Due to the traditional delegation of household tasks, these exposure risks are typically placed mostly heavily on women and children who spend the most time inside the household and cooking. The World Health Organization reported in 2012 that household air pollution (HAP), also referred to as indoor air pollution (IAP), from cooking and heating causes an estimated 4.3 million premature deaths per year (WHO, 2012). Of these deaths, the 71% of the burden is in Southeast Asia and the Western Pacific. Indoor air pollution related deaths occur from several causes including 27% from pneumonia (half of which are children under 5), 18% from stroke, 27% from ischaemic heart disease, 20% from chronic obstructive pulmonary disease (COPD), and 8% from lung cancer (WHO, 2017).

In addition to the negative impacts on health and deforestation, the combustion of traditional solid-state fuels contributes to climate change through the release of CO₂, methane, and other greenhouse gases (GHGs), and also poses a significant economic burden on households in either the form of time spent by women collecting firewood/other solid fuels or costs incurred from the purchase of these fuels when they are not readily available. The McKinsey Global Institute reported that the majority of women's unpaid work hours in developing countries are spent on fuel collection and cooking. In terms of climate change impact, the combustion

of unsustainably harvested wood fuel alone accounts for roughly 2% of global GHG emissions (Muthia, 2015).

The combination of all these environmental, health, and socioeconomic risks incurred from solid-state fuel use has led to the development of numerous ‘clean’ or ‘improved’ cook stove interventions. These intervention projects, traditionally funded through large grants from governments or non-governmental organizations (NGOs), distribute improved cook stoves to households (mostly in rural areas) that would otherwise use open fires with solid fuels for cooking. These programs have been implemented across the developing world in Latin America, Africa, and Asia. The type of cook stoves delivered range from biogas, LPG, or electricity powered stoves to simply ‘improved’ wood burning stoves designed to minimize the amount of fuel required by maximizing thermal efficiency and funnel smoke through a chimney.

A recent development in the field of cook stove interventions is the application of carbon market financing to subsidize the cost of clean cook stove distribution. These markets allow for emissions reductions created by switching from solid fuel use to be quantified and sold as carbon credits to other entities seeking to offset a portion of their emissions. Successful carbon financed cook stove intervention projects have been established in Kenya, Uganda, Nigeria, China, India, Vietnam, Guatemala, Honduras, and Mexico, among others (Muthia, 2015). Further development in this field has the potential to vastly increase the scale of future intervention projects. By achieving sufficient economies of scale, net carbon financing over the technology’s life cycle could exceed the cost of the technology. This would encourage entrepreneurs to start new projects and investors to finance them in search of a return. Sustainable and profitable growth would also minimize the risk of projects failing due to removal of funding or subsidies.

Most ‘clean’ cook stove interventions simply replace traditional open fire cook stoves to ‘improved’ models designed to funnel smoke and particulate matter from the household through a chimney and minimize the amount of fuel needed by maximizing heat transfer efficiency. However, these models still rely on the use of the same solid fuel sources (firewood, charcoal, animal dung, or agricultural waste) as used previously. Thus, while ‘improved’ cook stoves do reduce the amount of fuel burned, they still produce significant

amounts of GHG emissions and continue to contribute to deforestation. Furthermore, the use of solid fuels continues to present the risk of particulate matter formation. Even if most smoke and particulate matter is released through the chimney, their release will never be 100% efficient. One study found that while one type of improved wood burning stove (ceramic) did significantly reduce daily average suspended particulate matter concentration in Kenya, it only reduced concentrations by 48% (Ezzati et al, 2000). The WHO's air quality guidelines assume that an average of 25% of total emissions enter the room despite the presence of a chimney (WHO, 2014). Indeed, the only improved cook stoves that meet the health guidelines for indoor air pollution set by the WHO are those that use electricity or liquid fuels (LPG, ethanol, or biogas). Future cook stove interventions should therefore be improved to eliminate the use of solid fuels.

Biogas as a Cookstove Intervention

A study by the Clean Cooking Alliance (CCA) in which ten risk factors were evaluated among various fuel types found that the only fuel source with a low impact rating among all factors was biogas (Clean Cooking Alliance, 2013). It had the lowest total particulate matter formation (0.077 kg eq) with 2x less than sugarcane ethanol and LPG (~0.15 kg eq), 4x less than kerosene (0.31 kg eq), and over 60x less than firewood (4.72 kg eq). Biogas fuel also had the lowest global climate change potential (10.5 kg CO₂ eq), with 9.5x less than sugarcane ethanol (95.7 kg CO₂ eq), 18x less than kerosene (181 kg CO₂ eq), 30x less than LPG (~300 kg CO₂ eq), and over 500x less than firewood (539 kg CO₂ eq). Biogas was also the only fuel source with zero eutrophication potential and zero fossil fuel depletion. It depletes more water than firewood, but significantly less water than LPG/kerosene (~30x less), and sugarcane ethanol (88x less). Biogas also had the lowest terrestrial acidification potential and photochemical oxidant formation potential among the examined fuel sources. In the category of black carbon and short-lived climate pollutants, biogas had the third lowest impact behind LPG from NG (not from crude oil) and ethanol from sugarcane, due to the methane component of biogas (Clean Cooking Alliance, 2013).

Biogas stoves also offer additional co-benefits to those provided by other intervention technologies. The conversion of manure management from open field or riverine disposal to a closed system digester reduces nutrient release decreasing eutrophication potential. Instead,

the nutrients available from the waste are bacterially processed and recycled as a rich bio-slurry. This natural fertilizer can be applied to crops or sold to other community members. Fertilizer production produces cost savings for households that normally purchase artificial nutrients, and a potential source of income for households with a surplus. Reduced use of chemical nutrients will also decrease eutrophication impacts. Bedi et al. found that biogas installation at households in East Java led to a 45% reduction in household expenditure on energy, a 6-7 kg reduction in LPG consumption, an 85% reduction in time spent collecting firewood, and a 67% reduction in total firewood use (Bedi et al, 2017).

The greatest barrier to success in biogas stove intervention projects is initial cost of biogas digester construction and installation. Costs range from \$300-1,000 depending on the type of digester, which could represent 25 – 50% of the smallholder farm's annual income (\$1,967 in constant 2009 international dollar) (Schenck, 2018). The majority of this cost is traditionally financed through loans, which could take over a decade to pay back in the absence of other subsidies (Bedi et al., 2017).

Despite their high cost, biogas technologies are desirable to households due to values such as reduced need for firewood and time foraging, faster/smokeless cooking, production of bio-slurry fertilizer, and improved hygiene/odor from efficient waste management (Bedi et al., 2017). Reported compliance in biogas interventions is relatively high, ranging from 60% (BIRU) to 96% (Bedi et al., 2017). In the case of East Java, 47% of households reported they were “very satisfied” with their biogas digester and 52% reported “rather satisfied” (Bedi et al., 2017).

Focus should continue to be given to Southeast Asia, specifically Indonesia, due to the high potential for adaptation. Biogas is seen as a promising renewable energy solution in the region due to the large numbers of small family farms without access to grid power. In recent years the social stigma on biogas has faded in Southeast Asia and it has grown to be more culturally accepted as can be seen by the success of programs in Vietnam, Thailand, and Malaysia. While Indonesia has a promising start in biogas, it has much to do to catch up to its neighbors. For example, 250,000 digesters have been installed in Vietnam compared to only 23,000 in Indonesia, despite Indonesia having an over 2.5x larger population. Eutrophication from agricultural waste and chemical nutrients is a significant problem in Indonesia that can

create toxic algal blooms and hypoxic dead zones that can be a serious risk to human and environmental health. Additionally, Indonesia has existing physical and social infrastructure from the previously subsidized BIRU program. This creates an opportunity for a successful business model to restart momentum in the sector and expand the program to a competitive level.

Biogas Strategy in Indonesia

Indonesia is the world's largest archipelago consisting of more than 17,000 islands uniquely situated within the coral triangle of Southeast Asia. In terms of population, Indonesia is the world's 4th largest country with 264 million people in 2017 (the United States had a population of 325.7 million in the same year), yet by land area Indonesia is only the 16th largest. Indonesia contains significant reserves of fossil fuels (coal, oil, and gas), and has long relied on coal as their primary source of domestic power production as well as a main source of export income with 80% of coal production exported. This reliance makes Indonesia the world's largest coal exporter and the world's 5th largest coal producer, despite the fact that it contains only a fraction of global coal reserves (2.2%) (Zhang et al, 2013).

Fossil fuel based energy production is controlled by few dominant market players that maintain considerable political power due to the important revenue streams they offer to the government (up to 14% of total government income) (Silaen et al, 2019). Indonesia continues to rely on fossil fuels as a combination of development and population expansion rapidly drives up domestic energy demand. For example, as recently as 2015 the government of Indonesia allocated IDR 73.1 trillion (\$5.4 billion USD) for fossil fuel based electricity subsidies and IDR 23.6 trillion (\$1.7 billion USD) in subsidies for liquefied petroleum gas (LPG) (Bößner et al, 2019).

This fossil fuel dependence has led Indonesia to be the world's 8th largest emitter of greenhouse gases (Zhang et al, 2013). Energy access across Indonesia is variable with many rural areas unable to obtain subsidized gas and oil products. As such, 40% of the population continues to rely on solid fuels (mainly firewood and charcoal) for their cooking, heating, and lighting needs (Zhang et al, 2013). In 2006, it was estimated that

over 135,000 tons of solid fuels were burned in Indonesia, representing a significant impact on deforestation, greenhouse gas emissions, and public health (Nes et al, 2009). The World Bank estimates that the proportion of Indonesians relying on solid fuels could fall from 40% to 25% by 2040 if policy-based solutions (such as rebate programs) are employed to promote clean and sustainable alternatives (Zhang et al, 2013).

In 2016, Indonesia ratified the Paris Agreement and listed its Nationally Determined Contribution (NDC) as an emissions reduction target of 29% (41% with international help) by 2030. Furthermore, Indonesia's National Energy Plan (NEP) of 2017 set a target for 23% of total energy production to be comprised of renewable energy sources by 2025 (currently there is only a 7% share of renewables) (Silaen et al, 2019). However, a combination of continued investment in fossil fuel industry and infrastructure, the economic significance of fossil fuel production, and the political power of the dominant energy companies make it highly unlikely that Indonesia will meet its NDC or NEP targets without significant intervention.

Another significant industry in Indonesia is agriculture, accounting for 14% of the nation's gross domestic product (GDP) (FAO, 2018). High annual rainfall allows for steady rice production (the primary staple food crop) making Indonesia the world's third largest rice producer. Indonesia remains a net importer of grains (mainly wheat), and has primary export cash crops of palm oil and rubber. Agricultural land constitutes approximately 32% of the total land area (increased from 25% in 2005), and the agricultural sector is the nation's second largest employer with approximately 33% of the work force employed in agricultural jobs (FAO, 2018). Somewhat unique to Indonesia, the sector is dominated by smallholders with approximately 93% of all farmers consisting of small family farms (FAO, 2018). These smallholder farms produce the majority of both staple crops (rice, corn, cassava) and cash crops such as coffee, tea, spices, palm oil, rubber, and fruits and vegetables (FAO, 2018).

The average smallholder farm consists of small land plots (average 0.6 hectares) maintained by 5 to 6 family members. Approximately 89% of family farms are headed by men, with women typically upholding the duties of cooking, collecting firewood, and caring for children. The decentralized archipelagic nature of Indonesia means that the

majority of these farms are located in rural areas with limited access to energy resources and alternative work opportunities. As such, the average annual household income of small family farmers is only \$1,967 USD creating a poverty rate of 18% among smallholder farmers, which is higher than the national average of 11% (FAO, 2018). In total, it is estimated that there are 25 million households (57% of all households) that are considered family farms (Nes et al, 2009), of which at least 13.3 million (in 2003) were marginal farmsteads with less than 0.5 hectares of agricultural land (Zhang et al, 2013).

Due to such a large proportion of Indonesian households consisting of rural smallholder farms that traditionally rely on firewood for fuel, biogas has often been proposed as an intervention technology to enable universal energy access in Indonesia. One such example is the government of the Netherlands, which allocated 500 million euros to promote renewable energy in developing countries between 2008-2011. They identified Indonesia as one of the primary targets for the dissemination of this effort, with a specific focus on domestic biogas energy. In 2008, the Directorate General for Electricity and Energy Utilization (DGEEU) of the Government of Indonesia then requested the Environment and Water Department (DMW) of the Netherlands Ministry of Foreign Affairs (DGIS) and the Royal Netherlands Embassy (RNE) in Jakarta, Indonesia to complete a feasibility study that outlines the potential for a national biogas strategy in Indonesia. The DGIS and RNE together with the government of the Netherlands contracted the SNV Netherlands Development Organization, a non-profit international development firm with prior experience working in Asian and African countries, to complete the feasibility study and provide additional context for biogas in Indonesia (Nes et al, 2009).

Three types of biogas digester were examined in the study. The first design, originating from India, is called a floating drum and consists of a brick digestion chamber capped with a steel drum in which to collect the biogas. This design requires a high initial investment and the steel drum has been found to become susceptible to corrosion, shortening the lifespan of the unit. The second design, originating from China, is called a fixed dome digester and is constructed entirely of brick in which gas collection takes

place within the same chamber as anaerobic digestion. This design is the most difficult and costly to construct but could potentially have the longest lifespan estimated at approximately 15 years. The third design, called the plastic bag digester, was developed in Taiwan in order to decrease capital costs of the digester. In this design anaerobic digestion occurs within a cylindrical bag made from some version of plastic (e.g. PE, LDPE, PVC), and gas storage occurs in a separate plastic bag. Plastic bag digesters are the least costly to construct, are relatively simple, and make it possible to increase gas pressure by placing weights on the bag. However, this design also has the shortest lifespan (ranging from 2-5 years depending on conditions), and is prone to leakage due to material weakening during transportation or damage by rodents or other animals (Nes et al, 2009).

SNV Netherlands conducted consultations with stakeholders and households which had either previously installed a biogas digester or were eligible to receive in order to elicit the specific advantages and disadvantages of biogas that are valued in Indonesia. Valued advantages included reduction of foul smells from manure due to proper waste management, convenience, and having a clean and safe fuel for cooking that also leads to a clean cooking environment, clean cooking utensils, and clean clothes (Nes et al, 2009). They also mentioned the benefit of saving money from purchasing other fuels, saving time compared to cooking with firewood or kerosene/LPG as well as collecting firewood, and the production of bio-slurry (Nes et al, 2009). Bio-slurry is the term given to the digester's effluent, aka the by-product of anaerobically treating organic waste in the digester. The bio-slurry has high amounts of organic nutrients and bio-activators making it an excellent soil conditioner that also adds humus and enhances the soil's capacity to retain water (Zhang et al, 2013). As bio-slurry is fully fermented it is also odorless, does not attract flies, and is free of pathogens that could cause disease to humans or plants (Zhang et al, 2013). Application of bio-slurry to fields has furthermore been shown to increase crop production relative to artificial fertilizers (qualitative observation), and to be an effective natural pesticide and herbicide with one study showing a reduction in weed growth by up to 50% (Zhang et al, 2013). The bio-slurry produced offers a dual benefit to farmers by providing them a free organic fertilizer that can either be applied to their own crops (thus reducing their expenditures on chemical

nutrients) or traded/sold to other farmers in exchange for goods and services (thus providing an additional source of real or virtual income). Disadvantages of biogas identified by stakeholders were shortage or unsteady supply of manure to feed the digester, inadequate biogas production, leakage through various parts of the system, and limited lifespan of the unit (depending on the type of digester used) (Nes et al, 2009).

The SNV Netherlands feasibility study concluded that there was significant potential for biogas strategy implementation in Indonesia with capacity for at least one million units to be installed (Nes et al, 2009). They further concluded that smallholder farmers who invested in a biogas digester would receive an attractive financial rate of return (FIRR) when combined with a government subsidy. Another important development that was not included in the study by SNV Netherlands but should still be considered is that a Balinese NGO called Su-re.co is in the process of developing an enhanced version of the plastic bag digester using PVC (Silaen et al, 2019). Use of PVC material in the bag-style design allows for a compromise between cost and durability. PVC is more resistant to weather, transport, and animal induced damage and is therefore less likely to form leaks. It is predicted that the PVC digesters will have a functional lifespan of 5 years, and they are designed such that only the bag itself will need to be replaced (Silaen et al, 2019). Initial cost estimates for PVC bag digesters were listed at \$414 USD (Silaen et al, 2019), however Su-re.co is working to reduce the cost even further by producing larger quantities at a time to reach economies of scale (Su-re.co, personal communication).

In response to SNV Netherland's study, the government of the Netherlands decided to finance a biogas strategy project in Indonesia. Termed Biogas Rumah (BIRU), meaning biogas for the household, BIRU set the goal of installing 100,000 digesters by 2020 through partnership with the international development firm Hivos (also based in the Netherlands), which ultimately created (and later delegated management responsibility to) the Indonesian NGO Yayasan Rumah Energi (YRE) (Nes et al, 2009). The government of Indonesia agreed to provide a subsidy of \$200 USD (approximately IDR 2.75 million) towards each biogas digester that was installed. Provision of which was essential to meeting the finance targets set by the program. BIRU had a successful start, and by

2016 the program had successfully completed over 20,000 installations across nine provinces of Indonesia (Taylor et al, 2019). However, in 2017 the government of Indonesia changed its tune on biogas strategy and halted the \$200 USD subsidy entirely (Hivos, personal conversation). The removal of this financing caused the program to crash and there have been only been relatively few biogas digester installations since this time (Hivos, personal conversation).

Recent reports in the literature suggest that there are some limitations with the fixed dome digesters employed by Hivos. Reports indicate that alternating wet and dry seasons in Indonesia can lead to the frequent formation of cracks in the dome, causing users to stop using their digester (Taylor et al, 2019; Silaen et al, 2019; Bößner et al, 2019). These papers also tout the ability of Su-re.co's new PVC bag-style digester to overcome issues with cracking while providing a more affordable cost-effective option.

Project Objectives

1. Work with clients Su-re.co (Bali) and Hivos (Jakarta) to identify past problems and new developments in Indonesia's biogas sector. Identify the cause of recent reports on cracking, the seriousness of the problem, and if Su-re.co's model is really the solution
2. Add to existing knowledge on biogas by collecting data on flow rates, thermal efficiencies, particulate matter emissions, etc.
3. Use Gold Standard methodologies to enhance capacity for modeling emissions reductions (ERs)
4. Conduct financial analyses on different digester models; identify other ways to increase value for clients
5. Synthesize data and financial analyses to select the most appropriate digester model(s) to recommend for inclusion in the Gold Standard and focused expansion in Indonesia

Methodologies

Field work was conducted between February 1 – March 31, 2020 in Bali and Jakarta, Indonesia. Grant funding for this research was provided by the Energy Access Group at Duke University. The database of the Indonesia Domestic Biogas Program (IDBP) was analyzed to determine the distribution of livestock and people in recipient households to make assumptions about the target market. The percent of currently functioning and non-functioning digesters was calculated to identify trends among digester failure and non-compliance. At each client organization, initial analyses of operations were conducted by examining financial documents, technical papers, and business plans. Recommendations and improvements to general operations were made as appropriate.

To compare the potential of different biogas digester models, the Clean Cooking Alliance (CCA) methodology, ‘Water Boiling Test’ (WBT), was chosen. In the WBT, the stove is started at full power and the time taken to bring 2.5 L of water to the local boiling temperature (LBT; 99° C at sea level) is recorded. Once the LBT is reached, stove power is reduced to bring the water to a ‘simmer’ for 45 minutes while maintaining water temperature within 3° C of the LBT.

Water temperature is monitored with a thermometer and the volume of water remaining at the end of the test is also recorded. The WBT was originally designed to test improved wood burning stoves, and while modifications have been included to account for newer stove types such as LPG and kerosene, there are no established guidelines for applying the WBT to biogas (there is only one previous biogas stove test listed with the CCA (*Clean Cooking Catalog*, 2020)). The following three modifications were made to the WBT to adapt for biogas cookstoves in this project. Firstly, fuel consumption measurement (typically done by mass) was conducted with a biogas flow rate meter that yielded cumulative gas input in cubic meters. A flow meter was temporarily installed on systems that did not already have one. Secondly, an initial volume of 1.25 L was chosen instead of 2.5 L due to the relatively low power of certain biogas digester models. Lastly, the WBT typically calls for a second boiling phase succeeding the first to observe differences in boiling times when the stove is already in use (the ‘hot start’). The hot start

may be omitted if it is shown that there is no significant difference with the ‘cold start’. While this is not the case here (when tested the hot start was actually longer to boil due to limited gas supply), the hot start was omitted from the protocol due to the similarities of biogas stoves to LPG, which do not have a significant difference among tests due to the low heat absorption capacity of the gas stove (compared to a ceramic wood stove, for example).

To observe stove impacts on indoor air pollution, custom air quality meters were deployed throughout the ~1 h WBT as well as 20 minutes before the test as a baseline. The air quality meters were designed and provided by Michael Bergin at the Duke Pratt School of Engineering.

To estimate the financial impact of different digester models the net present value (NPV) and financial internal rate of return (FIRR) were calculated using excel. One of the most important next steps is the development of remote monitoring flow meters. In anticipation of this, models were created and tested to estimate emissions reductions from fuel displacement and waste management as a function of total gas consumed by the end user.

Results and Recommendations

Database Analysis

Analyzing Hivos’ database with entries from over 24,000 established digesters it was found that overall 63.6% of fixed dome digesters are listed as currently functioning while 36.4% are listed as non-functioning. While this non-functioning figure is lower than indicated in the literature, it is still significantly high. However, among those non-functioning only 21.5% are listed as a ‘technical’ issue while 78.5% are listed as ‘non-technical’. Technical issues are design issues or digester failure such as the reported cracking, while non-technical issues are due to social factors such as the farmer selling the cattle, moving houses, or simply ceasing to feed and use the digester. Thus, the majority of non-compliance among established digesters should not be attributed to cracking but instead to social issues which should be addressed in project design. In Bali, a previous program attempting to increase biogas use gifted cattle to

farmers along with digesters. Due to the lack of ownership, the majority of farmers then sold the cattle as investments. This failed program led Bali to have the highest percentage of non-functioning digesters in Indonesia (73.2% non-functioning) with 90.8% listed as non-technical reasons. This inflated statistic in Bali may be partially responsible for the recent literature reports claiming such high non-compliance and frequency of cracking.

The database was also used to understand the distribution of number of cattle and persons in the market. Figure 1 shows that the majority of households eligible to receive a biogas digester have 2 – 4 cattle with a mode of 3 cattle. Together, 90% of all households had 8 cattle or less.

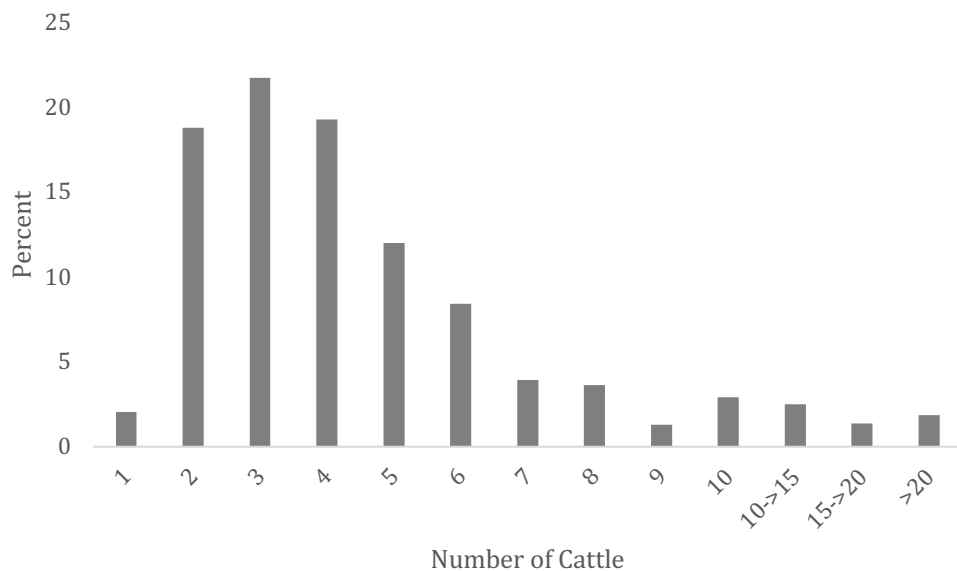


Figure 1: Distribution of cattle ownership in IDBP database

Figure 2 shows that the majority of biogas recipient households in Indonesia have between 3 – 5 household members with 4 people being the most common. This differs slightly from literature reports that most smallholder farms have 5 – 6 household members.

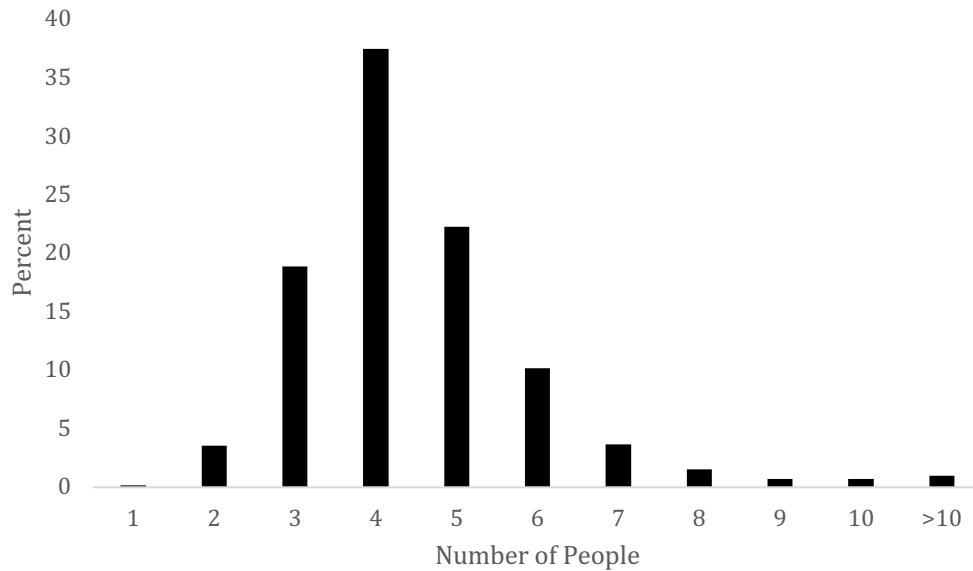


Figure 2: Distribution of people in each household in IDBP database

Su-re.co

Su-re.co operates on the islands of Bali and Flores with their main office in Canggu, Bali. Their business model includes selling coffee and cacao products from beans produced by partner farmers. Twenty-five percent of these local sales are then used to subsidize the distribution of their biogas digesters. Despite this business wing, Su-re.co is a non-profit organization that finances the majority of operations through grant funding and donations.

Su-re.co is the first biogas organization to incorporate a flow meter of any kind to their digesters, although their current model is limited in that it does not store nor transmit any data. Su-re.co has been involved in the biogas sector since 2015, a young program with only 24 deployed digesters. However, their digester design is simple and easy to deploy with a cost roughly half of fixed dome digesters. This allows Su-re.co to donate the digesters at no cost to the end-users. Su-re.co's goal is to become the 'IKEA' of biogas, meaning they can send their digester as a kit that can be installed on site by the end-users themselves. Currently all of the deployed digesters are a small 1 m³ capacity.

One of the first observations from evaluating Su-re.co's operations was that they had no method of recording farmer data such as fuel consumption, number of household users,

compliance, etc. To address this, baseline and end-user surveys designed for improved wood burning stoves as part of the CCA Kitchen Performance Test were modified to function specifically for biogas stove interventions. An online database was also created to allow Su-re.co to store the collected data. This will allow the client to quantify and track specific reductions in alternative fuel use before and after receiving a digester.

Water Boiling Test- PVC Bag-Style Digester

The first WBT's were conducted from February 10 - 14, 2020 on established Su-re.co digesters in Petang, a mountainous region common for small-scale coffee farmers. The 1 m³ digesters produced a medium flame initially raising the water temperature. However, after 10 minutes the rate of temperature increase slowed, and after 20 minutes the size of the flame was visibly smaller. The water failed to reach the LBT of 96.67° C with a maximum temperature of 92° C achieved between 20 – 25 minutes. Since the WBT was failed, the stove was continued running until the flame went out completely between 55 – 60 minutes. Figure 3 shows cumulative flow (m³) of biogas, where the curved nature indicates decreasing flow over time due to the lack of a pressure regulation system in the bag-style design. Figure 4 shows incremental flow (m³) over time as flow rate began high but quickly decreased.

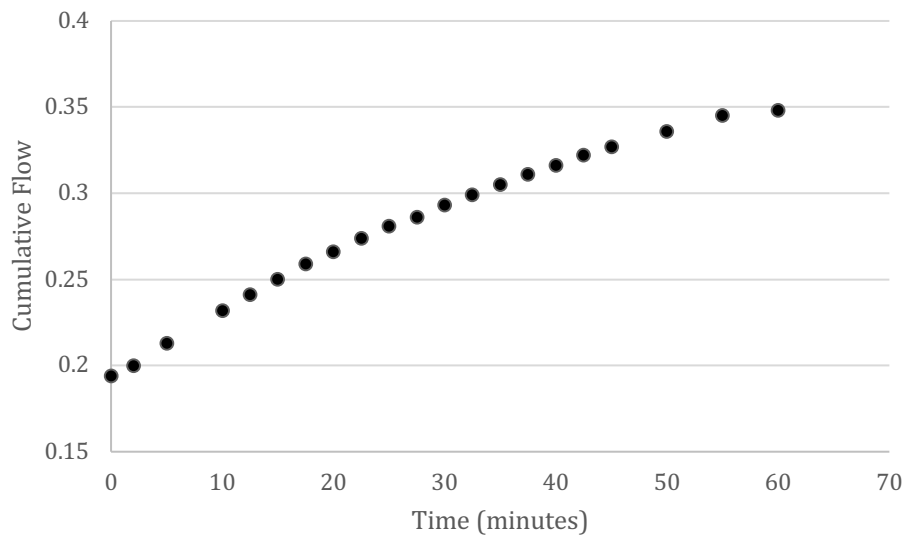


Figure 3: Cumulative flow (m³) over time for bag-style digester.

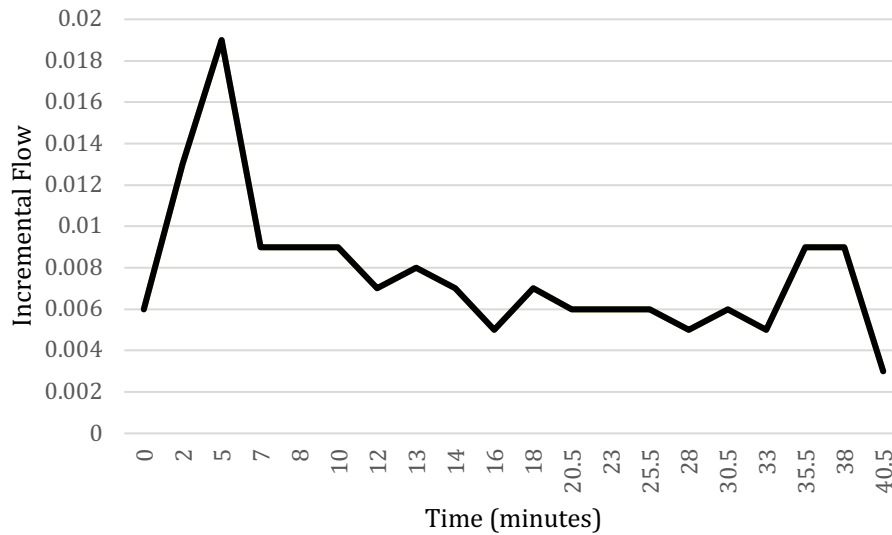


Figure 4: Incremental flow (m³) over time for bag-style digester.

The inability of the 1 m³ digester to maintain a strong flame longer than 20 minutes and a small flame longer than one hour indicates that this digester model is insufficient to actually offset end-user firewood consumption. As seen in the user surveys, the Su-re.co digester is used in the same way the family would use an LPG stove: for fast, short cooking needs such as preparing coffee or tea for an unexpected guest. As such, while digesters of this size may create ERs from waste management and offsetting LPG, it is incorrect to claim an impact on firewood use, deforestation, and health effects from indoor air pollution. It was also seen that these digesters increased the amount of time the family spent working instead of decreasing it, as farmers had to collect waste and feed the digester in addition to their normal routine of collecting firewood. The client was recommended to focus on testing and installing digesters of larger capacity to meet the goals of their organization. Designs for doing so were discussed and cost models for different sizes were created.

This issue also highlighted the need to select the proper size of digester to meet the needs of each specific family. In response, a biogas production and sizing model was created. In this model, the number of livestock owned by the farmer is input and the capacity of the digester is manipulated to obtain the optimal residence time, gas production, and cooking time. This allows biogas distributors to use the baseline survey questions on number/type of livestock and hours the family cooks each day to select the proper size digester to meet the family's

needs. This model was used to identify potential gas production for different digester sizes and number of cattle, summarized in Table 1. Overall a capacity of 3.5 m³ was identified as the most ideal size as it is the smallest capable of accommodating up to 8 cows while also producing enough gas for daily use (Table 1).

Table 1: Theoretical quantity of gas produced (m³/d) and hours of stove use per day depending on number of cattle for three different digester capacities.

# Cows	2 m ³		3 m ³		3.5 m ³	
	Q (m ³ /d)	h use/day	Q (m ³ /d)	h use/day	Q (m ³ /d)	h use/day
8					1.86	5.3
7					1.86	5.3
6			1.59	4.6	1.61	4.6
5			1.38	3.9	1.42	4.1
4	1.06	3.0	1.21	3.5	1.27	3.6
3	0.812	2.3	0.985	2.8	0.964	2.8
2	0.656	1.9	0.712	2.0	0.730	2.1
1	0.417	1.2				

Hivos and Yayasan Rumah Energi

Yayasan Rumah Energi (YRE) is the operating arm of Hivos SEA’s biogas program. While Hivos’ Jakarta office currently manages and funds YRE, the ultimate goal is for YRE to become financially self-sustaining through carbon market funding, marketization of bio-slurry, and private sector biofuel sales. Since the Indonesia Domestic Biogas Program began in 2012, all of Hivos’ 24,772 biogas installations have been larger sized fixed domes between 4 – 12 m³. However, they are now testing a smaller 2 m³ design made from a recycled PE water tank in order to lower costs and appeal to more users. Since the government pulled their 3 million IDR subsidy in 2017 YRE has amassed a list of ~1,000 households that are

waiting to receive a digester because they are not willing to pay the difference. The farmers have a willingness to pay (WTP) of 3 million IDR, and YRE provides a subsidy of 4 million, leaving a gap between available finance and the system's 10 million IDR cost. Thus, Hivos wants to find an effective and appropriately sized model for less than 7 million IDR (\$450 USD).

Under the TPDDTEC Gold Standard Methodology carbon offsets from biogas digester use are calculated through a series of complex equations with data collected through strenuous yearlong surveys and data collection. In an attempt to simplify these calculations, a TPDDTEC ER calculator model was produced in which the number of household members and livestock are input, and the output is tCO₂e reduced. However, the model created in this project was found to be less conservative than traditional heavy data driven methods. This illuminates the need to identify alternative methods for ER calculations that are conservative and based on real data but are more cost and time effective to implement.

Water Boiling Test- Fixed Dome Digester

Fixed dome digesters constructed by YRE were tested between March 16 – 30, 2020 in the villages of Depok and Bogor outside of Jakarta. Unlike the bag-style digesters, users of fixed domes reported 100% displacement of firewood and LPG stove use. Fixed dome digesters also successfully completed the WBT with an average time to boil of 8 minutes 45 seconds. The linear nature of cumulative flow in Figure 5 shows how the fixed dome's displacement chamber is able to adequately maintain stable pressure of gas at the stove over time. Figure 6, showing incremental flow over time, shows that flow rate did start off high before decreasing like with the bag-style design. However, after the initial decrease pressure stabilized and remained fairly level throughout the rest of the test. Figure 7 combines the incremental flow rate graphs from both the bag-style and fixed dome digesters to show that the fixed dome not only started off with higher pressure than the bag-style digester but also maintained a higher pressure than capable by the bag throughout the test.

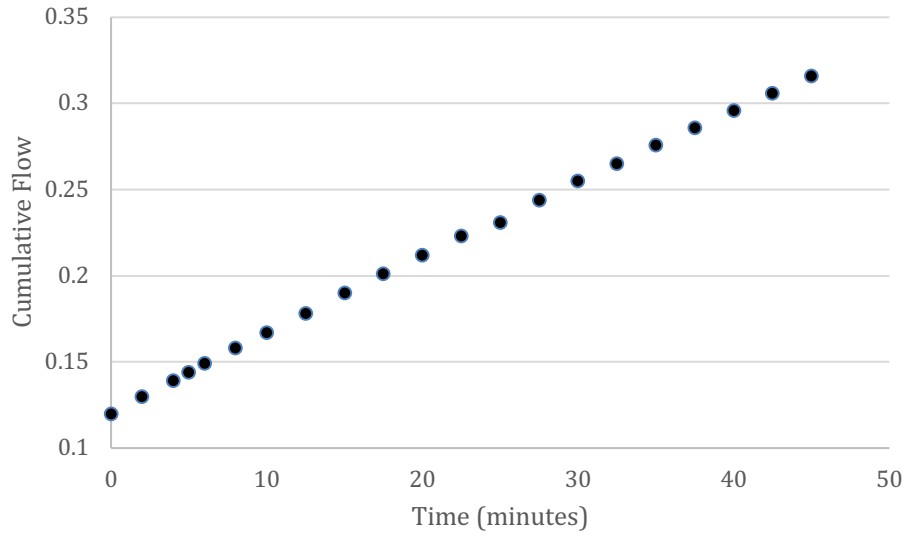


Figure 5: Cumulative flow (m³) over time for fixed dome digester.

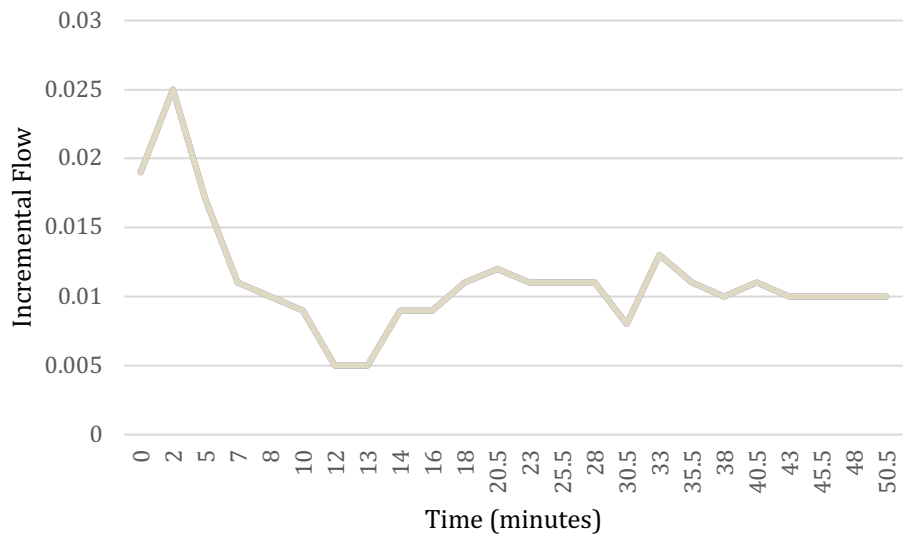


Figure 6: Incremental flow (m³) over time for fixed dome digester.

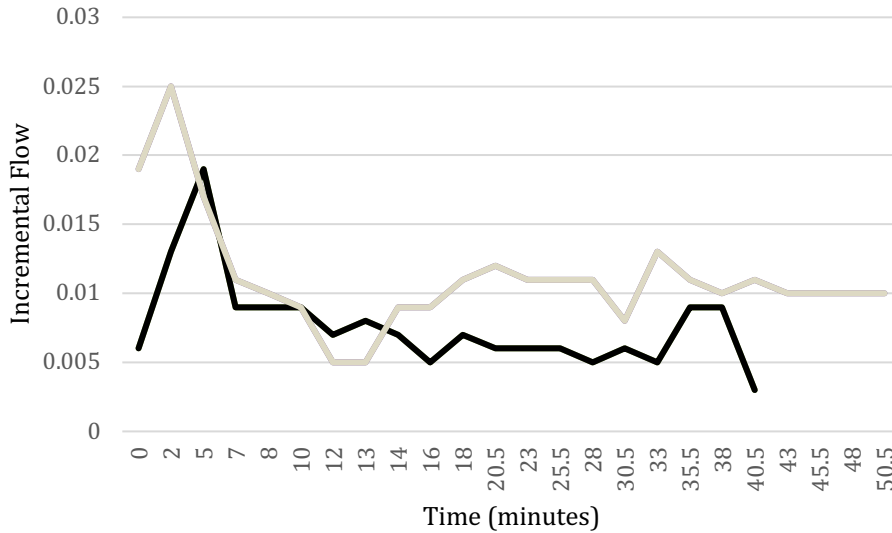


Figure 7: Incremental flow (m³) over time for both the fixed dome (grey) and bag-style (black) digesters.

WBT- PM, CE, and h_c

There was no significant difference in particulate matter (PM) emissions between baseline measurements and measurements while operating the stove in the WBT (Table 1). However, PM emissions were higher while the stove was operating than in the baseline, indicating that biogas does contribute somewhat to PM formation.

Table 2: Mean values of PM 1, 2.5, and 10 (µg/m³) in baseline measurements and while the stove was running in the water boiling test (WBT).

	PM1	PM2.5	PM10
Baseline	9.30	13.46	14.44
WBT	10.18	14.30	15.45

Combustion efficiency (CE) of the bag-style digester was calculated at 49.6%, while CE of the fixed dome digester was 44.1%. This result is counterintuitive as increased flow rate (pressure) typically increases CE, however the results are within the margin of error.

Thermal efficiency (h_c), calculated with the equation below, was found to be 29.4% for the PVC bag-style digester and 36.5% for the fixed dome digester. For comparison, LPG stoves typically have an h_c of 40 – 50%, increasing as pressure increases. As biogas digesters deliver fuel to the stove at a lower pressure than LPG, this result makes sense.

$$h_c = \frac{4.186(T1_{cf} - T1_{ci})(P1_{ci} - P1) + 2260 \cdot w_{cv}}{f_{cd} \cdot LHV}$$

Digester Model Recommendations

To bridge the gap between the 7 million IDR subsidy + farmer WTP and the 10 million IDR cost of Hivos' 4 m³ fixed dome model, it was proposed that a 3.5 m³ model should be constructed with a PE tank in the same design as the new 2 m³ mini-digester model in testing. The lower materials cost and simplified installation of this design brings the total cost down to 6.5 million IDR (\$420 USD), within the available finance limit.

To accommodate farmers with only one cow as well as provide a lower cost option the second recommended model was the 2 m³ PVC bag-style digester by Su-re.co. With a total cost of 3.2 million IDR (\$205 USD), this model could be given for free to farmers who have no WTP, and potentially sold at a profit to households in the private market.

Together these two models cover all farmers with 8 or less cows, representing 90% of the available market in Indonesia (Table 1).

Financial Analysis of Recommended Models

The 3.5 m³ PE digester design proposed for Hivos was found to have an FIRR of 23% with a payback period of approximately 6 years, becoming cashflow positive in year 7 (Figure 8). The NPV of the PE digester (incorporating savings on fuel and fertilizer plus returns from carbon finance) was found to be 19.2 million IDR. This analysis indicates that the 3.5 m³ PE digester is a worthwhile investment with an NPV greater than initial cost.

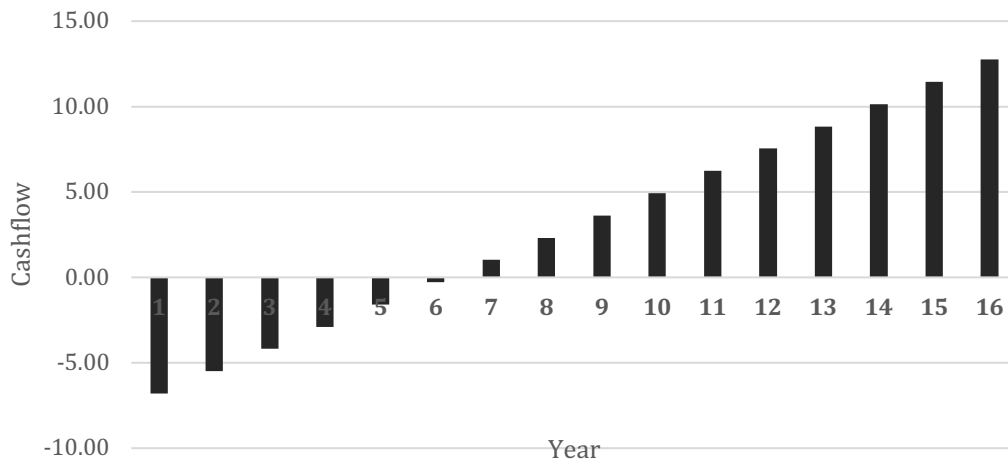


Figure 8: Cashflow over time for the fixed dome digester.

The 2 m³ PVC bag-style digester was found to have an FIRR of 8% with a payback period of 15 years and an NPV of 1.34 million IDR (Figure 9). While the FIRR of this model is positive, the NPV is less than the initial cost and furthermore it has yet to be proven how long this model will actually function before needing to be replaced. More information is needed on longevity and additional cost reductions would help bolster investment potential. This model still offers relative advantages due to its low cost and ability to be easily transported.

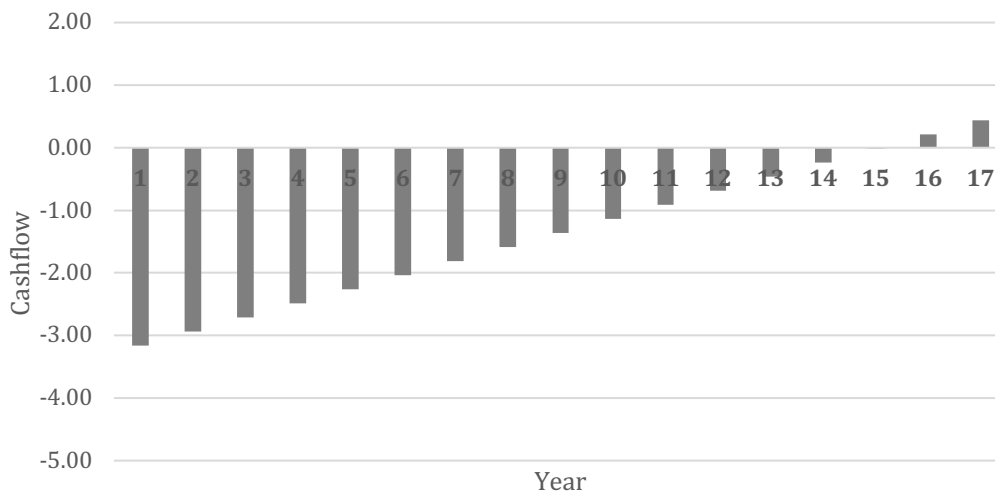


Figure 9: Cashflow over time for the PVC bag-style digester.

Memorandum of Understanding

The collaboration between Hivos and Su-re.co is being made official through a Memorandum of Understanding (MoU) that was completed and sent to be signed March 31, 2020. The MoU states that Su-re.co's 2 m³ bag-style digester will be included in Hivos' upcoming submission of the Voluntary Program Activities (VPA-3) document if certain conditions are met. Firstly, Su-re.co must finalize testing on their 2 m³ design and work to install a minimum of 100 digesters. Secondly, Su-re.co must maintain and update the database created in this project recording baseline and project fuel consumption, hours stove use per day, number of people and livestock in the household, etc. Operating status of the digester should also be included with a mandatory confirmation check between 3 – 6 months after installation. During this time Hivos will continue their work to modify the original Gold Standard Project Design Document to include digesters of less than 4 m³. Once these thresholds are reached, the clients will jointly finalize the VPA-3 for submission to the Gold Standard.

Remote Monitoring

To enhance the ability to accurately and efficiently monitor digester usage and quantify emissions reductions a strong focus on the development of remote flow rate monitors was recommended. If implemented, this measure could save the clients over \$10,000 per year on monitoring costs while increasing data access. In anticipation of this transition, a model was developed to translate quantity of biogas used to quantity of firewood displaced and quantity of waste that is efficiently treated to produce the biogas. Firewood displacement is calculated using net calorific values and waste management using a regression of gas production vs. volatile solid input ($R^2 = 0.9921$). Methane conversion factors and physical leakages are also accounted. The final output is tCO₂e offset by the exact amount of biogas used by each household from waste management (ER_{wm}) and firewood (ER_{bio}). The equations developed for use in the formula are:

$$\begin{aligned} \blacksquare \quad ER_{wm} \text{ (tCO}_2\text{e)} &= (VS * 0.13 \text{ (m}^3 \text{ CH}_4 \text{ * kgVS}^{-1}\text{)} * 0.662 \text{ (kgCH}_4 \text{ * m}^3\text{CH}_4^{-1}\text{)} \\ &\quad * MCF * GWP_{CH_4}\text{)} * (0.001 \text{ ton * kg}^{-1}\text{)} * (1 - (P_1 + n)) \end{aligned}$$

$$\blacksquare \text{ER}_{\text{bio}} (\text{tCO}_2\text{e}) = (G (\text{m}^3) * 3.47 \text{ kg} * \text{m}^{-3}) * \text{EF} (\text{tCO}_2 * \text{TJ}^{-1}) * \text{NCV} (\text{TJ} * \text{ton}^{-1}) * (0.001 \text{ ton} * \text{kg}^{-1}) * (1 - (\text{P}_1 + \text{n}))$$

The model was run using monitoring data collected by YRE from 2016 – 2018 to compare the model results with those of the yearlong field surveys. Survey data showed an average daily stove use time of 2.74 h. With a flow rate between 0.35 – 0.40 m³ * h⁻¹, daily biogas consumption can be approximated at 1.0 m³. Since the field surveys estimate ERs on an annual basis, 365 m³ biogas consumed was entered into the model. The results showed that the model appropriately predicts the expected outcome within a 10% margin of error.

Moreover, the model was found to be more conservative than the field results, reducing the likelihood of overestimating ERs. The model estimated ERs from firewood displacement at 0.852 tCO₂e (1.16% different from survey findings of 0.862 tCO₂e), and ERs from waste management at 1.42 tCO₂e (11.0% different from survey findings of 1.586). Overall, the model estimated ERs of 2.27 tCO₂e, only a 7.4% difference from the survey findings of 2.448 tCO₂e.

These results show that remote monitoring of gas consumption can be combined with this model to accurately and efficiently estimate ERs without the expense of yearlong field surveys. In addition to simplifying monitoring this strategy could also play an important role in incentivizing continued use of the digester by offering rebates for surpassing certain ‘milestones’ of biogas use (e.g. payment discount or cash back for every 100 m³ biogas used).

Key Recommendations

1. Applications from potential biogas users should include the number of livestock and number of hours spent cooking per day so that the gas production model can be used to select the appropriate size digester for the family.
2. Digester recipients should complete the baseline survey designed for biogas here, and the user surveys should be completed on follow up visits within one year of installation. These data should be stored in a shared database

3. Su-re.co should focus on finalizing and installing a 2 m³ PVC bag-style design instead of the current 1 m³ capacity in order to have the desired impacts on deforestation, health from indoor air pollution, and ERs from firewood
4. Hivos should bridge the financial gap between cost and subsidy + WTP by focusing on a 3.5 m³ PE tank digester design
5. The two recommended designs should be incorporated into Hivos' Gold Standard registration under VPA-3, together representing 90% of the market
6. Traditional monitoring should be modernized through the use of remote flow rate meters and gas consumption ER models, such as the one presented here

Next Steps

1. Sign and return MoU; modify PDD to allow smaller capacity digesters
2. Finalize designs for 2 m³ PVC bag-style and 3.5 m³ PE tank digesters. Work towards installing 100 digesters of each recommended model
3. After 100 digester threshold, jointly complete and file VPA-3
4. Begin remote flow meter development. Submit proposal for new methodology to Gold Standard
5. Sponsor research to increase stove combustion and thermal efficiencies
6. Develop additional biogas appliances (e.g. rice cooker, lamps, water heater, etc.) to increase demand and WTP
7. Grow private sector business model and establish additional revenue streams to increase client self-sufficiency

References

- Bedi, A. S., Sparrow, R., & Tasciotti, L. (2017). The impact of a household biogas programme on energy use and expenditure in East Java. *Energy Economics*, *68*, 66–76. <https://doi.org/10.1016/j.eneco.2017.09.006>
- Böbner, S., Devisscher, T., Suljada, T., Ismail, C. J., Sari, A., & Mondamina, N. W. (2019). Barriers and opportunities to bioenergy transitions: An integrated, multi-level perspective analysis of biogas uptake in Bali. *Biomass and Bioenergy*, *122*, 457–465. <https://doi.org/10.1016/j.biombioe.2019.01.002>
- Clean Cooking Alliance. (2013). *Ingredients for Sustainable Cookstove Interventions: Lessons Learned from the Indian National Programme for Improved Cookstoves (NPIC)*. Clean Cooking Alliance. <http://cleancookingalliance.org/resources/320.html>
- Clean Cooking Catalog*. (n.d.). Clean Cooking Catalog. Retrieved April 23, 2020, from <http://catalog.cleancookstoves.org/test-results>
- Ezzati, M., Mbinda, B., & Kammen, D. (2000, January 15). *Comparison of Emissions and Residential Exposure from Traditional and Improved Cookstoves in Kenya | Environmental Science & Technology*. <https://pubs.acs.org/doi/full/10.1021/es9905795>
- FAO. (2018). *Indonesia- Small Family Farms Country Factsheet (I8881EN/1/03.18)*. Food and Agriculture Organization of the United Nations.
- Muthia, R. (2015). *Clean Cookstoves and Fuels: A Catalog of Carbon Offset Projects and Advisory Service Providers - 2015 (2nd Edition)*. Clean Cooking Alliance. <http://cleancookingalliance.org/resources/381.html>

- Nes, W. J. van, Tumiwa, F., & Setyadi, I. (2009). *Feasibility of a national programme on domestic biogas in Indonesia*. SNV - Netherlands Development Organisation.
- Schenck, L. (2018). *Small Family Farming in Indonesia—A country specific outlook* | *FAO*. <http://www.fao.org/family-farming/detail/en/c/1111082/>
- Silaen, M., Taylor, R., Bößner, S., Anger-Kraavi, A., Chewpreecha, U., Badinotti, A., & Takama, T. (2019). Lessons from Bali for small-scale biogas development in Indonesia. *Environmental Innovation and Societal Transitions*.
<https://doi.org/10.1016/j.eist.2019.09.003>
- Taylor, R., Devisscher, T., & Takama, T. (2019). *Risks, barriers and responses to Indonesia's biogas development*. <https://www.sei.org/publications/risks-barriers-and-responses-to-indonesias-biogas-development/>
- Zhang, Y., Tuntivate, V., Aristanti, C., & Wu, Y. (2013). *Indonesia—Toward universal access to clean cooking* (No. 79279; pp. 1–90). The World Bank.
<http://documents.worldbank.org/curated/en/105441468044144806/Indonesia-Toward-universal-access-to-clean-cooking>