3. Thermal Energy Services with BIOGAS AND BIO-DIGESTERS

Sustainable Thermal Energy Service Partnerships

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FOREWORD

Development of biogas digester technologies, as well as products, appliances and services utilising biogas, has led to a developed market in many developing countries. Over the course of the last 30 years in particular, government and development agency projects have driven the dissemination of biodigesters; however private sectors for biodigester products and services, from production of biodigester components and complete models, to sales, marketing, installation and maintenance, have begun to play a major role in the sector.

Biogas programs and businesses have not always achieved their intended goals and outcomes, however. There still exist a number of barriers to the development of sustainable biodigester businesses or projects, which hamper businesses achieving sustainable scaling of their operations, as well as the success of government/NGO-led programs. Predominant among the issues most cited as affecting wider biodigester development is the relatively high up-front cost of digester technology, placing biogas outside of the reach of the majority of rural consumers. This is particularly important in developing countries, where rural consumers often have access to the best feedstock regimes for biodigesters from agricultural sources.Compounding the issue of capital cost is a lack of access to finance for potential biogas consumers. A number of government projects in particular have addressed this issue through subsidies (either direct capital subsidies for purchases or for operation and maintenance activities) or through establishing partnerships with microfinance institutions to offer loans to consumers at favourable, sometimes subsidised terms.

This document aims to address the major issues that affect biodigester development in the developing world, particularly focusing on Sub-Saharan African socioeconomic contexts. Through analysis of case studies and the literature, this document aims to provide concrete lessons and recommendations for policy-makers and entrepreneurs in the design of biogas programs and businesses.

- Xavier Lemaire, Daniel Kerr & Nandi Mbazima, 2018.

Acronyms

ABPP	Africa Biogas Partnership Program
AEPC	Alternative Energy Promotion Centre
BCC	Biogas Construction Company
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (English: Federal Ministry for Economic Cooperation and Development)
BPR	Banque Populaire du Rwanda
BSP	[Nepal] Biogas Support Program
CDM	Clean Development Mechanism
DGIS	Directorate-General for International Cooperation
EUR	Euro
FMO	Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden N.V. (English: Dutch Development Bank)
FRP	Fibreglass Reinforced Plastic
GGC	Gobar Gas Company
GHG	Greenhouse Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit GmbH (English: German Corporations for International Cooperation)
HDPE	High Density Polyethylene
KBP	Kenya Biogas Programme
KES	Kenyan Shilling
KfW	Kreditanstalt für Wiederaufbau (German development bank)
KVIC	Khadi and Village Industries Commission
LPG	Liquefied Petroleum Gas

Rs	[Indian] Rupees
RBI	Reserve Bank of India
NABARD	National Bank for Agriculture and Rural Development
MAFF	[Cambodia] Ministry of Agriculture, Forestry and Fisheries
MESP	Micro Enterprise Support Project
MFI	Multilateral Finance Institution
MININFRA	[Rwanda] Ministry of Infrastructure
NBMMP	[India] National Biogas and Manure Management Program
NBP	[Cambodia] National Biodigester Program
NBPA	Nepal Biogas Promotion Association
NDBP	[Rwanda] National Domestic Biogas Program
NGO	Non-Governmental Organisation
NPBD	[India] National Program on Biogas Development
ODA	Official Development Assistance
PPP	Public Private Partnership
SSA	Sub-Saharan Africa
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organisation)

Suggested citation for this paper: Lemaire X., D. Kerr. and N. Mbazima (2018), *Public-Private Partnerships for Thermal Energy Services with Biogas digesters*, UCL - Energy Institute / STEPs.

The authors would like to thank Willem Boers for his comments and input in this chapter.

This document is an output of the DfID-DECC-EPSRC funded project "Sustainable Thermal Energy Service Partnerships Project" – STEPs. More information on the STEPs project can be found on:
STEPs website: http://stepsproject.net/

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1.0 – Biogas Technology and Service Options for Developing Countries

1.1 Household-Scale Biodigesters

To generate biogas organic waste is used and the primary source is cow and pig manure. Biodigesters fed with animal manure provide not only biogas, but also bio-slurry as potent organic fertiliser for increased agricultural production. Depending on the context (like in Burkina Faso), the value of bio-slurry is higher than the value of biogas.

It is also possible that human excreta is mixed with cow or pig feedstock through an attached toilet. This improves hygiene at the household and does not have risk due to pathogens. Other organic waste streams can be used for generating biogas like kitchen waste and agri-waste. In addition to biogas as a source of thermal energy a biodigester offers (i) environmental benefits through reduced release of pollutants including black carbon, carbon monoxide and methane (Grieshop et al., 2011). Biogas stoves avoid the use wood or charcoal, which often is unsustainably sourced; (ii) health benefits through reduced household (HAP) and associated diseases in particular benefiting women and children and reduction of volumes of rotting organic waste and associated pathogens; (iii) economic and social benefits through low annualised costs of all technology options for cooking and reduced time that women and children need to spend collecting wood, creating more time for women to work in productive enterprise and for children to study.

To qualify for the installation of a bio-digester the household should ensure that enough day fresh feedstock is available, as a rule of thumb the minimum quantity is 20-25 kg of feedstock (cow dung) and clean water. Only household who fulfil these basic conditions qualify for owning a biodigester.

The production and utilization of biogas as a clean cooking fuel generated from organic waste can only be realized by using specific biogas technology. A brief overview is provided below on the main household biogas technologies. Without reliable, robust and quality biodigester technology biogas cannot be generated in a controlled environment. It is therefore important that for biogas market development proven biogas technology is used. Although some designs and biogas models are readily available it is important that continuous efforts are undertaken to develop innovative and new biogas technology for the biogas sector to open up new markets, reduce the investment cost and goes hand in hand with the development of new business models market biodigesters.

1.2 Brick-Built digesters

Household-scale biogas digesters have a long history, with the first models being produced in the 1920s in China. Until recently, within the last 30 years, biogas digesters were constructed primarily from brick, with the digesting chamber sunk into the ground in order to maintain an airtight system for the anaerobic digestion to occur. These systems had several advantages, including being relatively cheap to produce and the ready availability of construction materials in developing world contexts.

Figure 1. A Dome-Type Biodigester under Construction in Arusha, Tanzania

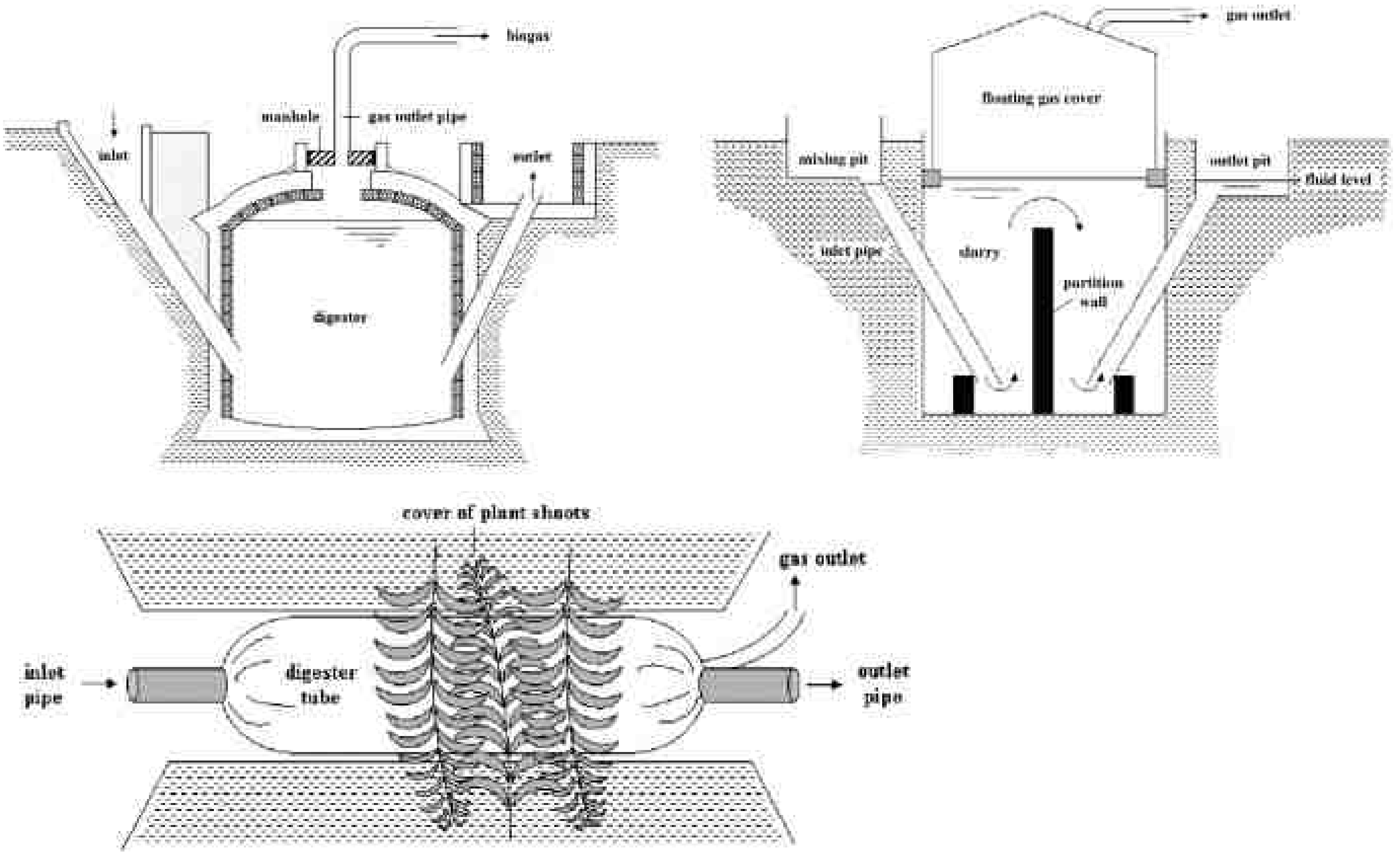
Image: Laramee & Davis, 2013.

The most common biogas technology used for household purposes is the fixed dome biodigester. A fixed-dome biodigester comprises a closed digester with a fixed, non-moving space for gas storage and an expansion chamber. The gas is stored in the upper part of the digester (dome). Gas production increases the pressure inside the biodigester and the feedstock or slurry is pushed into the expansion chamber. When the gas is extracted, a proportional amount of the slurry flows back into the digester.

The advantages of the fixed dome are the absence of moving parts and the absence of steel parts that may corrode. If well-constructed, fixed dome biogas models have a life span over 20 years. The underground construction saves space and protects the digester from climatic influence to maintaining a constant temperature inside the digester. The disadvantages are the relatively high upfront investment cost, the risks of gas leakage if the construction is not properly done and skills for construction. Fixed dome plants should only be constructed by trained and experienced biogas masons.

Alternative designs are floating domes (but with a costly moving drum in steel susceptible to corrosion) or low-cost rubber-balloon biodigester (but more susceptible to damages).

Figure 2. Common Biodigester Designs in Developing Countries



Top-left, fixed dome digester (as used in China). Top-right, floating cover digester (as used in India). Bottom, balloon or tube-type biodigester.

Bond & Templeton (2011), adapted from Plöchl & Heiermann (2006), Gunnerson & Stuckey, 1986.

Over the past 10 years a variety of fixed models has been developed to meet requirements and climatic conditions in various countries. These include biodigester models that can withstand the pressure on the construction due to a high-water table, biodigester models that can be operated in dry climatic conditions where there is limited access to water, smaller sized digester available are reduced cost. In addition, a variety of construction materials can be used like clay burnt bricks, cement bricks, natural stones, casted concrete or compressed earth/cement bricks. Out of about 50 million household digesters installed so far worldwide, over 95% is made from these construction materials.

1.3 The Evolution to Prefab Bio-digesters

With the evolution to plastic biogas digesters, efficiencies have improved greatly, as has their durability and reliability in their operation.

Figure 3. Prefabricated Biogas Digester by AGAMA Bioenergy in South Africa

Image: Agama Biogas PRO via Youtube.

Over the past year a variety of pre-fab bio-digesters models have been developed. The advantage of pre-fab biodigester models is that these can be erected within a couple of days but still require skilled persons for installation. A disadvantage is that pre-fab biodigester are made only at certain factories and require transport thus increasing the risk of damage and adding to the cost. The lifespan of a pre-fab bio-digesters depends on the materials used. In case certain plastics are being used the life, span might be far less then a brick-bio-digester. Some pre-fab models have been specifically designed with cow and pig manure as feedstock, others are designed to operate on kitchen waste as primary feedstock and others double as biodigester septic tank. A selection of prefab biodigester models is presented next:

Table 1. Prefab Biodigester Model

Name of company	Website
Agama	http://agama.co.za/
Flexigester	http://www.flexigester.com/
HomeBiogas	https://homebiogas.com/
PUXIN	http://en.puxintech.com/Home
Simgas	https://simgas.org/
Sistema Biobolsa	http://sistema.bio/
Overview of pre-fab biogas digesters	https://www.build-a-biogas-plant.com/biogas-kits/

As a result of technology development of biodigesters over the past year more biodigester technologies entered the market focussing on different users' groups, at reduced cost, improved efficiency and at the same time more providers entered the market opening opportunities to reach a broader market segment potential client.

1.4 Centralised versus Household-Scale Systems

Another approach to meet (household) energy demand for cooking is through the installation of centralised biodigesters and these are larger in size as compared to household-scale systems. Whereas a household-scale system may have a digesting chamber with a volume of 6 cubic metres, centralised systems have significantly larger volumes, often in the 50 cubic metres-plus range. Centralised systems commonly serve several households or a central village/town hub.

In terms of the scale difference, a study of a centralised biodigester near a village in the Fangshan district of north-east China requires 44 tons/day of cow dung to produce cooking and heating fuels, and slurry for intensive livestock farming (specifically cattle) for 1,900 households. This is equivalent to approximately 1,000 head of cattle, compared to the 4-6 head of cattle common for a household-scale biodigester to function. Centralised biodigesters also have advantages for the agricultural communities in that the digestate (feedstock that has already been processed in the digester) can be used as an effective fertiliser as is the case with household bio-digesters.

The main disadvantage of a centralized biodigester that advanced technology is required due to increased size, that the investment cot are higher and that advanced management skills are required to organise the community to operate and maintain the biogas digester as per the requirements. The daily feeding of the bio-digester should be organised such that each participants contributes more or less equally. The same applies to the even distribution of the biogas.

Studies in He (2013) have noted that centralised systems performed favourably in terms of reducing the maintenance load on farmers for using biogas for cooking, and reduced housework load in terms of collecting other cooking fuels. Comparing centralised systems to household scale systems, differences exist in environmental, economic and maintenance performance. Household digesters in general terms exhibit better performance in terms of operation and maintenance regimes due to their smaller size and decentralised nature. Medium-to-large biogas plants tend to have a higher energy efficiency and a greater social effect, reaching more users with a greater degree of performance (be that biogas resource itself, or reducing household/farm maintenance).

Table 2. Examples of Sizes, Costs and Requirements of Various Typical Biodigester Designs

Type of Biodigester	Digester Volume/Gas Production (m^3/day)	Feedstock Volume Required/Day	Cost of System (US$)	Number of People Serviced
Small Household Digester (Drum-based)	0.5-1.75/up to 1	1-2 kg kitchen waste/dung (2-4 heads of cattle)	100-150	~1
Large Household Digester (Dome-type)	2-15/up to 4	5-10 kg dung/day (as slurry) (4-10 heads of cattle)	150-400	~1-5
Institutional Biodigester	10-17.5	Up to 30 kg kitchen waste	600-1,000 (3-4 year payback period)	~20

Adapted from Raha, Mahanta & Clarke, 2015, Karve, 2013, Landi, Sovacool & Eidness, 2013.

Hence, the choice of scale and type of biodigester for biogas production is dependent on the local circumstances and context. There is no 'one-size-fits-all' solution; instead, decisions must be made based on the population density, feedstock availability and production requirements of the system to determine the best solution. Larger-scale, centralised biogas digesters are suited to more densely-populated regions, where multiple households can be served from the same system and supply it with enough feedstocks from multiple sources to do so. Household-scale biogas digesters, conversely, are more suited to individual rural applications, and farming households due to feedstock availability from livestock or crop wastes.

It must be note that although centralised bio-digesters offer opportunities for communities the number of systems installed seems to be limited.

1.5 Current figures on household biogas in use and size of potential market

As of 2017, SNV supported programmes have resulted into the installation of 837,609 digesters in 24 countries in Asia, Africa and Latin America.

Based on animal manure as feedstock, SNV estimated in 2006 a total of about 150 million household digesters worldwide out of which 18.5 million in Africa. Applying the same calculation methods, the assessment was repeated with 2018 data, mostly from similar sources. Over the 12 years both dairy cattle holding and the number of rural households having access to water augmented significantly. As a result, the technical potential for household biodigester programmes in Africa increased to nearly 33 million households.

Due to the increasing cost of fuels cooking and negative environmental impact like biomass, kerosene and LPG it is likely to expect that the market demand for biodigester technology will increase in the near future. Also, the cost of chemical fertilizer is likely to increase thus making bio-slurry an increasingly attractive replacement.

It is assumed that the latent market for bio-digesters in Africa is 33 million and that approximately through the African Biogas Programme Partnership approximately 130,000 bio-digesters will be installed between 2008-2017. This penetration corresponds to 0.4% of the market potential. In terms of marketing this indicates that the development of the biogas sector in Africa is still at its ''Innovators" stage. A similar calculation can be done for individual countries to establish the level of market penetration. To place market development in perspective it is noted that the mean rate of diffusion is 41 year, from cumulative distribution of 265 diffusion processes (Grubler et al., 1999)[1]. This explains that more time is required to support programmes like ABPP.

There is significant potential to expand biogas production in China[2]. The reference case for household biogas users in 2030 is 175 million, and the estimation under IRENA's REmap 2030 scenario is 240 million.

It is estimated that that worldwide and the number of biodigester installed is growing at about 10% annually (www.irena.org).

[1] Grubler A. Nakicenovic, N. & Victor, D.G. (1999) Dynamics of energy technologies and global change. *Energy Policy*, 27, pp. 247-280.

[2] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Dec/IRENA_Biogas_for_domestic_cooking_2017.pdf

2.0 – State of Projects and Lessons Learned

2.1. SSA Country Programs: the case of Rwanda

The Rwandan National Domestic Biogas Program (NDBP) was instituted in 2007, jointly implemented by SNV and Rwanda's Ministry of Infrastructure (MININFRA) and carried out in partnership with international donor organisations, with the objective of installing 15,000 biodigesters at a household scale by 2011 and developing a viable commercial biogas sector in the country (Dekelver, Ndahimana and Ruzigana, 2006). One of the key factors that helped launch the NDBP in Rwanda was the strong political will by the Government of Rwanda to support the growth of biogas for energy in the country, thereby helping to achieve key national policy objectives.

Additionally, given the unfamiliarity of biodigester technology in Rwanda, the Government championed significant investment in training and skills development, with the aim of promoting the uptake and successful use of the systems and build capacity to enable local entrepreneurs and the creation of jobs and small businesses (Ndahimana, 2010). This was aimed at upskilling various actors involved in the Program's development, from the beneficiaries of the biodigesters to the appliance manufacturers, banks, NGOs and government divisions involved.

The program was funded by several sources, including the Rwandan Government, SNV, international donors, farmer's contribution and local commercial banks. The project notably included a significant subsidy component, and also established a micro-finance scheme for rural households, in order to reduce the high upfront construction costs of the biodigester systems. Sizes of 4, 6 and 8 m^3 are available through the program. The 6 m^3 design costs approximately US$ 1,140, or 620,000 Rwandan Francs (Owekisa, 2008). Total subsidy provided through the program (initially through a 75% contribution from GIZ, but as of 2011 fully-funded by the government) is a flat-rate US$ 300 for all plant sizes. A fixed subsidy rate provides an added benefit to smaller farmers over large farmers, as they require smaller biodigesters and thus lower project costs, thereby receiving a relatively higher subsidy over their counterparts (Dekelver, Ndahimana and Ruzigana, 2006). However, even with this subsidy, the majority of rural households reported being unable to afford the scheme's digesters. This led to the establishment in 2009 of a partnership between the government and the Banque Populaire du Rwanda (BPR), which has funded through donor and government grants the provision for 3-year loans to rural households for the program.

As of 2011, revenue for the Rwandan NBDP Program stood at US$ 1.2 million, with 303 masons and 121 supervisors receiving training under the program to install biodigesters. Private-sector development is also good, with 53 independent biogas companies and 3 appliance manufacturers in existence as of 2011 (Binamungu, Ndahimana and Owekisa, 2011).

However, the program has not been without its challenges. In 2012, the program had only installed just under 2,500 of the initially planned 15,000 biodigesters (Bedi, Pellegrini and Tasciotti, 2013). As of 2016, there have only been 5,833 digesters installed (Kabera et al., 2016). The table below provides a comparison in the development of projected vs actual installed biogas systems under the NDBP from 2007 to 2012.

Table 3: Projected vs Actual Installed Biodigesters

	Year	2007	2008	2009	2010	2011	2012	Total
No. of digesters	**Projected installation**	150	1,150	2,300	4,200	7,200		15,000
	Actual Installation	366			627	755	699	2,447

Source: Adapted from Bedi Pellegrini and Tasciotti, 2013.

One of the key factors that has been attributed to the gap between planned and installed biogas systems has been the high initial cost of the biodigester systems; the actual market price of the systems was found to be significantly higher than that anticipated in the feasibility studies undertaken prior to commencement of the programme (Bedi, Pellegrini and Tasciotti, 2013). As such, this presented an unforeseen barrier to the purchase of a biodigester system by many of the rural households targeted.

Regarding the impact and effectiveness of the systems, the results are mixed. In a study conducted by Kabera et al. (2016), 70 households surveyed under the programme, almost half report that they are satisfied with biogas produced from the systems. However, one third noted dissatisfaction with the amount of biogas produced while 19% reported that their digesters were not producing any gas at all. Several factors may have played a part in this outcome. It was found that for flexi biodigesters installed under the programme, the construction time of the digesters was found to be considerably accelerated beyond the recommended construction time specified by MININFRA. This rapid construction may contribute to leakage or underperformance of flexi digester units, and a lack of monitoring of the systems post-implementation has meant that these problems go unresolved.

Additionally, under the NDBP, the criteria for households selected for the program was standardised and set at those that owned at least 2 cows or who had at least 20 kg of manure on a daily basis. This precondition was not adequate for larger biodigester systems of 8 m^3 or more. It was found that for the majority of households with systems of 8 m^3 or higher, the amount of feedstock necessary to enable sufficient biodigester performance was not adequate (Kabera et al., 2016).

One other crucial factor to note is that while women have an important role in energy activities in the household in Rwanda, ownership and decision-making undertaking under the NDBP has been heavily placed on male household inhabitants, and this has had a detrimental effect on women's attitudes toward biogas technology and use (Kabera et al., 2016).

The Rwandan program can be seen as a counter-example to previous large-scale dissemination programs, with a number of failure cases impacting on the implementation of the program. A lack of experience with the technology, lack of training and capacity within installing companies, ill-fitting criteria selection of target households, gender issues and improper follow-up post-implementation have affected the performance of digesters. In addition, limited access to subsidies and financing from the central government or financial institutions, and unanticipated high initial system costs have meant a much smaller proportion of the rural communities targeted under the program could afford to engage with it.

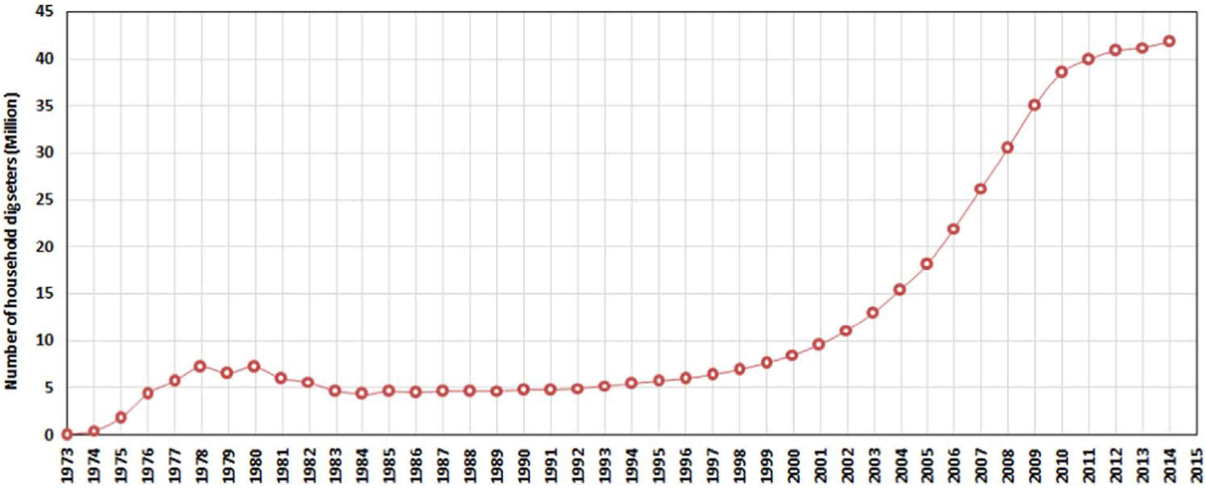
Other Sub-Saharan African countries

Donor agencies have continued to work in the biogas sector in Sub-Saharan Africa, notably in Uganda, with an SNV-Hivos Partnership, the Africa Biogas Partnership Program (ABPP), working in five countries in Central Africa, Uganda included. Biogas Solutions Ltd Uganda is the national implementing agency for the project, and Phase I from 2009-2013 saw 5,000 biodigesters installed in 28 districts in the country. The second phase of the program is ongoing, with good production figures for the last quarter of 2014, mostly attributed to ongoing capacity building for biogas construction enterprises, as well as training for masons, particularly targeting female entrepreneurs in the region. Targets for Phase II of the program amount to 13,000 new digesters by 2017 (SNV, 2016).

2.2 The Chinese National Biogas Program

The Chinese National Biogas Program is a prime example of a central government-supported national biogas rollout. Financial and strategic support has been provided for the program over the last few decades, and since 2001 government funding has been increased at the central and local scales. While biogas production has been present in China since the 1800s and has had successive waves of development, the industry really experienced rapid development in the early 2000s, coinciding with the increase in government support mentioned above. This can be seen in the figure below.

Figure 4. Development of Household Digesters in China



Source: Deng et al., 2017.

Multiple government policies were initiated to promote the establishment of digester systems and stimulate the production of biogas, including the ‘Prosperous eco-farmyards’ plan in 2000, the ‘Measures for the Administration of National Bonds for Construction of Rural Biogas and National Rural Biogas Construction plan in 2003 (Chen and Liu, 2017).

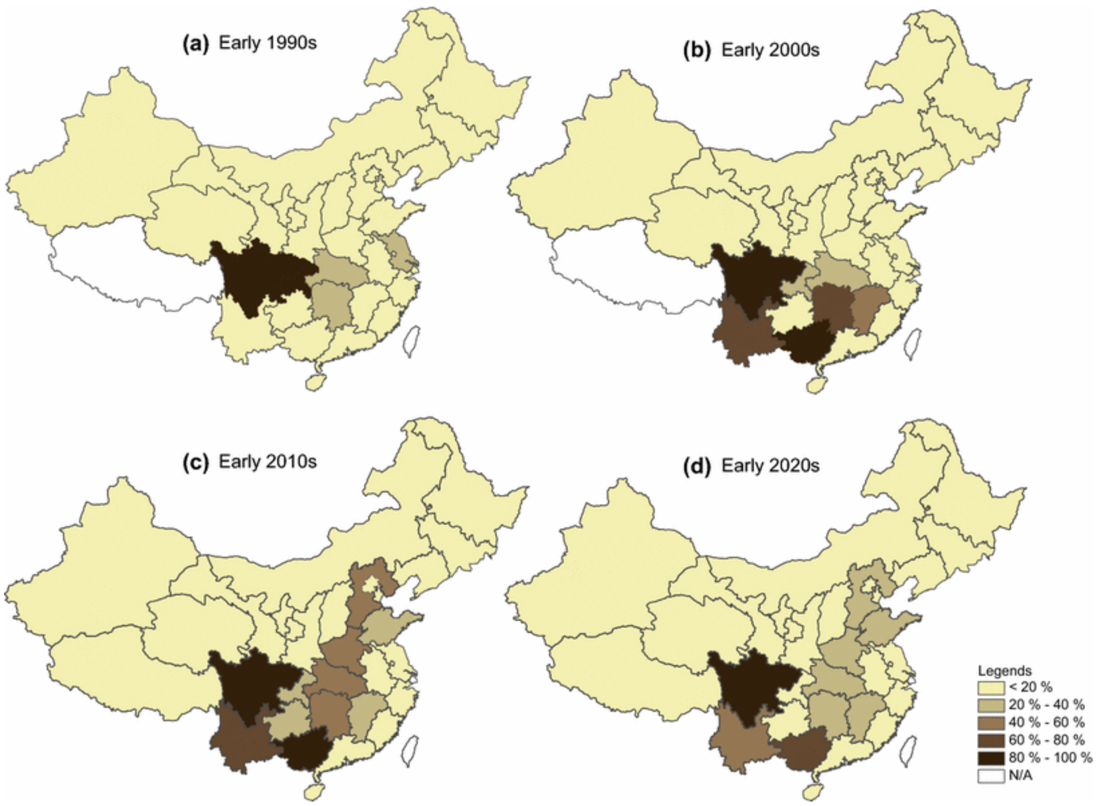
Construction subsidies are in the range of CNY 800 – 1,200 (approximately US$ 123 – 185) (Zhang, 2008), offered to poorer families wanting to invest in household-scale facilities. This subsidy is then used to purchase building materials for the digester, as well as appliances to utilise the biogas (stoves etc.), and to pay for installing technicians’ salaries. This subsidy covers the large majority of the cost of the biogas system, for the remainder credit loans are available from commercial banking organisations, with subsidies for covering interest on the loan available from the local government. Funding for loan guarantees has also been provided by some local governments and international funding agencies to further encourage commercial banks to participate in the program.

The scale of this program sets it apart from a number of countries; household-scale biogas users in China had reached 41.83 million households by the end of 2014 with an output of 13.25 billion m^3 of biogas in total in that year (Deng et al., 2017). The scaling of the program can attribute its success in part to the significant degree of government support, but also to the extensive experience of biodigester technology in the country, and as a result the long accumulated experience of rural communities in utilising the technology. Numerous digester designs have been employed in China, including hydraulic cylinder, floating bell-type, concrete and fiberglass-reinforced plastic digesters; additionally, varying digester construction modes have also been utilized – such as the “Three-in-one Combination” eco-agricultural model (a layout that combines the toilet and pigsty biodigester to provide timely feedstock for efficient biogas production) – that integrate household and farm waste management practices to improve production and efficiencies, allowing not only rural energy provision but also rural sanitation management (Chen et al., 2017).

Relative population densities have also been a factor in the selection of system type and the financing methods available in the Chinese national program. Eastern China is more densely populated than Northern or Western China, meaning that centralised biodigester systems are more cost-effective, whereas in dispersed rural communities in the East/North of the country, decentralised systems have been favoured. In addition to choice of system type due to variance in population densities, other regional differences affect the biogas production of these systems, including temperature differences, raw materials available, and regional differences in income and education levels. Several challenges experienced with household biodigester systems in China given these differentiations are explained below.

In 2007, only 40% of the digesters that were installed were not in operation, the majority of which were installed prior to 1990 (Chen et al., 2010). Reasons include a lack of maintenance and technical support post-implementation, as well as ill-suited systems in certain regions of the country. For rural communities located in colder regions such as northern China, digesters experience low biogas production rates in the winter given lower temperatures and thus inadequate thermal rates needed to provide sufficient fuel. For north China, communities receive satisfactory biogas rates for only 5-8 months of the year, while central and south China receive sufficient biogas rates for 7-9 months and 10-12 months respectively (Song et al., 2014). The regional difference in household biogas production is highlighted in the figure below, for previous and future production levels across China (Gu et al., 2016).

Figure 5. Regional Difference of Household Biogas Production from 1990 to 2020



Source: Zhang et al., 2016.

More recent statistics on the number of operational digesters in China broadly vary. The national statistic reported by the Ministry of Agriculture in 2009 was approximately 85%, while field statistics have estimated lower rates of operation; a survey of utilisation rates in Guizhou Province approximated operational rates between 37 and 69% (Zuzhang, 2013).

While financial support has been provided by central and local governments for the construction of biodigester systems, there has been a paucity of maintenance and technical support. Many of the rural digester owners have not been trained to properly manage the systems and there has been a lack of monitoring and follow-up support services. As such, this has led to poor-performing systems and a substantial number of system owners abandoning operation altogether (Yin et al., 2017), (Gu et al., 2016). This reinforces that beyond the importance of providing subsidies and supplementary financial support for biodigester construction, it is also vitally important that post-implementation support, such as technical, maintenance and monitoring support, is present under such programmes. Moreover, Gu et al. (2016) assert that more localized and detailed policy should take place to account for the regional differences that affect biogas production (Gu et al., 2016).

While these challenges have been experienced in the country, China has still seen considerable growth and dissemination of digester systems, including a move from decentralised to centralised systems for larger rural farms and commercial farms, as well as the use of medium and large-scale biogas plants at the industrial level that realise societal benefits beyond localised user benefits.

2.3 The Cambodian National Biodigester Program

The Cambodian National Biodigester Program (NBP) was initially conceived in 2004 following a feasibility study carried out by the Cambodian government in conjunction with the Dutch NGO SNV, which recapitulated the benefits of developing a national biodigester program to ease the consumption of firewood and charcoal for energy use, reducing deforestation rates, and promote social and economic development in rural communities. Although there were prior attempts to disseminate biodigesters, these failed due to substandard biodigester models installed and lack of maintenance (Dekelver, Ndahimana and Ruzigana, 2006). The program initiated in 2006, by SNV and Cambodia's Ministry of Agriculture, Forestry and Fisheries (MAFF), was developed from the bottom up with the overall goal of creating a "sustainable, market-oriented biodigester sector in Cambodia" (Buysman and Mol, 2013).

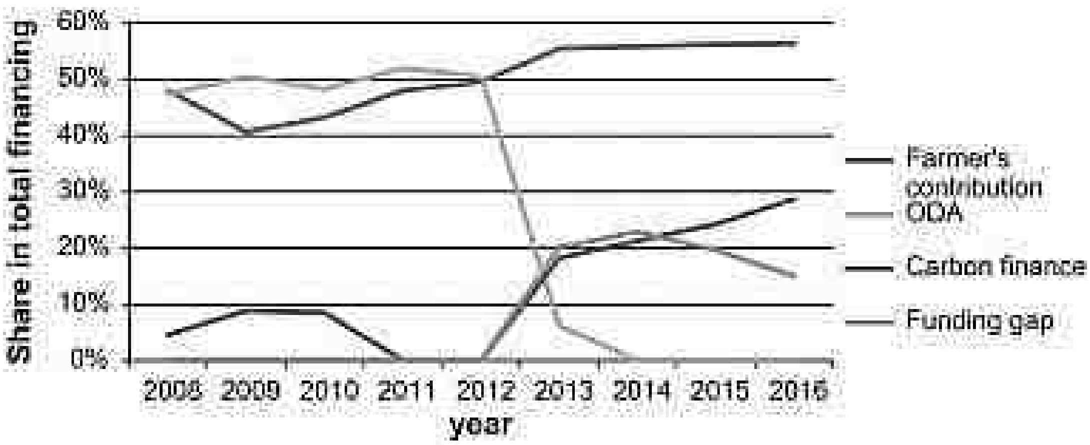
The Cambodian program had four key objectives:

1. "Increasing the number of household scale biodigesters to 20,000 from 2006-2012 in the twelve targeted provinces, and a further 40,000 by 2018,
2. Ensuring the continued operation of all biodigester systems installed under the program,
3. Maximising the benefits of the biodigester installations through reuse of bio-slurry (processed digestates),
4. Developing promotional, technical and managerial capacity of the stakeholders in the program for further development within Cambodia" (Buysman and Mol, 2013).

The provision of a suitable regime for maintaining and operating biodigesters following their installation is again highlighted in the objectives of the Cambodian program under points 2 and 4. The Cambodian government realised that without these provisions the potential for digesters to degrade and reduce in performance over time was high, so to keep utilisation and performance at a suitable level, the development of the technical and managerial capacity to maintain biodigester installations was crucial to the program's success.

A number of constraints were identified in the market, including the lack of skilled masons and other technical staff for the construction of biodigesters, the absence of facilities for credit or subsidies for biodigesters, and commercial loans having high interest rates generally in the country (3–5% per month). As such, key components of the program included a training element for the various actors within the programme – including but not limited to masons, office staff, managers and biodigester users – and, beyond the provision of a subsidy, a microfinance program with FMO to provide monetary assistance to ease and promote the purchase and construction of biodigesters. This has crucially supported the NBP over and above previous efforts to promulgate biodigesters in Cambodia. Other sources of finance for the NBP include overseas development assistance, technical assistance from SNV; carbon finance through the Clean Development Mechanism (CDM) and national government in-kind contribution. The figure below shows the funding source contribution to the NBP between 2008 and 2016.

Figure 6. Share of Different Funding Sources in Total Programme Funding



Source: Buysman & Mol, 2013.

A daily basis of 20 kg of manure was selected as the key criteria for eligibility for a farmer in the program. 500,000 farmers were identified in 2010 through a potential user survey as being able to support a household-scale digester (Buysman and Mol, 2013). Digesters from 4 cubic metres to 15 cubic metres were offered to the users, with a flat-rate subsidy of US$150 offered since 2008 for each digester (Buysman and Mol, 2013). This gives a higher subsidy to investment ratio for smaller digesters, thus benefiting poorer farmers over the more affluent segment of the cohort, while further providing administrative ease for subsidy disbursement.

Over 20,000 households have benefited from the program as of 2013, with monthly installation figures rising from 218/month in 2009 to 500/month in 2012 (Buysman and Mol, 2013). It was noted in 2016 that over 22,000 biodigesters had been constructed, with over 120,000 recipients directly benefiting from them. The most relevant factors for this increase are the provision of micro-credits from local micro-finance companies, and the establishment through the program of local Biogas Construction Companies (BCCs), who partner with local governments in the construction of biodigesters.

The Cambodian program described above succeeded due to the integration of local skilled construction companies with micro-finance organisations, operating in a favourable natural environment in rural farming communities with good feedstock regimes. Central government support in the form of the flat-rate subsidy, as well as the growth of biogas-focused microfinance within the existing financial institutional framework of the country, brought the affordability of digesters within reach of the targeted rural consumers, hence the growth in uptake of the program. While the NBP has had considerable success and has favourable prospects for future development, Buysman et al. note that the program will show concrete success if it can demonstrate long-term autonomous sustainability of the program, such as the continuation of a robust program beyond national and international funding support. The NBP has achieved the construction of over 25,000 biodigesters with 130,500 direct beneficiaries by July 2016 (National Biodigester Program Cambodia, 2016).

2.4 The Indian National Biogas and Manure Management Program (NBMMP)

The National Biogas and Manure Management Programme (NBMMP) was established in 2005 as a result of a merger between two prevailing programmes that existed in India at the time – the National Programme on Biogas Development (NPBD) and the Manure Management Initiative. While biogas plants, their dissemination and use have been in existence in India for many decades, the NBMMP was formulated to address the failure of the former NPBD target-based, top-down model used under the original project, which had led to unhealthy competition in the implementing agencies and a consequentially lower standard of results. Besides the Chinese National Biogas Program, it is one of the largest biogas programs in existence today. Since the start of the NPBD, 4.54 million biodigesters had been installed in India by 2012 (The Economic Times, 2018).

With the new program, the strategy taken has been a top-down approach with implementation of biogas digesters involving actors at different levels – from central government developing and mandating targets, to regional government departments and institutions acting as implementing agencies involving private contractors, while also having household and community members involved in the programme (Raha, Mahanta and Clarke, 2014). The restructured project sought to encourage rural consumers to switch to biogas technology to meet their domestic cooking and lighting needs. Household-scale biodigesters were the focus of the program, provided by Khadi and the Village Industries Commission (KVIC), focusing on concrete and plastic floating-dome technology. The systems were designed from the ground up to be multifunctional; reducing dependence on LPG and kerosene for cooking, reducing dependence on chemical fertilisers through the reuse of processed digestates, reducing the time burden of firewood collection for rural women and children, and improving sanitation through the provision of sanitary toilets linked to the biogas system. During the year 2014-2015, the target for biodigesters to be implemented under the program was set at 110,000. (Government of India Ministry of New and Renewable Energy, 2018).

Financing for the program came predominantly through central government subsidies provided to the state implementing agencies, with the size of the subsidy provided varying by region. In Assam state for example, 2 m^3 biogas digesters were eligible for a subsidy of Rs 24,300, with 4 m^3 digesters receiving Rs 32,025 (Raha, Mahanta and Clarke, 2014). Unlike the case studies that have been examined so far, the current subsidy provision under the NBMMP is not fixed but varies by biodigester size and by region, ranging from Rs 5,500 to Rs 17,000 for biodigester sizes of 1 up to 6 m^3 (Government of India Ministry of New and Renewable Energy, 2018).

Figure 7. Biogas Plant Models in India

(clockwise from top left) Floating Drum, Fixed Dome, and HDPE Prefabricated models. Source: Khandelwal, 2008.

Additional sources of financing for biodigesters include local financing institutions and commercial banks, such as the Reserve Bank of India (RBI) and the National Bank for Agriculture and Rural Development (NABARD), as well as carbon rebates, such as those attained through the Clean Development Mechanism (CDM) (Khandelwal, 2008).

However, a key failure mode of the program that developed over time has been the lack of awareness and undertaking of maintenance procedures by the state implementing agencies and private contractors. This can be attributed to a lack of communication; in Assam state for example neither village contacts nor private installers were aware of the four-year guarantee on the biogas plants, and no post-installation assessment of operation was ever made (Raha, Mahanta and Clarke, 2014). In addition, the program made provision for 50% of the received installation subsidy to be available for maintenance and repair once units were five years old, but no contractors nor village contacts were aware of this either. Hence, assessments later in the project found a high proportion of compromised-functioning/non-functioning digesters, leading to higher dissatisfaction with consumers.

There have been some important lessons learnt from an examination of biodigester implementation and utilisation in the region of Assam. These include:

- The lack of training received by women for the maintenance and operation of the biogas systems, despite being found as the primary household dwellers responsible for the management and use of the systems;
- Lack of awareness from biogas users of the multitude of benefits of biodigester systems, particularly the use of digestate as fertiliser;
- Deficient monitoring and evaluation of biogas plants that had been installed by the responsibly parties within the community;
- Acknowledgement that cultural perceptions exist of the use of certain feedstocks – such as human waste – as appropriate/inappropriate for use due to cultural and/or religious beliefs;
- Insufficient performance or non-operation of biogas systems due to rapid construction of biodigesters (Raha, Mahanta and Clarke, 2014).

As a result of some or a combination of the above, some of the biodigesters that have been installed in Assam are no longer in operation.

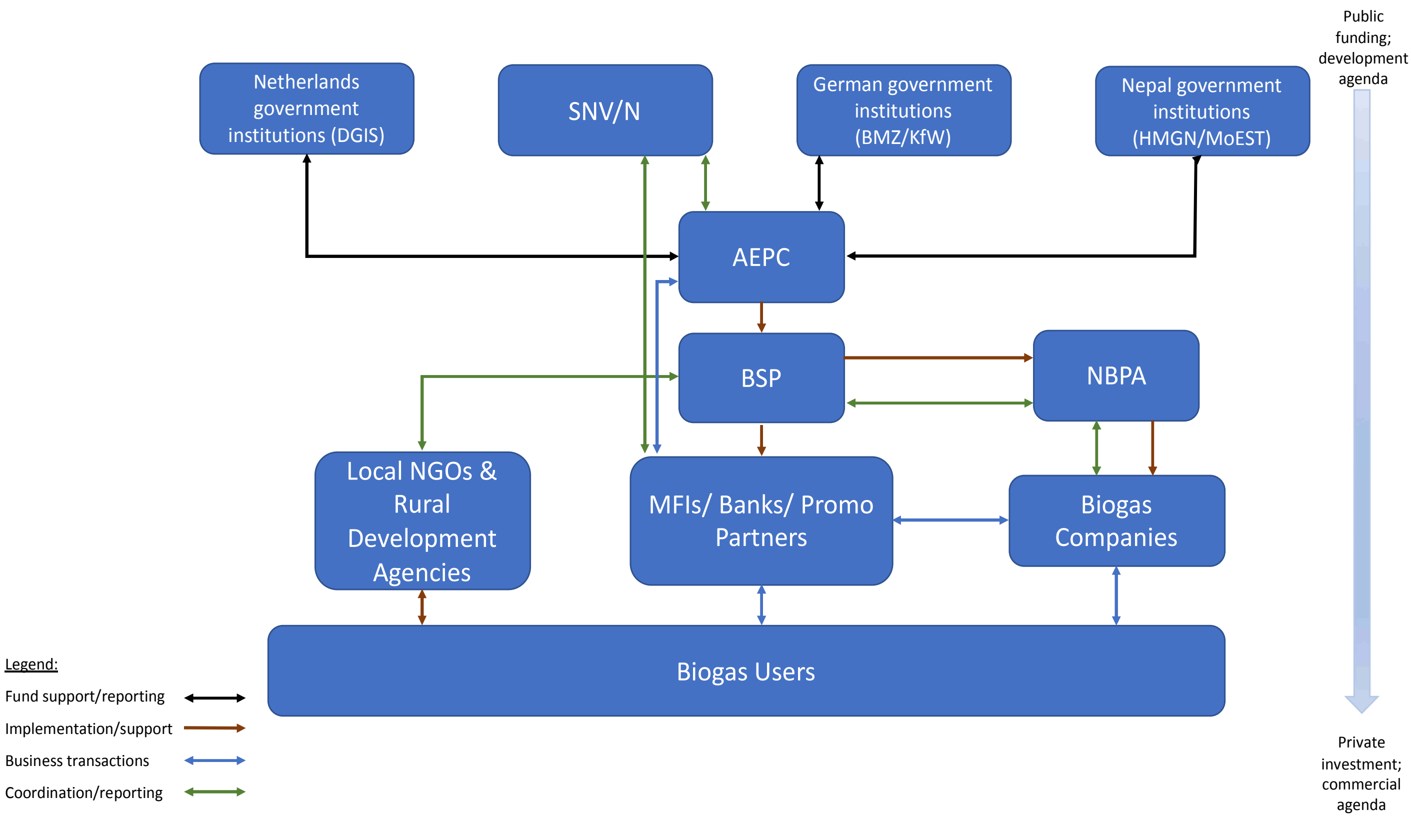
The rate of success of biogas dissemination in India differs depending on the region. In Uttara Kannada for example, there has been a “high success rate with all of the installed biogas plants remaining in operation” (Rupf et al., 2015). In other areas however, challenges that have been faced include high installation costs, inadequate education and awareness of biogas use, and insufficient follow-up services for systems post-implementation (Rupf et al., 2015).

2.5 The Nepal Biogas Support Programme

The Nepal Biogas Support Programme (BSP) is a prime example of a successful public private partnership (PPP) model for biogas development. While the Nepal government has been advocating for the use of biogas systems since the early 1970s, its subsequent partnership with government institutions of the Netherlands and Germany, and its collaboration with private sector companies and community members in Nepal, have allowed for significant flows of financial support for the program, the set-up of a crucial institutional framework involving both public and private entities, and the development of local capacity to enable the long-term construction, operation and maintenance of biogas systems.

Since the first phase of BSP, initiated in 1992, 268,399 biogas systems have been installed in Nepal up to 2012 (SNV, 2010). The main stakeholders include BSP-Nepal, SNV/N, KfW, BMZ, DGIS, Government of Nepal, AEPC, NBPA, biogas companies, MFIs, and the biogas users. The set-up of the PPP framework for biogas development in Nepal is illustrated in the figure below.

Figure 8. Institutional Set-Up of BSP Phase IV



Source: Adapted from SNV, 2010.

Particularly, the program has helped foster the growth of the private sector market for biogas construction and after-sales services (SNV, 2010). The industry was essentially a monopoly at the start of the program, with government-owned Gobar Gas Company (GGC) as the only supplier in the country; at the end of the third phase of the BSP, the market boasted an additional 39 private companies (Bajgain and Shakya, 2005). A key result of the growth of the local biogas supply market, which has enabled a competitive market, is that this has enforced stricter and higher quality standards for biogas systems; this has led to client satisfaction for plant owners and self-promotion of the technology, where biogas users communicate the benefits of biogas to potential biogas users (Bajgain and Shakya, 2005).

As with the other case studies that have appraised, BSP has provided technical, training and qualification support for biogas construction companies and biogas users. A notable lesson learnt with respect to the Nepal program has been the purposeful engagement of women in awareness programs, and construction and operations training of biogas systems (Shakya, 2017). In many of the rural communities in developing countries where national biogas programs are in place, women play an important role in activities in the household where biogas systems are involved. However, it is often found that it is men that are largely the recipients of the training support that is provided -and who are largely employed in jobs in the biogas supply chain. Additionally, ownership of digester systems in many countries is predominantly ascribed to men, who generally are entitled to take out loans for biogas purchase under the programs. Shakya (2017) notes that BSP is assisting in changing the lives of women in rural areas in Nepal through strategies such as encouraging women's participation in training for tertiary work in installation companies and providing additional biogas subsidies to single women, in addition to the poor and remote areas. She also notes that ownership of biogas systems by women has grown to almost 28% (Shakya, 2017).

Financial support for the BSP has been largely dependent on donor governments and organisations. The continued success and sustainability of the program will need to reduce dependence on donor financing and attract other sources of revenue, such as those obtained through Carbon Funds.

2.6 Kenya Biogas Programme

The Kenya Biogas Programme (KBP) commenced in 2009, under the umbrella of the African Biogas Partnership Programme (ABPP) which supports country biogas programs in Ethiopia, Kenya, Tanzania, Uganda, and Burkina Faso. While domestic biogas use in numerous African countries is relatively new compared to other countries around the world, it is not new to Kenya. Biogas production and use in Kenya first commenced in 1954, mainly using Indian and Chinese-type digesters (Laichena and Wafula, 1997). However, efforts at the time to expand biogas technology were not very fruitful and ultimately had limited success, due to high construction and maintenance costs, insufficient input materials, no credit or extension facilities, ill experience with maintaining and operating biodigesters, and low acceptance of the technology by farmers (Laichena and Wafula, 1997; Ashington Ngigi, 2009; Hamid and Blanchard, 2018).

Today, the KBP has constructed over 17,000 biogas plants across the country that has directly benefited more than 102,000 people (Kenya Biogas Program, 2018). Digester designs employed are now more varied and include the fixed dome digester, floating drum digester, inflatable tubular plug flow digester and the international flexi biogas digester system.

Figure 9. Biodigester Construction; Biogas-Generated Cookstove

Source: Kenya Biogas Program, 2018 at: https://kenyabiogas.com/media/#

Where there was no previous subsidization of the construction and operational costs of biogas systems (Laichena and Wafula, 1997), the KBP provided household subsidies for the installation of biodigesters, at a flat rate of KES 25,000 (~EUR 223) from 2009- June 2013, which was subsequently reduced to KES 18,500 (~ EUR 160) from June to December 2013, and ultimately withdrawn at the end of that year (Porras et al., 2015). The subsidy was largely made possible through public private partnership with subsidy funding made available by DGIS. However, withdrawal of the donor funding for the subsidy has meant that the program needs alternative funding channels effectuated to realise financial sustainability. Porras et al (2015) note that although too early to tell, "withdrawal of the farmers' subsidy from 2014 will undoubtedly have had an impact on the ability of poorer farmers to access the technology, taking it further out of their reach." (Porras et al., 2015) This further underlines the importance of financial support for biogas system dissemination for rural communities that are largely are dependent upon them.

Biogas promotion and dissemination is not just spearheaded at the national level in Kenya, but at the regional level as well. In Taita Taveta county for example, an NGO – Taita Biogas – approached residents of Wundanyi sub-county to pilot new biogas installations, due to the high prevalence of cattle farming in the region. To date, the NGO has installed over 600 household-scale biodigesters in the country, and has completed two institutional-scale biodigesters for schools in the region, with a third under construction (The Star, 2018).

The business model for the NGO provides an opportunity for consumers who are unable to afford the full biogas installation cost of a system. Taita Biogas covers half the installation cost and also arranges contractors to construct and commission the system. In recent years the NGO has expanded operations through partnership with the Micro Enterprise Support Project (MESP), another Kenyan NGO.

Figure 10. Household Biodigester User in Taita Taveta County, Kenya

Source: The Star (2018) at star.co.ke

The venture has brought about numerous benefits, such as reduction in money and time spent in collecting firewood and charcoal, and improvements in both cooking quality and ease of use when using biogas compared to firewood or charcoal. Additionally, the scheme is innovative in that householders are coordinating with the NGO to apply for regulatory permission from the Energy Commission of Kenya to bottle and sell biogas on the local market, as self-producers (The Star, 2018), which has the potential to become an additional revenue stream for the farmers.

Notably, Kenya has also established the first biogas facility selling surplus biogas-generated electricity to the grid, at a tariff of USD 0.10 per KWh, which is lower than the USD 0.38 per KWh obtained from diesel-generated electricity (Reuters, 2017), providing a fitting example of how green renewable power can play an important role in reducing GHG emissions and contributing to national clean energy objectives.

2.7 Lessons Learned[3]

From the case studies presented here, there exists a plurality of solutions for different contexts, critical in effectively managing biogas system sustainability. The diversity of the local context, in terms of natural, political, technical, economic and social factors, needs to inform the placement, size, technology type and organisational model of the biogas system. This organisational model in turn needs to be attuned to the size and technology of the digester, and must cover financing, operation and particularly maintenance of the biogas digester.

Failure modes of the program are useful to note for programs across Sub-Saharan Africa and the developing world more widely. These included: a lack of familiarity with biogas technology within regulatory departments and commercial organisations, a lack of skilled suppliers and maintenance personnel, limited financing from the central government with households bearing the majority of biodigester system costs, and an inadequate marketing and awareness campaign. Researchers have analysed the program in-depth, and noted financial challenges were also a failure factor. These included inherent financial institution aversion to financing products with no monetary return, as well as high upfront costs and limited access to subsidies.

Examples of programs that have succeeded and failed, as above, need to inform decision-making when designing a biogas program or business model. Local manufacturing has become a significant component of most cases detailed above, both as a method to reduce costs for the program over importing components, and to promote local economic growth and enhance the general business case for the biogas sector, either domestic or centralised. Other cases from above to use local manufacturing range from the small-scale Tanzanian domestic and institutional digesters, to medium-scale programmes serving several villages in Nepal although very limited in number, at a local business level, to the Chinese Domestic Biogas Programme.

Another common factor in the above case studies is the importance of a rigorous operation and maintenance regime, to be implemented post-installation of the digester, to maintain the effectiveness and efficiency of the installation and improve operational lifetimes. This includes ensuring proper feeding of the digester on a daily[4] basis with the correct levels of feedstock and liquids, as well as maintaining the integrity of masonry work and pipe network, reservoirs and appliances over a quarterly/yearly period. A number of the cases above suffered in implementation due to the lack of a maintenance regime, notably the Assam state biogas program under the Indian National Domestic Biogas and Manure Management Program, and the Ugandan National Domestic Biogas Program.

[3] One source is:
http://www.snv.org/evaluation_african_biogas_partnership_programme_executive_summary.pdf

[4] For optimum gas production *day-fresh* animal feedstock is preferred.

To enhance market development there should be increased focus in more pro-active and evidence-based advocacy towards governments, other development actors and other donors and look for more alignment with other development programmes and expand the number of strategic partners. Also, a clear communication strategy on the (decreasing) availability of subsidies and other financial incentives to avoid market shocks. A minimum subsidy could be maintained in order to cover the costs for biodigester quality control until another financing source for quality control is found.

3.0 – Financing, Sizing and Business Models for Biogas Installations

The investment costs of a biodigester are substantially higher as compared to other cooking devices but offer financial benefits on the long term. For example, a typical advanced ICS stove will have an investment cost of USD 45 and a typical biodigester an investment cost of USD 900. When comparing the annual operating cost these are USD 120 and USD 50 respectively. Then the levelized[5] annual cooking cost over a 30-year period are for a biodigester USD 82 and for an advanced ICS USD 122. Compared to the most common cooking devices (rocket-stove, charcoal stove, LPG stove, electric) biogas has the least levelized annual cooking cost. An electric stove the highest at USD 301.

The provision of consumer-side financing has been proven to be a critical factor in the success of a biogas business model in the developing world. In general, biogas plants require a significant initial capital investment that is out of reach of a majority of rural consumers. Therefore, a business cannot be viable without making provisions for credit facilities if targeting rural markets. This is a key point to consider in the design of any biogas system targeting rural areas, and, depending on income level, a large proportion of peri-urban/urban areas also.

There are six main principles guiding the design of a biogas business/organisation:

- Identifying the target market and regions
- Selecting technology type to best fit the target market/region
- Identifying/building capacity to install/maintain the technology choice in the region
- Identifying consumer-financing options to best fit the technology choice in the region
- Identifying the needs for financing of biogas construction enterprises
- Dissemination knowledge on the benefits of biogas use through education and awareness efforts

[5] The levelized cost of electricity (LCOE), also known as Levelized Energy Cost (LEC), is the net present value of the unit-cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime.

Rural markets are generally the best to target for biogas installations due to the more ready availability of potential feedstocks compared to urban/peri-urban areas. However, there are examples of sustainable biogas programs in urban/peri-urban areas in China, using human/food waste as a feedstock for digesters. Population density and feedstock transport to digester sites are then the key factors to consider in targeting potential biogas markets. Higher population densities mean a higher production of feedstock, but this is only useful if there is an efficient method of transporting this feedstock to the site of the biodigester, for example a piped sewage system or communal food waste recycling.

Feedstock availability is considered the most critical factor in a successful biodigester installation. What is considered a suitable feedstock regime can differ between countries and context, however general figures can be derived based on the size of biodigester system targeted. A rule of thumb of 2 head of large livestock (based on cows or pigs) per m^3 of capacity of the biodigester will lead to sustainable gas production. Farm practise should be taken into consideration as well as less day-fresh dung can be collected from free ranging cattle. A number of projects have based their assessments on land area owned by the consumer, for example the Ugandan National Biogas Program targeted users with 7-9 acres of farm land to support cattle. However, there are a variety of other factors affecting the quality of, and requirements for, biodigester feedstock, which vary according to biodigester design, ambient temperatures, and other factors. These can be addressed through diluting the feedstock to reduce the dry mass content or adjusting the operations and maintenance regime to more regularly distribute slurry.

Common volumes for household-scale systems are 5 cubic metres to 13 cubic metres. The minimum daily gas requirements is approximately 1 cubic meter per household of biogas and 25 kg of day fresh cow dung is needed to generate this. Larger-scale systems require a larger amount of feedstock per day (based on animal manure) depending on how much can be collected. Assessing the availability of day-fresh feedstock for a household is potentially the most critical factor in assessing the viability of the household as a biogas service customer. Households with low feedstock availability will not be able to operate the digester cost-effectively, due to the potential for maintenance issues such as the need to reset the digesting chamber's chemical/bacterial balance, as well as low satisfaction with the service, leading to reduced repayment rates for loans or service fees.

Quality of feedstock and its suitability for use in a biogas digester is another factor to consider, but is secondary to availability, as modification of the feedstock (for example through dilution or desiccation to modify consistency and water content) to better suit the required conditions for the type of biodigester being used is a possibility. However, this modification of feedstock, if required, will also add to the complexity of the feedstock system, and while this is achievable easily at a household scale due to low volumes of feedstock, setting up infrastructure for modifying the volumes of feedstock required for a centralised digester is another issue to consider when designing such systems.

There are, therefore, a number of ways to design business and financing models for biogas organisations and companies. The factors to decide upon are whether to focus on centralised systems or household-scale systems, and rural or urban/peri-urban markets. Population densities, as is the case with a number of energy businesses, can have a large effect on biogas business sustainability. Lower population densities, whilst they may indicate better feedstock regimes for consumers, will also increase operation costs for the biogas business, increasing transportation costs as well as sinking employee time into non-productive business activities. There needs to be a sustainable balance between targeting consumers with a suitable feedstock regime and managing the operating area of the business.

Then, the decision-making moves on to financing mechanisms, and how to assist low-income consumers in adopting biogas systems. There are again several viable options for financing biogas installations in the developing world.

The most applicable financing mechanism for biogas is a fee-for-service regime, where a biogas service company installs and maintains a biodigester in return for a monthly fee paid by the consumer. The service company can engage with commercial banks or central government programs for seed funding in order to offset the large upfront cost of purchasing systems to install.

The biodigester can either remain owned by the service company in perpetuity or can be transferred in ownership to the user after the initial cost-plus interest has been paid. Micro-finance is another viable option for consumer-side financing, with the service company offering a small loan with flexible payback periods and interest rates to the consumer. The consumer then owns the system and pays back the loan as normal. However, without some form of servicing and maintenance arrangement, the biogas system would be susceptible to reduced operating efficiency and failures, hence it would be advisable for a micro-finance-based biogas service company to offer these services to consumers.

Through a biogas programme and investment-subsidies is provided to individual farmers to establish a biogas installation. The subsidy, however, is paid through the company who constructs the installation. For this, the biogas programme has agreements with companies, which include certain quality standards. The biogas programme does regular checks to ensure quality. When the installation is finished and approved, the biogas programme releases the subsidy for the farmer, which is about 30% of the total costs for the farmer. Through this system of individual subsidies, biogas installations have been successfully scaled up in several Asian countries.

PayGo Biogas (Pay as you Go Biogas) is a company to promote the use of biogas energy. The high capital needed for constructing digesters and lack of technical skills have been the limiting factor for scaling up biogas. To overcome these two limitations assembly biogas digesters are used and installed. Farmers pay back daily until when they can fully own the digester.

Through crowdfunding[6] funds are collected that is turn will be used to offer loans to farmers for the installation of bio-digesters. This is directly handled through a biogas enterprises or project. The biogas farmers pay back the loan to the biogas company who will then payback the loan generated through crowdfunding.

4.0 – Institutions Supporting Biodigesters

The international organisations that specifically support biodigester technology can generally be split into two groups: organisations that provide funding to government agencies and departments for financing central/local-government biogas projects, and organisations that provide assistance/capacity-building/financing to smaller-scale biogas companies and individual entrepreneurs, often in the NGO sector.

The primary source of funding for government-scale biogas projects is often international donor agencies, for example the World Bank, European Union (EU) or the OECD. These organisations have demonstrated a commitment to biogas technology and development in the developing world over recent years. Regional development banks have also been involved previously in the development of biodigester technology, including the African and Asian Development Banks. Next a brief overview of several biogas programmes.

The EU SWITCH-Asia is funded by the European Union and is implemented by People in Need (PIN), Cz and local partner Janathakshan[7] in Sri Lanka.

The EU funded Indian Ocean Committee ENERGIES[8] programmes support the development of several biogas projects in their member states.

The Bhutan Biogas Programme[9] funded by the Asian Development Bank was introduced in 2011 to provide a sustainable energy source for households with livestock and help them reduce their dependency on firewood and expensive fossil fuels. The project has collaborated with the Bhutan Development Bank Ltd. who provides credit for biogas.

[6] https://www.lendahand.com/en-NL/articles/news/437-simgas-two-brothers-quest-for-clean-energy
[7] http://janathakshan.com
[8] http://commissionoceanindien.org/index.php?id=835
[9] http://www.moaf.gov.bt/biogas-for-a-cheap-and-sustainable-energy-source/

Through a partnership[10] between the Botswana Institute for Technology Research and Innovation (BITRI), the Global Environment Fund (GEF) and the United Nations Development Programme (UNDP) household biodigesters are being promoted using agro-waste in the districts of Southern-eastern Botswana.

In Zambia the biogas programme[11] is financed through Swedish International Development Agency (SIDA) in partnership with SNV Netherlands Development Organizations, Dairy Association of Zambia and other players in the industry.

The Tanzania Domestic Biogas Programme (TDBP)[12] is supported by Norway through the Royal Norwegian Embassy. The financing was through the bilateral agreement between Norway and Tanzania for support to Rural Energy Agency13 (REA), and cooperation with SNV Netherlands Development Organization.

In addition to this, at a government scale NGOs such as SNV Netherlands Development Organisation have been instrumental in the development of several country programs. Since 1989, SNV has supported the installation of more than 840,000 household biodigesters in the framework of national programmes in over 20 countries, such as the Nepalese, Rwandan and Kenyan programs above, which have gone on to enjoy wide-ranging success. This support was coupled with sector development, among others through capacity building services to enterprises, government and civil society organisations. However, international support for national biogas programs may not be sustained in the long-term, and governments then need to ensure that alternative channels of support can maintain financial sustainability for biogas programs going forward, like demonstrated in Nepal.

The Africa Biogas Partnership Programme (ABPP)[14] is a partnership between Hivos and SNV in supporting national programmes on domestic biogas in five African countries. The Programme aims at constructing 100,000 biogas plants in Ethiopia, Kenya, Tanzania, Uganda, and Burkina Faso providing about half a million people access to a sustainable source of energy.

There also exist a number of NGOs and other organisations with experience in promoting smaller-scale biogas projects and supporting businesses in the sector. In-country organisations and NGOs such as India's TERI, an NGO supported by the Government of India, provide expertise and partnership across the renewable energy sector, and TERI has been crucial in supporting India's National Biogas and Manure Management Program. International NGOs such as Germany's GIZ have in-country offices in a number of countries globally, including a number of Sub-Saharan African countries.

[10] http://www.bw.undp.org
[11] http://www.snv.org/update/building-bio-digester-market-zambia
[12] http://www.snv.org/update/10000-biogas-plants-be-installed-tanzania-support-government-norwegian-embassy
[13] http://www.rea.go.tz/
[14] https://www.africabiogas.org/

The Clean Cooking Global Alliance[15] is to support the development, sale, distribution, and consistent use of clean cooking solutions including biogas that transform lives by improving health, protecting the environment, creating jobs and income opportunities, and helping consumers save time and money.

In 2018 ENGIE[16] has invested 13% in Homebiogas, a pioneering company in the development of home-based biogas. This start-up has developed a small digester, adapted to the needs of families: 2 kg of waste can produce up to 2 hours of gas per day.

15 http://cleancookstoves.org/
16 https://www.engie.com/en/journalists/press-releases/invests-homebiogas/

5.0 Conclusions and Policy Recommendations

From the case studies discussed in this chapter, there is a plurality of solutions for successfully implementing a biodigester service company or program in the developing world. The critical factors for assessment in determining the solution most applicable to a specific context are:

- Over the past years the support to promote the use of biogas as a clean cooking fuel increased by the number of countries with (national) biogas programmes or biogas promotion projects and increased by the number of (international) institutions providing (financial) support in partnership with local organizations. This led to an increased share of biogas as a clean cooking fuel in the energy mix for households in countries in Asia, Africa and South America.

- Sufficient and constant availability of organic feedstocks (animal manure, human and agricultural wastes, food waste etc.) are crucial for generating sufficient biogas for (daily) cooking requirements.

- The population density of the targeted area and its settlement mode: a predominantly rural area with low population densities will be more effectively served with a different solution to a higher-population density urban area.

- The technology options available in the context, local manufacturing potential and local installation capacity, as well as the nature of the targeted consumers. Centralised biodigester systems are significantly more expensive than household-scale systems, but in a context with a number of potential large anchor consumers, servicing a larger organisation with a centralised system could be more profitable and sustainable than multiple household-scale systems. However, if the centralised systems require importing, and if there is a lack of skilled personnel in the context for installing and maintaining the system, the often-simpler household-scale digesters may be the more viable option, both economically and operationally.

- The availability of subsidies and/or consumer finance for biogas construction and installation in rural areas to help overcome the high investment barriers for potential biogas users.

- Biogas as compared to other clean cooking technologies is considered over a period of 30 years a cheaper option in that there are limited operational costs once a high quality biodigester has been installed.

- Development of the biogas market requires a long-terms strategy.

In conclusion, by considering the range of possibilities that affect biodigester system performance, biogas business performance, consumer satisfaction and the effectiveness of market-building activities, it is possible to tailor solutions to specific market contexts and enable sustainable projects and businesses.

Questions and Answers

What is the potential for biogas feedstock generation in the target area /region?

One of the key factors in designing a successful biogas technology-based energy intervention is the availability of feedstock for biogas digesters. This requirement changes depending on the scale of the digester, but the “rule-of-thumb” (Smith et al. 2010) of two large livestock (for example cows, or pigs) per cubic metre of biogas capacity will generate a sustainable source of gas. It is mportant to note that at least 20-25 kg of **day-fresh** cow dung is needed per day to generate a cubic meter of biogas. This figure was originally generated for a Sub-Saharan African country context, and other regions may experience some variance in this, for example based on ambient temperatures and humidity. In rural areas of developing countries, it is likely that households will be able to support a small household-scale biodigester installation if they own livestock. Larger, centralised biodigester systems, either at a village-scale or local-scale, as used for example in the Chinese case above, will obviously require a larger catchment area in order to fully serve the capacity of the installation with feedstock, and assessing whether this capacity exists and is sustainable is a vital first step to preparing business or policy models for these installations.

Does the demand in the market exist for consumers to satisfy their household thermal energy needs with biogas? Is there a market for industrial thermal energy consumption to be satisfied by biogas?

Assessing the market potential for thermal energy services in a given area involves looking both at household thermal energy use, as well as industrial and commercial thermal energy uses. Both of these modes can be satisfied by biogas installations. Market potential for biogas is also affected by the affordability and willingness to pay of consumers and organisations, as biogas systems are often have a higher investment cost than other sustainable thermal energy technologies.

Some projects, for example the Indian National Biogas and Manure Management Program (NBMMP, section 2.4), have specifically targeted household-scale digesters, as well as to a limited extent small village-scale system, as the assessment of the current modes of thermal energy use in the targeted regions (predominantly cooking energy use at a household scale) was suited to being replaced with small-volume biogas digesters. Other country contexts, for example large-scale centralised agricultural installations in Northern China (section 2.2) have benefited from the centralised approach, with biogas installations feeding both large-scale cattle farming operations with heating, as well as providing industrial process heat.

Can the targeted consumers for the biogas program/business afford installations? What financial assistance is needed?

Affordability and willingness to pay for biogas installations has been a stumbling block to the sustainability of many government and NGO-led projects in recent years, for example in the cases of South Africa and India. Domestic biogas installations, even if constructed from locally-sourced materials (for example, stones), are still a significant investment for rural consumers (USD100-150 for household digesters).

The existence of credit facilities or other financial assistance mechanisms for the diffusion of biogas systems is therefore important to the success of domestic biogas programs. For example, the Rwandan Domestic Biogas Program found that without credit facilities, system diffusion was poor due to the lack of affordability of systems for the targeted rural communities. The establishment of credit facilities under the Banque Populaire du Rwanda (BPR) gave the program the ability to reach scale more effectively through 3-year fixed term loans to rural consumers. The growth in the sector also helped development of the private sector, with 56 independent biogas companies existing in the country as of 2011.

What operations and maintenance provisions have been made through the business/program?

The provision of a maintenance regime for biodigester installations is an aspect of the technology that has often been overlooked in the design of government/NGO-led projects, as well as in private-sector interventions, in the developing world. Maintaining the integrity of the reacting chamber to produce the biogas, and the chemical balance (most notably pH) of the reacting mixture, is crucial to maintaining the effectiveness of the installation. Particularly with older designs, such as earthen dome-type digesters, regular maintenance is needed to ensure that the reacting chamber remains fully sealed. A number of projects, for example the Indian National Biogas and Manure Management Program (NBMMP), have experienced a high rate of digester failure after a few years of the project (up to 40% in some states). This is due to the lack of provision for an operations/maintenance regime within the program: failure of the integrity of the reacting chamber was the most common cause of digester failure under the program.

Given the existence of the maintenance requirement for biodigesters to continue functioning effectively, considering these maintenance needs when designing businesses/projects for biodigesters is important. This can include regular follow-up visits from technicians on a bi-annual basis, as is used in the Rwandan context. Whilst this approach can increase transaction costs for the company/ implementing agency (employment, travel etc.), combining this approach with others such as loan repayment collection or monthly payment collection if using a fee-for-service approach, will allow digesters to remain functional to the end of their expected life (5-6 years for earthen dome-type digesters, 10-15 for FRP/plastic digesters) effectively.

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World Bank Biogas Projects List: http://search.worldbank.org/projects?qterm=biogas

Appendix

Other Biodigester Business/Program Case Studies

Electricity Producing Biogas Development for Industry/Agriculture – SNV

Country	Feedstock Used	Volume of Digester(s) (m3)	Investment & Installation Costs	Payback Period	Fuel Cost Savings/Electricity Savings
Vietnam (small-scale farming)	Pig manure	50-500 (modules of 75, 100, 125)	30-45 EUR/m^3	7-10 years	N/A (biogas for own use)
Uganda (rice farming)	Water hyacinth/cow manure	183	36,600 EUR	10 years	960 EUR/a
Honduras (coffee industry)	Coffee wastewater	152 (2 modules of 48 and 104)	N/A	14 years	810 EUR/a
Mali (medium-scale livestock farming)	Cow manure, also improved feestocks such as jatropha presscake	26 (18 of slurry production, 8 of biogas)	2,444 EUR (incl. personnel, materials, transport)	8.5 years (expected: 4)	495 EUR/a
Peru (medium-scale livestock farming)	Horse/cow manure, crop residues	150 (2 modules of 75)	84,000 EUR (incl. generator, electricity network)	N/A	N/A (micro-grid for local use)

Table adapted from SNV-FACT, 2014.

Biogas-Producing Projects for Thermal Energy Services

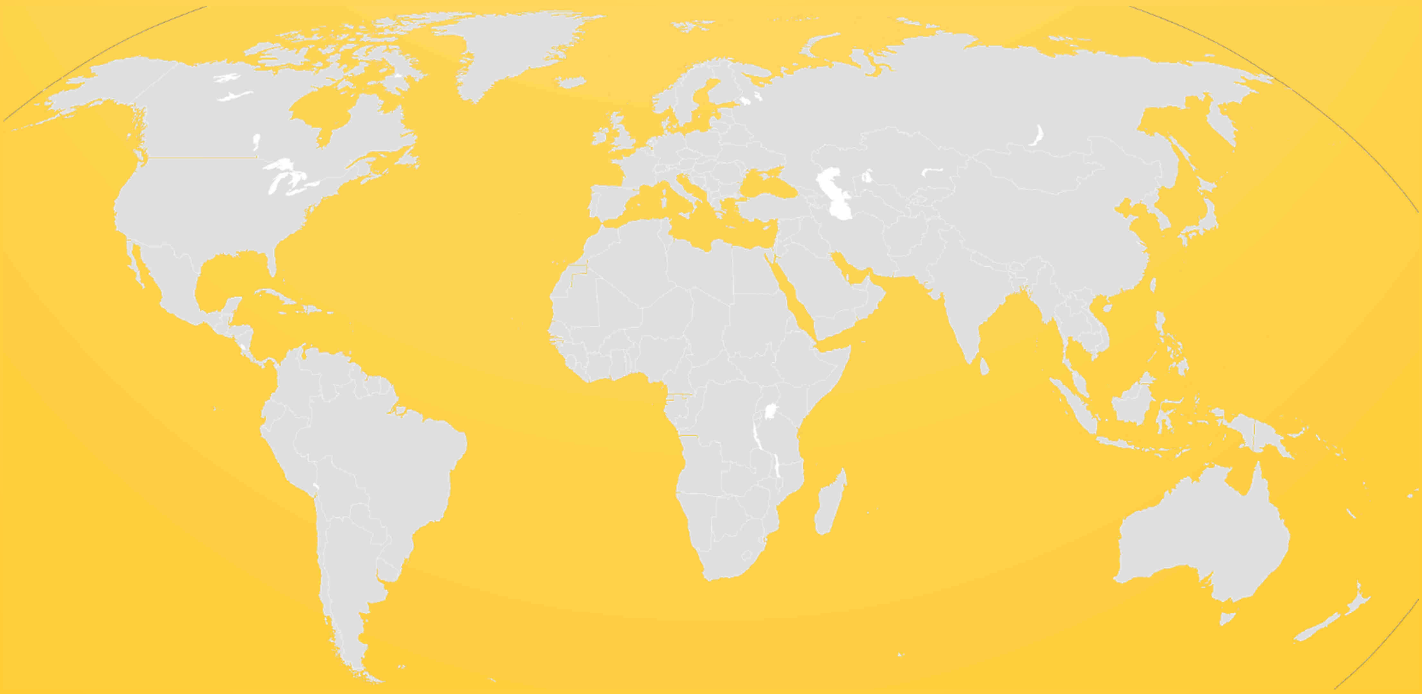
Country	Feedstock	Use of Biogas	Digester Volume (m^3)	Investment Costs (US$/$m^3$)
India	Market waste	Electricity for market lighting (5 kW)	25	1,398
India	Kitchen waste/human waste	Biogas for household cooking (3hrs/day)	2	296.5
Tanzania	Kitchen waste	Household cooking (45 mins), experimental facility so flared	1	420
Tanzania	Canteen waste	Replacing charcoal in school canteen cooking	4	534
Nepal	Human/kitchen wastes	Group and individual cooking in prison facility	1 3x10, 1x20, 1x35	206
Lesotho	Human/organic solid wastes	Home cooking & agricultural use of wastes	6-19	83-667
Argentina	Municipal solid waste	Heating of space and water	150	786
Argentina	Agricultural and domestic solid wastes	Water heating & processed food production	24.75	326

Table adapted from Vögeli et al., 2014.

GIZ Energy Programs with Biogas Components

Country	Project Name	Dates
Brazil	Diffusion of Climate-Friendly Biogas Technologies	2013-2017
Turkey	Resource-efficient and Climate-friendly Use of Animal Waste	2010-2014
China	Optimization of Efficient Biomass Utilization	2009-2013
India	Emission-Neutral Rural Energy Supply Program	2009-2014
Bangladesh	Programme for Renewable Energies and Energy Efficiency	2011-2013
Vietnam	Support for the Establishment of a Renewable Energy Agency	2010-2014
Various (SE Asia)	PEP Renewable Energy South-East Asia	2012-2015
Cambodia	Renewable Energies	2010-2012
Various (C. America)	Promotion of Renewable Energies and Energy Efficiency in Central America	2010-2014
Chile	Expansion Strategy for Grid-Connected Renewables (with Grid Study)	2009-2013
Serbia	Development of a Sustainable Bioenergy Market	2013-2017

Table adapted from Findeisen, 2013.



This document is an output from a project co-funded by UK aid from the UK Department for International Development (DFID), the Engineering & Physical Science Research Council (EPSRC) and the Department for Energy & Climate Change (DECC), for the benefit of developing countries. The views expressed are not necessarily those o DFID, EPSRC or DECC.