Productive Biogas:
Current and Future Development

Five case studies across Vietnam, Uganda, Honduras, Mali and Peru

SNV

FACT

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About SNV

SNV, the Netherlands Development Organisation is an international not-for-profit development organisation. Founded in the Netherlands in 1965, SNV has built a long-term, local presence in 38 of the poorest countries in Asia, Africa and Latin America. SNV's global team of advisors work with local partners to equip communities, businesses and organisations with the tools, knowledge and connections they need to increase their incomes and gain access to basic services, empowering them to break the cycle of poverty and channel their own development. By sharing their specialist expertise in Agriculture, Renewable Energy, and Water, Sanitation & Hygiene with local communities, SNV seeks to promote durable solutions to pressing global challenges. Through their Renewable Energy framework, SNV aims to:

- Realise access to sustainable, clean and reliable energy sources for domestic households and SMEs, while reducing greenhouse gas emissions;
- Create an enabling environment whereby local existing organisations are strengthened or established where required and sound policies, including regulation, quality assurance and governance, are developed.

About FACT Foundation

FACT is a business-oriented foundation providing advice training and R&D in local bioenergy solutions worldwide. The main objective of FACT is supporting income generation of the rural population in developing countries by the sustainable production and use of biomass for energy purposes, with a focus on bioenergy and biofuels.

To reach this objective, FACT intends to become the key knowledge and reference centre in the world for small-scale sustainable production and use of biomass for energy purposes in rural areas, aimed at alleviating poverty by additional income generation for their inhabitants. FACT assists partners in Africa, Latin America and Asia with know-how, capacity building and by the linking of counterparts worldwide.

Collaboration between SNV and FACT

SNV and FACT Foundation have been partnering since 2009 in Africa and Latin America, working together on a wide variety of bioenergy projects.

Both organizations share a commitment to promote and scale-up their experience in productive biogas so as to support the sector's expansion and advancement.

Through this publication, SNV and FACT believe they can contribute to the creation of a cross-country knowledge base that will promote and support the rapid emergence of productive biogas sectors and markets worldwide.

Credits and acknowledgements

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Disclaimer

Preface

The domestic biogas experience and expertise of SNV, Netherlands Development Organisation, are widely recognized. Thanks to a vast network of national and international partners like DGIS and HIVOS, and the backing of countless farmers that have chosen to invest into the acquisition of a biogas plant, over 580,000 biodigesters have been installed through SNV's work in 20 countries of Asia, Africa and Latin America. This has resulted in large and cross-cutting benefits for smallholders and households, especially women.

In 2013, it was estimated that 1.3 billion people lived without access to electricity, and that 2.8 billion people did not have access to clean cooking. Energy needs, furthermore, cannot be isolated from other needs. In the face of a growing world population, tied to a widespread depletion and degradation of natural resources, innovative models that address the energy-water-food–climate nexus in a holistic manner must be deployed. Biogas, by tackling energy needs, excessive workloads, nutrient recycling for food production, waste water and air pollution, and greenhouse gas emissions simultaneously, provides such an integrated solution.

Building on its prior experience in domestic biogas, SNV, alongside the FACT Foundation and other partners, has committed itself to developing and upscaling the relatively underserved area of "productive biogas". This is the "missing middle" between growing domestic biogas sectors and increasingly varied large scale industrial biogas applications. Productive biogas schemes are mostly comprised of medium sized biogas plants, serving the productive energy needs of small and medium enterprises (SMEs) and communities with no proper grid connection and/or sound waste treatment system.

The question that gave rise to this work was as to why no substantial productive biogas sector had developed in any developing country before. Which are the market barriers inhibiting sector growth? Why have productive biogas systems not reached a larger scale? Can productive biogas, particularly those systems that are community owned, be deployed in a sustainable way? When trying to answer these questions, contributors to this book realised that there was no significant body of knowledge available on this.

The five case studies outlined in this publication, seeking to fill these knowledge gaps, provide a detailed description of productive biogas projects led by FACT and SNV in Mali, Uganda, Vietnam, Honduras and Peru. As stated by one of our peer reviewers, they openly list the challenges and lessons learned which others should consider before replication.

The five cases demonstrate that productive biogas is technically and financially feasible, particularly in specialised markets requiring environmental solutions. Productive biogas is viable, provided investment and transaction costs can be tackled with innovative financing mechanisms like carbon finance and are supported by the creation of a conducive enabling environment, customer- and investor awareness raising, and seek to reach a scaled production in order to reduce unit costs.

The result of a close collaboration between SNV and the FACT Foundation, this book can be used by technicians, development practitioners and consultants, local and national governments, or any organisation wishing to start exploiting productive biogas. On behalf of SNV, I would like to thank the many organisations, authors and reviewers that contributed to this very significant work. My special thanks, finally, will go to the farmers, households, communities and entrepreneurs whose willingness to engage in an innovative venture was fundamental to create the novel practices documented here.

Andy Wehkamp
Managing Director Renewable Energy SNV

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I. Introduction

By Alexander Eaton, International Renewable Resources Institute, Sistema Biobolsa, REDBIOLAC; Jaime Martí-Herrero, Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE), Universidad Politécnica de Cataluña, REDBIOLAC; Mariela Pino, REDBIOLAC.

« We have reduced our energy costs by 90% and our fertilizer costs by over 80% », explains Maria Villada, as she watches workers converting local milk into cheese for sale in regional markets of Central Mexico. Five years ago, these costs, and potential environmental fines from the local government, were at the point of putting the medium-scale dairy producer out of business. Maria Villada, however, was offered a biodigester system including a biogas motor and cheese making equipment alongside a 12-month financing package by a local productive biogas company. By treating waste, producing energy and fertilizer, and reducing its production costs, the system has been paid off in just eight months and the business's challenges have been converted into opportunities for growth.

Maria's story provides one example of the many applications of productive biogas. This document, published in collaboration by the Fact Foundation and SNV, will outline five case studies of projects deployed in Mali, Uganda, Honduras, Vietnam, and Peru, casting a light on **how biogas can be a critical enabler for small businesses and institutions globally**. Through this work, SNV and FACT aim to consolidate the existing knowledge on productive biogas and its various applications, and thereby contribute to the expansion and the advancement of productive biogas sectors worldwide.

The RedBioLAC is a network of institutions involved in the applied research and advocacy of biodigesters for the treatment and management of organic waste, as a strategy to improve the wellbeing of the Latin American and Caribbean people.

I.1. Productive biogas: a working definition

Productive biogas is defined here as:

The application of anaerobic digestion technology appropriate to provide waste management, nutrient recycling and renewable energy services supporting economic activities of entrepreneurs, SMEs and institutions that are neither domestic nor industrial.

The term "productive gas" is used to describe projects that have previously been referred to as Biogas for Productive use, Medium Scale Biogas, Biogas for Business, and Institutional Biogas, and may include small, medium, as well as large scale biodigesters. This definition does notquestion the productivity of other biodigester applications, but rather, seeks to clearly articulate this important and distinct sub-sector and to promote solutions directly attending to its specific constraints and needs.

In line with the growing literature on *productive energy*[1], the notion of "*productive biogas*", beyond the sole creation of income or value, encompasses the broader implications of productive uses of energy for development, whether it regards health, poverty reduction or the environment.

[1] Cabraal, A., et al., 2005. Productive Uses of Energy for Rural Development; UN ESCAP, 2007, UN Recent Development in Biogas Technology for Poverty Reduction and Sustainable Development.

I.2. Productive biogas: mapping the sector

Small and medium scale entrepreneurs and enterprises (SMEs) working in agricultural and manufacturing business in a variety of countries have found that productive biogas projects can achieve high rates of economic return. The additional environmental, social, and economic benefits of these projects indicate that empowering SMEs with productive biogas technology represents a critical avenue for tackling numerous pressing development issues including food security, clean energy capacity, efficient waste and water management, and climate change mitigation and adaptation.

Experience from around the world shows that the productive biogas sector is growing: factories in China and Brazil now produce biogas generators and motors; food waste from markets in India and Indonesia provide decentralized renewable electricity and agricultural inputs for local farmers; prisons, hospitals, and schools in Rwanda, Haiti, and Sri Lanka are treating wastewater and food waste to provide institutional energy supplies, and, increased environmental regulation in Nicaragua has pushed recent biogas development in food processing. Other promising projects include a fish packing plant in Costa Rica now producing biogas electricity with waste that once contaminated the coast, a pig farm cooperative generating biogas to a Bolivian school, and a global crowd-funding platform lending money to a Mexican slaughterhouse for biogas plants.

Productive biogas, however, **has not yet received the attention it deserves** from the private or public sector, partly because it falls within a gap between the industrial and domestic biogas spaces and overlaps with other development sectors.

Within the broad spectrum of biogas technologies, scale is a critical component determined by technological viability, commercial availability, and financial feasibility. Industrial biogas, on one end of the spectrum, has a full ecosystem of complimentary technologies, sales providers, financing, regulatory frameworks and incentive packages available for industrial scale projects in the agricultural, food processing, waste management, and manufacturing sectors. On the other end of the spectrum, domestic biogas has several decades of experience and over 20 active national-level domestic programmes underway in Asia, Africa and Latin America with multilateral development agreements, national regulatory frameworks, and increasingly market-based sustainability within the sector. A healthy range of technologies are available, and networks of experts, businesses and policy makers are able to share best practices and improve the viability and development impact of the technology. Massive opportunity and need for growth in the domestic area remain, but strategies and technologies for future growth have been demonstrated and replicated.

Productive biogas, whilst sharing some characteristics with the domestic and industrial sectors is at the same time confronted with a unique set of challenges and opportunities that ought to be addressed. Productive biogas fills an important technological, social and economic gap by providing SMEs with a combination of waste management, nutrient recycling, and renewable energy services. This attends to a critical “missing middle” comprised of a wide breadth of agricultural, food processing, and manufacturing businesses that remain outside of the domestic context, but have not reached an industrial scale.

Productive biogas is a key tool to allow SMEs to "leap-frog" energy intensive and environmentally damaging business models and allow for environmental, social, and economic benefits for the business and broader community. In this view, it is critical to articulate sector-specific strategies for productive biogas to improve the efficiency and economic viability of SMEs that in-turn provide employment and economic activity in emerging economies while reducing soil, water and air pollution as well as greenhouse gas emissions.

I.3. Methodology and objectives

This document was developed in October 2013 in Granada, Nicaragua, and is the result of a collaboration between several international organizations and biogas experts under the Writeshop methodology defined by the International Institute for Rural Reconstruction (IIRR) in the Philippines and informed by the experience of Paul Mundy and tools for a systemic and result-based approach[2].

It delineates five case studies illustrating the wide application of productive biogas technologies across the world. Using a cross-country analysis aimed at highlighting some key lessons for those involved or willing to be involved in the productive biogas sector, it will additionally outline opportunities, challenges and further steps to support the development of productive biogas for SMEs and institutions in emerging economies with a view to strengthen food security, clean energy capacity, efficient waste and water management, as well as climate change mitigation and adaptation.

In order to gain an overarching view of the five chosen case studies, and draw some useful lessons for the advancement of productive biogas sectors beyond those individual cases, this document will conduct a systematic analysis, outlined in Chapter 7, and focusing on four different parameters:

Sustainability	The scheme's ability to satisfy the technological, economic, social and environmental demands of its users on a long-term basis, in line with local capabilities and resources supported by a favorable enabling environment.Sustainability is broken down into and assessed based on five components: technical sustainability; social sustainability; environmental sustainability; financial and economic sustainability; public policy and institutional sustainability.
Market readiness	The degree to which the deployment of productive biogas in the considered country and/or region compares to a mature market, in which a variety of actors create both supply and demand, alongside dedicated standards and institutions.
Replication potential	The potential of a project to be replicated, scaled up or adapted. It is determined by the identification of those niches in which comparable conditions exist and where a similar use of biogas can be applied.
Barriers for market development	The obstacles and constraints limiting the expansion or maturation of productive biogas technologies and related market development. They can be found at various levels, whether social and organizational, financial and economic, or institutional.

[2] International Institute for Rural Reconstruction (IIRR) in the Philippines, Workshop Proceedings Writeshops: A Tool for Packaging and Sharing Field Experiences.

I.4. Biogas and the global development agenda[3]

How does productive biogas help tackle key global challenges? At the cross-section of waste treatment, energy production and agriculture, productive biogas represents an attractive technological and economic solution in a context of interconnected global development challenges.

I.4.1. Economic development through renewable energy

Productive biogas provides clean, local and renewable thermal, mechanical and electrical energy to SMEs, allowing them to improve the efficiency and economic viability of their businesses, thereby offering opportunities for broader human and economic development. The economic benefits of productive biogas are clearly illustrated within communities with no access to the electrical grid or with high dependency on costly diesel generators and other fossil fuels, where biogas allows for the development of energy-intensive and cost effective businesses.

Furthermore, it is now widely recognized that true long-term economic development must be built upon sound environmental principles in a world with limited resources. Recognizing this, productive biogas directly incentivizes efficient waste and water management, use of renewable energy, and use of local renewable resources as an organic fertilizer.

I.4.2. Mitigation and adaptation to climate change

Productive biogas is an important tool against climate change as it mitigates the emission of greenhouse gases (GHG) both by capturing methane emitted from traditional organic waste management *and* by using this feedstock as an energy source to displace biomass and fossil fuels. In addition to the reduction of GHGs, productive biogas allows SMEs and communities to be more resilient against the effects of climate change by providing them with local clean energy and fertilizer from renewable local resources,strengthening them against global fluctuations of resource and energy distribution.

I.4.3. Increase of local food production and added income streams

Productive biogas increases the production, processing and commercialization of staple, commercial and forage crops by the local agricultural sector. Here, nutrient recycling improves crop yields, and local energy production allows for improved processing and refrigeration. The increased yields and reduction of crop losses allows for agricultural growth without the need to expand agricultural frontiers, water use or agricultural inputs. Additionally, the commercialization of biodigestion products and by-products – energy and bioslurry – offers potential added income streams for end-users.

I.4.4. Efficient waste and water management

Productive biogas can provide decentralized basic sanitation services, converting human waste into energy and nutrient resources. Here, more than two billion people lack access to sanitation services, a global challenge that can be put to productive use. Productive biogas treats organic waste streams that otherwise would contaminate local watersheds. By recycling the resulting slurry streams as irrigation and fertilizer, the efficient reuse of water is naturally incentivized, protecting watersheds from contamination and overuse. The development and conservation of soils, rangelands, and forests also improves water absorption, flood resistance, and reduces erosion within the watershed.

[3] For further scholarship on the following linkages, see for example UN ESCAP, 2007; IIED, Sustainable energy for all? Linking poor communities to modern energy services, 2012 or Kaygusuz, K., 2011. "Energy services and energy poverty for sustainable rural development" UNDP, 20008. Access to Energy and Human Development, Human Development Report

I.5. A cross-country analysis of productive biogas

This document outlines five case studies that illustrate various applications of productive biogas, demonstrating some of the associated development benefits, highlighting potential challenges for the expansion of productive biogas and suggesting future areas of work. Determined by the specific context of each case, these various parameters are crossed and analyzed *in* Chapter VII to derive some broader lessons for the productive biogas sector.

- In **Honduras**, we learn how environmental challenges currently bearing upon coffee production are converted into opportunities as a 150 m^3 modular up-flow biodigester design treats the contaminating waste water from the coffee harvest, producing over 4600 kWh of renewable electrical energy each year, bringing benefits to a cooperative of 580 coffee farmers.

- In the deep jungle of **Peru**, a highly isolated community now benefits from a community-based management system to convert the waste produced by the local cattle herd into electricity within a mini-grid that provides electrical service to each home. Through a community organization, 42 families have found a renewable energy solution with a 16 kW biogas electrical generator.

- The inhabitants of the Ssese Islands, **Uganda** arefaced with two major challenges: with access to electricity, they arealso struggling with invasive water hyacinth choking the waters around the island. Using a 180m^3 modular biodigester, the invasive is now converted into electricity that provides energy to a local rice mill and allows 100 families to charge batteries for household energy.

- In **Mali**, the Multi-Functional Platform is a diesel-powered motor that allows women groups to employ mechanical and electrical energy for productive use in local businesses. Purchasing the diesel used to be these groups' single largest cost. With the installation of three pilot biogas systems in the villages of Ferekoroba, Dongorona and Simidji, the beneficiary women have been able to reduce their diesel consumption by up to 23%, demonstrating that biogas has the potential to make their operations more efficient and energy independent.

- While pig production has become a flourishing business in northern **Vietnam**, with the growing size of farms, farmers are increasingly confronted with problems related to waste treatment. Through the installation of 9 Productive Biogas systems with volumes ranging from 100 to 500 m^3, innovative farmers have demonstrated how waste treatment solutions can open the door future renewable energy and fertilizer sources. Here, bioslurries are used as fertilizer to increase rice and agricultural production and to provide inputs to local fish farms.

We hope that these case studies are both inspiring and insightful for those interested in spreading the application and impacts of productive biogas, and that this document begins an active and inclusive global conversation on how this technology will help us confront today's key development challenges.

II. Case study 1- Market introduction of the medium-scale plugflow biogas digester in Vietnam

By Dagmar Zwebe, SNV Vietnam.

II.1. Introduction

With an excess of 20,000 medium-sized pig farms and a sector growing with an annual rate of 8%, Vietnam has identified the improper disposal of pig waste by farmers as a rising environmental and health hazard for the country. It is estimated that 6 million tons of CO_{2eq} are released annually by medium-scale pig farmers as a result of an estimated 73 million tons of pig waste disposed improperly into ponds, channels and sewerage **(Figure 2.1)** or merely left to decay into fields each year. This lack of proper disposal is associated with growing water, land and air pollution. Samples of wastewater taken from pig farms indicate that about 90% of them fail to meet national standards, Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels (BPD, 2009) as well as e-coli being of greatest concern. The traditional disposal of pig waste is altering water sanitation, with important health impacts (VN News, 2008), in densely populated areas in particular.

Biogas technology, by offering a solution to manage pig manure, is a potential response to these environmental and health challenges. From an environmental standpoint especially, biogas systems could offer multiple benefits: while reducing the reliance of medium scale pig farmers on fossil and other traditional fuels, biogas systems could also build their resilience to climate change by making them less dependent on external commodities subject to price volatility, and help them reduce their use of synthetic fertilizers and the embedded CO_2 emissions generated by their production. Through fossil fuel substitution and proper waste treatment, it is estimated that the construction of medium-scale biogas digesters could reduce overall levels of greenhouse gas emissions (GHGs) in Vietnam by an estimated 250 t CO_2 per year per digester.

Figure 2.1 Open pond treatment system of a medium scale farm releasing methane and over-flowing into a public irrigation canal. The "before biogas" situation of Mr. Tran Van Quang's Farm Bac Ninh province.

II.2. Background

Medium-scaled biogas digesters provide answers for two of the demands of pig farmers, namely the demand for animal waste treatment and the demand for energy provision. Due to restricted knowledge and technology, medium and large-scale biogas plants have not been successfully developed in Vietnam on a larger scale. It is estimated that less than 1% of the medium and large scale pig farms are presently served by anaerobic digestion systems (GFA, 2012).

In view of their already well-developed domestic biogas program, SNV were encouraged by the Ministry of Agriculture and Rural Development (MARD) to explore solutions to the negative issues associated with the growing medium-sized farming sector, possibly through an extension of their previous activities. The effects of pig farming on water and air pollution have indeed become an important concern, and are seen as a potential threat for the development of the economically crucial pig sector. While the recycling and reuse of organic waste in farming are highly promoted at state level, biogas technologies present an additional opportunity by replacing extensively used nitrogenous -chemical- fertilizers with organic fertilizers in the form of bioslurry and sludge from biogas plants, resulting in greater agricultural productivity and safety.

A consortium was thus formed, gathering the Institute of Energy (IE), the Green Energy Consultancy Investment and Trading Joint Stock Company (GECI) and the Stockholm Environment Institute (SEI) which all recognised the need to support the market through the creation of greater access to an affordable waste management solution called Biogas Technology. The project was financially supported by the EEP Mekong Facility, alongside contributions from all the partners involved.

Consortium members have chosen to focus on a further deployment of a design developed and already implemented by IE, a low cost plug flow biogas system built with locally available materials. For the ten demonstration digesters built under the first phase of the project, several selection criteria were used:

- Focus on farms with 500-1500 pigs and/or 1000-4000 kg/day of manure available for collection, with the collected amount corresponding to >90% of the manure produced.
- Focus on a province with high potential for scaling-up after the project.
- Space availability.
- Considering that the chosen farms may be pioneers and models of good practice for the region - right attitude of the farmer.
- Opportunity and willingness for optimal use of biogas and bioslurry.
- The ability of the farmer to contribute the majority of the total investment.

All the farms initially chosen for the pilot sites met all selection criteria. However, because three of the selected farms withdrew from the project in a later phase of selections, due to project time pressure and logistical constraints, they had to be replaced with farms that did not fully meet these criteria at the launch of the construction phase, but are aiming to do so within a few months after the project ends.

II.3. Process design, installation and start-up

Project activities

In order to create a sustainable market mechanism delivering affordable Medium Scale Biogas Technology to end-users, the consortium is primarily focusing on the demonstration phase of the initial design of sector development.

The activities of the project are defined as follows:

Implementation and operation of 10 medium scale digesters	▪ Select of farms ▪ Optimize basic plug flow biodigester model ▪ Develop farm-specific designs and bill quantities
Optimized application of biogas & bioslurry for optimal social, environmental and economic impacts	▪ Construct and commission digesters
Capacity building	▪ Support and build capacity of IE and GECI ▪ Build capacity of the masons team ▪ Raise awareness of farmers and provincial representatives ▪ Train en users in project application
Framework for market development	▪ Disseminate results at national and international level ▪ Develop M&E and quality control system ▪ Develop a road map for further scaling up and market development
Project Management	See below

The different roles of the project partners are described in **Figure 2.2.** SNV's role has been focusing on project coordination and management as well as advice to the local partners, with technical support and backstopping by the Biogas Design and health experts of SEI to further optimise the design of the digester and to integrate existing international experiences.

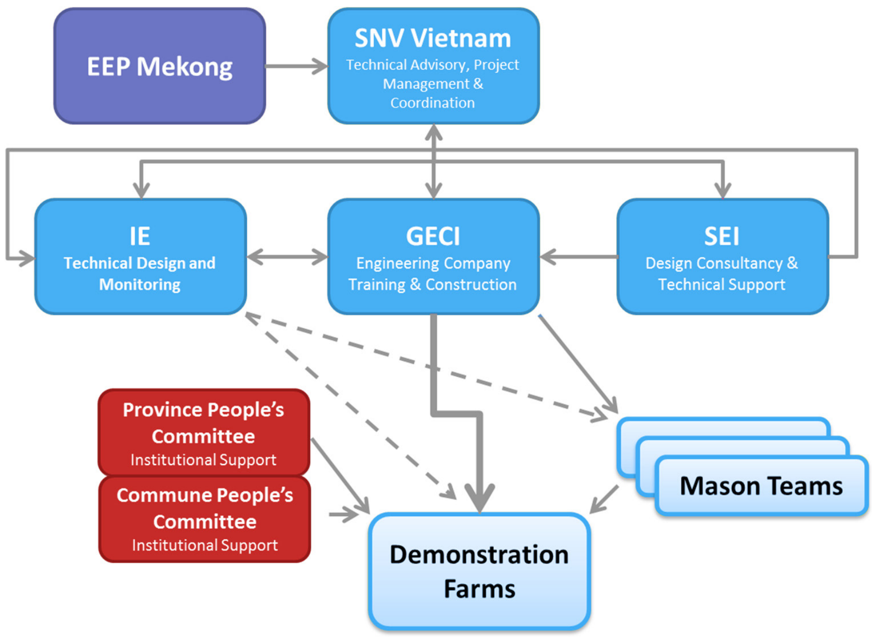

Figure 2.2
Project structure

Technical aspects

A plug flow digester is a manure management system designed following the operational principle of the simple fixed dome biogas plant with continuous and automatic filling -through gravity, with a controlled stable inlet volume and dilution ratio. The daily volume loaded into the system ranges between 0.6 and 4m^3 corresponding to a digester volume of 50 to 500 m^3. The optimal dry matter content loaded into the tank should revolve around 6-10%, which in the case of pig manure means a dilution ratio of 2-3 litre water for 1kg of fresh manure.

The digester is set up in a modular way, with modules of 75, 100 and 125m^3 ensuring that the total size of the digester remains flexible, i.e. adjusted to the farm's needs and potentially extendable in case the total of pigs owned by any given farm increases after it gets access to a waste management system.

The construction materials are all locally available, and purchase from local suppliers will support local development. Main construction materials are:

Brick	Type A or perforated (holes<1cm), compressive strength>75 kg/cm^2
Golden sand	Maximum diameter 3mm for joint mortar and fine sand for the plaster
Cement	Portland cement of PC 30 grade or higher
Gravel	Crushed stone and broken bricks used for concrete mixing
PVC	TCVN 6151:2002; For the inlet and outlet pipes
Plastic pipelines	For the gas; inner diameter≥25mm (depending on the length)
Steel	To reinforce the concrete with a compressive strength of 200 MPa
Safety valves	

The plug-flow design of **Figure 2.3** was built using these materials.

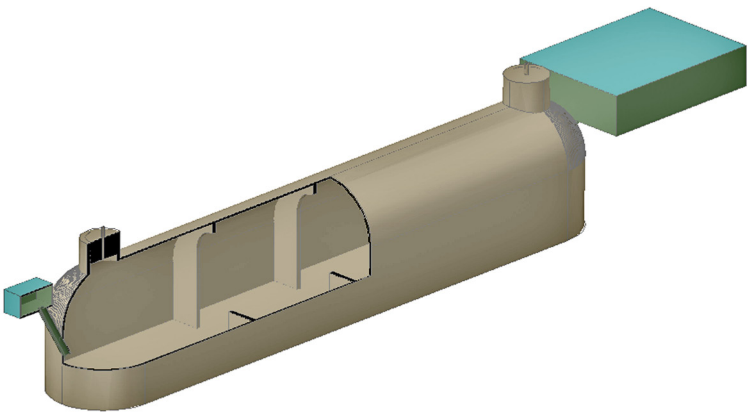

Figure 2.3

Design of a Plug Flow Digester with one modulea

The plug flow biogas plant consists of 6 main components:

Mixing tank	Outlet pipe
Inlet pipe	Compensation tank
Digester tank	Gas pipe

The time required for building and commissioning each digester ranged between 120 and 180 days -for digesters within the size range 150m^3-500m^3. A finer timeline of activities appears in the table below. As indicated in **Table 2.1**, the most time-consuming activity, regardless of digester size, is the filling of the digester.

ACTIVITY	DAYS
Site preparation (pit excavation/liquid pumping in settling pond)	14
Casting of the concrete bottom of the tank(s), incl. curing time	7
Tank construction (dome; plastering; surface treatment)	35
Construction of the compensation & mixing tank, incl. inlet/outlet	21
Checking of air and water tightness	7
Backfilling	7
Standby time (because of rain or other external influences)	14
Pilot operation, including filling of the digester with manure	35
TOTAL	**142**

Table 2.1 **Timeline to build and commission a 300m^3 digester**

Operation of the system

A plug-flow biogas plant works in two phases:

1. In the first phase there is no pressure in the system (P=0), the liquid (bioslurry mix) in the digester is at level zero. Methane production and accumulation will create pressure and will push the liquid down and into the compensation tank. When the compensation tank reaches its highest level ("overflow level"), the bioslurry in the tank is at its lowest level, and the biogas storage inside the digester is at its highest level (P=Pmax).

2. During the following gas consumption stage, gas is consumed or stored in external storage solutions, which lowers the pressure in the tank and makes the slurry flow back into the digester tank from the compensation tank. If all biogas is used, the digester will go back to the P=0 stage.

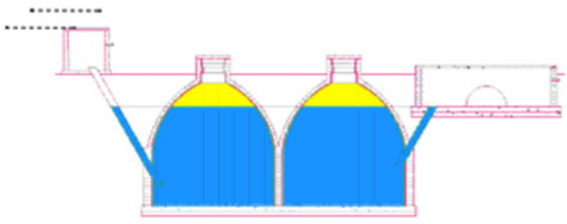

Figure 2.4 a

Digester - pressure is zero (P=0)

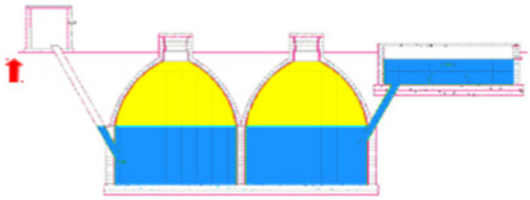

Figure 2.4 b

Digester - pressure is maximal (P=Pmax)

The compensation tank will control the pressure in the digester, and pressure safety is an important aspect. In each farm, a pressure meter indicates when there is a high pressure in the digester and biogas should be used, or potentially, for the larger designs, a flexible gas storage (PVC or HDPE) bag is added to the design that can be filled at this point for later use. Automatic valves linked to flares are also in place in case the high pressure goes unnoticed or remains ignored by the farmer.

Maintenance of the digester is necessary to secure long lifetimes and optimal, sustainable capture and use of the biogas produced by the manure. Maintenance needs for this design are minimal, and mainly consist in removing sediment and scum every 12 or 18 months.

II.4. Results and impacts

Given the growth of medium size farming and the Government's request to support the deployment of low-cost biogas solutions to support the development of this sector, this intervention has been initiated with a long-term vision. Designed to support the development of a sustainable market (supply and demand) for medium scale biogas technology, this project is seen as a first step with two major objectives:

1. To test the technical design of a locally designed model - a stepping stone towards other technologies also.

2. To test the market development approach developed by the consortium. Its results will feed into the design of a next phase focusing on the –further- development of the medium scale biogas sector in Vietnam.

Nine digesters are now installed and in operation -one digester had a technical failure and its construction was halted mid-way through.

Environmental impacts - The nine digesters are presently treating 8,500 tonnes of manure per year and avoid 2,200 tCO_2 equivalent per year. The biggest improvement mentioned by the farmers is an improved livelihood situation for the animals, farmer, staff and very importantly, the neighbours. Complaints from neighbours concerning odor pollution or official warnings from Government officials are often key reasons to invest in biogas technology as a waste management solution and to control the odor. In addition, with the use of bioslurry as an organic fertilizer by both the farmer and neighbouring farms, more and/or better quality products can be produced using the same land and less chemical fertilizer, reducing the costs for the farmer(s).

Social impacts - The reduction in odor pollution observed following the installation of the biodigestershas a positive impact on local relationships. The purchase of local materials, the enhanced capacity of construction teams and engineering companies, and the creation of a biogas market, also have a large social impact on Vietnam as a country.

Economic impacts are feltin the short-term through savings on the purchase of fertilizer, additional incomes through the use and sale of biogas, and through potential extensions of the beneficiary farms. Farmers are currently using the biogas for cooking for their family and workers, as well as for their pigs -pig feed requires long hours of cooking, and thus large amounts of fuel. The environmental pollution no longer stops farmers from getting approval for farm extension from the government. However, it can be noted that although the program was expected to stimulate the purchase of electricity-generating equipment, only a few farmers chose to make this - relatively large - additional investment. The bioslurry, finally, can also be used as fertilizer - saving costs for chemical fertilizer - and as fish feed in the fish ponds.

Average investments for these medium scale plug flow systems ranged between 30 and 45€/m^3 with an average of 40€/m^3. The costs of a generator of 10-15 kW for a 200m^3 farm is around USD 1800, although a generator of this size cannot replace the full electricity demand for all farms.

The payback period for beneficiary farms oscillates between 7 and 10 years when biogas is used to off-set on-farm use of LPG, backup fuel (often diesel) and the amount of energy used for power generation. One farmer which sold all the biogas he produced to a nearby factory is expecting a complete payback within 3 years. Average costs for electricity in the demonstration farms revolve around 8,000€/year; around 1,500€/year for back-up fuels and around 1,000€/year for other energy uses. Therefore, depending on what is replaced, the opportunities for cost savings are large.

It should yet be stressed that Vietnam's extensive electricity network -97% of the population has access to the national grid- and associated low electricity prices -current tariffs are estimated to be below 9€ cents/kWh- are presently hindering theinterest there might be in using biogas for electricity generation among farmers. Given the project's commercial orientation, following SNV's market-based approach, no subsidies were offered for generating electricity from biogas, and the decision to buy a generator lied entirely with the farmers. That being said, the efforts made to promote a productive use of biogas are starting to pay off, with four of the nine beneficiary farms having chosen to purchase a generator. With the electricity market opening fully by 2020, and the steady rise observed in electricity prices, conditions should become more favourable to an optimal use of biogas over the coming years. Feed-in-tariffs are currently under development and are expected to be in place in 2014-2015.

Ms. Trinh Thi My, Phu Luong commune, Que Vo district, Bac Ninh province.

Thanks to the biogas solution installed in our farm we were able to almost double the number of pigs. Our family is now aware that biogas helps protecting the environment and gives us access to clean energy at the same time. Our electricity costs are more than 3 million VND (150 USD) per month, and with biogas sourced electricity we are saving significant sums.

Mr. Tran Van Quang, Chau Phong commune, Que Vo district, Bac Ninh province.

We are trying to use all the biogas that is produced as efficiently as possible. My family is also selling biogas to the neighbouring brick factory, generating additional income for us. I am most satisfied with the elimination of the environmental pollution, 60-70% of the water pollution has been resolved.

Figure 2.5

Ms. My showing her biogas generator

You can also find a promotional movie, featuring both these farmers on the donor's websites home page: http://www.eepmekong.org/.

Awareness creation - Awareness raising at the local, national and international level appears critical for increased market operation given the limited knowledge of medium scale biogas solutions for farms characterizing Vietnamese decision-makers and farmers. Few local technology providers are available, and less than 0,5% of the medium scale pig farming market has installed a biogas digester at this point. In this context, the demonstration plants have contributed to enhanced understanding of the complexities and importance of maximising the use of biogas and bioslurry in the Vietnamese market:

- Through the farm selection process, project partners have informed over 60 medium scale farmers onthe benefits of biogas technologies, generating new interest in the potential purchase of such solutions.
- Through training, project partners have increased the knowledge level of the farmers that have installed the biogas digesters on their farms. These farmers are now advocates and champions for the technology in their region.
- Because the program involved local governments in all its developments, local government representatives now operate as advocates of the medium scale technology, and will encourage additional demand in their provinces.
- SNV and their partners have promoted the successful outcomes of the demonstration phase and the technology at numerous national stakeholder events; they have shared open source training materials and designs through the internet and other media with third parties and have presented Vietnam as an example for the region at multiple international events. Further promotion and information is still disseminated through SNV and the VBA.

Service Provider Development - As part of the consortium, the commercial biogas service provider GECI has been responsible for the marketing, sales, design, engineering and implementation of the constructed digesters. The development of and support to such a commercial biogas service provider being one of the goals of the project, GECI has received advisory and technical support from other consortium partners concerning the different elements needed to develop a sustainable business model. To build the demanded digesters, GECIcooperated with construction teams that were developed and trained by the project leaders. Four trainings have been organised, witha total of 112 attendees, including 90 masons and 22 farmers and staff members. 10 of the participants were women. GECI worked closely with these teams and individuals to reach the quality required by the initial criteria developed by the consortium. With all construction materials locally sourced, the construction of digesters also stimulates the local private sector. Already during the initial phase of the project, GECI received multiple requests from other farmers that were willing to acquire biogas technology for their farm, both on medium and larger scales. By the time the project ended, 8 additional contracts for implementation had been made. The design of the next phase will build upon the lessons that have been learned.

II.5. Key factors for the success of productive biogas

The following factors have been identified to be crucial for the success of a medium scale biogas sector in Vietnam:

Economic-financial factors - loans to support biogas technologies are not very common in Vietnam as biogas is not an income generating activity but merely a technology that will result in savings. Financial mechanisms to support the development of the biogas sector are currently under development.

Technological factors - Although the demonstration project has focused on one design, there is room for design improvement or additional designs, for example through installing an HDPE flexible cover. Close cooperation with local institutes like the existing partners will be necessary for further developments. Some improvements have already been introduced during the project implementation, with the lessons learned from early start-up and utilization.

Environmental factors - As discussed earlier, environmental factors, starting with odor pollution, appear to be a key driver for biogas investments in Vietnam, alongside social and political pressures.

Socio-cultural factors - Biogas solutions are benefiting social relationships by reducing odor pollution in all the locations visited. Continuous social pressure on the farmers will channel the decision-making process towards an investment in biogas. Capacity building of the sector’s key stakeholders, and creation and capacity building of additional service companies is key for further scaling in the market, as well as for demand and high quality supply creation. This includes awareness raising activities to assist the commercial sector in creating demand.

Political-institutional factors - The existing national legal framework indicates that animal manure waste management has to be arranged for; unfortunately, enforcement of this framework is limited in many provinces. Greater enforcement of existing laws would stimulate a further development of the sector. National coordination is currently absent, but a newly developed Vietnam Biogas Association (VBA) could play an important role as a market representative in the future. The pig sector and biogas developments are currently coordinated by the Ministry of Agriculture and Rural Development (MARD) while electricity generation and sales lie within the Ministry of Investment and Trade (MOIT).

II.6. Conclusions and recommendations

Many lessons have been learned during this first demonstration phase.

An Optimal Consortium - With one of the leading energy institutes (IE) of Vietnam, a private sector party (GECI) and additional international expertise through SEI alongside SNV's track record and expertise, the diversity of skills present within the consortium was a perfect foundation for the initial sector development in Vietnam and future developments should be designed in a similar way, with additional private sector parties. Closer cooperation with the local DARDs -the Departments of MARD in each province- could result in better and more widespread awareness raising activities beyond the targeted users.

The Right Technology - The chosen technology meets the demand of end-usersand fitsthe local context. As a result of the successful domestic biogas program previously deployed in Vietnam, brick and cement biogas models are the best known and most popular digester models in the country. Construction materials are available locally and stimulate the local economy. The fact that digesters follow a local design, developed by a well-known local institute -IE- also supports further development and acceptance by end-users and government officials. The project team, drawing on the IE's engineering expertise, will continue identifying opportunities to improve and/or simplify the designs while working on new designs and means to reach a broadermarket. Technology-wise, this demonstration project should only be seen as a first step.

Enhanced engineering skills. It was noticed quickly that the initial design, based on prior experience in the domestic biogas sector, and the assumption that mason teams could work independently on the design and implementation of digesters, would not deliver the expected results. The development of a medium scale productive biogas sector is now recognized to be more complex than previous domestic endeavours, involving higher level designs and technologies, as well as biogas application(s) and optimal bioslurry management. The way forward for a sustainable commercial medium scale biogas sector in Vietnam will therefore rely on the development of engineering companies with high-level skills and capacities and a good grasp on quality standards.

Awareness raising. Medium-scale pig farmers are well-aware of the environmental issues associated with animal waste, and demonstrate a particular concern for the foul odors altering their quality of life and that of their neighbours' and commonly acting as a barrier to farm expansion. They are typically not aware, however, of the cost and other benefits biogas systems can offer under such circumstances, nor do they know how to source appropriate medium-scale technologies and professional services. Farmers are neither maximizing the financial returns granted by biogas as a renewable energy source nor exploiting fully the use of bioslurry as a commercial product.

Bioslurry value chain. For a successful development of the medium-scale biogas sector, improved bioslurry application support needs to be created, alongside support for the creation of a value chain for organic fertilizer made from bioslurry. One way of doing this consists in building upon composting needs. Greater emphasis could also be placed on post-treatment of the bioslurry.

Biogas uses. Conversion of biogas into electricity will continue to be challenging due to low electricity tariffs. Currently, biogas is mainly used for domestic cooking, pig feed cooking and in some cases sold to neighbours or neighbouring factories, nevertheless significant amounts of biogas are still often flared. Access to and awareness of (additional) biogas applications is a necessity for future success, technology transfer to be able to produce locally made appliances, like biogas generators, is necessary for further scaling-up of the sector.

Dilution ratio. In Vietnam, pigpens are cleaned with more waterthan is recommended for optimal biogas production. As this has become a common practice that appears difficult to change, project implementers must take this into account when determining the digester size. Improved awareness around appropriate water use also needs to be created.

Improved monitoring. With many of the digesters having just started their operation when the project deadline closed, monitoring has remained minimal and the project is currently seeking additional funding to obtain more in-depth data, including biogas and bioslurry production. Such information will be used to further improve biodigester use and design.

Environmental standards. Additional data is needed ondigester effluents and their compliance with national appropriate standards. Although field observations have shown that pollution levels have decreased significantly, more evidence is needed to determine whether pollution levels now fully meet national standards.

Technical standards. At this stage, no medium scale digester standards have been developed or accepted by the Vietnamese Government. To fully support the further development of the sector, such standards need to be designed, approved and enforced. The VBA could play a supporting role in these activities.

II.7. The way forward

SNV Vietnam has developed a clear strategy on how the medium scale commercial biogas market can be developed further based on the demonstration project and on SNV's experiences in this sector worldwide. This strategy will include the development and capacity building of engineering companies country-wide and the introduction of new and adapted digester designs. Alongside technology transfer and awareness raising for a better use of the biogas produced, the development of a value chain for organic fertilizer made out of bioslurry will be an important component of the next phase. Post-treatment after digestion, and the identification of opportunities for co-digestion will also be necessary steps, with an underlying institutional support guaranteed by a close cooperation with the Department of Livestock Production (DLP) of the Ministry of Agriculture and Rural Development and the VBA.

Technical training programs have been designed with the support of international experts and will be updated based on the lessons learned and the new designs adopted in Vietnam. Business development is an important component of this package. The VBA can play a key role in these capacity building activities and in securing the program's sustainability. SNV's goal consisting in stimulating the local sector, intellectual property rights will stay with the designing partners, or, if open source materials are used, with DLP-MARD and/or the VBA.

For further improvements of Vietnam's rural hygiene situation, an additional study on the potential integration of human waste management within the biogas sector is strongly recommended. A value chain for human waste collection integration should also be developed.

Figure 2.6

Mr. Nhin's 200 m³ digester, Hanoi Province, a €7,800 investment

II.8. Bibliography

GFA Envest, 2012. Strengthening Project Management & Developing Strategies and Options for Biogas Development Program Expansion. Submitted to the ADB and DLP-MARD.

VN News, 8 April 2008. A cholera outbreak in northern Vietnam was directly traced to unsafe vegetables, according to the Ministry of Health in Hanoi.

III. Case study 2 - Battery charging and agro-processing services on biogas in the Ssese Islands, Uganda

By Sandra Bos, FACT Foundation.

III.1. Introduction

Water hyacinth is a native species from South America that has dramatically been affecting fresh water bodies outside its natural habitat. Since its first introduction outside its natural habitat in 1884, theplanthas spread across tropical and sub-tropical regions and has become the worst invasive aquatic weed in many regions. Water hyacinth propagates through vegetative reproductions and can double its biomass within 7-14 days. Growth is greatly stimulated by nutrient leakage from fertilizers, human and animal waste. When harvested repeatedly, the production can reach 40-80 tons of dry matter/ha/year.

Figure 3.1

Water hyacinth on the Ssese Islands

Africa has been particularly affected by the spread of water hyacinth, partly caused by a lack of their naturally occurring enemies. The plant was officially recorded for the first time in Lake Victoria in 1989-1990. At its peak, water hyacinth growth was estimated at 3 hectares (12 acres) per day (UNEP 2012).[4] Although the rapid proliferation of water hyacinth has been reduced by many control programs -80% reduction in 9 years on Lake Victoria- the invasive has recently been spreading again, blocking fish landing beaches, harboring mosquitoes and snakes, outcompeting native plants with ripple effects on aquatic species, and sapping out oxygen from the water, resulting in anoxic "dead zones".

Despite large monetary investments, existing methods have not been sufficient to control the aggressive propagation of the weed.[5] In recent years, control programs have shifted to biological control with weevil beetles. These programs do not seek to eradicate the weed, since this is practically impossible, but to reduce its spreadto a level that is no longer problematic. In the face of these challenges, the concept of using water hyacinth as feedstock for biogas production has started being explored by FACT as an additional control solution. From 2010 onwards, FACT has been working in this area, conducting a feasibility study[6] and a field investigation on the use of floating invasive weeds in Ghana and Benin.[7] The scheme has also been tested by others, such as a project supported by SNV in the Songhaï Centre of Porto Novo, Benin.[8]

[4] M. Theuri, 2012. Water hyacinth - Can its aggressive invasion be controlled? UNEP.
[5] J. Gichuki et al., 2012. Water Hyacinth Eichhornia crassipes (Mart.) Solms-Laubach Dynamics and Succession in the Nyanza Gulf of Lake Victoria (East Africa): Implications for Water Quality and Biodiversity Conservation.
[6] R. Hoevers, 2011. Aquatic biofuels for local development. FACT Foundation.
[7] O. M. Jandl, 2010. Barriers for the employment of floating invasive weeds for biogas production in local communities in West African Developing Countries. Technical University Eindhoven.
[8] Water hyacinth project for waste water treatment and biogas production supported by SNV Benin (Source: Jandl, 2010).

In 2012, FACT decided to invest in a pilot project to test the technical and economic feasibility of the use of water hyacinth for biogas production and improved household energy access in water hyacinth invested areas. The pilot was implemented by GRS Commodities, a Ugandan company active in bioenergy solutions, under the name *"Battery charging and agro-processing services for the Ssese Islands"*. Half of the funding was provided by FACT alongside extra technical backstopping through their DOEN funded innovation program.[9] Co-funding was found through an incubator program for bioenergy entrepreneurs of University of Wageningen in the Netherlands (StartLife)[10] which granted the project with 25% additional funding. The remaining 25% funding was obtained through a 5-year loan agreement.

III.2. Background

The target area for the pilot project is the Ssese islands group, located on the Lake Victoria, Uganda and comprised of 84 islands with 42,000 inhabitants. The predominant economic activities are fishing, farming and tourism. The biogas project is based on the main island, Bugala, a few kilometers outside the district town of Kalangala. The Ssese islands are not connected to the mainland national electricity grid. Kalangala is the only town that has access to electricity, thanks to a decentralized grid that runs on diesel generators with a total capacity of 500KVA. The town grid, however, does not offer a reliable electricity source due to maintenance and diesel supply issues.

Figure 3.2

Project Site on the Ssese Islands

Figure 3.3

Fishermen of the Ssese Islands

The island district has an effective control program for water hyacinth on its Northern shore, the main area for tourism. Other bays, however, have become nurseries for water hyacinth, especially in shallow waters. It is assumed that intensive palm oil production and animal husbandry have led to fertilizer leaching, leading to an influx of nutrients in the lake that accelerated the growth of water hyacinth, although no evidence has been found to verify these claims.

[9] See http://www.fact-foundation.com/innovation-projects
[10] See https://start-life.nl/

As part of the chosen business model, GRS Commodities responded to both these challenges by using water hyacinth and animal manure as feedstock for the production of biogas for electricity generation. The electricity was used to set up a reliable and affordable battery charging service for households that were previously depending on charging stations on the mainland, associated with high prices due to the transportation costs involved and long lead times up to 3 days.

Under earlier circumstances, charging fees could be as high as €1.78 per battery, the charging fee mainland being of €0,71 and additional transport costs to Masaka town reaching €1,07. With the newly deployed system, the proposed charging fee of €1,50 was expected to result in a cost reduction of €0,28 (18,6%). Charging 100 batteries per day was projected to result in a profitable business model, with a high replication potential for other infested areas.

Over the course of the project, rice milling was added to the business model as a supplementary electricity service fueled by biogas. Rice cultivation, indeed, has recently been introduced by the Kanlangala district government and is becoming an increasingly important economic activity for the islands' inhabitants in the face of declining fish stocks.[11] Milling services, however, remain extremely rare, and most of the rice produced leaves the island without being processed.

The objectives of the pilot project were to test the technical and economic feasibility of producing biogas from water hyacinth and generating electricity for battery charging. As a secondary objective, the project also anticipated to contribute to reducing the proliferation of water hyacinth on the Lake Victoria by harvesting water hyacinth and waste disposal of animal manure, and improving energy access by supplying households with off-grid energy solutions.

Selection criteria of the pilot project

Project funding to GRS was approved on the basis of their commercial approach. The proposed business model was designed to make the project self-sustainable. The potential market for battery charging services and the interest expressed bythe village council also appeared promising. Although the feasibility of alternative renewable energy options was not rigorously assessed, biogas was selected as the most suitable solution to meet some of the island's primary challenges and for testing the replication potential of biogas from water hyacinth as a solution for other infested areas.

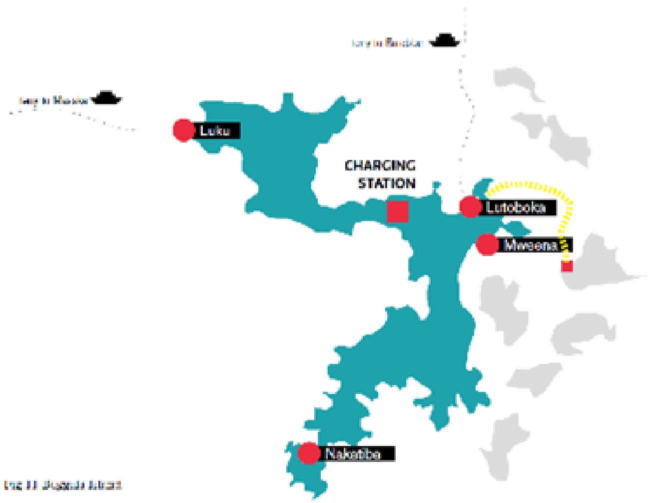

Figure 3.4

Water hyacinth on the Ssese Islands

The project site was chosen for its location outside of the town gird area, mainly to avoid competition with cheaper grid electricity. The site itself is located in between 2 potential water hyacinth hotspots. Both sides are accessible by truck, which allows efficient transportation of harvested water hyacinth to the project site. Also, the site is easily accessible to other villages as it is located along the Kalangala–Luku main road.

[11] Kalangala district office for production and marketing, personal communication, February 2012.

This will make it convenient for residents in these villages to access the selected project site. As the site is located outside the tourist areas with no nearby settlements, regulatory issues with odor pollution and noise nuisance were avoided. Other selection criteria included favourable land lease conditions (outside urban and tourist areas) and low ground water level as the biogas digester needed to be placed partly underground.

Selection criteria biogas digester

The project opted for a cost efficient, simple biogas technology that would not require any additional (electrical) hardware, such as a mixing or heating system that would increase the complexity, sensitivity and total cost. It was assumed that technical skills and expertise were not yet available on the Ssese Islands or present within the implementing organization. A plug flow system was selected as the most appropriate model as it could be installed relatively easily with technical support from FACT.

Different types of materials for plug flow models are available on the market. The quality and thickness of the PVC material determines the lifespan and the cost. For this project a good quality material with a lifespan of approximately 15 years was chosen over cheaper PE material with a lifespan of 1-3 years. After a tender process, the Dutch company Albers Alligator[12] was selected because of their renowned experiences on PVC biogas bags. Plug flow bags of this supplier have a lifespan of approximately 25 years under European conditions.[13]

III.3. Process design, installation and implementation

The sizing of the plugflow model depends on the required daily gas consumption. This can be calculated by expressing the expected electricity output (in kWh/day) in required gas yield (m^3/day). Based on the business model, charging 100 batteries with an average capacity of 80Amph/day would result in 78kWh/day (see **Table 3.1**). Using an efficiency factor of 1.4 m^3/kWh, the required daily gas production was calculated to be at least 55m^3. A minimum required digester volume would then be 167m^3 (one-third gas storage, two-third slurry storage). As digester bags were supplied in standard sizes, a 183m^3 digester bag was selected to meet the required volume and have some additional space for potential expansion.

[12] http://www.albersalligator.com/nl/producten
[13] Albers Alligator, personal communication; testimonies from biogas users Netherlands, 2011.

Parameter	Unit	value
No of batteries	no	100
Average capacity per battery	Amph	80
Dept of discharge	%	50%
Charging needs net	Amph/unit	40
Charging efficiency	%	
Charger	%	85%
Battery	%	85%
Total Charging efficiencies	%	72%
Charging needs brut	Amph/unit	55
Total charging requirement	Amph	5536
Voltage	V	14
Required energy needs	kWh/day	78
Charging time	hrs	8
Charging requirement brut	Amp	692
Charging cycles per day	no	1
Required power needs generator	kW	9,7

Table 3.1 **Required Energy Production**

The sizing of the plugflow model depends on the required daily gas consumption. This can be calculated by expressing the expected electricity output (in kWh/day) in required gas yield (m^3/day). Based on the business model, charging 100 batteries with an average capacity of 80Amph/day would result in 78kWh/day (see **Table 3.1**). Using an efficiency factor of 1.4 m^3/kWh, the required daily gas production was calculated to be at least 55m^3. A minimum required digester volume would then be 167m^3 (one-third gas storage, two-third slurry storage). As digester bags were supplied in standard sizes, a 183m^3 digester bag was selected to meet the required volume and have some additional space for potential expansion.

Estimated electricity demand - Within the project design, approximately 300 households were targeted for the battery charging services. It was projected that these households would charge twice a week -600 charges in total- which results in an average of 85 batteries charged per day. To include extra capacity, the number of batteries and corresponding capacity was rated at 100 batteries of 80 Amph. Based on 8 operational hours per day, a **biogas generator** capacity of at least 9,7kW was required. A slightly bigger size generator was selected (12kW) to anticipate on potential small-scale industrial loads for agro-processing activities. See **Table 3.1** for the calculations of the daily required energy needs.

Parameter	Water hyacinth	Cow manure
Biogas yield (m^3biogas/ton DM)	200	225
Dry matter content (%)	5	20
Retention time	50	50
Optimal dry matter content slurry mix (%) 10 %		

Table 3.2 **Feedstock parameters**

Feedstock requirements - It was assumed that it would be feasible to collect 2 tons of water hyacinth on a daily basis. A storage facility was included in the project design to store water hyacinth in case of momentary scarcity. In an initial phase, it would be stored in a wet state and function as a water reservoir at the same time. Chopped dry water hyacinth was also considered, and would be tested in the event that the first option failed. Additionally, it was decided to include cow manure as a second feedstock for the following reasons; to guarantee a suitable bacteria regime; to secure feedstock supply in the water hyacinth low season; and to guarantee certain spore elements in the slurry that might not be available in the other feedstock. Availability of manure was discussed with the district agricultural department. It was confirmed that many farmers on the island were involved in livestock farming, with farm sizes varying from 3 to 80 cows and a small number of commercial pig farmers (farm size: 100 pigs). In the proximity of the project site, 9 commercial farmers were promptly found that were interested in supplying feedstock to the project.

The feedstock parameters used are presented in **Table 3.2**. Based on these parameters a daily supply of 2 tons of water hyacinth would result in a gas production of approximately 22,5m^3/day. As the dry matter content of water hyacinth is very low, it was expected that an extra water input would not be needed. In addition, 750kg of cow manure were planned for co-digestion, with a daily gas production of 30m^3. Water input for cow manure would be approximately 750l per day. The total gas production was expected to be 52,50m^3 daily.

System components - The biogas system consists of the following processes and system components: Feedstock treatment (grass cutter), biogas production (plug flow digester), electricity generation (biogas generator), and electricity consumption (battery chargers and rice milling).

The **grass cutter** was prefabricated locally to reduce costs. The cutter is designed to chop the water hyacinth through a spiral shaft at a rate of one ton per hour. The cutter was placed next to the inlet tank where the chopped weed could directly be fed into the inlet. The spiral shaft is driven by a 15HP diesel engine. After installing the grass cutter, the cutting rate was considerably lower than was prescribed by the manufacturer. One Bag of water hyacinth (45kg) is cut in 25min (approx. 110kg/hr). The local operator manages to process a maximum of 10 bags/day (450kg). The diesel fuel consumption is 450kg of water hyacinth/liter. There is considerable scope for improvement. As a general rule, only 5% of the energy value of the feedstock is normally used for pretreatment.

The 183m^3 **plug flow digester** is made of grey PVC coated polyester fabric used for storage of gas, water, slurry. The dimensions of the bag are 22,2x6,35m, maximum height 1,25m, weight 330kg. The bag contains 2 sleeve connections for 110mm pipe to connect the in- and outlet to the digester bag, and 3 ventilation tubes to connect the gas hose, a small air pump for desulfurizing the gas mixture, and a third tube as spare connection. The bag can be repaired locally.

Figure 3.5

Installing the digester bag

The 12kW **biogas generator** is manufactured by a Chinese company[14] and supplied by EDC from Tanzania.[15] The related power of the generator is 12kW/15kVA. The generator was selected for its good quality alternator model Stamfort CR-12kW. According to the manufacturer, the gas consumption is less than 0,55 m^3/kWh, and the required gas pressure 10,8~16,3mm water column.

Figure 3.6 **Rice miller**

Single output **Victron battery chargers** of 15A and 10A were selected over group chargers -with multiple outputs, normally used by battery charging stations. It is difficult to guarantee a quality service by charging batteries with different levels of discharge with group chargers, as this normally requires uniform charging conditions. The 10A and 15A chargers were selected because they were deemed to correspond with the expected battery capacity to be charged: 10A chargers for batteries with a capacity of ≥50A (max. 20% of battery capacity), and 15A chargers for battery capacity of >75A (max. 20% of battery capacity). An additional Watts Up meter was connected to the battery chargers to monitor the performance of the batteries and the degree of energy transfer.

Investments	€	Depr. (y)
Loading truck 3m^3	9.000	10
Boat & Engine	3.610	10
Grass cutter	1.705	10
Water reservoir water hyacinth	1.000	10
Collection bins	700	5
Bag 200m^3	6.390	10
Digester fittings (pipes, hose, meters, electrical accessories)	2.197	10
Ground work (ditch, inlet, outlet, roofing)	1.000	10
Generator	9.000	5
Buildings	2.000	10
Total	36.601	EUR
Depreciation	4.630	EUR/a

Table 3.3 **Investment costs biogas system**

[14] Weifang Chaoran Gas Power Co. Ltd.
[15] See: http://edc-power.com/

A 7,5kW **rice mill** with a capacity of 500-800kg/hour was installed towards the end of the project -September 2013. The mill was bought under a hire-purchase agreement according to which the project will pay off the mill in monthly instalments. Currently the system mills 100-150 Kg/hour and is experimenting with different pulley sizes to increase its capacity. The breakdown of the investment costs of the complete system, including the above mentioned components, transport and installation costs can be found in **Table 3.3**.

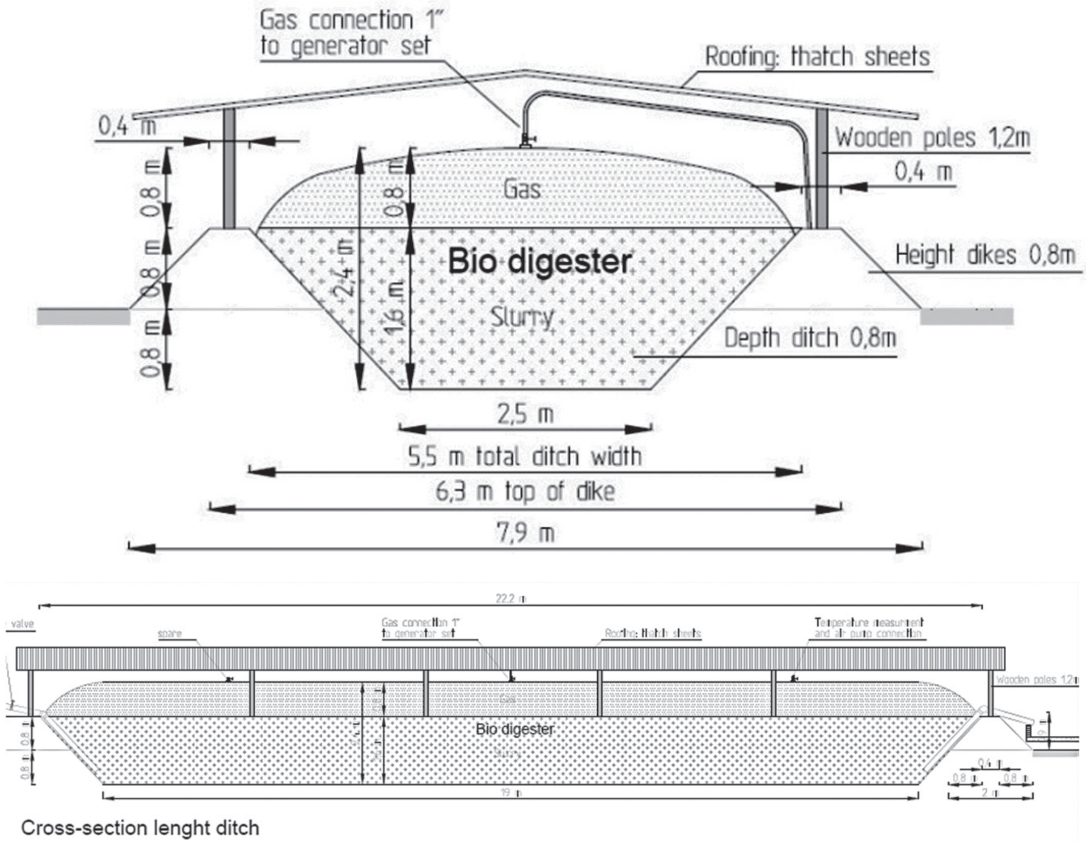

Figure 3.7 **Cross-section length digester ditch**

Installation of the biogas system - The plug flow system was installed in a half octagon digester ditch with the following dimensions: Length 22.2m, max width 5.50m, base width 2.50m (see **Figure 3.7** and **3.8**). By installing the digester half under ground, the digestion process benefits from constant soil temperatures that create a steady environment. The digester bag is covered with a roofing system for the same purpose and to protect the bag against ultraviolet radiation that could influence the lifespan of the PVC material. Digester walls are 1.6m high, which correspond to the maximum slurry level in the bag.

The **digester inlet** is designed as a 2m^3 round basin that can store 1 day of feedstock supply. The round shape was chosen to facilitate the mixing of the slurry and the flow from the inlet into the bag. The inlet floor is accommodated with a sand filter in which particles can settle and can be flushed regularly. The **digester outlet** is a square shaped reservoir that can store approximately 2 days of slurry output (4,8m^3). The outlet pipe is located approximately 5 cm above the maximum slurry level (1,6m). Surplus slurry will be pushed into the outlet tank through the outlet pipes by the created overpressure.

The digester was set up closely to the powerhouse to avoid **long gas piping systems**. Part of the gas pipe was installed underground to facilitate gas condensation with cooler soil temperatures. The condensed water is captured at the lowest end of the gas pipe in a closed condense pit that is regularly emptied.

The **powerhouse** consists of a 5x5m generator room and a 5x5m room for battery charging and agro-processing. The powerhouse is half open in order to allow sufficient ventilation to release the generated heat. It was decided to construct 2 separate rooms to prevent the generator noise as much as possible for visiting clients for the battery charging and processing services.

The powerhouse, the water reservoirs, the digester ditch and the inlet and outlet were constructed by a local contractor. This process took a significant amount oftime -about 3 months- because the construction took place during the rainy season. Availability of materials and labour on the islands also pointed out to be limited: material and services are more expensive on the islands, while quality and availability of materials cannot always be guaranteed.

Installation of biogas system and gas generator - Following the project agreement FACT was contracted by GRS to provide technical backstopping. The plug flow system was installed jointly so that both GRS and FACT would gain useful experiences. As for the preparation of the installation work, technical drawings including detailed material lists were developed by FACT. Onsite preparations such as excavation work and purchase of materials were coordinated by the GRS team. The installation of the biogas system was completed within one week. An additional 3 days were needed to make the electrical installation for the battery charge station. For the installation of the biogas generator, the project hired the service of the generator supplier (EDC), as no biogas generator installer is currently available in Uganda. The shipment of the generator was delayed which put the project on a hold for 4 months.

Start-up process - The project invested considerable time in setting up a feedstock collection system with neighbouring farmers for the supply of animal manure. In collaboration with the district officer for agriculture, a workshop was organized to sensitize the farmers regarding the digestion of manure and the use of bioslurry as organic fertilizer - farmers being used to dispose of their manure for fear of having their crops damaged due to acidity. Building upon the fact that the district officer is well-respected among the farmer community, GRS managed to convince a group of 9 farmers to supply the project with manure in exchange for slurry. The project started collecting manure mid-2012.

In October 2012 a first start was made with a few bags (approx.150 kg) per day. However, with the start of the rainy season, the water hyacinth disappeared from the selected harvesting bay. Due to heavy rainfall and stronger wave activity, it was discovered that water hyacinth has a tendency to start drifting too far from the island shore to be collected.

For the launch of the battery charging service a promotion campaign was initiated in collaboration with the district development office. Communities were identified that were expected to benefit from the battery charging service. Sensitization was carried out informally during routine visits, alongside advertisements with loudspeakers in the selected villages and radio commercials.

Operation - The biogas system is managed by two local operators. One operator is responsible for the activities related to feedstock collection -including driving the truck, maintaining contact with the farmers, coordinating the collection of the manure bins and the water hyacinth, monitoring of the collected volumes, and operating the generator, while the second operator is responsible for on-site activities -including pre-treatment of water hyacinth, mixing feedstock and feeding the digester, charging batteries, and cleaning of the biogas system. For feedstock collection the operator is paid per collection day in view that feedstock collection is not a daily returning activity. The second operator on the other hand has a fixed contract as his activities require his daily presence. On average, monthly salary costs are approximately €30-€40 per employee. The harvesting of the water hyacinth is outsourced to a local fisherman who is also member of the village council and is well informed about the water hyacinth situation on the lake. These activities include the harvesting and collection of water hyacinth on the lake, maintenance of the boat and engine, and scouting of the water hyacinth on the lakeshore. He is paid a daily fee of about 4,5€.

Manure collection - GRS has set up a collection system for the animal manure with 140l manure bins. Approximately 3 times a week, the project truck makes a route picking up the full bins in exchange for empty ones, which results in a average amount of 300kg collected manure per day. The number of bins are registered in a book-keeping system. As soon as the project has slurry output, farmers receive slurry in return -one full bin of slurry for each full bin of manure. Although farmers are aware that the slurry contains at least 50% of water, they are still interested in the manure mixture as it includes additional water hyacinth nutrients and it serves for watering at the same time. Because the farmers do not presently use their manure, they perceive the slurry as a higher value product. The current amount of about 300kg/day can be increased by involving more farmers if necessary. Until now however, running the biogas system on full capacity was not needed due to the low electricity demand.

Figure 3.8 **Manure collection**

The digester is fed every 2-3 days by mixing an equal amount of water with the manure. The manure and water are stirred using a simple wooden stick in order to break up and dissolve the manure into liquid slurry. The slurry is left to settle for about 30 minutes before it is released into the digester bag so that particles can sink to the bottom of the inlet tank.

Water hyacinth collection - Collection of the water hyacinth does not happen on a regular base yet, because of the rainy season (November–December and April-June). It was discovered that the processing of 2 tons of water hyacinth per day is not feasible due to limited processing capacity of the cutter. In the future, improvements can be made by investing in a larger cutter. Another limiting factor is the voluminous nature of water hyacinth. The project truck can only load 1 ton of water hyacinth. Collecting 2 tons per day would require 2 return trips with the truck, which would considerably affect the economic feasibility of water hyacinth collection. Over the course of the last 12 months, approximately 12 tons of water hyacinth were fed into the digester. In those cases that the water hyacinth is used, additional water is necessary to make the mixture sufficiently liquid to flow into the bag, even with the 5% dry matter content.

Battery charging service - At present, the project has 9 fixed clients that charge their batteries. The batteries are delivered to the charging station by the individual owners or by hired transport (minibus or motor taxi). The owners are residents of nearby villages. Most of the clients use second hand 50Ah car batteries, while only few people use batteries with larger capacity (80-100Ah). The number of clients has been disappointing and the project has difficulty attracting new customers. One explanation for this is that the charging batteries scheme has been picked up by other entrepreneurs. New battery services have been started in Kalangala for a much lower price (€0,60). Such competition had not been foreseen because the project design did not account for illegal energy procurement as a possible scenario. In the face of this serious competition, the project was forced to drop its price. It currently charges a fee of €0,60 for small batteries (50-70Ah), and €1,00 for large batteries (80-100Ah). It also appears that local operators have difficulty monitoring the performance of the chargers and the batteries due to a lack of technical skills. Some of the clients lost their interest for the charging service as batteries were not fully charged. Beside these factors, the main reason for these disappointing results turned out to be an unrealistic business model in terms of number of clients and in battery capacity.

Agro-processing service - Observing that the battery charging service was not taking off as expected, GRS invested in an additional rice mill towards the end of the project. No data on the feasibility of this activity can be given yet, as the service just started. However, it looks promising. The project offers its milling service to a group of 8 rice farmers for a price of €60/ton. The farmers' supply varies between 500 and 2000kg per season - with 2 seasons per year. The service is growing gradually, attracting rice farmers from neighbouring islands.

Slurry sale - The project intends to sell the slurry to farmers on the island, most of whom are involved in palm oil production, facing high costs for high input requirements. The surplus slurry that remains after returns to the supplying farmers will be sold in 20l jerry cans. In collaboration with the agricultural district officer, GRS is currently marketing the product to palm oil farmers. An estimated sales price will be set at approximately €45/ton slurry. No figures are available yet, considering the sale of bioslurry has not started.

Operational costs	EUR/a
Personnel	4.860
Fuel (diesel)	237
O&M	1.098
Total operational costs	6.195

Table 3.4 **Operational costs**

Operational costs of the biogas system - The breakdown of operational costs can be found in **Table 3.4**. The costs are calculated on an annual base and include personnel costs -a monthly management fee of €300 and operator costs of €105/month. The fuel costs were calculated on the basis of the current average feedstock collection measured over the last 12 months of the project.

Maintenance - Regular maintenance activities of the biogas system include cleaning the inlet mixing pit by flushing the sand filter, checking gas leakages and a daily check and release of the condense pot. Maintenance of the biogas generator includes checking the oil- and cooling water levels; checking generator temperatures; checking the gas pipes on leakages and condense and making sure that the system stays clean. After every 250 operation hours the oil and air filters need to be checked and changed. Furthermore, the spark system, the belt tension, all pipes and bolts need to be checked and cleaned regularly and replaced if necessary. Service and repair should be done by a qualified engineer, which turned out to be a major challenge. No expertise was found to fix the generator after its breakdown during the first months of operation. It would have been too costly to contract the supplier from Tanzania, and GRS did not find qualified engineers in Uganda. As a result, the project was put on hold for 6 months. Eventually GRS got involved in a new energy project in which qualified technicians from India support Ugandan energy companies in running gasification systems. GRS could benefit from this support to get the generator repaired.

Role of supporting actors

GRS - GRS is a Ugandan based company active in bioenergy. Although it did not have the technical skills to implement and test the concept, FACT decided to invest in GRS as a private partner because of its business approach, expected to contribute to the sustainability of the scheme after the project phase. Because of the loan agreement with the third party investor, the project will continue for another 3 years in which the feasibility of the model will be further tested. All hardware will remain under the ownership of GRS over the coming five years.

FACT - Since experiences and technical skills on biogas were limited within GRS, FACT provided technical backstopping on hardware sourcing, biogas system design and installation, charging station design and remote trouble shooting.

District - The collaboration with the island's district office has become crucial for the project. During the implementation phase, permits, licenses and contact with local authorities were established. The district agricultural department was very supportive in identifying farmers for the manure collection system and sales of fertilizers. The district fisheries department gave approval for collecting water hyacinth from the lake, and helped identifying water hyacinth hotspots.

III.4. Results and impacts

Operational results - The project activities ended in mid-2013. A period of 2 years resulted in a fully installed and operational biogas system. It was expected that the system would run on full capacity and would offer a profitable business. This was not a realistic assumption and will require more time than the planned 2 years. Getting the system operational and creating the intended demand for the energy services turned out to be harder than expected. As demand for battery charging is low, there was no need to become fully operational - this would have led to wasted energy and excessive operational costs. Due to the disappointing demand, the project changed its strategy by including a rice milling service.

Over a period of 12 months, a biogas production of 12,38 m^3/day was reached. Generator efficiency was tested within the project and it seems that the estimated conversion rate of 1,4 m3/kWh was excessively high. A conversion rate of 1,25 appears more realistic, resulting in a daily electricity production of 15,47kWh.The sale of slurry is not yet realized. Since biogas production has been so low, the system has not produced surplus slurry at this stage.

Change/results in knowledge, competencies and capacities - Although the technical complexity of the system was high in comparison with the level of capacity within GRS, useful experiences have been gained through trial and error. The local operators progressively got to know the equipment better. All the employees involved are residents of the island and the island mechanic has been working closely with the Indian generator technicians. This will ensure that built capacity remains on the islands. Experiences are now embedded within GRS, who intends to continue working as an energy company on the Ssese Islands. GRS is one of the first private sector actors specialized in this type of systems in Uganda. This will contribute to the establishment of a support network for productive biogas, much needed for its further promotion.

One of the most notable achievements of the project is its full integration within the island's farming community. As water hyacinth collection turned out to be more challenging than expected, manure became essential as an additional feedstock. The project team managed to establish a solid, reliable network of farmers by creating a win-win situation for both parties. A close relationship with the district office also helped significantly in getting the project known around the island. All participating stakeholders are enthusiastic and proud to see new knowledge and technologies brought in, the islands being generally considered one of the least developed districts of Uganda.

Electricity production costs		
Annual electricity produced	5.569	kWh/a
Operational costs	1,11	EUR/kWh
Depreciation	0,83	EUR/kWh
Financing	0,41	EUR/kWh
Total costs	1,94	EUR/kWh

Table 3.5 **Electricity production costs**

Change/results in practices and routines of the producers - Getting the system operational and overcoming disappointing results has been a relatively slow process, hence the difficulty of drawing immediate conclusions as regards changes in practices and routines of the producers. This is partly to be attributed to unforeseen factors, such as the 3-month failure of the ferry, a 4-month generator shipment delay, unexpected behavior of the water hyacinth during rainy season, and antibiotic use and restock by animal farmers. Towards the end of the project however, the implementing partner acted adequately and included an additional service within his business model. Although figures are not available yet for rice milling activities, this activity appears to be growing rapidly.

Economic impact - The business model for the project is not viable yet due to disappointing sales and high operational costs. In the current situation, electricity production (15,47kWh/month) results in a price of 1,94€kWh (see **Table 3.5**).

Feedstock	Current cost price (€/MT)[18]	Energy value(€/MT)[19]
Manure	€4,50	€8,-
Water hyacinth	€11,-	€2,-

Table 3.6 **Current feedstock price**

At present, the price of water hyacinth is €11/ton for an energy value of around €2. Manure costs are around €4,50 for an energy value of €8. As the operational costs of chopping water hyacinth are higher than those of collecting manure, it is expected that the operation will mainly focus on the latter for the coming period. Income from the battery charging service over the considered period was less than expected. Because the book keeping system was not kept up to date it is difficult to give exact figures. A tentative number of 9 charges per week -one weekly charge per client- and a charging fee of €0,60 can be assumed, corresponding to a monthly income of €21,60. This is not sufficient to cover operational costs. The business can only become economically feasible if around 185 tons of rice are processed annually -the maximum capacity being 400 tons/year- or if around 100 batteries can be charged on a daily basis. A combination of both activities could also be carried out. According to the latest prognosis, a production of 100 tons/year can be expected. Under such circumstances, the scheme is expected to reach a breakeven point at an additional battery charging rate of 35 batteries per day. The start of milling activities, however, can be expected to raise income to a large extent, with the kWH dropping accordingly. The commercialization of slurry should also enter in consideration and has not been tested at this stage. it is too early, therefore to draw conclusions on the financial sustainability of the scheme.

Environmental impact - Feedstock collection by farmers and manure recycling are deemed to have a positive environmental impact by reducing pollution, chemical fertilizer use and improving soil structures. This, however, remains to be validated within the scope of the project. Harvesting of water hyacinth can also have a positive impact, as nutrients are recovered from Lake Victoria and recycled back to cultivated land. The latter impact can yet be expected to become greater over time as current harvesting activities remain limited.

[18] Efficiency improvements can still be made by optimizing harvest, transport, pretreatment etc.
[19] This does not include the potential values on nutrient or social and environmental impact.

Social impact - It is still too early to draw conclusions in this regard considering the battery charging service did not work out as expected. If the milling operations run successfully, the project will enhance livelihood prospects for rice farmers, by adding value to their product and reducing the costs of importing expensive rice from the mainland.

III.5. Key factors for success of productive biogas

Technological factors - Technical skills are key, as the technical requirements of productive biogas systems are high and require all-round technical skills such as mechanical and electrical engineering. Even simple construction work can be a challenge and requires solid capacities. Project leaders should therefore ensure that technical skills and a support network are available, or invest in it.

Economic-financial factors

- The business model of any productive biogas project should be based on existing energy usage. Investing in potential energy demand requires a solid market study, but nevertheless remains a risky investment.
- Investments in and installation of hardware should be done gradually, in alignment with the progress of the project and requires a business-minded approach rather than a typical project set-up. Within this particular project, most of the hardware was purchased during the implementation phase; after the system became operational, some activities required changes while investments had already been made. A harvesting boat was for instance bought in the first phase of the project while water hyacinth turned out to be an unreliable feedstock later on. Outsourcing this activity to local fishermen would have reduced the investment and would have contributed to local employment.
- Investment instead of grant funding contributes to the economic feasibility of the project: the fact that this project received grants for 75% of its total budget probably contributed to the limited urgency felt when faced with the obligation to respond to unforeseen circumstances, leading to disappointing project results. However, because 25% of the budget still has to be repaid, the implementing partner is incentivized to turn this project into a business.

Social factors - Creating a win-win situation for the beneficiaries/clients of the productive biogas project is key: strong incentives for both parties will enhance the sustainability of the project. In this particular case, the farmers appear keen to supply the project with manure, while the entrepreneur is obliged to give them slurry in return, thereby securing the feedstock supply.

Political-institutional factors - A good relationship with the local government turned out to be crucial in order to convince the farmers to participate in the project. It should yet be noted that the well-respected position of local authorities on the islands is quite exceptional. The unique conditions of the Ssese islands have created mutual dependencies underlying strong networks between institutions and the inhabitants.

Environmental factors - We identify a need for productive biogas projects to target areas with a prior need for waste treatment and fertilizer usage. Besides energy production, productive biogas can contribute to sustainable farming and enhanced food security through improved sanitation organic waste management.

III.6. Lessons learned

Feedstock - Water hyacinth, given its voluminous nature and seasonality, remains a complex and costly feedstock, with numerous processing steps and a low dry matter/energy content. Potential improvements for future projects include assessing the long-term availability of the feedstock before the project is implemented, and, despite a dry matter content of 5%, adding water may prove necessary to make the feedstock sufficiently liquid to flow into the digester.

Technical feasibility

- It was realized that a support network for productive biogas systems does not exist in Uganda and external service and maintenance companies are very expensive for projects of this size.

- Selection of local partners is key to ensure project success and sustainability: in this case, testing the feasibility of the concept proved somewhat difficult because it required systematic monitoring of data; the entrepreneur and local team of operators did not have the appropriate skills to carry out these activities.

- Importance of quality: well-functioning equipment with a warranty from a qualified company are important in this early stage of development of productive biogas since support/distribution networks are not yet available if technical problems arise. Here, the capacity of the cutter was too low.

Economic feasibility and financial sustainability

- Investing in a business model and system design based on a potential -not yet proven- electricity demand remains risky. In this project the expected market for battery charging turned out to be unrealistic and had to be compensated for by the addition of a rice milling service into the project design. The solidity of the initial market study should have been verified. The project shows, however, that multiple energy services can increase the economic feasibility of a productive biogas scheme and may be sought after as a means to limit financial risk.

- Agro-processing, furthermore, proved to be a valuable addition by providing direct economic benefits for the islanders, in contrast with battery use that was merely an additional expenses on the household budget.

- The payment-in-kind model was effective in this project.

Contextual conditions

- The Ssese islands offer a unique context for productive biogas, with a strong need for energy and organic fertilizers and no available agro-processing services. Integrating these three elements in a productive biogas scheme will create multiple business opportunities.

- Project funding does not encourage a proactive attitude from implementing partners in the event of undesirable results, and undermines economic sustainability. If management costs are funded, project incomes become less essential for the existence of a company.

III.7. Recommendations

Select appropriate partners - R&D-related works should be carried out by R&D partners that are present locally. Hardware sourcing and installation work should be done by qualified technicians/advisors that truly understand the technical specifications and functions of the equipment. The technological level of productive biogas systems is quite advanced in the context of Uganda.

Optimizing the use of water hyacinth

- To reduce operational costs, water hyacinth can be pretreated close to the landing site, allowing much larger volumes to be transported in trucks. Cut and dried water hyacinth yet require water for mixing, which could increase costs. To reduce the need for additional water, water hyacinth could be cut in smaller pieces, if the capacity of the cutter allows, or by using larger PVC input pipes.
- To solve the issue of water hyacinth seasonality, pre-treated water hyacinth could be dried and stored for usage during the rainy season. Water hyacinth could also be grown and harvested in controlled areas like ponds. This may however be a sensitive topic in many areas.

Assess slurry quality - Further validation of the toxicity of water hyacinth is needed to exclude the risk of crop contamination; the nutrient levels of water hyacinth co-digested with manure and the long term effects of the use of slurry for crop production and soil improvement should also be assessed to better determine the economic value of slurry.

Location - The choice of an appropriate location and the use of semi-mechanical harvesting may reduce operational costs and thus improve economic feasibility. This requires further evaluation.

System investment - Making smart investments and being flexible within the project design if demand is not yet proven appears crucial: making the system operational first, and then start with small-scale experimentation of the envisioned services and activities will allow changes in the project design and prevent unnecessary investments in hardware.

Economic feasibility - To make the business sustainable, it is recommended to invest in more intense marketing activities, to optimize transport -increased load or decreased feedstock volumes, to improve pre-treatment equipment and to reduce the price of charging batteries in order to increase market demand.

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IV. Case study 3 - Electrical generation with biogas from coffee wastewater in the coffee industry, Honduras

By Osmer Ponce Valladares, SNV Honduras; Carlos Bueso Varela, SNV Honduras; Joaquin Viquez Arias, Viogaz.

IV.1. Introduction

Coffee production is Honduras' primary industry, and is prominent in regions like Copán, La Paz, Comayagua, Santa Barbará, Ocotepeque, Lempira, Intibucá and El Paraíso. The coffee sector generates more than one million direct and indirect jobs along the entire value chain, representing over 8% of the employment market in the country - 22% of the jobs available in rural areas. In economic terms, it represents 8% of the gross domestic product (GDP) and approximately 30% of the agricultural GDP, providing the national economy with over 400 million USD in foreign exchange, more than any other agribusiness industry in the country (IHCAFE, 2007). It is estimated that the potential for biogas generation by this sector may represent as much as 12% of the total net biogas potential for the country - 44 320 230 Nm3 per year.[20]

COCAFELOL,[21] a cooperative located in the department of Ocotepeque and involved in the production, processing, commercialisation, credit and export of high quality certified coffee, was identified by SNV as an appropriate structure to test the integration of biogas within the Honduran coffee industry. COCAFELOL is comprised of around 550 members, including 165 women belonging to the group AMPROCAL[22] and taking part in processing activities as part of the value chain. Its facilities receive the coffee berry for wet processing, which involves depulping, fermenting and washing the aromatic coffee. The cooperative holds several certifications[23] that guarantee the sustainability of its operations and its contribution to improving the life conditions of the communities involved, particularly from an environmental standpoint.[24]

Drawing on this, COCAFELOL installed a biogas production project aimed at treating the wastewater generated in the process. This case study offers relevant information about the model implemented in COCAFELOL and enables coffee sector enterprises to consider the replication and scaling-up of this experience.

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[20] Nm^3: normal cubic meters.
[21] COCAFELOL: La Labor Ocotepeque Ecological Coffee Cooperative, Limited.
[22] AMPROCAL: La Labor Association of Women Coffee Processors.
[23] UTZ Certified, USDA – Organic, Rainforest Alliance and Fairtrade Certified.
[24] With financial support from the Spanish International Development Cooperation Agency for the pre-feasibility study and implementation of the biodigestion system and with support from the Embassy of the United States through the Energy and Climate Partnership of the Americas (ECPA) for the implementation of the electrical generation systems to use the biogas.

IV.2. Background

The project began in 2011 with the treatment of one of the major waste products generated in the wet processing of coffee, the coffee wastewater (**Figure 4.1**). Based on this, a pre-feasibility study was conducted[25] to define the potential for biogas production and its equivalent in electrical energy, the design of the biodigestion system and the specifics of the entire project including the characteristics of the feedstock, seasonality and the productive processes of the cooperative.

Figure 4.1

Generation of coffee wastewater in the wet processing of coffee

The study determined that the major components of the renewable energy production system under consideration in COCAFELOL were:

1. A system for pre-treatment of the coffee wastewater ;
2. An anaerobic upflow digester ;
3. Biogas-based electrical energy generators aimed at improving the competitiveness of the company and directly impacting the treatment of its waste and its carbon footprint.

IV.3. Process design, installation and start-up

Design

The design of the productive biogas system includes the combination of the following treatment units:

1. **Equalisation tank**
2. **Fine solids separator**
3. **Alkalinity tank**
4. **Anaerobic digesters**
5. **Electrical generation system**

Figure 4.2 is a diagram of the system with its components and general dimensions:

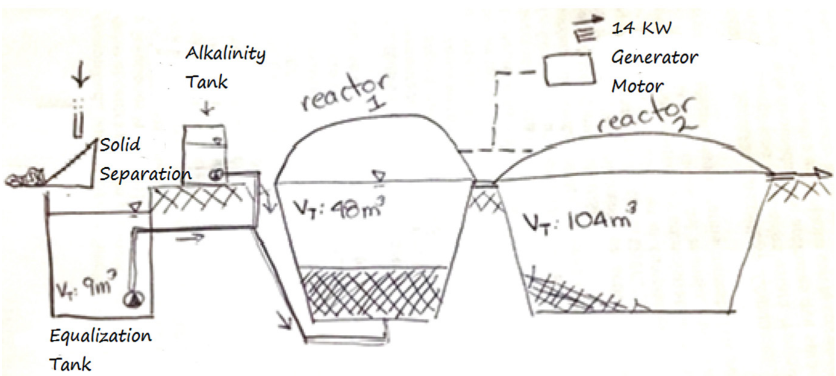

Figure 4.2

Design of the Biodigestion System and its Components

[25] A study was conducted to measure the carbon footprint of a hundredweight of exportable green coffee from the cooperative to determine actions to reduce this carbon footprint.

The waste water (see Analysis in **Table 4.1**) first flows into a concrete tank where it is recirculated back for coffee processing. After two cycles, it is pumped into the treatment system. The wastewater receives a first solid separation treatment using a stainless steel screen. It then enters an equalization concrete tank to be pumped to the reactor using a submersible pump.

1. **The equalisation tank** receives the wastewater generated in the depulping and demucilaging processes, to be later pumped into the biodigestion system over a period of four to five hours.

2. Before it enters the digester, the wastewater is filtrated passing through a **final solid separation point**. This prevent solids from entering the digester.

3. **The alkalinity tank** additionally pumps a solution of sodium carbonate dissolved in water into the line that feeds the wastewater to the reactor. This model reduces the risk of high accumulation of volatile fatty acids in the reactor.

4. Biodigestion includes the configuration of two reactors installed in series; the first **reactor** has a capacity of 48 m^3 with feedstock entering upflow, making the first contact of the wastewater with the microbial biomass. The second reactor has a capacity of 104 m^3.The system was initially designed with an upflow entry, coffee waste water being highly diluted and characterized by high dissolved solids and low suspended solids, requiring the use of a reactor capable of decoupling hydraulic retention time from solids retention time. The dimensions were chosen based on an organic loading rate of 4 kg COD/m^3 of reactor per day. Difficulties in the installation required change to a plug-flow system. The biogas produced is collected and scrubbed in order to remove hydrogen sulfide using a biological filter. The dig estate, rather than being stored, is bottled right away. When no bottling is done, it flows to post **oxidation lagoons** treatment.

Table 4.2 summarises the design parameters used for the biodigestion system.

Parameter	Value
Chemical Oxygen Demand (COD; mg/L)	16 294
Biochemical Oxygen Demand (BOD; mg/L)	9 502
pH (Units)	3,83
Total Solids (TS; mg/L)	6732
Total Suspended Solids (TSS; mg/L)	1 200
Total Nitrogen (TN; mg/L)	162
Total Phosphorous (TP; mg/L)	85,6
Alkalinity (mg $CaCO^3$/L)	0

Table 4.1

Results from Coffee Wastewater (February 2012)

Design Parameter	Value
Intake Flow (m3/day)	9,12
Organic Loading Rate (OLR: Kg COD/m3/day)	1
Hydraulic Retention Time (days)	16,7
Cellular Retention Time (days)	> 30
Upflow Velocity (m/hr)	<0,5

Table 4.2

Design Parameters Used for the Biodigestion System

It was decided that the **5. Electrical generation system** would be an internal combustion engine with a 14 KW capacity, i.e. sufficient capacity to replace the energy consumed in the mill's administrative area. The size of the plant was decided based on the calculation of loads and the energy balance between the biogas generated and the energy required.

Installation

The project installation process included four steps:

1. **Ground preparation** included stabilising slopes, forming terraces and digging ditches to prepare the terrain for the installation of the equalisation tank and the two anaerobic reactors.

2. Later on, the **civil engineering** involved the construction of the equalisation and alkalinity tanks, inspection traps, roof and structure for the placement of the generator motor.

3. **Installation of the digesters**: the digesters[26] were prefabricated in PVC geo-membrane. A prefabricated system was chosen because other models, especially concrete ones, greatly increased the investment costs both financially and time wise. The digesters were placed in the ditches, inflated and interconnected through multiple connections for liquid input and output (**Figure 4.3**). Electrical connections were installed for feedstock pumping and the alkalinity metering pump. The system was designed to allow the liquids to enter the reactor through semi-automatic pumping by using level sensors in the equalisation tank.

Figure 4.3 **Installation work**

4. **Installation of the generator**: the electrical generation system was installed one year later. This included the hydrogen sulphide filtering system, a blower to increase pressure and flow in the biogas, a 14 KW generator and a manual transference.

[26] Fabricated by VIOGAZ® Inc. Costa Rica and jointly installed by SNV – COCAFELOL – VIOGAZ.
[27] Brand: Generac

Start-up and operation

Once the biodigestion system was installed, during the first harvest milled (2011) the reactors were started, adding anaerobic slurry from anaerobic lagoons that had previously been used to treat the wastewater in the same facilities as the mill, in order to help the methanogenic microorganisms to proliferate (**Figure 4.5**). The goal was to fill 30% of the volume of the reactors in anaerobic slurry.

Following the inoculation of the digester, the coffee wastewater was slowly added, until a daily biogas yield of 9,12 m^3 had been reached. The pH of the reactor was maintained through the alkalinity tank, by adding sodium carbonate, as shown in **Figure 4.6**.

Figure 4.4 a

Extraction of anaerobic slurry as inoculantto

Figure 4.4 b

Addition of Na_2Co_3 increase buffering capacity production

Figure 4.4 c

Digester starting of biogas

IV.3.4. Operations and Maintenance

Following the launch of the biodigestion system (**Figure 4.5**), operations and maintenance manuals were distributed alongside training of the personnel. Operation and management activities are undertaken on a daily, weekly, monthly and annual basis previous and during the coffee harvest season.

Figure 4.5

Electrical generation system

Daily: The coffee wastewater must be diverted from the process to the equalisation tank. Operators should check the pH of the wastewater as well as the slurry from both reactors to determine the need for addition of alkalinity. In addition, they should ensure that the solids separation is working properly.

Weekly: Operators should calibrate the pH meter, check the condition of the pumping systems, the supply of sodium carbonate available, andoperate the electrical generation system (**Figure 4.7**). The bioslurry is placed in containers, mixed with other minerals and microorganisms, and eventually sold to members of the cooperative. Part of the bioslurry is put in one-gallon containers weekly; the remainder is sent to the cooperative’s treatment lagoon.

Monthly (and based on hours of use): Operators should change oil, the air filter and the oil filter of the generator motor.

Seasonality The coffee wastewater is only generated during 120-140 days of the year, during the coffee harvest and milling process. Given the seasonal nature of the feedstock, at the end of the milling period, the reactor enters a hibernation period. The operators slowly decrease the loading of coffee wastewater in the reactor until it is stopped completely. This occurs as a result of the drop in coffee production toward the end of the milling process. When the milling process is re-initiated in the following harvest, the biodigester is slowly loaded to reactivate the microbial biomass. If necessary, slurry is added again.

Expected Products

The productive biogas project in COCAFELOL offers a series of projected products that still require validation. These are summarised in **Table 4.3**.

Expected Products	Value
Production of Biogas (m3/day)	45,4
Production of Bioslurry (m3/day)	9,12
Reduction in COD of the Effluent	65%
Electricity Generated (kWh / year)	4 600
Reduction of Greenhouse Gases - GHG (tCO2e/year)	50,3

Table 4.3

Projected Results from the Implementation of the Productive Biogas Project

IV.4. Results and impacts

The implementation of the productive biogas project, integrated with the use of biogas to generate electricity, has led to a series of positive results.

The project, firstly, has enabled the coffee cooperative to change its energy consumption as it is now partially using renewable sources. COCAFELOL intends to increase biogas production in the future, based on other waste products. The installation of a biogas system has also enabled COCAFELOL to optimise its wastewater treatment system, thus enhancing its water quality parameters and significantly reducing unpleasant odors.

Secondly, the cooperative has implemented a bioslurry distribution system that now provides an incentive for quality coffee production among smallholder coffee growers who receive free bioslurry fertilizer, the remainder of which is sold commercially.

Change in knowledge, competencies and capacities - The project has helped enhancing local capacities for construction and adaptation of the equipment and assembly of the plants. It has also strengthened the capacities of local infrastructure providers. Knowledge was transferred to the cooperative personnel; training regarding the operation, maintenance and application of biogas was offered to employees and managers of the cooperative facility.

Economic Impacts - Thanks to its new biogas system, COCAFELOL has reduced its consumption of electricity by 4600 KWh annually, reducing the company's costs by an estimated 1110 USDper year. In addition, the commercialisation of bioslurry has introduced a new revenue stream for the cooperative, raising 895 USD annually, which has greatly contributed to the COCAFELOL's overall productivity. The payback period for the project is estimated to be around 14 years. Economic savings are also realized by cooperative members through the partial replacement of the synthetic fertilizers typically used in their farms. Furthermore, the cost of a biogas system is likely to be much less than that of not intervening, as poor treatment of coffee wastewater may result in lawsuits for the cooperative, loss of its certifications, reduced competitiveness and a deterioration of the image of the cooperative.

Given that COCAFELOL operates via a cooperative model based on the redistribution of profits and/or income from the sale of its coffee and the facilitation of technical assistance and capacity-building for member families, the reduction of costs realized through this model of energy generation thus represents a potential improvement in payment for the coffee of its members.

Social Impacts - The quality of life of COCAFELOL's neighbours has improved significantly through the control of unpleasant odors that were previously generated by the poor disposal of the coffee wastewater. In addition, when biogas starts being used to fuel the coffee roasting systems as it is currently being planned, the project will have an additional impact by helping women groups realizing savings on liquefied petroleum gas (LPG).

Environmental Impacts - The acquisition of a biodigester has significantly reduced the cooperative's footprint. COCAFELOL is now only partially using the oxidation lagoons, which represent a considerable source of methane emissions. Including the reduction achieved through the replacement of energy from the grid with renewable energy, this represents a reduction of 50,3 t CO_2e. In addition, a substantial decrease was measured in the consumption of electricity from the national grid, based on traditional fossil fuels for over 60%. Finally, the introduction of a biogas system has made it possible to partially treat the coffee wastewater, reducing chemical oxygen demand by about 65%.

IV.5. Key factors in the success of biogas for productive use

Drawing from the experience gained in the design, installation and implementation of this project, a series of remarks can be made for the optimisation of future biodigestion projects based on coffee wastewater.

Technical Factors

Design of the biogas system - accurate data on the quantity and composition of the feedstock to be used is crucial. Anaerobic slurries must be kept stable within the reactor. It is also important to facilitate the contact between the latter with the organic material that is continuously loaded during the milling period.

Inoculation of feedstock - coffee wastewater lacks methanogenic microorganisms; operators should thus, from the beginning, add good quality anaerobic slurry with proven methanogenic activity to the mix to reduce the time needed for the digestion to start and increase the stability of the reactor over the long term.

Economic - Financial Factors

Project funding - To ensure empowerment and project acceptance from biogas users, projects similar to the one described here should be deployed with limited financial support or, at maximum, a partial subsidy and/or shared risk, ensuring that the beneficiary enterprise provides an economic contribution.

Opportunity cost - Provided that fossil fuels like LPG are directly replaced by biogas for roasting coffee, the project can be more profitable than the replacement of electricity, as it requires equipment with lower investment costs.

Socio-cultural Factors

Inclusive participation - The beneficiary cooperative should be involved in project development to the greatest possible extent: here, local members participated to the set-up of a biogas system from the beginning to the end of project activities, appointing personnel for the coordination and implementation of the recommended measures, providing information and reinforcing their knowledge and skills, participating in training activities, publicity and experience sharing.

Cross-cutting benefits - The benefits biogas can deliver on cross-cutting issues should be articulated clearly For example, COCAFELOL is an enterprise striving to generate an economic, social and environmental impact through its operations, a vision biogas can help achieve.

Organisational structure - A clear managerial vision and solid organisational structure are key for such projects to succeed, as it ensures commitment throughout the entire beneficiary cooperative.

Environmental Factors

Carbon Footprint - By tracking its carbon footprint, COCAFELOL identified emission sources that represented an opportunity for improvement, including within its electricity consumption, chemical fertilizers use and waste management processes. The cooperative's oxidation lagoons were identified as a particularly large source of GHG emissions. This carbon footprinting exercise, to which the biogas project was later connected, pertains to COCAFELOL's broader vision, according to which it is to become a carbon neutral enterprise.

Re-assessment of coffee waste - There is a large potential for contamination from coffee waste, posing a threat for nearby water sources and the surrounding communities and ecosystems. Alongside the opportunity of using biogas to generate electricity, this represents a strong rationale for investing in productive biogas technologies in the coffee processing industry.

IV.6. Recommendations and conclusion

Based on COCAFELOL's experience, the following recommendations are made:

1. Ensure that the design and implementation of the biodigestion system are sufficiently robust: for example, install a water pump with a important flow and the ability to avoid obstruction by solids - i.e. capable of eliminating particles larger than 0,5 mm - and improve the design of the upflow reactor and in the fine solids separation system.

2. Work with good quality anaerobic slurry with proven methanogenic activity for the start-up and initial phase of the project.

3. Identify, train and designate the personnel that will be responsible for the operation of the biodigestion system within the cooperative.

4. Validate the benefits of the bioslurry for use, dosage and improvements in yields in the coffee crop.

5. Consider potential uses of biogas to scale for direct replacement of fossil fuels and electrical generation as a secondary option.

6. Update the measurement of the carbon footprint annually to monitor the impact of the project, in order to reduce GHG emissions on a consistent basis.

IV.7. Bibliography

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V. Case study 4 - Biogas in the Multi-functional Platform, Mali

By Bart Frederiks, FACT Foundation; Gaoussou Coulibaly, Ecole Nationale des Ingénieurs (ENI); Winfried Rijssenbeek, FACT Foundation.

Figure 5.1 A Multifunctional Platform in Mali

V.1. Introduction

The Multifunctional Platform (MFP) is a stand-alone power unit providing mechanical and electrical energy access for rural communities. It consists of a low speed diesel engine that can drive a number of applications such as cereal mills, oil presses or alternators to recharge batteries. An MFP can free up time by mechanizing intensive tasks that disproportionately fall on women and girls. Hence, the access to energy services provided by the MFP is critical for empowering women and enhancing girls' chances of receiving an education.

The MFPs are run as small businesses by groups of women that gain their earnings from crop processing services and, in some cases, through battery and telephone charging. Many MFPs operate at lower capacity than foreseen. To date, some 1500 MFPs have been installed in West Africa, the majority of which operate in Mali and Burkina Faso, although some MFPs can also be found in Senegal, Ghana and Guinea.

It appears that the costs and limited availability of fuel form a large obstacle to the operation of MFPs. Diesel fuel represents the single largest operational cost component of an MFP (see **Figure 5.2**) and its supply remains a logistic hurdle for many MFPs located in rural areas. Earlier attempts to address this barrier focused on using locally produced vegetable oil (e.g. jatropha oil), which were moderately successful.

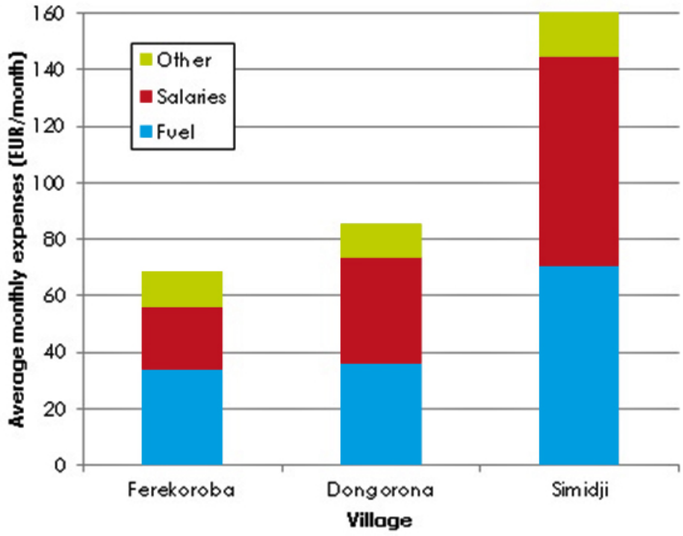

Figure 5.2

Typical cost structure of MFP. Fekekoroba and Dongorana data is based on (3), Simidji data is estimated based on Dongorana.

An alternative option for fuel diversification in MFP's is the use of biogas. The possibility of using biogas in diesel engines -known as dual fuelling- is common knowledge and widely applied. On a technical level, it entails the introduction of biogas into the engine cylinder along with the combustion air. The gas-air mixture is ignited by injecting a limited amount of diesel fuel. In conventional diesel engines, some 80% of diesel consumption can be replaced by biogas; in modern engines, special purpose diesel engines, this can be less than 5%.

Biogas appears to be a particularly appropriate technology for powering MFP units.[28] It is a relatively straightforward energy source that has proven to be suitable for use in a rural setting in many parts of the world. It can be combined with other renewable energy sources like vegetable oils whose by-products can be used as feedstock. It makes use of local resources -dung and other agro-residues like shea processing wastes and press cakes- and is well-suited for integration in agricultural systems -by offering nutrient recycling for example. In terms of economy and cost recovery, biogas constitutes a high-value application by replacing expensive diesel fuel.

As a productive biogas application, MFP units also present significant advantages: MFP units are already operational, and from operational records it is fairly easy to determine beforehand if a unit is running well. Few technical modifications are required to include biogas as an additional fuel, and in the event of biogas shortages, the MFP can continue to operate on diesel. Furthermore, the installation of MFPs is typically associated with an extensive training of beneficiaries, whom are taught how to manage and operate the MFP units, thereby forming useful organizational structures for the potential introduction of biogas an additional energy source.

V.2. Background

The idea of using biogas in MFP units originated at FACT Foundation and was developed further in cooperation with its partner Mali Biocarburant (MBSA). MBSA has an MFP unit installed at its production site in Koulikoro, and uses the latter for carrying out jatropha oil tests; in 2010 a small biogas unit was installed to carry out feedstock digestion tests and dual fuelling tests with the engine.

[28] Within the context of existing MFPs, it is the only feasible renewable energy option that does not essentially change the existing technology infrastructure

The idea of using biogas in MFP units originated at FACT Foundation and was developed further in cooperation with its partner Mali Biocarburant (MBSA). MBSA has an MFP unit installed at its production site in Koulikoro, and uses the latter for carrying out jatropha oil tests; in 2010 a small biogas unit was installed to carry out feedstock digestion tests and dual fuelling tests with the engine.

In 2011, FACT and MBSA defined a larger testing project in a number of villages in Mali, and integrated this into a broader biofuel project that was eventually presented for funding to the Dutch Daey Ouwens Fund and the DOEN Foundation's Innovation in Biofuels programme. The stated objective of the MFP/biogas project was *«to field-test the production of biogas and its use as an MFP fuel in five villages in Mali. The project is to provide operational experience with the biogas production and its use, the application of digester bioslurry as fertilizer, and lead to improvements in both the digester model as the MFP engine adaptations. It should ultimately lead to an uptake of biogas use for MFPs in Mali and elsewhere in Africa, thereby improving the economics of MFP operations and reducing the energy dependency of rural communities.»*

Selection of sites for inclusion in the project was done on the basis of the following criteria:

- Level of MFP operation in terms of daily operating hours and diesel consumption. Activities of the MFP during the site visit -e.g. kind of agro processing used, and resulting organic waste potential- were also considered as indicators.
- Estimations of feedstock availability, based on the number of cattle present year-round and vicinity of wells.
- Available space for installation near the MFP buildin.
- Approval and involvement of village chief.

Eventually, the following sites were selected:

Ferekoroba (biogas unit installed February 2012), a small village just south of the town of Ouelessebougou, some 5 km off the RN7. The MFP has a very "average" profile in terms of operation, but the group of women running the unit is strongly motivated.

Dongorona (biogas unit installed March 2012), a larger village on the RN7 north of Ouelessebougou. The MFP in this village was until recently very active, processing agricultural products for neighbouring villages.

Simidji (biogas unit installed December 2012), a village on the RN7 just south of Dongorona. In this village, AMADER had recently installed a minigrid supplying electricity for lighting to some 50 households and a water pump, using the MFP. This adds some 3-4 operational hours and a consumption of 4 litres of diesel per day to the "normal" MFP operations.

Badougou Nafadji (installed July 2013), a village just off the RN5 to Guinée, 50 km southwest from Bamako. Apart from its normal operation, the MFP unit feeds a small electricity grid supplying some 20 households.

A fifth unit should be installed in December 2013 in **N'Tobougou**, a village 200 km east of Bamako. Here also, AMADER has set up a minigrid and is supporting a number of productive activities such as fruit drying, and the production of juices and jams.

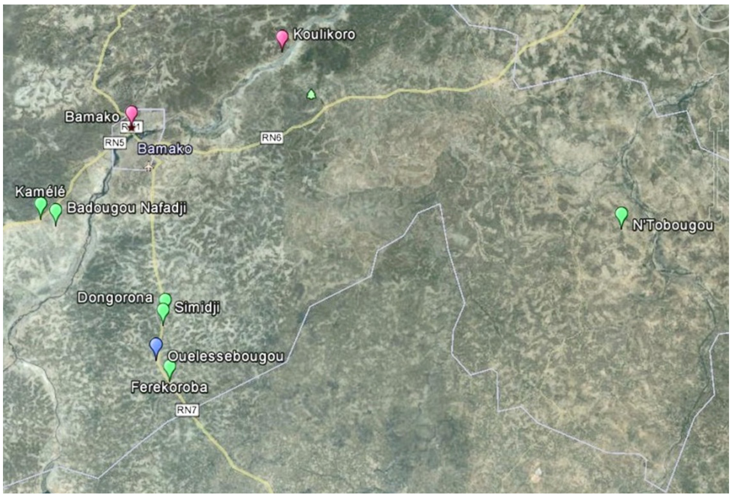

Figure 5.3

Typical cost structure of MFP. Fekekoroba Map showing current and prospective MFP/biogas sites

Figure 5.4 provides an overview of operational data of the MFPs in Ferekoroba, Dongorona and Simidji. On average, the units of Ferekoroba and Dongorona run for 2.5-3.5 hours per day, but the averages are much higher during harvesting season (6-7 hours per day). Average fuel consumption is about 0.9 litres/hour, resulting in average daily fuel consumption of about 2-3 litres with peaks of about 5-6 litres per day during harvesting months. Consumption for Simidji is substantially higher because of electricity production in evening hours.

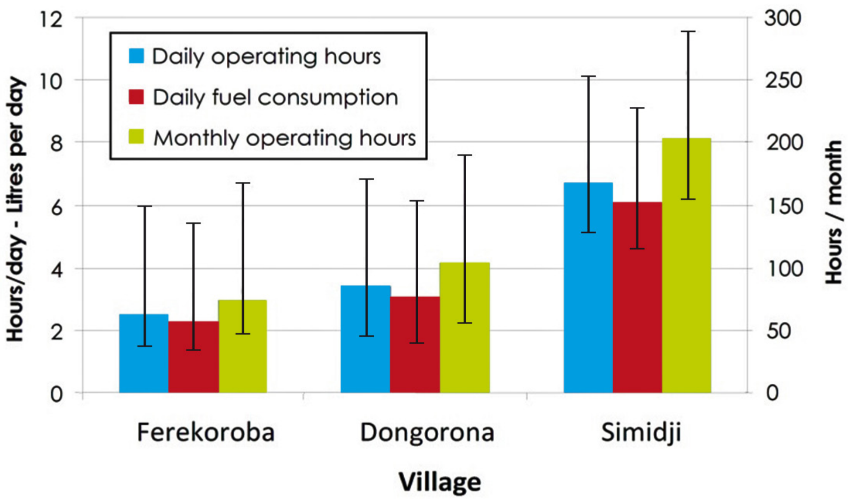

Figure 5.4 **Typical cost structure of MFP. Fekekoroba MFP monthly average operational data from 2009.**

Note that it concerns monthly averages: on specific days, the MFPs could be running all day, with fuel consumption of more than 10 litres per day.

Dongorona and Ferekoroba were selected from the sites that were included in the previous project using jatropha oil as fuel. Other sites were selected on indication of national structures (National MFP coordination body PTFM, National rural electrification agency AMADER).

V.3. Process design, installation and start-up

For the production of biogas, it was decided to use plug-flow digesters made of flexible fibre-reinforced PVC. The main considerations in the selection process were the following:

Robustness - Although PVC digesters are not expected to have a life span equal to that of fixed dome systems for example, they are very rugged and life span is expected to be at least 10 years.[29] There are no heating or stirring devices that could be prone to breakdown.

Simplicity and ease of installation - The units can be installed by staff with little specific skills. Installation takes 1-2 weeks. Operation is straightforward.

Cost advantages - PVC systems are expected to be the cheapest option, despite the need to import the PVC bag.

Innovativeness - Innovation is considered to be a key aspect for arriving at affordable and economic biogas solutions.

The system features the following parts[30] (see also sketches in **Figure 5.5**, and photos in ***5.6.a***):

- A long **bag of UV resistant fibre-reinforced PVC** (1.15 kg/m^2) with flat dimensions of 2.80 x 13.50 m. On each end, the bag is fitted with flanges through which 110 mm hard PVC tubes can be inserted as in- and outlet. On the top, three smaller flanges are mounted to which 1" flexible hose can be connected. As it is flexible, its contents will depend on the way it is installed. When installed as described below, it will have a volume of about 18m^3 of slurry and 8m^3 of biogas. The length/width ratio is 6.

- The **PVC bag** is installed in a ditch with a depth of 0.60m. The ditch is surrounded with a wall of cement bricks, with a height of 0.40m. In normal operating conditions, the slurry level is equal to the top of the wall; earth is distributed around the wall in order to compensate for the pressure by the fluid. On each side, a structure is constructed in cement bricks, one for the input of feedstock, one for the collection and temporary storage of output slurry.

- A **roof of plastic** sheeting is put over the bag in order to protect the material from direct sunlight, increasing the bag's lifespan. The sheeting is supported by a wire structure made out of 12mm concrete iron is welded in place.

- The **gas piping system** is done in ¾" galvanised steel pipe. On one end, in the middle of the system, the pipe is connected to the digester with a ball valve and a 1" flexible hose. From there, it runs underground for 10m to allow the gas to cool and the water vapour it contains to condensate. The pipe goes down under a few degrees towards a condense trap. The trap also functions as an over pressure system, protecting the bag from pressures higher than 20mbar. After the condense trap, the pipe goes into the MFP building, where it is metered with a G2.5 gas meter and connected to the air inlet through a ball valve.

[29] Similar material used in Western Europe has shown to resist unshielded outside weather conditions for over 20 years.
[30] Note that the design has evolved considerably over the course of the project. The system described here refers to the eventual system, as installed in Badougou Nafadji.

The biogas storage pressure is atmospheric. Gas is not pressurised prior to its use in the engine: the gas flow is generated solely by the under pressure created by the MFP engine. Various tests have shown that this pressure is sufficient for creating a gas flow sufficient for replacing the diesel consumption with 60-85%.

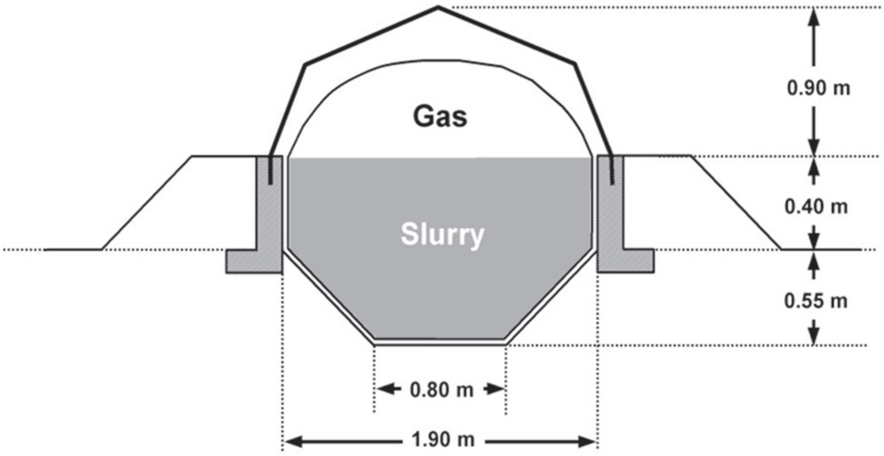

Figure 5.5 a **Cross section digester**

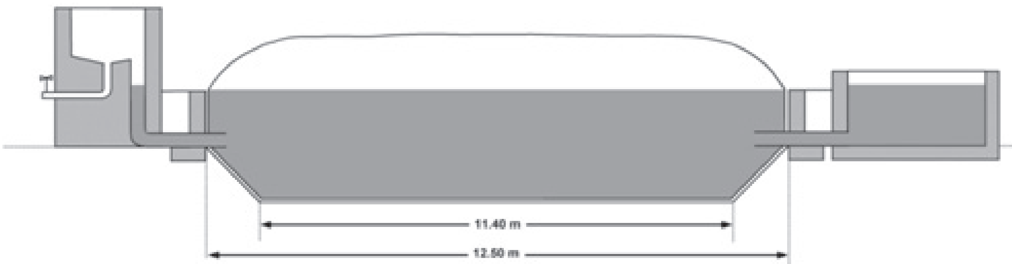

Figure 5.5 b **Longitudinal section digester**

Figure 5.5 c **Top-view of civil works**

The installations were designed to produce up to 6m^3 of biogas per day on cattle dung. With a gas of average quality -i.e. 60%- this would be sufficient for replacing approximately 3L of diesel per day. About 180 kg of daily fresh dung should then be required and mixed with an equal amount of water. The intention is to include other feedstocks like jatropha presscake from own pressing operations or from external sources, but this remains to be done. A daily feed could then be 50 kg dung, 12kg press cake and 160 litres of water -for instance.

Installation and start-up

Installation of the biogas system takes about 5 days; starting it up -filling with dung and water- takes another 2 days, during which MFP operators are trained in system operation and maintenance. When the biogas starts to produce -typically within 15-20 days, the gas is tried in the engine, and the operators are trained in its daily use. At least one additional follow-up visit should then be made to check whether all systems are functional, whether O&M practices are appropriate, and provide additional training if needed.

Figure 5.6 a Digester after start-up

Figure 5.6 b Gas connection to the MFP

Total installation costs are shown in **Table 5.1** below. Note that within the project, alternators are installed at MFP units when they are not yet present. This allows the MFPs to extend their range of activities to phone / battery charging, welding, public lighting, water pumping etc. These costs have not been taken into account in the overview presented below. Also, fencing is typically added to protect the system from children and free-ranging animals.

With total costs of 2,444 EUR, it should be possible for commercial operators to supply a system for 3,000 EUR and still have a profit margin of more than 20%. Options for costs reductions include scaling up numbers of systems (price advantages when purchasing larger numbers of materials) and -possibly- local manufacturing of the bags.

	Units	Quantity	Unit price (€)	Costs (€)
Materials				**1,437**
Digester bag (incl. transport)				950
Ditch construction				193
Roof				153
Gas piping system				142
Transport materials + personnel	**j**	**10**	**50**	**500**
Personnel costs				**507**
Unskilled labour	h-j	54	3	162
Masons	h-j	8	10	80
Welder	h-j	1	15	15
Supervisor	**h-j**	**10**	**25**	**250**
Total				**2,444**

Table 5.1 Digester installation costs

Several organisations were directly involved in project implementation:[31]

- **FACT Foundation** is the main implementing body. FACT has developed the program, manages it and provided the necessary Technical Assistance during site selection, systems installation and follow-up. For local day-to-day management of the project, FACT hired a local consulting technician (Mr. Gaoussou Coulibaly).

- **Local MFP organisations**. In each village, the MFP is managed and operated by a small group of women, usually assisted by 1-2 men for specific operation and maintenance tasks. The MFP staff provides assistance during construction and start-up of the system -e.g. arranging labour- and is responsible for the operation and maintenance of their biogas system.

- **Mali Biocarburant SA** (MBSA) and the **Agence Nationale du Développement des Biocarburants** (ANADEB) are FACT's partners in the project, providing managerial and logistical support to the project.

Other organisations that have been involved include:

- Programme Plate-formes Multifonctionelles (PTFM) is the national coordinating body of the MFP programme. They have provided technical advice and supported in the process of site selection. In addition, they are involved in ongoing attempts to further develop the project into a large program.

- Agence Malienne pour le Développement de l'Energie Domestique et de l'Electrification Rurale(AMADER) has in recent years been working on extending the MFP activities to electricity supply to households and productive uses. Like PTFM, they support the project by advising onsite selection and by accompanying site selection missions.

Operation and maintenance

Typical operational tasks include:

- Collecting dung: this is organised by the MFP operators, in agreement with the village chief;
- Mixing dung and feeding the digester;
- Collecting slurry;
- Using biogas: starting the engine as normal, beginning the work, gradually opening the gas valve, closing the gas valve before the end of the work.

In addition, a straightforward system of administration of several parameters (amount of dung fed per day; amount of gas consumed; amount of diesel consumed; time operated) was discussed with the MFP operators. Despite various attempts, to date little operational data has been recorded.

Typical maintenance includes:

- Check system daily for irregularities (gas/fluid leaks in bag or flexible hose, cracks in walls, damages in roof);
- Verify working of the condense trap / pressure safety system;
- Clean the bag regularly with cold water (every month);
- Check for water build-up in the gas meter (every half year);
- Stick to engine oil change frequency.

[31] The MFP/biogas component in the larger project has a separate budget of approximately 200,000 EUR.

V.4. Results and impacts

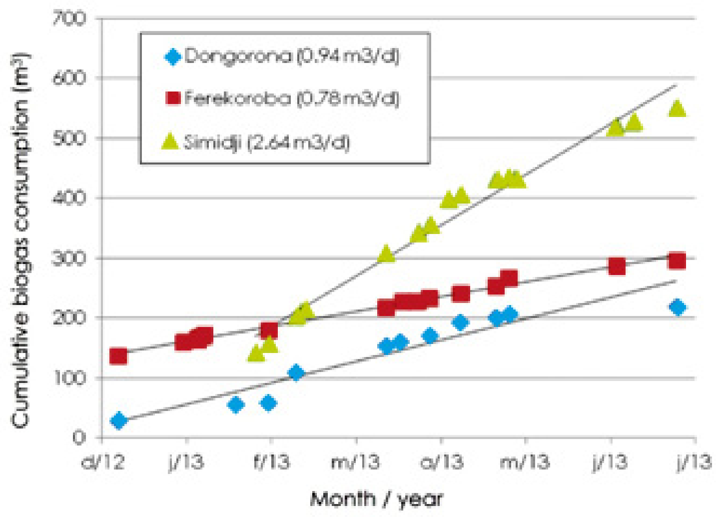

Figure 5.7

Cumulative gas consumption in 3 MFP biogas systems

Operational results

As indicated earlier, there have been great difficulties in setting up a structure for monitoring technical indicators on system effectiveness. Gas meter readings from different sites (see **Figure 5.7)** indicate that actual system usage is limited. At this stage, the reasons for this remain unknown. Current observations indicate that feeding is limited -exact quantities are unknown- and irregular, one stated reason being that during the busiest periods of MFP use, there is very little time available for collecting dung.

Although actual gas output of the biogas systems is limited, gas quality was always found to be very acceptable, with methane levels revolving around 57-59% and no significant levels of sulphurous compounds.[32] The condense trap is working well, with no water build-up being observed in the gas meters.

The table below shows the results of measurements of gas consumption and diesel replacement under different engine load conditions.

Village		Diesel only		Diesel + gas			Replacement	
	Power (kW)	Cons. diesel (ml/min)	Efficiency (%)	Cons. diesel (ml/min)	Cons. biogas (l/min)	Efficiency (%)	Diesel reduction (%)	Diesel reduction (l/m³ biogas)
Ferekoroba	2.0	25.6	12.5%	10.3	35	11.2%	61%	0.44
Dongorona	2.8	29.5	15.9%	5.1	50	15.4%	84%	0.52
Simidji	2.8	20.6	23.9%	5.1	49	15.8%	75%	0.32

Table 5.2 **MFP engine performance tests in 3 villages**

* *Measured engine efficiency and fuel consumption with diesel only are likely to be erroneous only in Simidji and should be in line with what was found in Dongorona.*

[32] The H_2S levels were tested in different places, on different occasions, but were always found to be below 20 ppm. A possible explanation is that local cattle does not have a high protein diet.

Using the average daily gas consumption and the diesel replacement values (l of diesel per m^3 of biogas) found in the tests, diesel savings can be calculated; they are shown in the **Table 5.3** below. The percentile reductions are calculated using monitoring data from 2009, shown in **Table 5.2**. Diesel replacement falls considerably behind the targeted figure of 60% reduction.

Village	Average daily gas use (m^3/d)	Diesel reduction (l/d)	Diesel reduction (l/a)	Diesel reduction (%)
Ferekoroba	0,78	0,34	125	15%
Dongorona	0,94	0,49	179	16%
Simidji	2,64	1,37	502	23%

Table 5.3 **Biogas consumption and diesel replacement in 3 MFP villages**

Change/results in knowledge, competencies and capacities - Knowledge on the production of biogas and some of its possible uses was available with some of the people included in the project, namely M. Gaoussou Coulibaly and the staff of PTFM. However, besides this, a good understanding of biogas was lacking. Although it was not the immediate objective of the project, the latter contributed to improve knowledge on biogas, digester installation, use of slurry etc. with all parties involved in the project, directly or indirectly.

The eventual level of understanding of the biogas systems found into the villages that benefited from the project varies. In some villages, the knowledge did not surpass that what was required for operation, although the possibility to reduce diesel consumption by two-thirds was experienced by all operators. In others, notably in Ferekoroba, the operators were able to alert the team on a leak in the gas supply line as they noticed that diesel consumption had suddenly dropped.

The awareness on the possibilities of productive biogas is starting to grow. According to the local project team, there have been a large number of villages and entrepreneurs enquiring about the possibilities and costs of biogas systems in the past half year. Cooperation with local organisations like ANADEB, PTFM and AMADER is likely to help with the dissemination of knowledge of the project.

Change/results in practices and routines of the producers - The results on daily practices at local level are limited. The MFP operators spend some additional time on feeding the biogas system; however, they need to buy diesel less frequently; whether the availability of biogas has increased MFP operations because of the reduced logistical hurdle of buying diesel is unknown. Bioslurry is being collected for use in vegetable gardens, and there is anecdotal evidence that the vegetables grow much better than before.

Impacts

Economic impact - The project has had a noticeable impact on the normal expenses of the MFPs. Based on the biogas usage and the related level of diesel savings, annual cost reductions range from 123 to 495 EUR, or 12 to 24% (see **Table 5.4)**. In some villages -Ferekoroba and Simidji- the processing fee has been reduced so that all villagers benefit from the acquisition of a biogas system. In Ferekoroba, the MFP staff indicated that they managed to save approximately 200 EUR per year since the installation of the biogas unit but this amount does not represent the total diesel savings, especially in combination with fee reductions. Whilst the total cost reduction may appear limited, it concerns a portion of those costs that would otherwise directly exit the village.

Village	Average daily gas use (m^3/d)	Diesel reduction (l/a)	Cost reduction (EUR/a)	Cost reduction (%)
Ferekoroba	0,78	125	123	12%
Dongorona	0,94	179	176	22%
Simidji	2,64	502	495	24%

Table 5.4 Impact of biogas use on operating costs

Social impact - The rationale for this project was that fuel cost savings would benefit the MFP as well as the community as a whole, as has indeed happened in Ferekoroba and Simidji where processing fees were reduced. The dung collectors are part of this process, but their extra input is not directly remunerated in any way. Although this issue was discussed with the MFP staff, to date, no change has been made in this regard.

Environmental impact - The project does not set out to address specific issues related to environment or sanitation. Animal dung is converted in a bioslurry that is applied to gardens and fields, as was done with the dung before the project.[33]

V.5. Key factors for the success of biogas for productive use

The following factors are keyfor a successful use of biogas in the MFP units:

Technological factors - Of key importance here are the ruggedness of the system - to minimise the chance of breakdowns; the quality of locally available materials - the quality of these materials is often low and they should thus not be used in critical parts of the system,and the ease of installation - which facilitates organisation at the MFP level and reduces overall costs. Feedstock availability (dung/co-substrates) matters also, as it influences the eventual level of system output. A situation in which the user owns the feedstock is preferable to one where it must be collected.

[33] In most farming communities, concentration of nutrients close to the homestead is common. This is related to land use, going outwards from intensive (gardens) to extensive (grazing) use.

Economic factors - Critical factors considered here are investment costs, which determine the payback period, and the ability of biogas to replace expensive diesel - the value of biogas is about 0.5 EUR/m^3 as opposed to 0.1 EUR/m^3 for wood for cooking in rural areas. Installation costs for biogas systems -which were at the charge of the project- remain unaffordable to the beneficiary communities. Although some villages managed to raise a multiple for infrastructural improvements, some type of financing mechanism will have to be put in place for future scale up. Considering about 90% of the costs involved in installing MFPs are currently being subsidized, there may be a role for donor funding for biogas-MFP combined systems. However, in view of the savings that can be realized and that may well be expanded with improvements in system design, there may also be some rationale for investing community funds. This could be achieved with the support of NGOs organizing saving systems that could provide for at least a portion of the required installation costs.

Political-institutional factors - The existence of the MFP programme was a great advantage as it guaranteed that investments in local organisational capacity building had already been made. In addition, the MFP programme was a great help in identifying villages that could benefit most from a biogas system.

Socio-cultural factors - Key factors here are the involvement of village chiefs, which can facilitate organisational work, and the degreeof organisation of the village and/or of MFP organisation required for community projects. An additional driver is the level of confidence in innovations among MFP operators and other potential users, which may require a prior demonstration of the new technology.

Another factor of importance to be considered for this project is the lack of modern energy that characterizes rural areas in Mali. The presence of an MFP is a great improvement; biogas provides a cost advantage by making the service more accessible, and by allowing cost-effective supply of additional energy services (charging, water pumping and public lighting).

V.6. Conclusions and recommendations

Table 5.5 shows the results of the most successful project (Simidji), expressed in monetary value, in relation to the expectations at the onset of the project.

	Expected	Actual
Unit costs	3000 EUR	3000 EUR
Cost savings	6m^3 biogas per day saving 3 l/d on diesel during 300 d/a = 900 EUR/a	2.6 m^3 biogas per day saving 0.52 l/m^3 during 365 d/a = 501 EUR/a
Expenses	5% of total investment = 150 EUR/a*	N/A (assumed 150 EUR/a)
Payback period	3000 / (900-150) = 4 years	3000 / (501-150) = 8.5 years

Table 5.5 **Expected and actual business model for Simidji (February - July 2013)**

** These expenses include some maintenance parts, cement/brick fixing, and the replacement of tubes that were damaged.*

The comparison shows that while significant, the actual cost savings fall behind those expected by 47%, resulting in a payback period of 8-9 years rather than the expected 4 years. The main reason for this is the lower than expected gas consumption observed: as the MFP makes long hours -due to electricity production, insufficient feeding is the most likely explanation. In the other villages, low system utilisation rates result in less cost savings, barely sufficient to cover the assumed maintenance costs, let alone recover the investment costs.

Lessons learned

In terms of positive lessons learned, the technology appears to have been well chosen. All units have been installed with relatively little effort, and all are operational. Cost estimates are fairly accurate and it is expected that commercial entities will be able to supply systems for 3000 EUR each and make a profit, as long as substantial numbers of units can be installed. Openings for further cost reductions can also be identified, in particular as regards material costs.

An unforeseen development once the biogas system was installed, however, was the limited amount of effort invested into digester feeding. Although this requires further analysis, there are indications that low system usage results from low biogas system output rather than low energy demand, which in turn is likely to be caused by insufficient system feeding. Possibly, the amount of work required for dung collection was underestimated, especially during the harvesting period.

As for challenges ahead, a more performing monitoring system is to be set up to learn more about the actual performance of the MFP/biogas concept, and the causes for low or high performance. Biogas system output, largely depending on its use, is to be improved. This couldbe done by placing an incentive on dung/water supply; testing more performing feedstocks; or creating access to new services conditional to the feeding of the system (e.g. water pumping).

Replicability

Replicablity to other MFP units is part of the project rationale. At present there are some 1500 MFP units in West Africa and their number is growing steadily. Based on experience in Mali, it is assumed that some 10-30% of these units could benefit from a combined biogas technology. Beyond the sole MFPs, countless small agro-processing businesses exist all over Africa that use a similar technology; the biogas concept could be applied to these systems also. As suggested earlier, this will however require some efforts in order to reduce the high payback period observed for such systems. Based on current experience, this long payback period is to be attributed to the low rate of use of the system rather than its actual design. Incentives should thus be found for organizing dung and water collection, as detailed in the recommendations below.

Recommendations

- For an improved monitoring system, a dedicated administrator could be identified in each village, which would be paid for administering the amount of dung/water supplied, daily gas and fuel consumed, and operating hours of the MFP. After a sufficient monitoring period, a detailed financial analysis with sensitivity and risk assessments could then be made.

- A system of incentives for supplying feedstock could be developed, offering a financial reward for each bucket of dung supplied to the digester. This could be done in several ways, for example direct payment; discount on the processing fee or free telephone charging.

- Alternatively, an exchange of dung for slurry could be implemented - provided that the value of the bioslurry as a fertiliser is demonstrated. This could be validated through trials in vegetable gardens.

- Another sort of high-performing feedstock that could be tested or demonstrated is the jatropha presscake. A trial of 3 months with 5-10 kg of presscake per day could be carried out, on the condition that the monitoring system is functioning well. The trial should be placed in the context of the future installation of a jatropha press; as such it should be carried out in a village with sufficient jatropha seed production to justify the installation of a press.

- Other possible feedstocks that could be tested include ground Ximenia Americana nuts (savage shrub, with seeds containing some 50% oil) or Euphorbia tirucalli.

- A future follow-up programme should include a social and environmental impact assessment in at least a sample number of villages; including a baseline study before installation, and a second assessment within 1-2 years after installation.

V.7. Bibliography

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VI. Case study 5 - Rural electrification with biogas in isolated communities of the Peruvian Amazon

By Fernando Acosta, SNV Peru; Martijn Veen, SNV Peru.

VI.1. Introduction

The use of biogas-fueled systems for providing access to electricity to isolated communities remains a rarity. SNV's work with the community of Santa Rosillo in the Peruvian Amazonis a pioneering example in this view. For Julio Barbaran, the community administrator of the system, this project *«is very important and new for the Chipurana Valley, for San Martín and even for all of Peru. It is a project with a real impact»*.

The project presented in this case study seeks to validate an electricity generation model for isolated communities, using biogas produced from local biomass waste and proposing a community-based management scheme for the operation, maintenance and administrationof the chosen generation system.

The BioSynergy project seeks to demonstrate the technical, social, economic and environmental feasibility of an integrated and self-sufficient energy model based on local production of biogas from biomass to generate electricity in remote communities of the Peruvian Amazon for domestic, social and productive use. The project was executed by SNV in alliance with Practical Action and local partners, with funding from Cordaid and FACT Foundation.

Through the validation of this experience, SNV and its partners will seek to replicate this project in other areas of the country and beyond, as an alternative way to power isolated communities and to increase the quality of life of the low-income segments of these populations, recognizing a key role to play for the private sector in implementing these models.

VI.2. Background

The BioSynergy Project, or project for *"Access to Renewable Energy and Inclusive Business Promotion with Sustainable Biofuels in Isolated Communities of the Peruvian Amazon"*, has been financed by the Catholic Organisation for Relief & Development Aid (CORDAID) and FACT Foundation and executed by SNV in alliance with Practical Action and the Regional Government of San Martín with its Regional Department of Energy and Mines (DREM).

The project was built on the hypothesis that isolated communities are capable of producing electrical and/or thermal energy based on their own natural resources, without dependence on fossil fuels, meeting their energy needs partially or totally. The project was based on a model promoting the use of vegetable oil from *Jatropha curcas* as a fuel for electricity generation and for connecting Santa Rosillo with the emerging market for biofuels of the San Martín region, in the Peruvian Amazon. It entailed the installation of a small biodigester that would be used to enrich the oil/air mix used by the envisioned generator in order to increaseits efficiency. After an assessment of different communities and the selection of Santa Rosillo as the most favourable candidate to implement this pilot project -see selection criteria below- a variety of technical, economic and environmental considerations led to replace the mixed generation model initially envisaged, to one fueled by biogas only, to be produced with locally available cow dung and other biomass residues.

The major reasons for modifying the project approach included:

1. The planting of *Jatropha curcas* could entail the exploitation of land in areas covered with primary forests.

2. The price per kilogram of *Jatropha curcas* seed would not be economically viable for the farmers, especially considering the incipient biodiesel market.

3. Crop management and yields for *Jatropha curcas* were not yet validated, representing a challenge for technical assistance to the farmers, particularly considering the level of isolation of the community.

Selection of the community

The community was selected after an assessment of 35 isolated communities, identified in conjunction with several institutions and local programmes. Of these, 10 communities with greater potential were visited, seeking to fulfil various criteria, including:

- The level of organisation and leadership capacity within the community.
- Accessibility and availability of communication channels year round.
- Lack of favourable alternatives for access to energy or prospects for developing those (e.g. mini-hydroelectric plants with no nearby waterfalls.
- No inclusion in the *«Light for All»* Project of the Regional Government of San Martín or other projects to become incorporated into the national grid.
- Existence of agriculture and animal breeding at a scale sufficient for producing the necessary amount of feedstock, namely, the existence of a communal corral of a sufficient size.
- A minimum of 40 families/households in a relatively high density area.

The community of Santa Rosillo was selected because it was an isolated population centre that met the established criteria. A key factor was the level of organisation of the community and the presence of youth leaders, perceived as important elements for the successful development of a project of this type.

Most of the residents of Santo Rosillo work in agriculture, mainly growing cacao, manioc, rice, and beans, and in cattle ranching, managed through a semi-stabled system, with the peculiarity of enclosing the cattle at night in a communal corral near the town. This provided the opportunity to use biodigesters as the most appropriate alternative technology for generating energy. The improvement of pastures -a component that was added to the project- creates a possibility for growth of the cattle in the same pasture areas, reducing pressure on forests, an important element for the sustainability of the project.

The decision was made to work with lagoon-type biodigesters, covered with a geo-membrane, as the logistical cost would be much more affordable and the installation simpler and faster. The project mapped the local companies and other stakeholders with the capacity and experience to provide the necessary service in accordance with the standards required.

VI.3. Process design, installation and implementation

The design and installation process involved several stages. These were:

1. **Community survey,** which involved:
   - A socio-economic description of the community, including income levels and monthly expenses by family, energy demand, payment capacity, amongst others.
   - An understanding of the major crops and types of agricultural and livestock waste.
   - The identification of the number of head of cattle near the town and measurement of the mount of manure generated daily in the corral.
   - Measurement of the waste generated in the kitchen of each house.
   - An evaluation of the type of system to be applied and additional elements to be considered, given the characteristics of the community, including access to water.
   - An assessment of the degree of interest of residents, the features of community organisation and identification of possible roles and functions.

2. **Geo-referencing of the Community**: A GPS geo-referenced map was developed and digitalised in AutoCAD, to be used as the basis for the technical dossier for the project and to design the extension of the secondary networks.

3. **Coordination Meeting** to report on progress with the project, agree upon upcoming activities, form the Communal Electrification Steering Group (GIEC) and conduct training activities.

4. **Preparation of the Technical Design** in conjunction with the Regional Department of Energyand Mines of San Martín to calculate the current and projected energy demand of the community, the scale of the biodigesters, the generation system and secondary networks, and to plan the implementation of the project.

5. **Purchase and Installation of the System**: Suppliers of biodigesters, generators and accessories for the installation of the system were identified and the project proceeded to acquire and install the system in a joint effort between the suppliers and the community.

6. **Management Model roll-out**: Administration, operation and maintenance of the system to be installed defined with local stakeholders to ensure sustainability. The executed model was adapted from the management model experimented for several years by Practical Action for hydraulic micro-hydro plants in Peru.

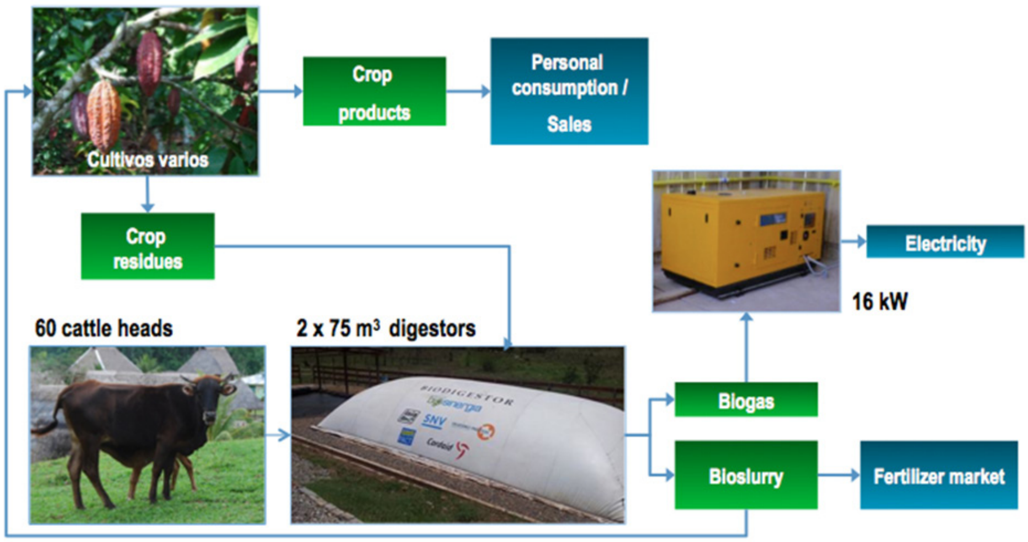


Figure 6.1

Operational Scheme for the System

Design and Dimensions

The technical design of the system was based on the data generated in the survey conducted at community level. In addition to the adjustment made to the cattle corral and the installation of a water pumping system with solar power -the latter being an additional component to the model not originally planned- and the electricity distribution networks throughout the community, the design was based on two key components:

1. Dimensioning of the Electricity Generation System and,
2. Dimensioning of the Biodigester System and related infrastructure.

The power of the generators was calculated using the aggregated demand for energy of the 42 houses (224 people) of Santa Rosillo, projected 20 years into the future. The power of the generator was calculated based on the following considerations:

- Domestic Demand, based on a family consumption of 400 W, according to the official standard in Peru as being applied by the Ministry of Energy, resulting in a total demand of 16,8 kW. For the purposes of calculating the capacity of the generator, factors of simultaneity and use were considered, decreasing the demand to 10,58 kW.

- Public Lighting, a load comprised of thirteen 70-watt neon bulbs installed in strategic locations in the community, for a total of 1,12 kW.

- Institutional Demand combining electricity demand by the school, the local community hall, the church and the medical post, an estimated total of 2 kW.

- Demand for Productive Uses, which did not yet exist when the project began; however, based on the characteristics of the community, its location and productive activities, it was assumed that the demand for productive uses in local businesses, including from mechanical and carpentry shops and miscellaneous businesses, would rapidly grow. For the purposes of the project, the demand for productive uses was estimated at 5 kW.

The design included a daytime demand (three times per week) and a nighttime demand (every day). The result was a demand of 12.4 kW as the required power. This assumed that the entire community would use energy as soon as the system began to operate.

Type of	Maximum	Daily Load			Nightly Load		
Load	Power (kW)	sf	uf	Power (kW)	sf	uf	Power (kW)
Domestic	16.80	0.20	0.50	1.68	0.70	0.90	10.58
Public Lighting	1.12	0.00	0.00	0.00	1.00	1.00	1.12
Institutional Demand	2.00	0.60	0.60	0.72	0.20	0.50	0.20
Productive Use	5.00	0.30	0.50	0.75	0.20	0.50	0.50
		Daily total		3.15	Nightly total		12.40

Sf: simultaneity factor, uf: use factor

Table 6.1 **Calculation of Power**

A projection of 10 years of use of the system was assumed, with an annual population growth rate of 2,6%, according to data from the National Statistics and Information Institute (INEI). According to projections made, the power required for the year 2021 would be 16 kW.

CURRENT POWER NEED	= 12,40 kW
POWER IN 2021	= 16,00 kW
POWER IN THE DESIGN	= 16,00 kW

Table 6.2 **Power in the Design**

Dimensioning of the Biodigester System

The biodigester system design was defined by calculating the amount of manure produced daily, obtaining an average production of 162 kilograms of fresh manure (from cows and horses) which is concentrated in the corral at night between 6 pm and 5 am. **Table 6.3** lists the main data:

Item	Unit	Amount
Total liquid volume of the biodigesters	m^3	150
Liquid volume of each biodigester (x 2)	m^3	75
Mixing Ratio	Manure : Water	1:6
Generator 1	kW	6
Generator 2	kW	10

Table 6.3 **General Data on the Installed Systems**

A mix ratio of 1:6 was calculated to prevent problems with solids within the biodigester and to make the mixture more liquid.

Two biodigesters with a liquid volume of 75 m^3 were used (made of 1.2 mm-thick PVC geo-membrane, reinforced with fabric) in order to have a back-up if any problem were to occur in one of the digesters, requiring maintenance.

Two generators were used; one 6 kW and one of 10 kW, in order to have a back-up and to adjust the use of energy to the demand, in an energy efficient fashion - flexibility in using the generators from 6 kW to 16 kW).

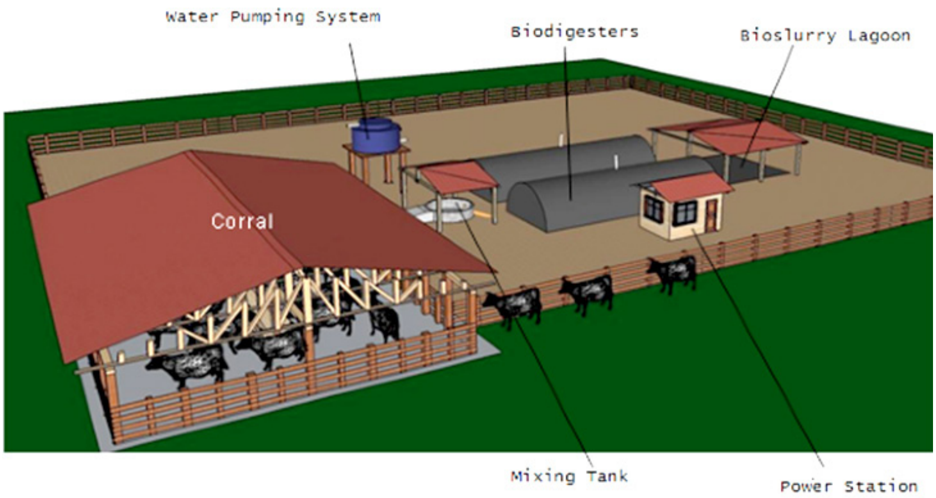


Figure 6.2 Visualisation of the Installed System

Management Model

The project entailed the design of a management model for the operation, administration and maintenance of the electrical service system by the community itself, in coordination with local authorities, making it sustainable over time. The proposal for the management model was intended to:

- Define the roles of the participating agencies and stakeholders.
- Promote a community-based business culture, in which decision-making is driven by the economic, social and environmental aspects of the service.
- Strengthen the local organisation through institutional consolidation of a business organisation that manages a sustainable service for the common good.

For this, the different stakeholders participating in the management model are:

The Communal Electrification Steering Committee (GIEC) - The purpose of this coordination and organisational body at the community level is to serve as a liaison between the implementing institutions and the community members. GIEC is comprised of community authorities and leaders elected in a general assembly of the community. Its major functions are:

- Serve as liaison between the community and the executing institutions for the project - SNV and Practical Action.
- Facilitate meetings with the community, the executing institutions and other agencies, such as the District Office of the Municipality, the Regional Government - DREM, service providers and others.
- Promote activities that are part of the project implementation: installation of systems, meetings and training of users, selection process for the Communal Energy Services Unit (USEC, see below), and others.

The GIEC will be in effect until the consolidation and implementation of the energy system. The USEC will then replace the GIEC in overseeing the operation and maintenance of the system.

The Communal Energy Services Unit (USEC) comprised of one or two individuals from the community with the appropriate skills, selected in the general assembly of the community and trained by the technical team. The USEC is responsible for conducting activities related to the operation, maintenance and administration of the system. It has a direct and ongoing relationship with the users, the community and municipal authorities. Its responsibilities include:

- Establish individual contracts with the users and collect the monthly fee.
- Deposit the monthly fees in a joint account.
- Be responsible for the proper administration, operation and maintenance of the electricity generation system.
- Prepare financial and operational reports, which should be presented every three months to the community and to the oversight body.
- Be part of the maintenance fund and participate in the joint account to be opened in a banking institution.

The Municipality - Being the closest entity to the community with legal status, the Municipality becomes the formal owner of the system. Through a contract, it will commission the USEC to be responsible for the operational and maintenance duties for the system. It will perform the following roles and duties:

- Represent the community members.
- Hire an operator and an administrator for the system, in coordination with the community assembly.
- Supervise the USEC in fulfilment of its responsibilities.
- Receive information from the USEC on the management, operation and administration of the electricity service on a quarterly basis.

The Users - These are the families that are direct beneficiaries of the electricity service from the system. The members of the community can decide whether they wish to be connected to the microgrid, which entails the following responsibilities:

- Manage the corral: two community members are designated for this on a weekly basis with a rotation across the community; this involves cleaning the corral and collecting the amount of manure required for feeding the biodigester; as a mandatory community task, this does not earn any compensation to those in charge.
- Sign individual contracts with the USEC for the supply of energy.
- Pay a monthly fee for the service - at present, households pay 10 sols per month (EUR 2.56) and shopkeepers 30 sols per month (EUR 7.69). A small portion of this fee is used to pay a montly stipend to the system operator while the rest of it goes to the maintenance fund
- Have a connection in their houses.
- Participate in the assembly of users and authorities.
- Fulfil the obligations indicated in the contract for supply of energy.
- Participate in activities to support the USEC, such as: maintenance of the energy generation system; cattle corral; biodigesters etc.
- The household installations are the responsibility of the users - depending on their own requirements.

Support and Oversight Unit - The GIEC, after its activities conclude, becomes the Oversight Unit, supervising the fulfilment of the activities of the USEC and the users. The oversight work is governed by the provisions in the regulations.

Maintenance Fund - The fee paid by the users is primarily used to compensate the operator and administrator of the system, pay logistical and administrative costs, and generate a fund which will be used to maintain the system, cover unforeseen costs and provide the capital needed for replacing the equipment over the long term (with complementary funds from the municipality).

Alongside these various assigned responsibilities, the implementation of the management model entailed the development of educational activities for all the stakeholders involved, including training on rational energy use, administration, operation and maintenance of the service etc. Executing institutions play the role of facilitators throughout the process, involving all stakeholders and providing recommendations on technical, legal, social and organisational aspects.

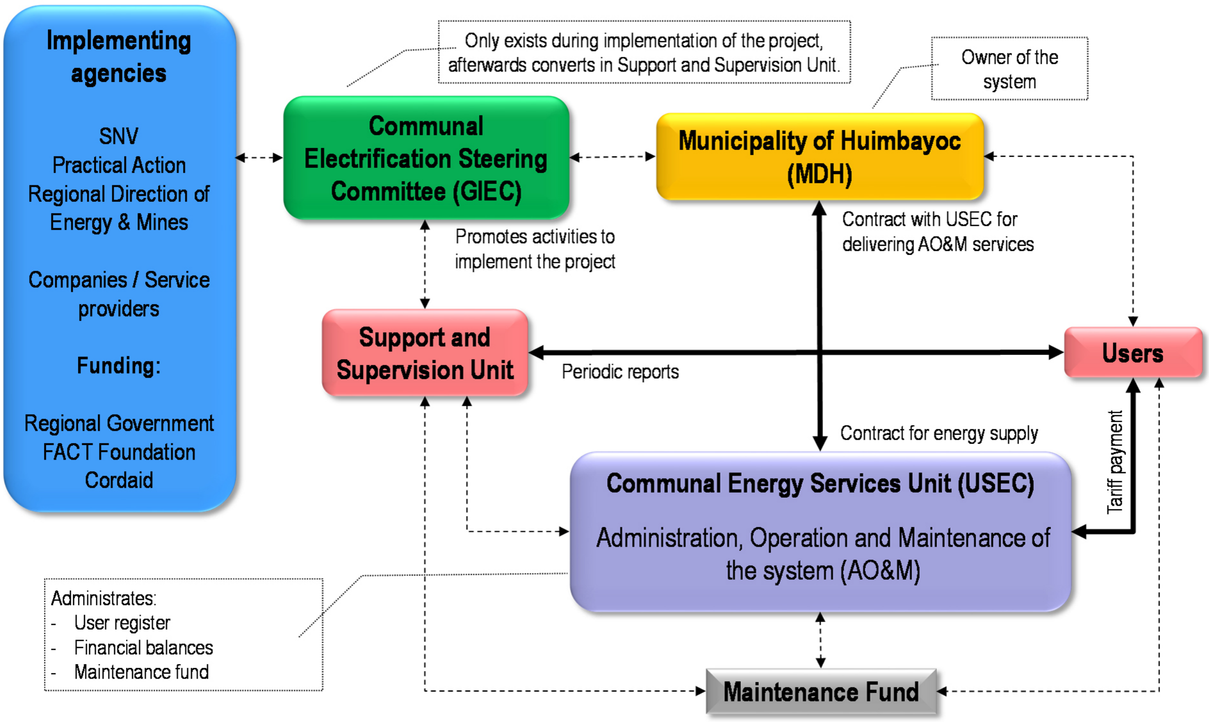


Figure 6.3 **Management Model**

VI.4. Results and impacts

Theintegrated nature of the proposed biogas solution has led to several significant impacts from an environmental, social and economic perspective:

Access to sustainable energy is the most visible impact of the implemented model. Although biogas consumption has remained relatively low initially (slightly less than 20 m^3 per day as measured after the installation of the system), mainly because Santa Rosillo's households presently own a limited number of electricals, the system has sufficient capacity to provide for the present and future energy needs of the entire community, and the use of energy in the domestic and public sectors is highly appreciated by the population, alongside its associated benefits. These benefits include large social and economic gains, including greater access to services like education and health services, so far inaccessible due to the remoteness of the community. In the longer run, the installed biogas system creates a greater potential for the creation of various businesses by community members -e.g. small carpentry shops- which will result in a productive use of energy for employment and income generation. Currently, the use of energy for production is limited to a small scale, mainly in juice vending, communal television, and few other services.

Climate change and environmental protection – The installed biodigesters also offer a large potential forclimate change mitigation through the reduction of methane emissions, one of the most potent GHGs. The system consumes an average of 18 m^3 of biogas per day -6570 m^3 of biogas annually- consisting for over 60% of methane gas that is no longer emitted to the environment. Considering that 2 m^3 of biogas replace approximately one litre of diesel, the consumption of biogas in the community replaces the use of 3,285 litres of diesel per year. In addition, the introduction of improved pastures for better cattle management reduces the pressure on surrounding forests and thereby contributes to avoided deforestation.

Sustainable agriculture

While the community did not make any productive use of the manure collected nightly in the corral before the project, the bioslurry obtained from the operation of the system is used as an organic fertilizer to increase local crop production. The project also promotes the use of bioslurry in the cultivation of pastures to improve cattle feed. Although the increased crop and pasture productivity associated with bioslurry application has not been measured scientifically, a possible outcome may be a reduction in the existing pressure on surrounding forests that are being converted to crops.

Costs and economic feasibility

The installation costs for the system, following the technical design, was S/.326,628.87 in Peruvian Soles (US$125,000), distributed as follows:

- Installation of the energy generation system: S/.226,060.40 (US$87,000), financed by the BioSynergy Project (donors: CORDAID; FACT Foundation).
- Installation of electricity networks: S/.100,568.47 (US$38,000), financed by the Regional Government of San Martin (GORESAM).

The model went through an extensive financial analysis, including a comparative study of different electrification scenarios for the community using several alternative energy sources, with the following results:

- The maximum energy produced over 2011-2031 will be: 619.040 kWh. Taking into account the costs of installation -infrastructure, transportation, personnel-O&M during 20 years, the cost of electricity reaches US$0.59/kWh.
- With modifications to the system -adapting generators available on the local market and without the need to install a solar pumping system for water, among others, the cost could down to US$0.41/kWh.
- Valuing the bioslurry at S/0.10/litre (US$0.036), the cost of energy decreases to US$0.10/kWh.
- A comparison to other alternatives that generate the same power in the same period, shows the following results:

  a. Diesel generator: US$0.58/kWh
  b. Photovoltaic solar energy: US$0.82/kWh
  c. Diesel/solar hybrid: US$0.51/kWh

Based on this analysis, biogas driven electrification seems to be a financially attractive alternative for communities with no prospect to be connected to the national grid and that cannot rely on other local energy sources like water falls that may allow to install a (mini) hydroelectric plant.

Figure 6.4 shows a comparison of different potential technologies for the electrification of isolated communities with no available water resources or connection to the national grid. It features the costs of installation, maintenance and replacement parts over a period of 20 years. Under these conditions, the implemented model (A1) appears to be competitive with an electrification model based on diesel generators, with the additional advantage of producing bioslurry, a free organic fertilizer associated with raised agricultural productivity. Provided that certain modifications are made (A2 and A3), biogas driven electrification appears to be more profitable than using diesel. Electrification using photovoltaic solar energy (C1: 99.5% reliability, 4 days of autonomy, 12 batteries) is much more costly (installed capacity of 16 kW for 5.3 hours/day => Emax required = 84,8 kWh/day; 12 kW required in Year 1 plus a 2,2% increase per year).

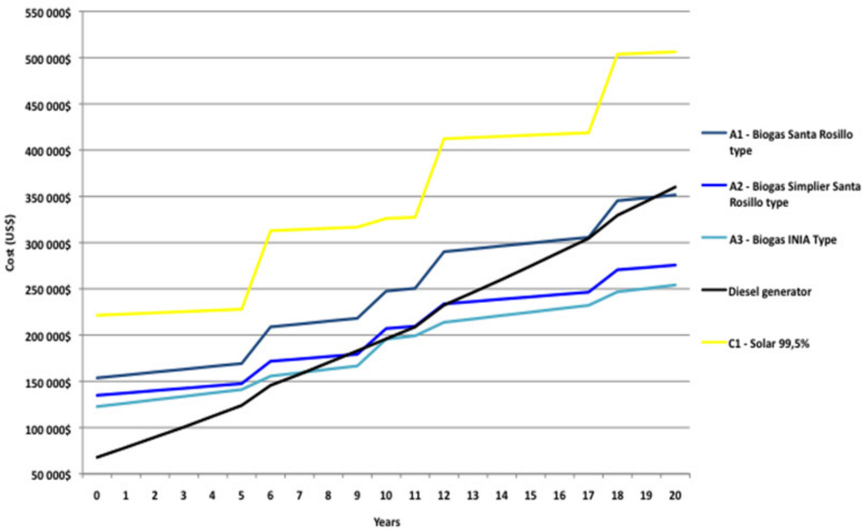


Figure 6.4 **Comparison of Costs of Different Technologies for Rural Electrification (not accounting for the value of bioslurry as an organic fertilizer)**

VI.5. Key factors for the success of productive biogas

As demonstrated by this project, the technology for biogas driven electrification exists, has been validated and can be competitive with alternatives including diesel generators and photovoltaic systems, particularly when the increased productivity and income derived from the application of bioslurry are considered. A number of critical factors have yet been identified to help ensure the success of similar schemes.

A solid organisation of the community, firstly, is a fundamental requirement in the development of such initiatives. If the community has organisational deficiencies, these should be addressed before the project can be executed.

A proper analysis of the local economy, furthermore, will help in the formulation of appropriate rates or fees for the electrical service to ensure that it can be accessed by the majority of the community without affecting the family economy or resulting in service interruptions.

An adequate management model must be formulated for each community, informed by an in-depth analysis of its main geographic, social, organizational and economic features. A proper management model is one that is understood by all the community members and in which all the residents agree on their role.

Local customs including internal organisation, hierarchy and cultural beliefs, should be carefully observed, especially at early implementation stages. This will help create local ownership of the project, and ensure it is not seen as a foreign and unwanted innovation. The project should thus be aligned with local practices to the greatest possible extentin its early implementation, and a proper adoption of the project by its beneficiaries be achieved, before the changes required for optimal system use can be made.

In all cases, **sustained communication with the community** will be needed, ensuring that all users areawareof the responsibilities that come along with the project. The opinion of residents should always be sought after before any important decision can be made. Any decision contravening local practices and preferences may indeed cause the project to fail.

Residents or members of the USEC would also benefit from **visiting other similar projects**, which may provide them with valuable information on appropriate management models that can be adjusted to their own situation. Once their system is in place, residents will also be able to compare their ownresults to those achieved by other communities, and will likely learn from their neighbours' difficulties and successes.

Given the isolation of the community, for the purposes of demonstration, research and strengthening of capacities, **an additional pilot project** was conducted in the «El Porvenir» Experimental Centre in the National Agrarian Innovation Institute (INIA) using a digester with a 60 m^3 liquid volume and a 5 kW gasoline generator adapted to biogas. This project serves as a demonstration model for companies, cooperatives and farms with potential for installing similar systems.

Figure 6.5

Additional pilot project
as conducted by the National Agrarian Innovation Institute (INIA), generating 5kW for productive use, including a grass cutting machine, a milking machine, and lighting of the stables during early milking hours. The bioslurry is being used in the surrounding agricultural research plots (Martijn Veen).

VI.6. Restrictive factors or barriers

Success factors come along with a number of constraints that are listed here for future scale-up.

As highlighted earlier, project replication is highly dependent on the degree of organisation of the community. This entails careful **community selection**, and a strong emphasis on the development and implementation of an **appropriate management model** alongside any technical considerations.

The use of biomass to generate electricity will generally involve changes in the **habits** of the residents of the community. Therefore, if community members are not clearly aware and favorable to these changes and aware of their newly assigned responsibilities, it is likely that the project will fail.

The availability of electricity in the community is currently limited to four hours at night, the amount of biogas produced being reliant on the **availability of biomass waste**, particularly cow manure. There must be a minimum number of animals year round for the system to work efficiently.

The operational logic of the technology is based on a **chain of activities** that are interconnected. If the farm and manure collection are not performed appropriately in the established timeframes, the production of biogas and, consequently, the generation of electricity, are affected.

There is still a question about how to **use the bioslurry** appropriately. The community is not used to applying fertilizers and while there has been training on its use, some residents remain reluctant to spread it on their fields. Difficulties have also been faced as regardsthe transport of bioslurry tofarmers' land. Further identified needs include training on making compost from bioslurry, and business development - i.e. sales of compost and bioslurry.

Due to the encountered **lack of companies** with sufficient capacity to install the system and all its components, the project team was obliged to ensure the system installation itself while facilitating the implementation of the management model. Although companies were involved and training was provided to local agencies -including the Regional Department of Energy, the municipality, the National Agrarian Innovation Institute and the Biofuel Technical Roundtable for Bioenergy- it would be preferable to create and train specialised companies for further scale-up and replication.

VI.7. Lessons learned

Implementation of the management model alongside the execution of the system itself. The management model, in order to achieve full sustainability, must be implemented before, during and after the implementation of the initial technical design and installation. Each phase has its own characteristics, but the beneficiaries must take ownership of the existing technology and, for this to happen, there must be ongoing work on building in a sustainable model for the administration, operation and maintenance of the system. Some delays were faced in the development of the project, especially in the fabrication of the biodigesters. This required changing suppliers. During the period of inactivity, members of the community lost enthusiasm and it was somewhat difficult to regain their support once activities resumed.

Development of knowledge products tailored to community member capacities.
Knowledge products such as informational guides and brochures should be prepared in line with the abilities and educational level of the targeted audience. This requires particular care and precaution: over the course of the BioSynergy project, it was realized that the formats initially chosen were excessively lengthy and unattractive to users. Their content had to be changed to be made more accessible. This was done through the adoption of a comic book format, with three comic books that were developed and released: one on energy efficiency, one on operation, and one on overall community management.

Effectiveness of the management model and fulfilment of obligations.
A rigorous application of the management model, and a timely interruption of the service to users failing to pay their imposed electricity rates reduces the overall risk of failure for the system. At the beginning of the project, numerous users refused to pay their monthly fee for electricity access. Once the service was cut and complaints were raisedat community meetings however, with reminders of their obligations made to users, improvements started being observed in collection rates. At present, there are virtually no shortfalls in the payments received for access to the electrical service.

Delays in the activities may affect the expectations of the population.
The delays faced in the installation of the system decreased expectations and, consequently, the desire to support the project activities among community members. To prevent such reactions, project planning must include support activities or a contingency plan in case the main project activities are delayed, especially those that are directly related to important dates for the community, particularly the launch of the electricity generation system.

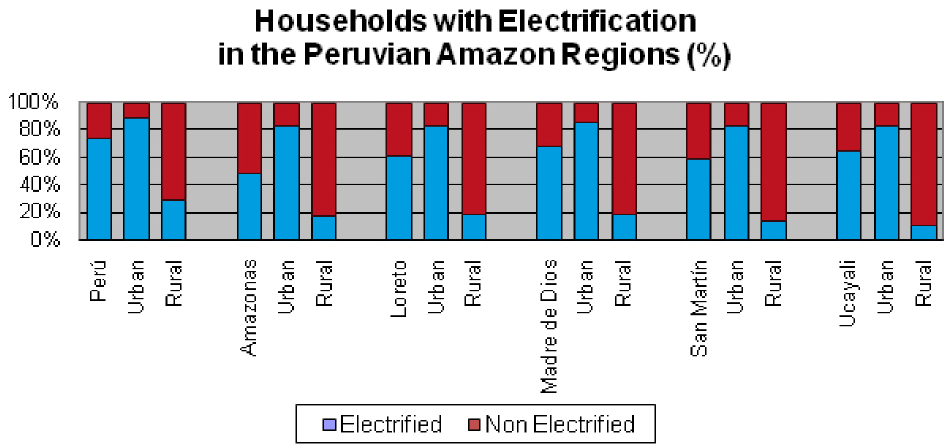
Proper and ongoing communication with the population.
Considering the antagonisms likely to be raised by any technology innovation introduced within a community and including some unknowns and behavioral changes (project managers had to deal with statements like "*produce electricity with cow dung, how is this even possible?*", resulting in "*…the executing institution just wants to earn money from the system*", "*it is all a farce; this system doesn't work*"), there must be a very clear and direct channel of communication with the community. Residents must not be intimated to communicate their doubts to the executing institution and must be able to rely on an established level of trust with the executors to clarify those doubts to prevent misunderstandings.

Seek quick, simple and economical solutions to technical problems.
During the project, some difficulties arose as regards the elimination of slurry from inside the biodigester, which were rapidly resolved through meetings with the executing team and the company that manufactured the biodigester, ultimately leading to a simple solution to the problem.

VI.8. Potential for replication

The Peruvian Amazon region represents almost 60% of the national territory (754.139,84 km²), but it is the area with the least population in the country, with approximately 2.538.247 inhabitants, representing around 9,3% of the national population including only Amazonas, Loreto, San Martín, Ucayali and Madre de Dios. Approximately 36% -910.444 inhabitants- of the population in the Amazon lives in rural communities and has limited access to basic services such as energy, water and sanitation.

According to the data collected by the 2007 census, 83% of rural families in the Amazon do not have access to electricity due to the difficulty and high cost of expanding the electrical distribution networks in this region. Of the 196,000 houses found in the area, only 32,000 have access to electricity, which is often derived from diesel generators that only operate temporarily or have stopped working for various reasons, including fuel shortages or improper maintenance. Furthermore, the transportation of fuel to those remote locations increases its price, making it impossible for isolated households to rely on this source of energy on a constant basis, despite any government subsidies. In houses that do not have access to sustained electricity services, families use candles or kerosene lamps for light, and batteries for the operation of flashlights and radios.



Source: Developed by authors, based on INEI data (2007)

Figure 6.6 **Households with Electrification in the Peruvian Amazon Regions**

In this context, the production of energy from biomass appears to be a promising option for rural electrification of the Amazon. The experience of Santa Rosillo has demonstrated that, even in the most isolated communities, electrification derived from biogas is a technically, socially and economically viable alternative compared to other technologies. With no prospects of accessing electricity by other means, those remote communities can obtain biomass from agricultural or livestock waste and use it to produce biogas, thereby meeting their energy needs. Several institutions could support the dissemination of biogas systems to these communities, including local NGOs and Regional Energy Agencies. Given the novelty of the technology used, these organizations will have to strengthen the capacities of users and ensure a sustained technical assistance.

As pointed earlier, such dissemination efforts will not be achieved without any challenges. In particular, a major difficulty to be overcome for further scale up is that of obtaining sufficient finance for the installed systems. At this stage indeed, biogas systems remain unaffordable for most communities. In Santa Rosillo for example, the average monthly budget of a household revolves between S/. 60 and 120 (EUR 15-34), far from what would be required for financing a biodigestor of the appropriate size. The cost of such projects, therefore, should fall upon the government when there is no other more attractive energy source available. In Peru, replication could be funded by the Department of Energy and Mines as part of its Energy Fund for Social Inclusion (FISE), which has started considering biogas as one of the potential means to expand energy access to vulnerable communities and sectors. This would help the FISE achieve its goal of reaching an additional 20% vulnerable people by 2014.

VI.9. Conclusions

The BioSynergy project in Santa Rosillo was based on a non-recoverable investment. The idea was to demonstrate that sufficient electricity could be generated through biogas production from local crop residues and cow dung to meet an entire community's energy demands for domestic, social and productive uses, this while making an optimal utilization of the associated by-products, namely bioslurry. This goal was achieved thanks to the relentless efforts of the beneficiary community.

The project thus demonstrates the feasibility of bringing in a technically, socially, environmentally and economically viable solution for rural electrification based on the use of locally available biomass residues. The viability of this model integrates costs of infrastructure, installation and transportation; however it excludes the costs of technical assistance.

In future replications, necessary cost reductions for the implemented model can be achieved by: (i) reducing the costs of technical assistance through a systematisation of the experience, manuals elaborated and methodologies applied; (ii) curtailing the installation costs by using locally available/cheaper equipment and building solely the minimum infrastructure needed. Biogas, it should be stressed, is only viable if it is a solution for many in a concentrated area. For those communities that cannot strictly rely on biomass, dual diesel/biogas systems are another pathway to be explored.

Proper design and implementation of the management model is key to the success of this type of project. Instigating institutions and companies responsible for establishing rural electrification with isolated systems should consider the management model as an integral part of these projects, which must go hand-in-hand with the technical aspects.

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For more information and downloads, see www.biosinergia.org.

VII. Analysis

Based on the five case studies outlined in the previous chapters, some valuable insights can be drawn for a further deployment of national and regional productive biogas markets worldwide. Using a methodology described in Chapter 1 and focusing on the four elements described hereunder, this Chapter proposes a broader analysis of FACT and SNV's experience in Vietnam, Honduras, Mali, Peru and Uganda.

While the aim of this publication is to make both concrete and widely applicable recommendations, a caveat should yet be placed on the generalization of the analysis offered: as will already have been noticed by the reader, this document only considers a limited sample of projects deployed by FACT and SNV to test the viability of productive biogas in various sectors and applications, offering a partial view of the development of the productive biogas sector worldwide. Each of the projects examined here mobilizes large resources unlikely to be available under non-pilot circumstances, generating high transaction costs that may be reduced if the installation of biogas systems was integrated into a specialized market, a social business and/or carried out at a greater scale. Alongside these projects, significant efforts to promote the establishment of productive biogas markets are also carried out under non-soft funded conditions, for example by Sistema BioBolsa in Mexico and Viogaz in Costa Rica.

VII.1. Appraisal criteria for analysis

The analysis delineated in this chapter relies on four major evaluation criteria:

1. **Sustainability** of the scheme, including technical, environmental, social, institutional and policy aspects (see Appendix I)
2. **Market readiness**
3. **Replication potential**
4. **Barriers for technology and market development**

1. **Sustainability** - Targeted in all cases, the sustainability of a productive biogas system can be defined as its ability to satisfy the technological, economic, social and environmental demands of its users on a long-term basis, in line with local capabilities and resources supported by a favorable enabling environment. For the purposes of the analysis, sustainability is broken down into five elements evaluated for each case study based on the subcriteria outlined in **Appendix I**.

2. **Market readiness** refers to the stage in which the deployment of productive biogas compares to a mature market of supply and demand, where all relevant actors -suppliers, customers, financiers, intermediaries, R&D, educators etc-understand and fulfill their roles and responsibilities as part of the market; when all these actors are aware of the technology and its applications, and when standards for quality and operation are formulated and enforced. Readiness is considered "zero" if none of this applies. Various degrees of market readiness can then be identified depending on the various stages of development of the four aforementioned appraisal criteria.

3. **Replication potential** - In line with the definition proposed by the Food and Agriculture Organization (FAO),[34] we define replicability or replication potential as *"the potential of a project, pilot or innovation to be replicated, scaled up, expanded, or adapted(...)"*.

   Testing the replication potential of a project will help *"determine whether one can achieve a certain outcome at scale. The replicability potential should be understood as the first step in deciding whether one can upscale a certain project"*, and is determined by the identification of those "niches" in which similar conditions exist and where a related use of biogas may be applied. For those projects for which such niches cannot be found, the required adjustments needed to make the project applicable to other areas should be made evident by those in charge of project execution and design.

4. **Barriers** designate the obstacles and constraints limiting the growth or maturation of productive biogas technologies and related market development. Barriers can be found at various levels, whether social and organizational, financial and economic, or institutional.

VII.2. Analysis

VII.2.1. Sustainability

1. Technical sustainability

Availability of local capacity for design, equipment sales, installation, operation and maintenance - Although a large variation may be noticed between cases in this regard, overall, capacity for designing, installing operating and maintaining biogas systems remains very low. Relative to other places, Vietnam appears slightly more experienced as a result of the prior dissemination of biogas systems across the country; yet, even there, the need for training masons and operators and to promote enhanced engineering skills is strongly emphasized. In Mali, Peru and Uganda, where biodigesters have been installed in a community setting without any previous introduction of biogas technologies, local capacity appears even more limited and suppliers remain virtually absent. Under such circumstances, capacity building for both suppliers and users appears to be a key requirement for any productive biogas market development.

Adaptation and suitability to the physiological context, including climate, geography, and edaphological conditions - Both the Peruvian and Ugandan cases described difficulties resulting from climatic and geographic constraints, as illustrated by the unexpected delays that arose from the rainy season in the Ssese Islands and the challenges faced in order to transport bio slurry from the biodigesters to the fields in the community of Santa Rosillo. This, however, was not the case in Honduras, Vietnam or Mali, where biodigesters havebeen located close to the processing plant or Multi Functional Platform infrastructure, and where any complications related to climatic conditions have been foreseen.

[34] Bogdanski, A. (2014, forthcoming) Evidence-based assessment of the sustainability and replicability of integrated food energy systems. A Guidance Document. Green Paper Series. FAO.

Long-term availability of feedstock and water - In all cases, the long-term availability of feedstock was taken as a point of departure for the design of the installed biogas system. Seasonal supply -coffee in Honduras; water hyacinth in Uganda- appears to be a slightly complicating factor, but in both cases, this additional constraint was eventually accounted for by the project, whether through temporary operation or co-digestion with other feedstock inputs.

Optimal use of biogas, bioslurry, and appropriate waste management - Out of the five case studies presented in this publication, three targeted the productive use of biogas as a primary goal. In Uganda, Mali and Peru indeed, the chief motivation behind the installation of biodigesters was that of producing energy for motive power, namely, the provision of electricity for the community of Santa Rosillo; fueling the Multi-Functional Platforms of several women groups in rural Mali, and the creation of battery charging and rice milling services for the residents of the Ssese Islands in Uganda. The installation of biogas systems in the coffee and pig farming industries in Honduras and Vietnam, by contrast, was above all driven by the need to treat effluent appropriately in order to reduce local pollution and comply with environmental standards.

While some correlation can be found between those various drivers and the degree to which biogas and bioslurry have been exploited in the projects so far, no general conclusions can be drawn in this regard. In Vietnam, for example, bioslurry and biogas have not yet found substantial applications, although both types of uses are currently being expanded. This must be contrasted with the case of Honduras where biogas has been integrated into COCAFELOL's production processes in order to reduce the company's fuel consumption -4,600 liters per year are currently being replaced- and thereby improve its carbon footprint. In Mali, Uganda or Peru, biogas is also being converted to diesel or electricity. In all cases however, the exploitation of biogas remains sub-optimal and there is room for improvement, as reflected by the operational data outlined in **Appendix II.3**. This applies even more when it comes to bioslurry use, with only Peru and Honduras mentioning a widespread application of the by-product as an organic fertilizer, either directly or through sales to other potential users. All projects, it can be noted, identify a need for bioslurry to be further integrated into an incentive-based system and/or a proper value chain.

2. Social sustainability

General awareness of biogas technology In all five case studies, awareness of biogas was virtually absent when the project started. Through training, demonstrations and capacity building, projects contributed to raising the local levels of knowledge and interest in the use and potentialities of biogas for productive purposes, several of them generating some additional demand. The extent to which new awareness was effectively created, however, has varied depending on the setting: unlike in Vietnam, where significant interest has been generated within the pig farming sector thanks to a partnership with the national government and the deployment of 9 productive biogas projects, awareness raising has been limited to the beneficiary community in Peru, Uganda and Mali, where only one project has been installed in a relatively isolated environment. Overall, it can be noted that schemes with a focus on market sectors implying high replicability -Honduras, Mali and Vietnam- seem to enhance awareness for market development quicker than cases focusing on specific communities.

Local appropriation of the technology by users, namely enterprises, farmers or community groups, appears to have been promoted in all cases, although the eventual level of ownership observed among project users has depended on the initial rationale, set-up, and overall effectiveness of the productive biogas scheme in place. In Peru for example, appropriation by users was high, thanks to their newly gained access to energy, as was the case among pig farming communities in Vietnam whom recognized the large effects of biogas systems on reducing local pollution. By contrast, interest in the Ssese Island's biogas project only started to emerge with the inclusion of rice milling services alongside the not-so-popular battery charging service initially offered.

Net employment generation effects have overall been limited. While the employment picture associated with productive biogas may appear somewhat bleak, it should be noted that biogas technologies are not aimed at employment generation, but at servicing energy and providing environmental and agricultural benefits for a minimum additional workload. Although productive biogas as such has limited employment effects, it should be seen that in the case of Vietnam for example, the reduction of odor pollution will help remove important bottlenecks for farming expansion countrywide. In Honduras also, productive biogas can help coffee producers meet the stringent environmental standards set by the green/fair trade production labels, preventing them from losing large market shares. In this view, productive biogas may be seen as an instrumental means for avoiding employment losses under increasingly tight environmental, climate and safety regulations, while also creating new opportunities for employment generation within the supply chain in a context of sector development.

Access to Energy - As revealed by the existing literature on this topic,[35] one of the primary benefits of biogas is its ability to create or enhance access to energy for isolated and resource poor communities. Two of the five projects were specifically targeting those. In Peru, the installation of a biogas system in the isolated community of Santa Rosillo demonstrates how biogas can be a financially attractive means (see **Appendix II.4** for a comparison with other energy sources) to provide a secure access to energy to an entire village. In Uganda also, even after the relative failure of biogas fueled battery charging services, the installation of a biodigestion system has helped unlock new energy to create a new productive service for the community, reducing its dependence on expensive mainland rice milling systems.

Food security - Besides the new services and direct benefits it supports, enhanced access to energy through biogas is also closely connected to food security, whether it is food availability (by potentially increasing the productivity of crops or agro-processing processes), food access (by allowing users to increase their income and/or savings) or food transformation and use.[36] The linkage between productive biogas and food security is illustrated by several of the case studies: in Peru for example, the newly acquired biogas system was found to have a positive impact on food supplies through the procurement of additional cooling products. In Mali, where energy access is directly related to food-processing activities, the replacement of expensive diesel by cheaper biogas is also deemed to have exerted a positive impact. Although in Honduras and Vietnam, energy access and food security were not prime motivations, in Uganda, energy access for consumptive use and agro-processing were the primary driver for the installation of digesters. In all cases, it can also be noted that any income saved -through reduced fuel consumption or increased energy efficiency- can potentially be used to buy more diverse and/or copious amounts of food by project beneficiaries.

[35] UN ESCAP, 2007; Al Seadi et al., 2008. Biogas Handbook.
[36] Kaygusuz et al., 2011; FAO, At a glance: the role of energy for food security, 2011.

Beyond these various channels, biogas systems' ability to contribute to food security could yet be enhanced further with a more extensive use of bioslurry as a fertilizer. Although the effects of bioslurry on agricultural productivity still require more in-depth investigations, a number of studies indeed highlight the positive effects of biogas effluent on the growth of several types of crops and cereals.[38]

The equitable distribution of workload and benefits from biogas and the potential inclusion of disadvantaged social groups, a crucial aspect in the determination of the broader development impacts of any energy-related projected,[38] was addressed to various degrees by the five cases. The fair distribution of benefits arising from the installation of biogas systems, and the inclusion of marginalized groups was considered mainly by those projects that targeted communities: in Peru or Mali for example, the equitable distribution of benefits was an important criterion in the community selection phase. In Peru, it led to the designation of the isolated and energy-poor community of Santa Rosillo as the beneficiary of the project, while in Mali, focus was placed on MFPs that use a gender sensitive design. In Honduras also, the gains realized through the installation of a biodigestion system were expected to benefit women who represent a significant share of the members of the COCAFELOL cooperative. For the more enterprise-oriented cases, a fair distribution of benefits was not a driving consideration in project design, although in Uganda, improving energy access by providing a battery charging service can be seen as beneficial for isolated communities on the islands. Overall, even for those projects that included women or other disadvantaged groups as beneficiaries like in Mali and Uganda, the projecttook current relations and values as baseline conditions and did not specifically aim at changing the gender balance. In most if not all cases, progress also remains to be made as regards the full and long-term inclusion of disadvantaged social groups and the monitoring and evaluation of not only the benefits delivered through the project, but also the potential negative externalities that result from it, for example, the impact of biogas production on the workload of operators.

3. Environmental sustainability

Improvement on air, water and soil quality - The case studies show that improvement of water quality and air quality -odor pollution in particular- can be a driving factor in the installation of biogas digesters for certain industries, for example in medium scale pig breeding in Vietnam and coffee production in Honduras. This appears particularly crucial in the context of strict environmental regulations and standards. In Peru, Uganda and Mali, the improvement of air and water quality was perceived to be a positive side effect. Soil enhancement was considered in Mali, a country characterized by long-term intercropping and small-scale jatropha production culture practices. Four of the projects make use of secondary sources. In all cases however, it may be useful to determine specific parameters for the monitoring and evaluation of those aspects, which may be seen as important benefits arising from biogas systems.[39]

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[37] Möller, K.; Stinner, W.; Deuker, A.; Leithold, G. 2008. Effects of different manuring systems with and without biogas digestion on nitrogen cycle and crop yield in mixed organic dairy farming systems; Svensson, K.; Odlare, M.; Pell, M., 2004. The fertilizing effect of compost and biogas residues from source separated household waste ; Odlare, M.; Pell, M.; Svensson, K., 2008. Changes in soil chemical and microbiological properties during 4 years of application of various organic residues.
[38] UNDP, 2008; Srinivasan, 2008.
[39] Srinivasan, 2008.

Greenhouse gas emission reductions through organic waste management have been reported by Vietnam and Honduras and have also been indicated in the case of Uganda, although they have not been properly measured (see **Appendix II.2**). In all cases, the use of biogas has also led to the replacement of traditional fuels, opening a potential access to carbon credits for these projects, whilst reducing the carbon footprint of the corresponding productive processes. The substitution of chemical fertilizer with bioslurry is another channel for future GHGe reductions, and the five examined cases thus suggest the potential contribution of biogas installations to climate change mitigation.

As hinted previously, it should yet be noted that **applications of bioslurry**, although considered in all projects, have rarely been investigated further, a need strongly emphasized by the existing scholarship and international experience on the matter, which have revealed mixed results and hurdles that remain to be addressed as far as by products management is concerned.[40] In China, for example, bioslurry production appears excessive with regards to the potential application on crops, raising the question of bioslurry treatment and storage.[41] In Vietnam, applications have been proposed but have not yet been implemented; in Peru, Mali and Uganda, the use of bioslurry as an organic fertilizer is currently being tested. End uses for bioslurry need to be explored in greater depth, as this may create an extra revenue stream and reduce feedstock input costs, in addition to recycling organic matter for soil fertility conservation purposes.

The effects of biogas systems on **ecosystem resilience** are not entirely clear and require further investigation. In Uganda, the use of water hyacinth as a feedstock has had a positive impact on surrounding ecosystems.The improvement of air, water and/or soil quality observed in several projects may also contribute to biodiversity conservation. Bioslurry, however, can also involve negative impacts, when discharged into waterways or lakes for example.[42]

4.Financial and economic sustainability

The **payback period** for each project, which ranged between 7 and 14 years,must be examined with regards to the initial project motivations. In Vietnam and Honduras, the installation of biogas systems was a response to environmental pressures and appeared cheaper than the cost of not intervening at all-which may involve legal proceedings; environmental fees or highly damaging pollution. In the other cases, the energy component was the primary focus, and it appears more difficult to determine whether biogas systems are the least-cost renewable energy option. In Peru, the costs per kWh appear high, and so are the required investments. All other renewable systems would yet have faced similarly high costs due to the isolated nature of the receiving village, as revealed by the comparison of energy prices outlined in **Appendix II.4**. The digesters installed in Mali were projected to have a payback period of 4 years, and would have qualified as the best renewable energy option under that scenario, had collection issues been avoided. In most cases, it is estimated that the revenues gained through potential bioslurry sales could make a large difference.

[40] See Möller et al., 2008; Odlare et al. 2008 and Svensson et al. 2004
[41] De Groot & Bogdanski, 2013 Bioslurry = Brown Gold?
[42] Ibid 41.

The affordability of investment for the project owner appears low in most cases, as revealed by **Appendix II.3**. In Honduras, installation costs were comparable with other investments in processing equipment; however, including transaction costs, the total investment remains substantial. In Peru, the biogas system, given the costs of the foreign equipment used, remains completely out of reach for the community with installations costs of over 100,000 USD. The biogas systems installed in Mali, although in absolute terms reasonably priced (55 USD/m^3 digester) remain unaffordable -their price is equal to 3 times the investment required for an MFP. In Uganda again, investment costs -25,000 USD per system- would be out of reach of a local private investment for agro-processing. In Vietnam finally, the chosen digesters, which used local design, were the cheapest available model on the market; expenses yet remain large for medium scale farmers. The relative cost of biogas systems for their users is therefore a key aspect of focus for future scale up and replication.

Access to financial services and adequate credit products including carbon finance is limited in all cases. In Honduras, a support was found via SNV who funded part of the equipment; the Peruvian project was fully supported, as were the projects implemented in Uganda and Mali. In Vietnam, government subsidies have not yet been obtained. As for future opportunities for accessing financial services and credit products, in Honduras the BCIE is now interested to provide loans to productive biogas projects while in Peru the local government has shown growing interest in supporting stand-alone projects where grid connection is not feasible (20,000 USD). In Mali, productive biogas projects could possibly find support at the Amader World Bank Rural Energy Fund and have already received some carbon credit funds. In Vietnam the VBARD might be interested, although pig farmers may also rely on their investment resources. In all five regions, traditional banks are likely to be reluctant to fund such projects, seen as excessively risky in the absence of prior experiences.

5. Public Policy-institutional sustainability

The national institutional and regulatory setup and the existing economic, environmental and energy policies do not facilitate the development of a productive biogas sector in Mali, Peru, Uganda or Honduras, with the exception of punitive measures for improper waste management. Most of the examined countries, it appears, are characterized by strong institutional barriers to the deployment of biogas or other types of renewable energy, including subsidized prices of fossil fuels. When environmental laws exist, like in Vietnam or in Honduras, they are seldom fully enforced. Dialogue and collaboration with public authorities thus appears critical for initiating the first steps of market development, as illustrated by the case of Vietnam, where the Ministry of Agriculture and Rural Development is increasingly supportive of the development of solutions to deal with pig waste in medium scale farms.

The existence of institutions or actors in training, education extension and advice is limited to non-existent in all but one of the countries. In Honduras and Peru, only a few academic institutions have the expertise to provide training. In Mali and Uganda, no institutions are working on productive biogas at this stage, although some could take up this role in the near future. In Vietnam, the institutional context appears slightly more favorable with some support from the Institute of Energy and the Ministry of Agriculture and Rural development. The emergence of some productive biogas technologies and service providers is yet noticeable in some countries, with for example VACVINA in Vietnam, Biogaz in Costa Rica, or Biobolsa in Mexico.

The institutional framework required for innovation is poorly developed in most of the countries, and does not facilitate biogas market and technology innovation processes, although public support is sometimes provided like for example in Peru. This is not to say that there are no research and development institutions that could be involved in productive biogas development such as the Zamorano Agricultural School in Honduras, the agricultural university La Molina in Peru, the Technical University of Hanoi in Vietnam, the Institut Polytechnique Rural in Mali, and the Makerere University in Uganda.

VII.2.2. Market readiness and market potential

Although the market readiness for productive biogas varied across cases -the Vietnamese and Honduran markets may be developed more readily given the strong demand for waste treatment that is currently being seen in driving economic sectors like the pig farming or coffee industries- none of the five case studies appeared to have an established and properly functioning productive biogas market at this stage. Few or no suppliers were available; potential customers did not know about the technology and its applications, resulting in limited demand; intermediaries like financiers, researchers or educators had not yet become involved. In none of the cases did standards operate for the productive biogas sector, nor the governments provide a conducive environment. All projects were implemented under grant support and entailed high transaction costs to cover awareness raising among customers, train suppliers, pilot potentially risky schemes, and monitor project results and impacts.

The potential market for productive biogas driven by environmental constraints and energy access needs is already significant: farmers, agro-processors and waste operators are faced with increasingly stringent legislation and standards on pollution or local pressures to reduce odor pollution and inhibited waste streams release. Environmental certifications in agro-processing industries like coffee and cocoa, in particular, will likely add wastewater treatment as part of their requirements. Other drivers like a contribution to sustainable agriculture using organic fertilizer could further enhance this potential. It seems that market development within defined business sectors -e.g. pig breeding, coffee processing or the palm oil industry- can make for a faster pace than feedstock dominated markets. From a high level perspective, one can notice that due to urbanization and higher income levels, a growing number of people depend on processed food from the agro-processing sector, which is expanding as a result.

SMEs and industries involved in relevant activities in turn require a greater input of raw agricultural products, creating positive growth prospects for productive biogas used in agro-processing.

VII.2.3 Replication potential

Two out of the five case studies -Peru and Uganda- describe relatively confined initiatives developed as trials to validate a community based biogas scheme. In both cases, biogas proved to be a sustainable energy source for meeting users' electricity needs. These initiatives, although isolated, could be disseminated in their respective countries, or even further, as noted by the Peruvian case study which stresses the potential role for biogas in rural electrification across isolated regions in Latin America. Replication, however, will only be feasible if innovative financing models are developed or if public funding is deployed to provide for the high installation costs of such schemes (see **Appendix II.4**).

The Honduras, Vietnam and Mali cases, on the other hand, consisted in the installation of multiple biogas production systems within an existing kind of industry -the coffee processing and the medium scale pig farming sectors for Honduras and Vietnam- or subsector, as illustrated by the Multi Functional Platforms in Mali. From a market development standpoint, the latter approach appears more attractive and the potential for dissemination higher. If potential users belong to a specific sector, especially a growing sector with a strong internal organization, existing marketing and communication channels can be used to promote productive biogas, which is likely to be expand faster.

In these cases also, the replication potential will be largely determined by the reduction of installation and operational costs, which involve substantial transaction costs at this early stage of development. Lower costs will likely result from economies of scale related to further market development.

Conditions for market development both on the supplier and the customer sides include:

For the SMEs and end users:

- Affordable pricing of technology;
- Access to finance;
- Availability and accessibility of reliable technologies and spare parts;
- Availability and accessibility of training and technical assistance services;
- Demonstrated added value of the technology, including economic, social and/or environmental benefits.

For the biogas service provider:

- Existing demand and sufficient potential demand for growth;
- Potential to move from a donor-based market to a more autonomous market ensuring supply chain sustainability when subsidies are no longer accessible or are significantly reduced;
- Sufficiently scaled markets to justify private investments in stocking spare parts and technical assistance services deployment;
- Supportive actions or policies from local and national governments, including the design and enforcement of environmental and sanitation standards, support to the introduction biogas in rural electrification projects, and potential tax exemptions for biogas technologies.

VII.2.4. Barriers for technology and market deployment

The main barriers identified by project stakeholders can be listed as follows:

Limited awareness - Even in slightly more experienced markets like Vietnam, there is a large void in the information available to potential customers as regards the benefits arising from the installation of productive biogas systems in view of their specific needs and activities. This void is even larger when it comes to other actors that may facilitate the emergence of a market for productive biogas. Training of intermediaries, financiers and investors is therefore a crucial step for further market development in the examined countries.

Service and technology providers - Across the wide range of potential productive biogas users, very few have access to a reliable and proven technology available commercially and at affordable costs. The same situation holds as regards the availability of after sales services and spare parts. Here, market development and the generation and exchange of new knowledge appears critical. Once suppliers become more numerous and better resourced –in both knowledge and technology- more actors will be willing to fulfill their role as intermediaries.

Lack of access to funding - As private development funds support the development of large scale industrial biogas markets, and donor focuslies on the domestic sector, the "missing middle" has no access to the appropriate mix of public-private financing to establish and scale an actual productive biogas sector. Funding for the installation of productive biogas systems remains absent or highly restrictive, that is, limited to special programmatic funding of limited relevance for targeted groups of customers like SMEs, cooperatives or waste operators. Access to credit facilities for biogas products appears equally limited. Cooperatives and waste operators, given their close relationship with local and national governments and funds that may be able to roll out or identify additional resources, may play an important role as facilitators in this context. Additionally, in some specific sectors like small dairy production in East and West Africa, linkages with credit facilities exist and could provide opportunities for sector-based productive gas investments. This includes supporting both market development and further research and development.

Public policy and institutional environment - Among the examined countries, none possessed a favorable regulatory framework or well-defined incentives for productive biogas. None of the case studies -all pilot projects aimed at trialing a innovative biogas concept within a given community or sector, had initiated any advocacy measures at project closure. Only the Peruvian BioSynergy project was conducted with the technical support of the Regional Department of Energy and Mines, while the Vietnamese scheme was followed with some interest by the national government, which encouraged SNV to explore the potential use of biodigesters for pig waste treatment although it did not provide any formal support. In order to advocate for the development of more conducive policies, project leaders need to connect with other potential biogas stakeholders at the local or national level in order to communicate the key benefits that can derive from productive biogas to the relevant authorities and facilitators. Further details on the route to follow to promote an enabling environment for productive biogas market development are outlined in Chapter VIII.

VIII. Conclusions

The conclusions hereunder are based on the five case studies carried out by SNV and FACT with their partners. All were projects aimed at testing or demonstrating the feasibility of productive biogas for a new application and/or usage, rather than scaled-up investments in a commercially viable sector. The conclusions reflect the opportunities and limitations associated with this approach.[43]

VIII.1. Viability

In all five case studies, productive biogas has proven to be an effective and financially attractive technology for environment pollution control and/or stand-alone renewable energy supply when compared to other alternative technologies and provided that transaction costs -namely, the additional installation costs arising from the absence of any previously existing market structures, such as costs related to technology imports, awareness raising, suppliers and installers search etc- are left out. Payback appears moderately appealing at this stage. The end uses of bioslurry in either sales or direct application on crops couldhelp improve such results and prospects by securing an added income stream for the projects and/or providing additional rewards to users. Biogas installations' ability to reduce GHG emissions through organic waste management and fuel replacement should be regarded as a key opportunity for increased financial sustainability, with the potential integration of productive biogas schemes into carbon accounting schemes opening access to carbon credits.

VIII.2. Cross cutting issues

Although not directly measured in all cases, it is clear that the installation of biogas systems has had a direct and positive impact on the **environment by** reducing air, soil and/or water pollution, reflecting the scholarly findings in this regard.[44] **Sanitation effects** through the reduction of disease vectors like insects and rodents have not been recorded but should be further investigated.[45] This requires to place a stronger emphasis on the **monitoring and evaluation** of the projects, which should be systematically integrated into project design.

While the contribution of bioslurry to the **sustenance of agriculture**, and hence to food security, is still being tested by several projects, this relationship has been assessed externally through agricultural trials,[46] and documented experiences are becoming available through the FAO or Hivos. Markets for bioslurry already exist in countries like Bolivia and Peru, with high trade prices due to its easy application and booster effect on agricultural crops.

[43] In other sectors, such as the palm oil industries biogas (covered lagoons) of Honduras, large scale biodigesters appear to be commercially viable, but this experience is not included here.
[44] Srinivasan, 2008; Al Seadi et al., 2008
[45] See De Groot & Bogdanski, 2013.
[46] See for example Arthurson, V., Energies 2009. Closing the Global Energy and Nutrient Cycles through Application of Biogas Residue to Agricultural Land – Potential Benefits and Drawbacks; Möller, 2008, Odlare et al., 2008.
[47] See for example De Groot & Bogdanski, 2013.

Access to renewable energy was a primary driver in several of the cases, and positive results have been clearly demonstrated in this regard. The unique features of productive biogas as a source of energy delivered on demand and with the ability to be stored could yet be further leveraged by the examined projects. Summing up, it appears that:

1. Although in this first stage of development, projects have faced some learning issues and have been characterized by high investment costs, putting transaction costs aside, there are clear indications that productive biogas technologies are a **financially attractive option** for environmental pollution control, and renewable energy supply. It is expected that this potential will be significantly enhanced through the development of national and/or regional supply chains and markets for biodigestion systems, as well as further research into bioslurry applications and greenhouse gas emissions reductions through biogas systems.

2. As illustrated by the growing interest noticed among users as a result of several of the projects, there is a **large potential to increase the demand** for productive biogas by raising awareness on the multiple benefits of biogas systems and increasing the affordability and efficiency of such systems.

3. Many **barriers** yet remain to be overcome to reduce transaction costs and promote greater market deployment of productive biogas: customer awareness is limited, technical skills are lacking, and suppliers, financers and intermediaries remain dispersed. In most countries, the current policy and institutional framework does not create a level-playing field, and there is little incentive for installing biogas systems. The provision of non-recoverable finance may therefore be required, especially for strengthening sector support.

VIII.3. Recommendations

VIII.3.1. Institutional context

Given the critical importance of environmental, agriculture and energy policies for biogas market development, such policies need tobe further developed so as to promote a more favorable enabling environment for productive biogas. Some key measures in that sense include:

- The design and enforcement of environmental policies and/or waste disposal policies for farms, agro-processing companies and waste operators;
- The design and enforcement of fuelwood policies against indiscriminate use by rural institutions and large heat consumers; the use of organic residues for energy production should also be incentivized;
- The design and enforcement of soil conservation policies promoting the use of organic fertilizers as an alternative to chemical fertilizers;
- Government support for productive biogas as a RE solution assisting rural electrification and grid stability;
- The inclusion of biogas power into existing or planned feed-in-tariffs;
- The application of taxation incentives for biogas as a RE technology;
- Greater government support to training programs and R&D in this area;
- Open funding lines for RE systems, environmental improvements and soil fertilizers for productive biogas.

In order to advocate such policies and regulations at a government level, productive biogas actors and stakeholders should organize as a “sector” by forming networks, associations or other collective structures. Members of such alliances should include suppliers, consumer and producer associations, financial and educational institutions as well as other intermediaries. Red Biolac, a network of institutions promoting applied research and advocacy around the use of biodigesters for the treatment and management of organic waste across Latin America, is one example of this sector development approach.

A roadmap of activities for such networks can be outlined as follows:

Advocacy - Network members should initiate a dialogue with local/national authorities stressing the large potential benefits of productive biogas for food security; local water and air quality; reduced chemical fertilizer use; enhanced sanitation; reduced GHG emissions and other cross-cutting development goals. Government support could be spurred by visits to neighbor countries with existing pilots or more advanced productive biogas sectors.

Education of potential productive biogas end users or promoters should cover the basic technical features of biogas, potential costs and the associated benefits. Such information should be made widely available to potential customers. One recommended strategy consists in organizing training courses for sectors where productive biogas could potentially become an attractive option for waste treatment and/or energy generation, like for slaughterhouses. Other means to reach out to potential end users and promoters include publications, pilot schemes and exchange visits.

Knowledge sharing - Given the incipient nature of productive biogas worldwide, many issues, both technical and non-technical, remain to be addressed, as highlighted by the case studies. Enhanced knowledge will result from a longer operation of productive biogas systems. Active efforts should also be directed towards active knowledge sharing, and could notably involve business to business (B2B), which has demonstrated its worth in other sectors.

VIII.3.2. Technology

The case studies have clearly illustrated that productive biogas technology is a viable option for waste management, environment protection, energy security, organic farming and enhanced quality of life of end users. All five cases have resulted in a certain degree of innovation. However, some important technical challenges for a greater deployment of productive biogas remain, calling for:

- Designing customized and integrated solutions, increasing benefits and reducing costs, and building upon customer capacities and needs. Training, knowledge management and local capacity building should be part of the technological package for each project.
- Determining optimal end use of products and by-products -biogas and bioslurry, and their competitiveness with alternative products at the stage of project design, in collaboration with end users. Appropriate waste management -e.g. through lagoons or wetlands- should be considered as part of the same process.

- Past the pilot stage, there is a crucial need to cut down on investment by limiting equipment expenses by avoiding imported technologies and supporting the strengthening of local supplier networks, or through trade-offs between digester lifetime and quality.

- A close monitoring is key for promoting learning and greater sustainability.

VIII.3.3. Funding/Finance

While there is a recognized need for piloting new productive biogas concepts and testing novel ideas, which may require a high concentration of resources and non-recoverable expenses, experience shows that grant funding as opposed to investment usually does not guarantee the sustainability of productive biogas over the long run.

It is therefore recommended that acomprehensive financial analysis of the returns on investment for each digester be undertaken to ensure that only viable ones are constructed. Grant funding or subsidies should only be sourced or applied for if the sustainability and business case of the scheme are clearly seen, which can be facilitated by developing a comprehensive value chain for bioslurry or other supplementary income streams making the projects more viable.

In the case of biogas for electricity generation in isolated communities, subsidy can however be conceived as a government responsibility to provide universal access to basic services. Under such circumstances, the government may be approached and asked to provide for at least some of the installation costs, leaving the community responsible for system maintenance.

For all productive biogas schemes, business plans should be developed, submitted and discussed with local Micro Financial institutions (MFI) in order to obtain additional credit to users and/or producers. Carbon finance should be considered as another potential revenue stream: despite the current difficulties involved in obtaining carbon credits for biogas schemes, successful precedents exist, and registration with the voluntary carbon market was for example reached by SNV's Domestic Biogas Program in Vietnam in 2012.

The financial sustainability of productive biogas schemes can finally be enhanced by adopting flexible and/or step-wise approaches, leaving room for accommodating unexpected constraints and challenges to avoid sunk investments.

Overall, for productive biogas to become a viable and sustainable sector, existing and future schemes will have to prove successful in offering a least cost environmental clean-up solution and/or a viable business for energy and organic fertilizer production. Proven viability is to be actively communicated to potential investors in order to create greater confidence in the sector.

VIII.3.4. Sustainability and project design

The sustainability of a productive biogas scheme can only be guaranteed if all the key elements of sustainability (see **Appendix I**) have been carefully assessed before embarking upon the intervention. Alongside technical and financial considerations, productive biogas schemes should, from the start, incorporate a rigorous socio-economic analysis covering availability of supplies, rates, incomes, seasonal variations, workload and livelihood strategies of the beneficiary families and enterprises, as well as end user expectations and needs. Preliminary research should also include a comparison of the costs and benefits of biogas with those of other renewable energy options as well as petrol and diesel.

Resolving any developmental contradictions, for example by optimizing the harvesting of a feedstock like water hyacinth without creating the impression among end users that the expansion of invasive aliens is being promoted, and ensuring that projects are inclusive and strongly supported by end users appears critical. This entails clearly defining the social, economic and environmental impacts of the scheme and how these can be articulated and promoted at the start of project design. Such goals should be defined in collaboration with end users, and be informed by and embedded in broader development policies.

Recognizing that at this stage, productive biogas applications and technology remain in most cases unknown by potential customers and intermediaries, and that in certain groups resistances may be strong, expectations management, communication and trust building between project advisors and users are key for productive biogas systems' sustainability.

Often insufficiently addressed, equity issues should receive a closer attention in project design, which ought to ensure a fair distribution of the benefits and workload arising from waste treatment and biogas production among genders and community groups. The installation of a productive biogas system, although it cannot always promote a greater inclusion of marginalized groups, should not exacerbate gender and socio-economic disparities.

VIII.3.5. Environmental sustainability

Beyond compliance with national regulations, productive biogas schemes should integrate international best practices and sustainability standards, including wastewater standards and appropriate nutrient recycling.

In a context of emerging climate policies and governance, productive biogas schemes could become part of carbon footprinting strategies and should target GHG emissions reductions more effectively. A better grasp on how to gain access to carbon credits appears critical for current and future projects.

VIII.3.6. Replication

Even at a pilot stage, replication should be a driving concern. Most of the pilot cases demonstrate that replication is possible with some adaptations to other contexts. Important objectives for the sector in this view are to fine-tune design and modalities of digesters while developing a solid knowledge base drawing on global experience. This requires to place a greater emphasis on documenting project successes, struggles and failures.

Although the case studies benefited from "incubating" conditions, it appears necessary to test the sensitivity of such projects to less optimal conditions and to determine whether the same levels of input mix/output could be sustained.

VIII.4. Future horizon of productive biogas

While capacities are being strengthened and technological innovations tested, interest in productive biogas is growing worldwide. Expectations are high: a doubling of the market volume is foreseen within the next decade, with most growth expected in Asia, Latin America and Africa.

As revealed by the previous chapters, market development for productive biogas nonetheless represents a real challenge for the future. Recognizing what remains to be achieved, recommendations have been outlined for the development of both supply and demand and on efforts towards creating a more favorable enabling environment. Market development will require the involvement and contribution of the broadest possible range of stakeholders, including suppliers, operators, financial institutions, NGOs, knowledge centers, local and national governments.

In this process of building active networks and markets for the dissemination of productive biogas, the role of NGOs and other support organizations like SNV, FACT and their partners includes:

1. Linking biogas entrepreneurs in order to build extensive supply networks;
2. Raising awareness around the multiple and cross-sector benefits of productive biogas to raise end-user demand;
3. Ensuring education and technical assistance for local users, producers and retailers, and develop innovative funding models to make productive biogas more accessible;
4. Highlighting the potential role of productive biogas in meeting multiple development goals and facilitate synergies with other sectors like food security or water and sanitation;
5. Promoting sustainable legislation and incentives, and remove institutional barriers to facilitate the development of productive biogas.

Underlying all these actions, the importance of **knowledge development** and **sharing** must also be stressed. Enhanced communication among productive biogas actors, and a greater availability of information for all potential stakeholders should be targeted as primary drivers for market development.

Through this publication, SNV, Fact Foundation and their partners hope to have contributed to such goals.

IX. Glossary

AMADER (Mali) - Agence Malienne pour le Développement de l'Energie Domestique et de l'Electrification Rurale, the Malian Agency for the Development of Domestic Energy and Rural Electrification.

AMPROCAL (Honduras) - Asociación de Mujeres Procesadoras de Café la Labor, the Labor Association of Women Coffee Processors.

ANADEB (Mali) - Agence Nationale du Développement des Biocarburants, i.e. the National Agency for the Development of Biofuels.

Anaerobic digestion - A microbiological process of decomposition of organic matter, in the complete absence of oxygen, carried out by the concerted action of a wide range of micro-organisms. Anaerobic digestion has two main end products: biogas and bioslurry. The process is common to many natural environments and it is applied today to produce biogas in airproof reactor tanks, commonly named digesters.

Barriers (constraints/obstacles) - Barriers are referred to as the obstacles and constraints limiting the growth or maturation of productive biogas technologies and related market development. Barriers can be found at various levels, social/organizational, financial/economic, policy and institutional.

Biogas - A combustible gas derived from the decomposition of organic waste under anaerobic conditions. Biogas normally consists of 50-60% methane (CH_4) as well carbon dioxide (CO_2) and may include small amounts of hydrogen sulphide H_2S) moisture and siloxanes.

(Bio)slurry/effluent/digestate - The liquid or gas discharged from a process or chemical reactor, usually containing digestate from that process. Bioslurry has a high nutrient content, and can therefore be used as manure for crops, soil conditioners and feed for animal and fish.

BOD/Biochemical Oxygen Demand - The amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at a certain temperature over a specific time period.

Carbon footprint - Total amount of greenhouse gas emissions (GHGe) caused by a given entity. It can be measured by undertaking a GHGe assessment or carbon accounting. Biogas production contributes to reducing organizations' carbon footprint by recycling organic waste that would otherwise have released GHGe in the atmosphere and by providing a renewable alternative to fossil fuels.

COCAFELOL (Honduras) - Cooperativa Cafetalera Ecológica La Labor Lda, La Labor Ocotepeque Ecological Coffee Cooperative, Limited.

COD/Chemical Oxygen Demand - The standard method for indirect measurements of the amount of pollution -which cannot be oxidized biologically- in a sample of water.

Coffee wastewater - A by-product of coffee processing. Its treatment and disposal is an important environmental consideration for coffee processing as wastewater is a form of industrial water pollution.

Compensation tank - The compensation tank is an important part of the digester that regulates the pressure in the digester tank through the liquid that will be pushed in and out of the tank.

Demucilage (coffee production) - Process through which the sticky fruit pulp, or mucilage, is removed from freshly picked coffee beans by scrubbing in machines.

Depth of discharge (of a battery) - An alternate method to indicate a battery's state of charge.

DLP (Vietnam) - Department of Livestock Production.

DREM (Peru) - Dirección Regional de Energía y Minas de San Martín, i.e. the Regional Office of Energy and Mines of San Martín.

EEP Mekong - The Energy and Environment Partnership Programme With the Mekong Region (EEP Mekong) (2009-2012) is funded by the Ministry for Foreign Affairs of Finland and the Nordic Development Fund.

Feedstock/Substrate - Any material that is converted to another form or product. In the case of biogas, this includes various types of organic waste such as manure, sewage, municipal waste, plant material or crop residues.

GECI (Vietnam) - Green Energy Consultancy Investment.

GHG - greenhouse gases.

GIEC (Peru) - Grupo Impulsor de Electrificación Comunal, Communal Electrification Steering Committee.

Greenhouse gas (GHG) - Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other GHGs include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Hydraulic retention time - A measure of the average length of time that a soluble compound remains in a constructed bioreactor -here biodigester. It corresponds to the volume of the aeration tank divided by the feedstock flow rate.

IE (Vietnam) - Institute of Energy.

IIRR - International Institute for Rural Reconstruction.

INEI (Peru) - Instituto Nacional de Estadística e Informática, i.e. the National Institute of Statistics and Computer Science.

INIA (Peru) - Instituto Nacional de Innovación Agraria, National Agrarian Innovation Institute.

kW - kilo Watt.

kg - kilogramme.

LPG - Liquified petroleum gas.

MARD (Vietnam) - Ministry of Agriculture and Rural Development of Vietnam.

Market readiness - Refers to the stage in which the deployment of productive biogas compares to a mature market of supply and demand, with available suppliers, financers and intermediaries, regulations and demand.

MBSA (Mali) - Mali Biocarburant SA, i.e. Mali Biofuels Inc.

MFP - The Multifunction Platform is a concept and structure developed by UNDP and deployed in a growing number of West African countries, as well as Tanzania and Zambia. MFPs allow to mechanize a range of productive tasks such as grain milling, reducing the labor burden for women who usually perform these tasks.

MOIT (Vietnam) - Ministry of Investment and Trade.

Multifunctional platform (MFP) - A stand-alone power unit providing mechanical and electrical energy access for rural communities. It consists of a low speed diesel engine that can drive a number of applications such as cereal mills, oil presses or alternators to recharge batteries. An MFP can free up time by mechanizing intensive tasks that disproportionately fall on women and girls.

PFR - Plug flow reactor.

Plug flow reactor (PFR) - A continuous, flowing system of cylindrical geometry in which one or more fluid reagents are pumped and no mixing occurs. The chemical reaction proceeds as the reagents travel through the PFR. It is to be contrasted with a continuous stirred-tank reactor (CSTR), describing a tank reactor equipped with an impeller that stirs reagents to ensure proper mixing.

Productive biogas - Application of anaerobic digestion technology appropriate to provide waste management, nutrient recycling and renewable energy services supporting economic activities of entrepreneurs, SMEs and institutions that are neither domestic nor industrial.

PTFM (Mali) - Programme Plateformes Multifonctionelles, i.e. the Multifunctional Platform Programme.

PVC - Poly(vinyl chloride), the third most widely used plastic.

Replication potential (replicability) - The replication potential of a project is determined by the identification of those "niches" in which similar conditions exist and where a similar use of biogas could be applied.

SEI - Stockholm Environment Institute.

SME - Small and medium scale entrepreneur.

Sustainability - The sustainability of a productive biogas systems refers to its ability to satisfy the economic, social and environmental demands of its users on a long-term basis and in line with local capabilities and resources.

USEC (Peru) - Unidad de Servicios Energéticos Comunales, Communal Energy Services Unit.

VBA (Vietnam) - Vietnam Biogas Association.

W - Watt.

Wet processing (of coffee) - Coffee processing in which the fruit covering the seeds/beans is removed before they are dried, requiring the use of substantial amounts of water.

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XI. Appendices

XI.1. Appendix I - Sustainability criteria for productive biogas systems

Technical sustainability	Availability of local capacity for design, equipment, installation, operation and maintenance of a productive biogas system
	Adaptation and suitability to the physiological context, including geography, climate, edaphologic conditions etc.
	Long-term availability of feedstock and water
	Optimal use of applications of biogas & bioslurry
	Appropriate waste management
Social sustainability	General awareness of biogas technology
	Local appropriation of technology by the users
	Net employment and income generation potential
	Contribution to access to energy
	Contribution to food security
	Equitable distribution of benefits and workload *(across genders & socio-economic groups)* and inclusion of disadvantaged groups
Environmental sustainability	Improvement on air, water and soil quality
	GHG emissions mitigation
	Appropriate nutrient recycling (bioslurry)
	Contribution to ecosystem resilience *(biodiversity & forest conservation)*
Economic/financial sustainability	Payback period
	Affordability of investment for the project owner
	Access to financial services and adequate credit products (including carbon finance)
Policy/institutional sustainability	Existence of enabling economic, environmental and energy policies and framework
	Existence of institutions and actors in training/education, extension/advice
	Institutional support for innovation (R&D)

XI.2. Appendix II - General data on case studies

Appendix II.1. Biodigester design and characteristics

	Vietnam	Uganda	Honduras	Mali	Peru
Biodigester model	Medium scale plug flow digester	Plug flow biodigester	Upflow digester	Plug flow digester (flexible fibre-reinforced PVC)	Lagoon type biodigesters
Feedstock used	Pig manure	Water hyacinth, cow manure	Coffee wastewater	Cattle dung + later on other kinds e.g. jatropha presscake	Horse + cow manure and crop residues?
Required energy production (kW)	-	9.7	-	Approx. 4	Current: 12.40 Future (2021):16.
Required daily gas production (m^3/d)	-	55 (Contention rate: 1.4)	-	6 (to replace approx. 3L of diesel/d, avg 60%)	-
Built digester volume (m^3)	50-500 (Modules: 75-100-125)	183	48 + 104 = 152	26 (18m^3 slurry + 8m^3 biogas)	150 (2x 75)
Generator capacity (kW)	n.a.	12	14	7.5	16 (6+10)
Feedstock required (kg/d)	-	WH: 2000 CM: 750	9,12 m^3/d	180 kg fresh dung OR 50 kg dung + 12 kg press cake	Feedstock produced daily: 160
Mixing ratio (feedstock: water)	1:2 or 1:3	1:1	Not applicable	1:1 with fresh dung	1:6

Appendix II.2. Planned results

	Vietnam	Uganda	Honduras	Mali	Peru
Expected biogas production (m^3/d)	0.034 m^3 per kg pig manure/d	52.50	45.4	6	18
Expected biogas yield (m^3/ton dry matter)	80%	WH: 200 CM: 225	245 approx.	150	Not available
Expected bioslurry production (m^3/d)	Unknown	2.5-2.8 ton/d	9.12	0.35	Not available
Expected energy production (kWh/d)	6 kWh * 0.29 * amount of m^3 biogas	68	4,600 kWh/a = 12.6 kWh/d	5	84.8

Appendix II.3. Operational results

	Vietnam	Uganda	Honduras	Mali	Peru
Daily volume feedstock loaded& treated per digester (m^3/d)	Not available	300 kg of manure + 150 kg of water hyacinth (full capacity: 2 tons of feedstock)	9.12	Not available	160 kg
Total biogas produced (m^3/d)	Not available	12.38	45.4	F: 0.78 D: 0.94 **S: 2.64**	**18**
Total biogas used (m^3/d)	Not available	12.38	45.4	F: 0.78 D: 0.94 **S: 2.64**	**18**
Total bioslurry produced (m^3/d)	Not available	900 l/d	9.12	Not available	1- 1.4 m^3 per manure load (not done daily)
Total energy produced (kW/day)	Not available	15.47	12.6	F: 2.0 D: 2.8 **S: 2.8**	16
Fuel replacement (l/m^3 biogas)	Not available	1.01	100% of the LPG used at full system capacity	F: 0.44 (61%) D: 0.52 (84%) **S: 0.32 (75%)**	-
Fuel (l/a) **or electricity** (kW/a) **savings**	Not available	4,562 l/d based on current biogas production (20,258 at full capacity)	4,600	F: 0.34 l/d = 125 l/a D: 0.49 l/d = 179 l/a S: 1.37 l/d = 502 l/a	3,285 l/a
Reduction in COD of effluent (%)	Not available	-	65%	-	-
Reduction in GHGe (tCO_2e/year)	2,200	Not available	50.3	Not available	Not available

Appendix II.4. Financial results

	Vietnam	Uganda	Honduras	Mali	Peru
Installation/ investment costs (EUR)	30-45 EUR/ m^3	36,600	Not available	2,444 *(incl. perso. materials, transport)*	84,000 (energy generation system + electricity network)
Operation costs (EUR)	Not available	6,195 *(incl. fuel & perso.)*	~250,000	Not available	0.36 EUR/kWh
Feedstock cost price (EUR)	Free	4.50€/MT (CM) 11€/MT (WH)	-	-	-
Energy value (EUR)	So far, biogas is used by the farmers for their own purposes	8€/MT (CM) 2€/MT (WH)	Not available	0.5 EUR/m^3 0.1 EUR/m3 for wood for cooking in rural areas	0.41EUR/kWH (0.30 possible w/ changes in system) 0.40 for diesel 0.60 for PV; 0.37 for hybrid solar/ diesel)
Bioslurry sale revenues	Bioslurry for own use	None yet, but price of 45EUR/ton is to be set	654 EUR/ year	-	Not yet
Cost savings (fuel reduction) (EUR/a) **ORincome from biogas** (EUR/a)	Not available	Estimated annual income from rice milling (with an average of 1 ton per season): 960	810	F: 123 (12%) D: 176 (22%) S: 495 (24%)	Not available
Payback period (y)	7-10 years	Depends on the rice milling potential on the island (219T of rice need to be milled annually to break even and cover depreciation over 10 years; ice milling potential is currently assessed)	14	8.5 (expected: 4)	Not available

Cover photos:

Main photo: Installation of one the biodigesters in Santa Rosillo, San Martin, Peruvian Amazon, as part of the system installed for community electrification.

Woman with the hat: Ms. My, a newly equipped biogas user in Vietnam.

Two men holding leaves: Water hyacinth: a potential feedstock for biodigestion in the Ssese Islands, Uganda.

SNV

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