Preliminary Cost Benefit Analysis of a Biogas Digester - Case study in Solomon Islands

Anna Rios Wilks

Technical Report 200

June 2014

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List of Acronyms

BCR	Benefit cost ratio
Btu	British thermal unit
CBA	Cost benefit analysis
CH4	Methane
CHICCHAP	Choiseul Integrated Climate Change Programme
CO_2	Carbon dioxide
FAO	Food and Agriculture Organisation
FJD	Fijian Dollar
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
LPG	Liquefied petroleum gas
MAL	Ministry of Agriculture and Livestock
NPV	Net present value
PDF	Provincial Development Farm
SBD	Solomon Island Dollar
SPC	Secretariat of the Pacific Community
TTM	Taiwan Technical Mission
WASH	Water, Sanitation and Hygiene

EXECUTIVE SUMMARY

The Choiseul Integrated Climate Change Programme (CHICCHAP) aims to reduce vulnerability of the Lauru people of Choiseul against natural hazards, food insecurity and climate change threats. It is a jointly implemented strategy between the Solomon Islands Government, Choiseul Province and seven development partners; the Secretariat of the Pacific Community (SPC), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Secretariat of the Pacific Regional Environment Programme, United States Agency for International Development, Australian Aid Programme of the Australian Department of Foreign Affairs and Trade and the Nature Conservancy and the United Nations Development Programme.

A part of this work is being implemented through the Tarekukure Provincial Development Farm (PDF); a Government extension facility farm, which provides assistance in agriculture-related matters to the local communities of Choiseul. A new part of their project is the introduction of biogas digesters into Choiseul communities, to increase energy security and resilience to external price shocks. As a first step, the PDF Government team, Tarekukure, will set up a biogas digester next to their piggery in their demonstration site to make use of the swine manure waste. Data will be collected by the PDF team on the costs and benefits of this demonstration and, if overall benefits are produced, this message can be disseminated to the communities. The long-term objective is to create demand-driven development at the village level through trainings and raising awareness.

Several steps in order to facilitate the evaluation of biogas digester technology have already been carried out. Three economists from SPC and GIZ provided an interactive four-day training course on cost benefit analyses (CBAs) in Honiara during February 2014. The participants were all Government Ministry officers who carry out project evaluations and decision making in their daily work. Two extension staff from the Tarekukure PDF completed the training and have been consulted extensively in the writing and review of this document.

Objective

This document seeks to provide information to the PDF and the Ministry of Agriculture and Livestock (MAL) management of the potential range of costs and benefits associated with setting up and running a digester, providing a guide for collecting data from the demonstration site, and identifying the risks and uncertainties which will affect biogas digester viability at the community level.

Employing a CBA methodology, this document;

- Provides background information on digester technologies.
- Describes the CBA methodology.
- Explains all potential costs and benefits associated with a biogas digester.
- Conducts a preliminary economic analysis, using the data currently available to give a first estimate as to whether the demonstration digester will provide overall benefit.
- Provides a monitoring and evaluation plan, which the PDF team can use to collect the data required to assess the economic viability of implementing digesters.
- Provides insight into uncertainties and risks, which must be taken into account if digesters are to be implemented in the communities.

Using the risks identified, recommendations are made for ways in which to address them and maximise the potential benefit that a digester system could generate.

Key Messages from Each section

Section 1: Background

Biogas digesters breakdown organic matter in an anaerobic environment and produce various gas products including methane, which can be usefully combusted as a cooking gas or in a generator. Biogas could be a highly valuable resource in the case of the Solomon Islands, reducing reliance on imported fuel and vulnerability to external shocks from changes in fuel price, primarily petrol. Petrol prices in the Solomon Islands have risen steadily from 499 cents/litre in 2005 to over 1,070 cents/litre in 2013 (Solomon Islands National Statistics Office, 2014), making energy ever more expensive. Oil imports make up a high percentage of the value of imports, averaging over 20 per cent between 2000 and 2006 (IMF, 2007). Continued increases in the price of imported fuel, such as petrol will directly increase the cost burden on consumers and incentivise increased burning of raw biomass, which causes negative health and environmental impacts. Biogas could provide a sustainable and environmentally friendly way to produce energy in the Solomon Islands.

Section 2: Methodology of CBA

Cost-benefit analysis (CBA) is a systematic process to identify, value and compare the costs and benefits of an activity. Unlike financial analyses, costs and benefits in a CBA are valued from a whole-of-society perspective, attempting to quantify all costs and benefits (both financial and social) and express them in monetary units These costs and benefits are then weighed up against each other to evaluate whether a project is expected to produce overall gains or losses to society.

Section 3: Benefits and Costs of a Biogas Digester

There are three general benefits produced by biogas systems; biogas used for energy, greenhouse gas emissions (carbon credits) and digestate[1], which can be used as a fertiliser. For the case of communities in Choiseul, other benefits might also be reaped, such as reduced reliance on imported energy sources, health benefits of using a cleaner form of energy and health benefits from improving sanitation by collecting and processing manure, rather than leaving it on the ground.

Most costs will be incurred during the setting up of the digester; the material cost of constructing the digester itself, and the labour time needed for its installation. Once the digester is up and running, there are three further costs involved in using a digester; the two tangible inputs (water and manure) and the intangible time input provided by community members to keep it running. Finally, there will be maintenance costs associated with keeping the digester going and the costs associated with using the outputs of the digester, such as the time required to apply digestate to crops.

Section 4: Preliminary Quantification of Benefits and Costs

Given the data available, the only benefits that were quantified in the economic analysis were the biogas and carbon emission reductions. Similarly, not all of the costs are quantified. If all the benefits and costs had been quantified, the results might potentially be different. However, at present, those results that can be quantified indicate that for each SBD invested in the digester, only between 0 and 0.74 cents might be expected in return. As displayed in figure 1, without sufficient value for fertiliser and possible health benefits produced, the digester would not breakeven and losses would increase with every year the digester is running.

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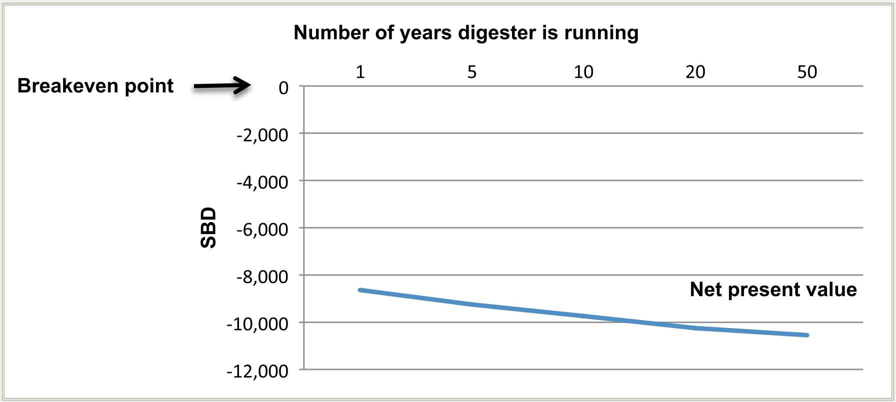
[1] Digested organic matter left as a bi-product of biogas production.

Figure 1: Net present value, depending on the life time of the digester.



A break even analysis — summarised in table 1 — also demonstrates that for the digester to produce enough benefits to outweigh costs, the PDF would need to produce between 20 and 30 kg of manure produced per day, depending on how long the digester can be kept running.

Table 1: Break even analysis: manure input required to allow benefits to cover costs.

Working life span of the digester	Kg manure/day required to break even[2]	Number swine required (1 swine produces 3kg manure/day)
5	28.21235	10
10	23.46879	8
20	21.38711	8
50	20.63071	7

It is important to remember that the PDF should always be covering the costs of keeping the swine through other, non-digester related activities, such as selling meat or piglets in order to make any of the above digester scenarios feasible.

Section 5: Data Collection Required for Evaluating Economic Viability of Digester

A complete plan to collect all the data needed in order to conduct a full CBA of the demonstration site digester has been detailed. It is strongly recommended that the data is collected during all phases of the digester's life span in order to provide valuable information, which is, as of yet, not available.

[2] Using a 10 per cent discount rate.

Section 6 and 7: Recommendations for Increasing the Chance of Success in Communities

1. Use of alternate biomass: Even with five swine, the digester is unlikely to produce enough useful products to make the project worthwhile. In fact, manure from 8 to 10 swine would be expected to be required for the digester to break even. Making use of plant biomass, such as adding coconut husks and rotting food to the manure input, may increase productivity when swine manure is scarce.

2. Suitability of current technology: While manure digesters are popular in Africa and Asia, adoption is low in the Pacific. The fact that so few digesters have been set up – despite the Taiwan Technical Mission already offering to install digesters and train communities free of charge – suggests a community preference not to use digesters.

3. Learning from the demonstration digester: If the PDF can find a way to make the digester produce overall benefits, through effective use of the digestate fertiliser and/or making use of plant biomass in addition to manure, the team could use this to create awareness of the digester's benefits and potentially increase demand from communities for adopting the technology. To fully value the costs and benefits of a digester system, information detailed in appendix 1should be collected from the outset. This includes data from field trials that can determine the scale of benefits from digestate fertiliser. Such information can inform decisions on whether the technology should be altered to better suit the Choiseul environment.

4. Community ownership: To increase the likelihood that communities will continue to run and maintain digesters, communities would not only need to have enough water and biomass input, but would also need to express an interest in having a digester in the first place, be trained in the technology and contribute to the construction of the digester so that they have incentive to keep it running.

5. Water scarcity: The digester is expected to be less successful in areas that suffer water shortages. To reduce risk of digester failure and to minimise further exacerbating the already stressed water supply, it is recommended that the implementation of digesters takes water availability into account and that rainwater harvesting tanks are included in project designs where necessary.

6. Manure and water sourcing: The running of the digester depends on these two principle inputs so structures must be put in place to motivate community members to share their own valuable manure and water resources. As an example, digestate fertiliser might be used to reimburse households for manure for the digester.

7. Gender: To optimise the likeliness of the biogas digester being used and maintained, it is recommended that both men and women are trained on the digester, the labour requirements and best practices at each stage and how this will impact the quality of outputs (benefits) produced.

8. Making safe use of all benefits: A major benefit produced by the digester is the digestate, which can be used as a crop fertiliser. In order to reap this benefit, communities must be made aware of its value and of how to safely apply it through demonstrations and trainings at the PDF.

9. Time required to begin digestion process: A 5m^3 digester requires around 15 swine and takes between 4-6 weeks to fill and to allow the chemical processes to gather momentum before gas can be extracted. With less swine, the fill time will need to be increased.

10. Hob adjustment: In order to ensure that the biogas produced can be used efficiently, it is necessary to make alterations to the cooking gas hob. Reductions in the efficiency of the hob could produce significant reductions to the benefits of the system and increase the greenhouse gas emissions it creates.

INTRODUCTION

The Choiseul Integrated Climate Change Programme (CHICCHAP) aims to:

- increase the resilience of the Lauru people of Choiseul Province, Solomon Islands to the impacts of climate change and threats of natural disasters;
- enhance their food security; and
- strengthen the resilience of natural ecosystems in Choiseul.

The project — which is jointly implemented between the Government of the Solomon Islands and several development partners — targets a variety of outputs:

Output 1	Governance Structures and Leadership Skills Strengthened in Choiseul
Output 2	Livelihoods Supported through Healthy Ecosystems
Output 3	Partnerships and Coordination Strengthened
Output 4	Sustainable Economic Development Promoted
Output 5	Support Awareness Raising and Education
Output 6	Food Security Enhanceds
Output 7	Appropriate and Climate-Friendly Infrastructure and Technologies in Place
Output 8	Increase Water Security
Output 9	Strategies to Ensure Sustainability of Programme Developed and Implemented.

In response, principally to Outputs 2 (healthy ecosystems) and 6 (enhanced food security), the Government of the Solomon Islands — through its Ministry of Environment and the Ministry of Agriculture and Livestock — have nominated to use the project to integrate renewable energy technologies for enhanced agricultural productivity.

To this end, the Government is using the CHICCHAP project to introduce biogas digesters in the Choiseul community. The work will be delivered through the Tarekukure government extension facility farm which provides assistance in agriculture-related matters to the local communities of Choiseul. As a first step, the Tarekukure government team wishes to set up a biogas digester at their demonstration site to enhance agricultural productivity through the generation of organic effluent, which can be used as fertiliser (thereby targeting Output 6), while reducing waste (thereby targeting Output 2) and increasing access to biofuel (thereby targeting Output 4). The digester project will not introduce more swine to the PDF. The biogas digester project is separate from the PDF livestock activities (such as purchasing swine and feed, etc.), which are assumed to already be producing enough benefits to cover their costs. By demonstrating to local families the value of using digesters, the Government hopes to create local demand for digesters, generally in Choiseul, encouraging voluntary adoption of such systems at the village or household level, based on the model at the Tarekukure government farm.

Although the one-off cost of supplying a single digester is not high, given that digesters are to be promoted on a wider scale in the communities, it is appropriate to consider first the likely value of benefits from digesters in Choiseul, plus to identify any risk issues that need to be considered in implementing digester schemes broadly. To this end, this document provides a preliminary economic analysis of the range of costs and benefits associated with setting up and running a digester and the risks and uncertainties, which will affect its viability. Additionally, in the interest of targeting Output 1 (improvement governance and leadership) and Output 9, this assessment has been delivered as a capacity building activity in which government officers are provided with training in basic cost-benefit analysis and involved in data collection and review of the assessment.

The remainder of this report takes the following format:

Section 1 (background): This section explains the digester technology and gives examples of digesters used in the Solomon Islands setting.

Section 2 (methodology): A brief explanation of the CBA methodology is provided.

Section 3 (benefits and costs): A CBA framework is used to identify and describe all possible benefits and costs, which could be associated with implementing biogas digesters at the community level.

Section 4 (preliminary quantification): This section provides a preliminary economic assessment, based on Tarekukure government farm specifications. Given the data available, not all costs and benefits were able to be quantified. Yet the analysis provides some first indicators as to whether the digester might be beneficial overall.

Section 5: The information needed for a more complete analysis to be undertaken is detailed. Much of the data needed can be obtained by observation of the demonstration digester, which will be built in the next months. This information could be used to complete a cost-benefit analysis ahead of replication at the community level. The information and any lessons learned could then feed into recommendations for implementing the digester at the community level.

Section 6 (uncertainties and risks): This section identifies some of the risks that threaten the potential success of the digester activity and which may be targeted in the future to improve outcomes.

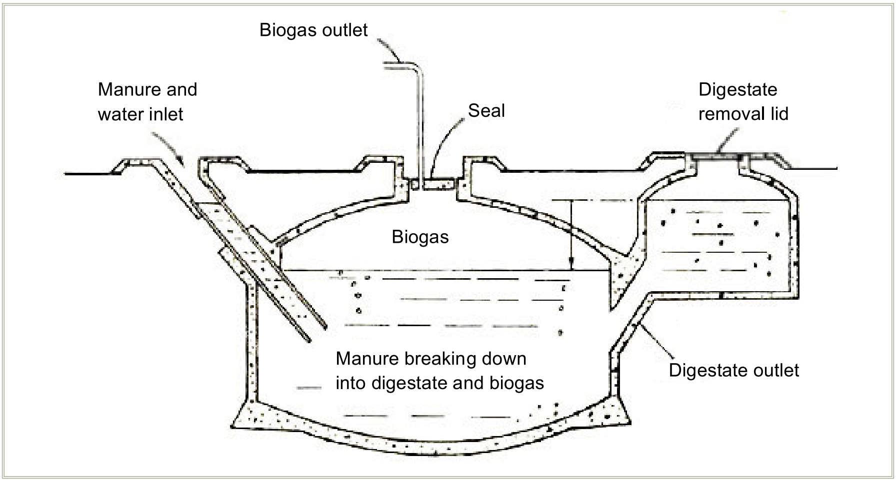
Section 7 (recommendations): This section summarises some first stage recommendations, which could be used to address risks identified in section 6.

SECTION 1: BACKGROUND

Biogas Digester Technology

Biogas digesters breakdown organic matter in an anaerobic environment and produce various gases. One of these gases is methane, which can be usefully combusted as a cooking gas or in a generator. Typically, organic material and freshwater are fed into the digester, and gas and digester effluent (also called digestate) are produced. The gas is captured and used as a form of energy and the digestate can be used as a natural fertiliser.

Figure 2: Diagram of simple biogas digester (Chinese model).



Source: http://www.i-sis.org.uk/graphics/chinaBiogas.jpg

Biogas digesters have been used extensively all around the world in various forms. The size of the digester, the inputs used in the digester, and the expertise of those using and maintaining the digester, affect the volume of useful outputs produced.

Previous Economic Studies of Biogas Digesters

There exist a variety of economic analyses that have been produced to appraise large-scale digesters in more developed nations; Netherlands (Gebrezgabher et al 2010), UK (Rural Futures Ltd, 2010), Denmark (Møller and Martinsen, 2013) and Brazil (Lassner, undated), showing potentially good returns to investment. These digesters operate with hundreds of livestock and are located in regions with a high degree of technical expertise.

By comparison, economic analysis literature on the use of small-scale community biogas digesters with swine manure is relatively scarce and the findings in terms of viability varied. On the positive side, Hemstock (2008), conducted a theoretical analysis for large-scale digesters for Tuvalu and found positive expected returns for large-scale piggeries. Woods et al. (2006) also produced an analysis for a large-scale (300 swine) biogas digester in Fiji. A financial analysis with zero per cent interest rate indicated it would take around three to six years to break even. This digester did run without problems for four years but was then decommissioned due to lack of maintenance (replacement of a broken part).

Particular recommendations from these Pacific Island-based reports have focused on the importance of training and awareness-raising on digesters with on-going support being given by technicians. This will be the approach taken by the PDF if digesters are to be introduced at the community level.

Similarly, the Food and Agriculture Organisation (FAO) Agricultural Services Bulletin (Marchaim, 1992) provides an overview of community digester projects, noting varied success internationally, but notes that success of has been recorded for small-scale digesters in China and larger scale digesters in other parts of Asia under certain conditions. The results are dependent on the type of inputs used in the digester, the alternative energy sources, appropriate use of all outputs including digestate and other social factors.

The Solomon Islands Case

Biogas could potentially be a valuable resource in the Solomon Islands, reducing reliance on imported fuel and vulnerability to external shocks from changes in fuel price.

The Solomon Islands are currently highly reliant on imported energy sources, primarily petrol. Petrol prices in the Solomon Islands have risen steadily from 499 cents/litre in 2005 to over 1,070 cents/litre in 2013 (Solomon Islands National Statistics Office, 2014), making energy ever more expensive. Oil imports make up a high percentage of the value of imports, averaging over 20 per cent between 2000 and 2006 (IMF, 2007).

Liquefied Petroleum Gas (LPG) is commonly used as an energy source (used in the PDF) and more remote communities also use kerosene and burn biomass. Continued increases in the price of imported fuel, such as petrol will directly increase that of LPG, increasing the cost burden on consumers and incentivising increased burning of biomass, which causes negative health and environmental impacts.

Biogas can be produced using locally available products. Digesters can be fed with many different inputs, from cattle manure to plant residues. Although digesters using cattle manure have tended to be more popular due to the higher percentage of manure to body weight production of cows compared to pigs, the use of cattle manure would likely be infeasible in the Solomon Islands. Even before the ethnic tensions that began in 1998, less than 10 per cent of households had any cattle (Mackay 1989) and, since then, almost all cattle have been slaughtered (Emma Rooke, Chief Veterinary Officer, MAL, personal communication 2014). By comparison, a survey conducted in 2004 showed that 85 per cent of livestock activities at the household level were based on pig farming (Nonga and Keqa, 2004). Consultations with MAL indicate a similar situation today, although there are preliminary plans for cattle to be reintroduced at some point. Although the 2004 survey also recorded 90 per cent of households also owning chickens, Honiara-based Taiwan Technical Mission (TTM) livestock specialist, Donald Wang, has advised against the use of chicken manure in biogas digesters. Consequently, this project plans to use pig manure as the principle input for the digester. In the future, if plans to reintroduce cattle are successful, then the digester input can be changed accordingly[3] .

Currently, very few digesters are used in the Solomon Islands but, due to the potential benefits that could be reaped by using such technologies, the TTM has already constructed a demonstration site in Honiara, and offers free training and assistance in constructing digesters to the population. Although the digester at the TTM farm successfully produces cooking gas and fertiliser, few farmers seem to have taken up the offer of assistance. This could be due to a lack of local awareness, but it could also be an indication of a revealed local population preference for purchasing gas energy,

3 Plant residues, such as coconut have also been suggested as a source of biomass, which could be used as an input to supplement manure in communities with less livestock Hemstock (2006).

rather than using their time and water resources producing it (see for example Woodruff, 2007). This pilot activity will clarify this situation.

Examples of Pig Manure Digesters Used in the Pacific

The technical specifications of the CHICCHAP biogas unit have not yet been determined. However, they will be influenced by units existing in the region.

To date, at least two models have been used in the Pacific:

- Chinese model – 15-swine unit used in Honiara TTM farm
- Smaller model – a small number have been used in Fiji

Chinese model: The Taiwan Technical Mission runs one 15-swine digester at their Honiara site. The digester contains a 5 m^3 digesting tank and 15 swine provide inputs for this digester, each adult pig producing around 3 kg manure/day. The digester unit produces 1 hour of gas per day for a single hob cooking burner. The slurry mixture spends approximately 2 weeks in the digester before being removed as effluent, stored for a few months and then used to fertilise crops (TTM livestock specialist, Donald Wang – personal communication, Feb 2014).

African model: These digesters have been used in Fiji. They use a digestion tank of 4 m^3 and cost around FJD 2,000 (approximately SBD 7,960[4]) to establish. The longest lifespan recorded in Fiji of one of these digesters is 14 years; nevertheless, the average lifespan in the Pacific setting may reach 20 years (Animal Health and Production specialist, Andrew Tukana, personal communication 2014). No information on the number of pigs used in these digesters or the gas production has been recorded.

Table 2: African model digester dimensions.

Tank radius	0.69 m
Height of slurry in tank	1.38 m
Height of gas in tank	1.30 m
Total height of tank	2.68 m
Volume of slurry	2.06 m^3
Volume of gas	1.94 m^3
Total volume of tank	4.01 m^3

While the larger TTM unit requires around 15 swine for inputs, swine at the local village level are presently scarce, so smaller units could be used. Nevertheless, given the limited number of suppliers of tanks in Honiara and limited number of personnel able to assist in setting up the digester, the CHICCHAP digester is likely to have to take the same form as the 5 m^3 TTM plant. The main consequence of this will be that the time required to fill the digester before gas is removed will be much longer with less pigs supplying it. The recommended fill time for digesters is between 4-6 weeks in normal conditions to allow for sufficient input to build up, for its bacterial colony to reach an adequate size and for the gas pressure to be sufficient to power a burner for any length of time (Frank Vukikomoala, SPC energy data base officer – personal communication 2014). With less swine, this fill time will be increased.

[4] Exchange rate of FJD 1 = SBD 3.98 source: http://www.xe.com/.

SECTION 2: METHODOLOGY OF CBA

A Cost Benefit Analysis (CBA) aims to give decision makers information on all the economic costs and benefits of different options available to them. Ideally, these costs and benefits are quantified in monetary terms. To assess the economic impact of the CHICCHAP digester, the wellbeing of the community without the digester should be compared to the wellbeing of the community with the digester.

The costs and benefits are totalled in each year, converted to their present day value and aggregated in order to determine the final contribution of the digester to the community. Additionally, the CB will estimate a benefit-cost ratio (BCR) for the digester, which allows the project stakeholders to see for every SBD spent, the number of SBD they can expect the project to produce in return, expressed in 2014 values.

The analysis will provide estimates of the overall effect of a digester, depending on the number of years it is running. Results are provided for digesters, which last for 1, 5, 10, 20 and 50 years.

The digester project is separate from the livestock activities in the PDF with regard to any costs and benefits that keeping the swine produce. The digester is expected to simply be set up alongside an economically viable livestock facility (i.e. the swine cover their own feed and rearing costs by producing meat and piglets for sale) and use its manure waste products. The keeping of the swine is a separate activity, already taking place at the PDF and so none of the livestock activity costs or benefits are included in the digester project CBA.

Cost and Benefits Schedule

Ideally, the costs and benefits described in section 3 should all be reflected in the economic analysis to inform the overall effect a digester on the communities.

Table 3 summarises the costs and benefits that might logically be expected each week over the life of the digester.

Table 3: Benefit cost schedule over digester life span.

	Week 1: set up	Week 2-8: filling and cultivating digester bacteria	Week 8 until end of the digester's life
Benefits			• Biogas energy • Increase crop yield though use of digestate fertiliser • Health benefits • Carbon emission reduction
Costs	• Tank • Other materials for construction • Labour used in construction	• Time collecting, inputting and mixing manure and water in digester • Cost of water/litre • Cost of manure	• Labour used in running and maintaining digester • Cost of water • Cost of manure • Time spent collecting and applying digestate to crops • Cost of purchasing spare parts for maintenance

Items marked in black can already be quantified given the data currently available. The items in red cannot be valued without further information. Section 5 details the data that will be required in order to fully quantify the costs and benefits associated with digesters.

Much of this data can be obtained through observing the demonstration digester at the Tarekukure Government farm and Appendix 1 provides guidelines on how the outcomes of the demonstration digester can be recorded.

SECTION 3: BENEFITS AND COSTS

All the potential benefits and costs associated with implementing digesters at the community level are described below.

Potential Benefits of a Biogas System

There are three general benefits produced by biogas systems; biogas used for energy, greenhouse gas emissions (carbon credits) and digestate, which can be used as a fertiliser[5]. For the case of certain villages in Choiseul, other benefits may be reaped through health benefits of using a cleaner form of energy and health benefits from improving sanitation by collecting and processing manure, rather than leaving it on the ground. Each benefit is now described.

Biogas

Biogas is a mixture of approximately 55–70 per cent methane (CH4), 30–45 per cent carbon dioxide (CO_2), and various trace gases (USDA, 2014), which can be used unfiltered as cooking gas, or can be used as the input for electricity generators after purification.

The villages of Choiseul province could benefit from both cooking and electricity generation uses of the methane gas. Currently, liquefied petroleum gas (made of butane or propane) is used as the principle cooking gas. LPG is purchased from a single supplier based in Choiseul and costs SBD 37.1 per kg on average (Andrew Loli, Chief Field officer, MAL – email correspondence March 2014). Cooking with biogas is a simple procedure and requires only small volumes of gas. By comparison, fuel for electricity would be required in larger volumes. Presently, electricity is provided only at certain times of day and only in certain areas at a minimum cost of SBD 0.2 per hour for households and SBD 4.5 for offices/organisations[6]. Nevertheless, given the higher cost and level of expertise involved in converting methane into electricity, this analysis will focus on the simplest use of methane gas, as a substitute for LPG cooking gas.

Biogas could also provide energy security, reducing vulnerability to imported fuel price shocks and changes in availability of fuel due to transport or delivery issues.

Carbon credits

The use of biogas rather than imported LPG has benefits in terms of carbon emission reduction. Although the carbon emissions produced through the combustion of methane is higher than that for the combustion of LPG, per kg of gas burned, the use of a biogas compared to the use of LPG can be argued to be a more environmentally friendly way to provide cooking gas. This is for two reasons:

1) The CO_2 emissions produced through the natural breakdown of manure left on the soil will be almost equivalent to the carbon emissions produced through the same manure being used in the digester, the total combustion of the resulting methane in the biogas and the breakdown of the resulting digestate.

[5] One further benefit is the heat produced through the exothermic reactions of the decomposition process, which can heat homes built on top of digesters in cooler countries. This will not be useful for the Choiseul case.

[6] Taro has electricity power supply rationed between 8AM to12 noon, 1PM to 4PM, and 7PM to 10PM on normal working days. On weekends and holidays, electricity is only available between 7PM and 10PM. Households are charged SBD 50 per month and offices/organisations are charged SBD 1,000 per month fixed rate (Andrew Loli, Chief Field officer, MAL – email correspondence March 2014). Many villages have no electricity supply (Daniel Farkas – email correspondence June 2014).

2) The emissions produced during combustion of LPG only account for a fraction of the CO_2 emissions that are produced during the full lifecycle of LPG gas. The process of extracting propane and butane from natural gas, compressing it into liquid form and transporting it to its destination of use also produce carbon emissions. Nevertheless, if the methane is not totally combusted then some will escape into the atmosphere. Given that the greenhouse effect of methane is 72 times that of carbon dioxide over a 20-year time frame (IPCC, 2007), the overall effect on the atmosphere of using a digester will depend on the efficiency of combustion of the biogas. Aside from maximising the productive use of the biogas for heating, the costs of letting methane escape into the atmosphere mean that to maximise benefits, the kitchen gas hob should be altered for use as a biogas burner rather than an LPG burner.

Fertiliser

The third benefit is often overlooked but may be the most economically important for the Choiseul case; the use of the digestate as a crop fertiliser. The use of digestate fertiliser can potentially increase agricultural yield.

As explained by Arthurson (2009), the use of digestate as a fertiliser has three principle benefits:

1) The majority of nutrients needed for crop growth are provided (halting soil degradation, and conserving its fertility);
2) The soil structure and humus balance is improved (decreasing water and wind erosion of soil);
3) Dead bacteria from the digesters add to the minerals found in digested slurry used for plant growth.

Community livestock are fed, using locally grown copra meal and vegetation and the community themselves eat locally grown agricultural produce. If their organic waste was the input for the digester, the use of the digestate output as a fertiliser would ensure that the nutrients used in the growth of the agricultural produce are recycled back into the land, reducing soil degradation, sustaining crop yield, which may otherwise decrease over time.

The first two benefits listed above would also be produced if raw manure was used to fertilise crops, but;

1) The collection of raw manure for crop fertilisation does not usually occur in these villages (Andrew Loli, MAL - email correspondence 2014);
2) Digestate has been found to contain 25 per cent more of the form of ammonium that is accessible to plants for growth, compared to untreated liquid manure, making it even more valuable (Monnet, 2003);
3) Cassava, a common crop grown in Choiseul, has been found to benefit more from digestate compared to raw manure; producing higher leaf biomass and protein content (Chau,1998);
4) Digestate has been found to reduce the probability of plant diseases in crops (Yu et al. 2006);
5) Some seeds from the raw manure input are broken down during the fermentation process, so the use of digestate as fertiliser has been found to reduce the growth of unwanted plants or ‘weeds’ in crop fields compared to using raw manure (Banzi, E and Mmbaga, unpublished);

6) Unlike raw manure, digestate is odourless, and does not attract insects, such as flies, dung beetles, etc. (Personal communication with Donald Wang; biogas expert – Honiara Taiwan Technical Mission site, February 2014).

Alternatively, if externally produced synthetic fertilisers are used;

1) They may not replace nutrients in the same quantities as those taken out, leading to excess nutrients, leaching into water bodies;
2) The organic waste produced by animals is not used for any productive purpose;
3) The production of synthetic fertilisers uses energy which could otherwise be used for alternative economic productivity (Urea, a common fertiliser, requires 29-42 Giga joules of energy per tonne to produce (IPCC, 2006) and many of the inputs in their production are limited resources (although these two costs will be already captured in market prices);
4) The transport of fertilisers from their site of production to their site of use produces greenhouse emissions.

This can all be summarised in table 4.

Although there is substantial evidence to suggest that digestate produces higher yields when compared to no use of any fertiliser (Rivard et al., 1995; Tiwary et al., 2000), this review of the literature on crop yields after treatment with digester effluent compared to raw manure or synthetic fertilisers was inconclusive about which produced consistently higher yields.

Table 4: Summary of costs and benefits of various fertilisers.

Scenario	No use of any fertiliser	Use of raw manure as fertiliser	Use of synthetic fertilisers	Use of digestate as fertiliser
Costs	Raw manure is left uncollected and untreated, causing possible drinking water and sea water contamination The breakdown of raw manure emits CO_2	Time spent collecting waste and applying to crops Possible drinking water and sea water contamination after heavy rain Possible contamination of food with bacteria The breakdown of raw manure emits CO_2	Cost of buying fertiliser Time spent applying fertiliser CO_2 emitted during its production and transportation Raw organic waste is left untreated, causing possible water contamination Possible leaching of excess nutrients into water bodies	Time spent collecting manure for input to digester Time spent applying digestate to crops Possible drinking water and sea water contamination after heavy rain (less likely than using raw manure) Possible contamination of food with bacteria (less likely than using raw manure) The breakdown of digestate emits CO_2
Benefits		Soil nutrients maintained Soil structure maintained	Some soil nutrients maintained	Soil nutrients maintained Soil structure maintained Dead bacterial matter adds to nutrient content Reduced weed growth Reduced plant disease

Table 5, provided by estimations from the Government PDF, suggests that the use of digestate may increase the average crop yield to some extent but without field tests, it will be difficult to be conclusive of the effect using digestate will have. This study will not quantify the value of digestate fertiliser as a result. In the meanwhile, this report includes an example field trial in section 5 to be carried out on the PDF to evaluate the impact of applying digestate to the soil on implications for crop yield.

Table 5: Expected change in average crop yield if digestate applied to crops.

	Type of fertiliser	% of time used in current farming practices	Expected change in average crop yield if digestate used instead
Government farm (Tarekukure)	Chicken manure/raw material	45	Equal or slight increase
	Synthetic fertilizer	35	
	Nothing	20	
Surrounding villages	Chicken manure/raw material	10	Increase
	Synthetic fertilizer	1	
	Nothing	89	

Source: Andrew Loli, Tarekukure Government Farm Chief Field Officer, MAL – Email correspondence March 2014.

Health benefits

In many villages, biomass is burned to produce energy as well as the use of kerosene and LPG. The use of biogas for cooking would reduce exposure to harmful smoke when burning raw biomass.

For certain villages in Choiseul, another benefit of waste digestion in the biogas plant would come from sanitation. At present, both animal and human waste is commonly left untreated either in the animal pens, bushes or along the beach. By collecting animal waste for input to the digester, there is likely to be a reduction in ground and sea water contamination after heavy rainfall that would otherwise wash waste into water reserves and the sea. Currently, there is incidence of water borne disease after heavy rain recorded in one of the two surrounding villages (Susumu, 2013). Information provided by the report suggests that the domestic farm animal and human waste is one of the sources of contamination in Sepa village, given the proximity of streams feeding Sepa's water supply source to village gardens. The Solomon Islands' Water, Sanitation and Hygiene (WASH) advisor (Bryce McGowan, Water Supply, Sanitation and Hygiene (WASH) Adviser, Solomon Islands, personal communication February 2014) also highlighted the fly and insect transmission of bacteria between waste which is left in the open air and food consumed by villagers as another form of contamination that exists in these areas. It may be that the biogas digester will provide incentive to collect or redirect waste for use as an input in gas production and reduce these causes of contamination, but due to traditional taboos, human waste is still unlikely to be collected unless an extensive education campaign was to be carried out (Nichol Nonga, Animal Production Specialist, SPC personal communication 2014). For this reason, the remainder of this report will ignore the possibility of biogas digesters resolving human waste issues.

Nevertheless, risks remain. First, there is little evidence to suggest that all harmful bacteria are removed during fermentation. The digestion of manure in small holder digesters takes place under mesophilic conditions (at temperatures between 30-42 degrees Celsius). At these conditions, it is not possible to remove all harmful bacteria from the manure and food, and ground water contamination could still occur (FAO, undated; Slana et al., 2011). Consequently, if digestate is to be used as a fertiliser, safety measures must be put in place (such as composting of the digestate before application to crops). This will entail cost, in terms of labour time, which should be included in a CBA for a community-level digester.

The safety procedures undertaken using raw or digested swine manure have yet to be recommended and no baseline data has been recorded for the incidence (cases per year) and costs (time the patient is unable to work or attend school, cost of treatment) of water borne disease in the villages. Consequently, this analysis will not include any health effects.

It is assumed that leaving raw manure on the ground (status quo), using raw manure on crops or using digested manure will have similar health implications. This is a weakness of this analysis, but given that collection of health data before and after digester implementation would still not be sufficient to estimate the percentage of health change attributable to use of a digester ceteris paribus, it makes little economic sense to waste resources quantifying this specific benefit.

Potential Costs of a Biogas System

Most costs will be incurred during the setting up of the digester; the material cost of constructing the digester itself, and the labour time needed for its installation.

Once the digester is up and running there are further costs involved in using a digester; the two inputs (water and manure), the purchase of spare parts for maintenance and the time input provided by community members to keep it running, keep it maintained and to use the outputs.

Material Costs

A list of material costs can be found in appendix 1. All fixtures must be plastic to prevent rusting caused by the sulphur content of the biogas.

Labour

Time is valuable, even when money does not change hands to pay for it. The cost of continuing to run the biogas digester can be valued by calculating what a person would have been doing if they had not used their time working on digester activities. Because the alternate use for their time could be to earn a wage elsewhere, this “opportunity cost” of time is typically valued in monetary terms by using the wage rate. The average casual wage rate is SBD 50 per man day (8:00am to 3:30pm), including an hour lunch break or SDB 7.69/hour (Andrew Loli, Tarekukure Government Farm Chief Field Officer, MAL – Email correspondence March 2014). In this analysis, the cost of running the digester was included. The cost of the labour used in constructing a digester is not quantified but section 5 details the data, which will be collected from the PDF demonstration digester in order to include this cost in future.

Water

The ratio of manure to water reportedly used varies between 1:1 and 1:3, depending on the source. That is, for each 1 kg manure, between 1 and 3 litres of water would be needed, added before input to the digester[7]. In the villages, water is usually collected from wells, therefore, in order to calculate the cost of water it is necessary to know information, such as the time it takes to collect a gallon of water from wells, whether there is ever water scarcity, and where and how much it

[7] Swine Manure contains approximately 6 grams total solids per litre (Oklahoma Cooperative Extension Service, undated). The low percentage of solid to water content in swine manure means that the density of swine manure can be plausibly assumed to be similar to that of water. Using this assumption, 1 kg of manure has a volume of around 1 litre.

costs to obtain water from alternative sources when there is a drought. This information is currently unknown so water cost could not be included in this analysis. These data gaps have been included in Section 5 and will be collected from the PDF demonstration digester.

Manure

Manure is the second most important input to the digester. It has a lower opportunity cost than water because, although the best alternative use would be to apply it directly to the soil to boost agricultural yield, it is possible to use digestate for the same purpose. As there is no conclusive evidence to suggest that the nutrient and productivity benefit differs between applying raw or digested manure, it can be assumed that there would be no change in crop yield if digested effluent was used instead of raw manure. For this reason, the only cost associated with the raw manure input in the digester is the cost of its collection for input into the digester. Pig farming in the villages commonly uses intensive farming methods[8].

Consequently, it is assumed that the collection of raw manure, mixing with water, inserting into digester and mixing of slurry mixture inside the digester would consume a maximum of 1 hour of time per day for an average household or small farm.

Summary of Potential Benefits and Costs

The table below displays the potential costs and benefits of a digester, which is set up in order to make use of the manure waste produced by a pre-existing livestock facility.

Table 6: Key costs and benefits.

		Expected relative significance for outcome
Benefits	Biogas cooking/heating energy	High
	Increased energy security	
	Greenhouse gas emission reduction	Low
	Digestate fertiliser for crops	High
Costs	Improved health	Medium
	Construction materials	High
	Labour used in construction	Medium
	Labour used in filling, running and maintaining digester	Medium
	Labour used collecting and applying digestate to crops	Medium
	Cost of water	High
	Cost of manure	Low
	Cost of purchasing spare parts for maintenance	Medium

[8] Pigs confined to a pen and fed with copra and vegetation (Email correspondence, Donald Wang, TTM specialist).

Distribution of costs and benefits in the community

At the community level the cultural roles of men and women will mean that different digester related activities will likely be carried out by different groups. The construction of the digester is conventionally be undertaken by the adult males. The maintenance and general running of the digester is also likely to be carried out by adult males or by youths helping with household/farming chores. By way of contrast, the users of the biogas might be expected to be the women in their daily cooking activities. Although the cooking activity and reduction in cost of buying fossil fuels will be beneficial to all the family, the women may take more of a direct interest in the quality of biogas they have to use.

Table 7: Cost and benefit distribution.

Costs	Group directly affected	Benefits	Group directly affected
• Tank structure and other materials for construction	Family (general income)	• Biogas energy	Women (use in cooking/heating)
• Labour used in construction	Adult men	• Increase crop yield through use of digestate fertiliser	All family
• Labour used in filling, running and maintaining digester	Men or youths		
• Labour used collecting and applying digestate to crops	Men or youths	• Health benefits	All family
• Cost of water (time collecting water)	Men or youths		
• Cost of manure (time collecting water)	Men or youths	• Greenhouse gas emission reduction	Global
• Cost of purchasing spare parts for maintenance	Family (general income)		

As shown in the table above, the fact that the main users of biogas, the women, are not those who are responsible for overseeing the healthy running of the digester could mean that the incentive to ensure on-going maintenance of the digester occurs is not as strong as it might be. In other words, the fact that the quality of the biogas and the quantity produced is not directly affecting the men in the society means that they have low incentive to ensure the digester runs healthily (to its maximum efficiency).

This CBA has based its values on a 100 per cent efficient digester, if maintenance and good oversight of the digester is not undertaken then the value of the benefits produced by the digester are likely to be below those estimated in this analysis. In order to increase the chance of success, it is recommended that all groups of the community are trained in how the digester works, so that they are all aware of what each other's roles must be to maintain the digester running effectively.

SECTION 4: PRELIMINARY QUANTIFIED CBA FOR THE TAREKUKURE PROVINCIAL DEVELOPMENT FARM

Because the Tarekukure PDF demonstration digester will be used to inform decisions as to whether digesters should be pursued at the community level, this section attempts to provide a preliminary analysis of whether the digester will produce greater benefits than costs. Using the data currently available, it quantifies the benefits and costs associated with changing from the status quo "without digester" scenario found at the PDF; where there is no digester and LPG gas is used for cooking, to the "with scenario"; where a digester is constructed, run and the gas used.

The CBA is done from the perspective of the PDF. The PDF is a Government body and so is not subject to taxation. By using these tax-free values in the analysis, the results could be more easily extendable to a National Government perspective (where taxes and subsidies are not included in the CBA).

Summary of the Costs and Benefits that can be Quantified

All costs and benefits are summarised in Table 8 below. Those in black can be quantified given the data currently available and the remainder of this section details how they were calculated. All those in red are unknown and can only be estimated after the Tarekukure PDF have collected the data specified in Section 5.

Table 8: Costs and benefits quantified in this analysis.

Costs	Estimated value	Benefits	Estimated value
• Tank structure and other materials for construction	SBD 8,038.00	• Biogas energy	SBD 2609.75 per annum
• Labour used in construction		• Increase crop yield through use of digestate fertiliser	
• Labour used in filling, running and maintaining digester	SBD 2806.85 per annum		
• Labour used collecting and applying digestate to crops		• Health benefits	
• Cost of water			
• Cost of manure		• Greenhouse gas emission reduction	SBD 29.20 per annum
• Cost of purchasing spare parts for maintenance			

Assumptions Made in Quantification

Uncertainties always exist when estimating the outcomes of projects and the values of the costs and benefits produced. In order to produce any economic analysis, an economist must rely on a multitude of assumptions. The assumptions employed in this analysis were produced through research of the literature and documented scientific findings, coupled with communication with experts in the given field to aid judgement as to the most suitable to use. Throughout the analysis, when an assumption is first used, its reference can be found alongside.

The assumptions used in this quantification which are not based on scientific fact (not 100% certain) are also listed below:

- Only the costs and benefits of the digester demonstration project are included. This CBA is separate from any analysis of the swine rearing facility.
- Cost/benefit values are based on those faced by the PDF and are assumed to remain constant over the life time of the analysis.
- There is full employment on the PDF and an average casual wage rate of SBD 7.69 per hour (Andrew Loli, Chief Field Officer, MAL, personal communication 2014).
- One hour of labour is needed per day to collect manure, fill and maintain the digester.
- The digester runs off manure from five swine (producing a total of 15 kg per day).
- The digester is efficiently functioning all year round.
- The cooking hob is able to efficiently use 100 per cent of the methane produced in the digester.
- The traded monetary value of reducing carbon equivalent emissions by 1 tonne is USD 5.9 or SBD 42.6 (Peters-Stanley and Yin, 2013).
- A discount rate of 10 per cent is used[9].

Quantifying the Costs

The only costs for which there is data are the estimated material costs of constructing the digester (which will be comprised of four recycled oil tanks) and that of the time spent filling, running and maintaining digester; which is assumed to take one hour per day.

A full table of material costs can be found in Appendix 1 and the total material cost of the digester structure is estimated to be SBD 8,038.00.

The cost of labour per hour is taken at the average casual wage rate of SBD 7.69 per hour[10]. For a digester in a village setting, the cost of labour may plausibly be decreased to 50 or 75 per cent of the average wage rate, depending on the level of unemployment[11]. If one hour of labour is required per day at a cost of SBD 7.69, then the annual labour cost of filling, running and maintaining the digester at the PDF site is SBD 2806.85.

Quantifying the Benefits

Only two benefits can be quantified given the data available; the value of the gas produced and the value of carbon equivalent emission reductions. These are quantified in appendix 2 and their combined value is estimated to be SBD 7.23, each day the digester is functioning with five swine (15 kg manure). If digesters are set up with different numbers of swine or manure input, this value can be adjusted accordingly.

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[9] Any change in the discount rate does not alter the sign of the NPV or allow the BCR to reach 1.

[10] The average casual wage rate is SBD $50 per man day (8am to 3.30pm), including an hour lunch break (Andrew Loli, Chief Field Officer, MAL – Email correspondence, March 2014). This indicates an hourly wage rate of SBD 7.69.

[11] Greer Consulting Services (2007) have employed this technique in an economic analysis produced for Kiribati.

CBA Results

As explained in table 9, the only benefits of using a digester quantified in this analysis are those of the biogas and emissions reduction. The only costs quantified are those for the construction materials and the daily labour needed to keep the digester running. As displayed below, the digester does not break even given the current data available.

Table 9: Yearly benefits and costs.

	Year 1	All future years
Total benefits (SBD)	2,212	2,613
Total costs (SBD)	10845	2,807
Net benefits (SBD)	-8632	-193

With the quantified information available at present, losses would be expected in every year. Nevertheless, once the data on the benefits produced through increased yield after applying digestate are collected and included, this may change. If these benefits of using digestate are larger than the cost of time used when applying it, this would boost the overall benefits of using a digester. Similarly, if health and safety regulations are produced for the use of digestate on crops, the collection of raw manure and treatment in the digester before application to crops is also likely to produce benefits. Nevertheless, with the current data gaps, it is still unclear as to whether the digester would break even when all of the remaining costs and benefits are included in the analysis.

For the data that has been included, two measures can be used to explain the expected overall outcomes of the demonstration digester, given the number of years the digester is running; the net present value of the digester and the benefit cost ratio. The net present value (NPV) represents the overall gain or loss expected to be produced by the digester after a certain amount of years. The NPV must be above zero in order for the project to produce overall benefits. The BCR shows the SBD expected to be returned for each SBD spent on the project. The BCR must be above one in order for the project to produce overall benefits. Table 10 and Figures 3 and 4 below display the results.

Table 10: Net present value and benefit cost ratio[12].

	Year 1	Year 5	Year 10	Year 20	Year 50
Net Present Value	-8,632	-9,246	-9,746	-10,251	-10,549
Benefit cost ratio	0.00	0.53	0.64	0.70	0.73

[12] 10 per cent discount rate assumed. A lower discount rate would imply lower BCR's and more negative NPV.

Figure 3: Benefit to cost ratios, depending on the lifetime of the digester.

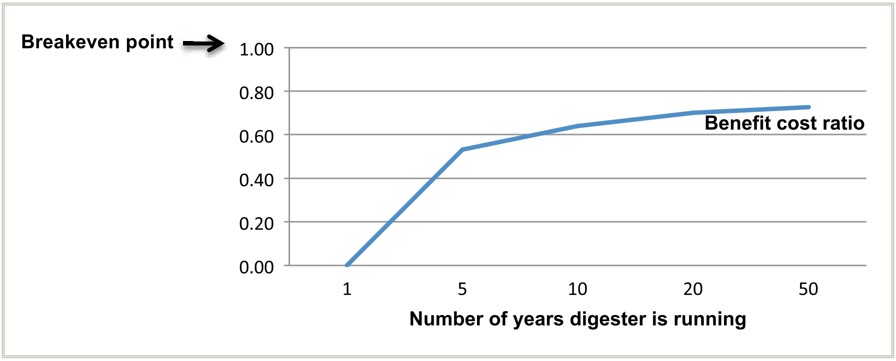
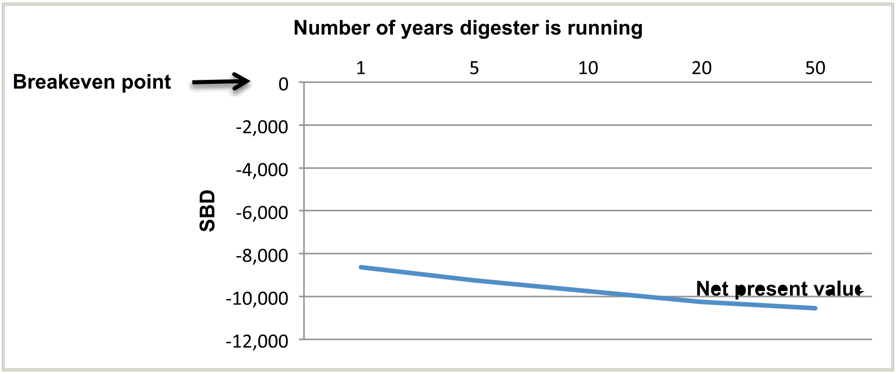


Figure 4: Net present value, depending on the life-time of the digester



At present, without having a sufficient value for fertiliser benefits, a digester using 15 kg manure per day would not be expected to breakeven, and losses would be expected to increase with every year the digester is running.

Even if fertiliser benefits were quantified, using only 15 kg swine manure used as input per day, it is possible that the digester will not produce enough benefits to cover its costs.

This could be one of the reasons behind the fact that very few digesters have been set up in the Pacific. It is likely that these rational individuals have already undertaken some form of simple cost benefit analysis and decided not to invest in a digester.

Breakeven analysis

For the digester to produce enough biogas and carbon credits to offset the costs of the digester, more manure input would be required. If it was assumed that:

1) The same size digester could be used with a larger supply of manure[13]; and
2) It would take a similar amount of labour time to run the digester with 30 kg manure as it would with 15 kg manure[14];

then it would possible to calculate the amount of manure input required each day for the digester to break even.

As there are large up-front costs for the digester project, the shorter the life span of the digester (smaller the time it is running after being set up), the higher the benefits (of biogas produced) each day need to be, and the higher the required manure input must be.

The table below summarises how much manure is needed each day in order to make the digester break even over four different life spans; 5, 10, 20 and 50 years. From this, the number of swine needed in the livestock facility to supply this manure can be discovered.

Table 11: Break even analysis.

Working life span of the digester	Kg manure/day required to break even[15]	Number swine required (1 swine produces 3 kg manure/day)
5	28.21235	10
10	23.46879	8
20	21.38711	8
50	20.63071	7

From table 13, it is possible to see that for the digester to produce enough benefits to outweigh costs, the PDF would need to produce between 20 and 30 kg of manure per day, depending on how long the digester can be kept running. For example, if the digester ran only for 5 years, the PDF would need 28.2 kg of manure per day (10 swine to be producing waste manure for the digester). It is important to remember that the PDF should be covering the costs of keeping the swine through other/non-digester-related activities, such as selling meat or piglets in order to make any digester project feasible.

Given the results from the CBA and the break even analysis, it is vital that the results from the field tests are recorded and included in the analysis in order to determine whether there are any benefits large enough to make the digester a good investment. It is recommended that this be done before any further resources are put into setting up digesters on a wider scale.

[13] This is a realistic assumption because the digester used here is designed to run from a larger livestock facility (such as that of the TTM site in Honiara).

[14] This is a fairly realistic assumption because collecting the manure is only one of the activities involved in running the digester and so collecting more manure from the pig pen next to the digester should not increase labour time significantly.

[15] Using a 10 per cent discount rate.

SECTION 5: DATA COLLECTION PLAN

Given the data gaps (written in red font) in table 7, more information will be required in order to complete an economic analysis.

These data gaps can be collected as part of the monitoring and evaluation data specified in this section.

Data for Collection from the Demonstration Site

The following table details the information which is strongly recommended to be collected, during the set up and running of the demonstration site digester in order to monitor and evaluate the actual outcome of the project.

Although health benefits may occur, it is not possible to calculate their significance without a far more detailed analysis of the surrounding conditions and this goes beyond the scope of this project.

Table 12: Data collection table.

Benefits/Costs	Questions	Answer
Gas produced each day and carbon emission reductions	Volume of digester?	……m^3
	Number of swine used for digester?	……swine
	Breed of pigs used for digester?	
	Total kg of feed they are given each day?	……kg
	Total kg of manure they produce each day?	……kg
	Days needed to fill digester before ready for gas production?	
	Once digester is up and functioning, how many minutes of burn time per day does digester give on the 1 hob burner?	……minutes per day
	What was the cooking gas used previously (before biogas)?	
	How much/many hours of the previous gas still used each day?	……minutes per day
Increase crop yield though digestate fertiliser	Results will be taken from field trial table (detailed below).	
Materials for construction	How much did all the parts cost in total?	……SBD
Rain water tank	Was a rainwater tank built to sustain increased water demand? How much did it cost to construct the roof guttering, buy the water tank and join it to the guttering?	……SBD

Benefits/Costs	Questions	Answer
Labour used in construction	How long did it take to construct digester (hours)?	……hours
	How many people were working?	……men & women
	On average, how long does it take each day for someone to carry out all the digester running activities?	……minutes per day
	How many adults live in the PDF or village?	
	How many of them have enough work to take up around 8 hours of their day?	
	On average, how many hours will a man spend working, fishing or attending to agriculture each day?	……hours
	On average, how many hours do women spend doing chores around the house, attending agriculture, fishing and looking after children each day?	……hours
Cost of water/litre	Where is water usually obtained?	
	How much does it cost per litre?	…..SBD per litre
	Number of days per year of water shortage?	
	Where is water sourced during these drought times?	…..days per year
	What is the price of this water or how many hours does it take to collect it during these times?	
	Do you have to pay for transport? How much does this cost?	Costs…….SBD per litre and takes…….. minutes to collect …….SBD
	What are the alternative uses of the water during these scarce times (would it be taking water away from other uses?)	
Cost of manure and synthetic fertiliser (value of using it as fertiliser)	Field trials (detailed below)	
Time spent collecting and applying digestate to crops	How long does it take to apply digestate per month on average?	……hours per month
Cost of purchasing spare parts for maintenance	Total price of spare parts for maintenance per year?	…..SBD per year
Labour used for maintenance	On average, how long does it take each month for someone to carry out repairs and cleaning of the digester?	…….hours per month
Life span of digester	How many years/months does the digester last?	……years and ……. months

Field Trials to Assess Digestate Fertiliser Value

To assess the general impact that using digestate versus other fertilisers has, it is recommended that the PDF keeps a record of differences in crop yields before and after the digestate is used as fertiliser. The changes in yield could be recorded in a table similar to table 13 below.

Carry out the following steps, filling in table 13 along the way.

- Step 1: Select a plot of land which has similar characteristics across its entire surface (exposure to sunlight, exposure to rain, soil type is the same, same slope). Within this piece of land, demarcate an area that is 8 meters by 2 meters in size.
- Step 2: Select which type of crop to plant (e.g. a staple food crop) and prepare the land for planting that crop. Note which crop will be planted at the top of the table.
- Step 3: Divide the land into 4 lots, each 2 meters by 2 meters.
- Step 4: On each of the 4 lots, use one of the following types of fertiliser; digestate, raw manure, synthetic fertiliser, or no fertiliser. Use only 1 type of fertiliser on each lot. Put the stick markers into the ground of each lot, so that each can always be identified.
- Step 5: Buy or collect the fertilisers to have them all ready to apply on the same day. The Government PDF Agriculture Officer should recommend how much of each to use, but it is critical that the amount of raw manure used and the amount of digestate used is the same.
- Step 6: Note how much of each fertiliser type is applied. For each fertiliser, note down how long it took to purchase or collect it and, if it cost money, note down how much was paid for it.
- Step 7: On each plot, apply its fertiliser type and note down how long it took to apply the different types of fertiliser.
- Step 8: Plant seeds (all obtained from the same source) at equal distances and depths over all 4 lots on the same day. Make sure each lot has the same number of seeds planted in it.
- Step 9: Always treat the 4 lots the same when pruning and watering them (water at the same time of day with same amount of water, etc.).
- Step 10: As the plants grow, note down any differences observed but do not carry out any weeding or pest removal. The only care given to the crop should be watering, each with the same amount of water if needed.
- Step 11: Each time crops are harvested from any of the lots, note down the weight of the crops collected and eaten or sold. Any rotten crops or ones which could not be used should not be counted; they should be thrown away.
- Step 12: At the end of the season, for each of the 4 lots, sum the yields harvested and used, so that the total productivity of the crops on each lot can be determined.

As different crops will react differently to different fertilisers, this type of exercise should be done with all main crop varieties grown in the area.

Table 13: Field trial to evaluate costs and benefits of using digestate versus other fertiliser.

Crop used for this field trial: ………….			
Lot	**Fertiliser to use**	**Costs involved**	**Yield effect – each time you harvest from this plot, note down in a box the weight of the edible crops in kg**
Put a single stick in the middle of the plot to identify the plot	Digestate	How much digestate will you use on the plot? ……………kg of digestate How long did it take you to collect the digestate from the biogas digester? ……………..……..minutes How long did it take to apply the digestate to lot 1? ……………..……..minutes	…….kg …….kg …….kg …….kg …….kg Total weight of all the harvests: ………..kg
Put two sticks in the middle of the plot to identify the plot	Synthetic fertiliser	How much fertiliser will you use on the plot? ……………..….kg of fertiliser What are the ingredients of the fertiliser? ………………………………. ……………………………….. How long did it take you to go and buy the fertiliser? ………………………..hours How much did you pay for it per kg? ………….……..SBD per kg How long did it take to apply the fertiliser to lot 2? ……………..………minutes	…….kg …….kg …….kg …….kg …….kg Total weight of all the harvests: ………..kg

Put three sticks in the middle of the plot to identify the plot	Raw manure	How much raw manure will you use on the plot? ……...............kg of raw manure How long did it take you to collect the raw manure from the pig pens? ……….................minutes How long did it take to apply the …..............kg of manure to lot 3? ….......................minutes	…….kg …….kg …….kg …….kg …….kg Total weight of all the harvests: ….........kg
Put four sticks in the middle of the plot to identify the plot	Nothing		…….kg …….kg …….kg …….kg …….kg Total weight of all the harvests: ….........kg

SECTION 6: UNCERTAINTIES AND RISKS OF IMPLEMENTING DIGESTERS IN THE CHOISEUL ENVIRONMENT

This section identifies and explains uncertainties (elements about which we cannot be sure) and risks (factors which might have a negative impact on the success of the digester), which should be taken into account when implementing.

Accessing full benefits

The Tanzania Domestic Biogas Programme of the SNV Netherlands Development Organisation have noted that a considerable amount of the possible benefits from biogas digester projects were not realised because communities saw the principle output from the digesters as gas energy, and did not always use the slurry fertiliser (Banzi and Mmbaga, unpublished). It was recommended that more emphasis be put on education and awareness of how to use this secondary product. This would also be crucial for the Choiseul case, as the production of biogas alone appears unlikely to provide sufficient benefits to cover the costs of the digester.

Under the correct conditions, harmful bacteria are removed from the manure during the biogas production, the slurry is likely to be a safer way to fertilise and, with education, it should be possible to reduce the negative association that Pacific islanders might have with using animal waste on their food crops and increase the use of natural fertilisers in Choiseul. As the rate of success of any project will depend heavily on community input into design, and given the taboos regarding waste in the Solomon Islands, it is vital that local preferences be included in the project design.

Social challenges in sharing the digester products

A major element that needs to be considered is how to set up a community digester so that it will benefit all households. Those with experience in training and implementing digesters in the Solomon Islands have warned that, if some households are provided with a digester while others are not, it is likely to lead to internal conflict within the community (Donald Wang, biogas expert – personal communication Feb 2014). Given that not all households would have sufficient supply of biomass as input for a digester, it is recommended that a single digester be set up in a community and be shared. This, in turn, will have its challenges and thought should be put into whether there needs to be a designated person responsible to the fair sharing of digestate and biogas as well as ensuring its smooth running.

Efficiency of burning the biogas

Gas hobs are built in order to work on LPG gas. Before the hob can use biogas efficiently, it must be altered for two reasons:

1. The useful cooking time enjoyed will decrease if the hob does not burn the biogas efficiently and this will reduce the value of methane, as shown in the final column of table 11.
2. The fact that methane causes approximately 72 times as much greenhouse effect as carbon dioxide over 20 years (IPCC 2007) means that the carbon equivalent emissions produced in the digester scenario may be far less favourable if the cooking hob is not efficient. Nevertheless, as displayed in the table 13 below, the carbon equivalent emissions with a digester are never as high as without a digester.

Table 14: Value of methane and emissions, depending on efficiency of combustion.

	Efficiency of combustion	CH4 (kg/day)	Co_2 (kg/day)	Total carbon equivalent emissions (kg/day)	Total heating value of CH4 (SBD/day)
With scenario (5 swine digester)	0%	0.039	0.065	0.884	0.00
	25%	0.029	0.092	0.701	1.79
	50%	0.020	0.119	0.539	3.58
	75%	0.010	0.146	0.356	5.36
	100%	0	0.173	0.173	7.15

Price of LPG

The price of LPG will have an impact on the value of biogas. If the price of LPG continues to increase, the relative value of biogas to the communities will also increase because they will be able to replace some or all of the LPG by biogas and not incur this expense.

Transport costs (which are determined by the price of crude oil-based fuels) are a major variable in determining the price of any imported fuel (including LPG gas). Transport costs are also likely to be highly positively correlated to the other variables, affecting the price of imported fuel (such as the inputs into LPG production – also derived from crude oil).

Consequently, in the future, if imported fuel costs continue to increase, it can be expected that biogas digesters become ever more economically viable.

Availability of manure

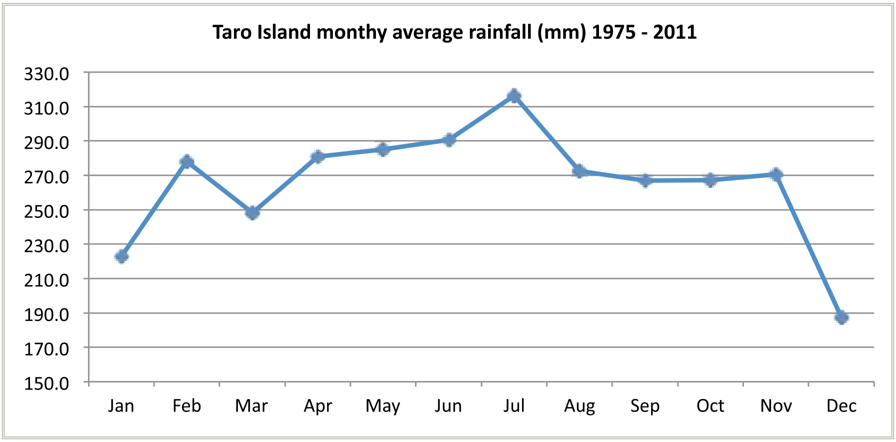
Incentives of households to provide community digesters with manure must be provided. Households have no incentive to contribute to a communal digester with their household livestock manure when they could instead be using it on their crops. A shortage of manure input would lead to the inefficient functioning or failure of a community digester. Nevertheless, given that the slurry output from the digester can be used as a fertiliser in the same way, it should be possible to incentivise individuals to give manure, as long as they can be sure of being compensated with digestate fertiliser in return.

In future, work in this area might also consider the use of plant-based biomass, such as coconut husks as suggested by Hemstock (2008).

Climate variability and availability of water

Although the exact number of days with water shortage is unknown, the graph below indicates that for two months of the year, monthly rainfall dips below 250 mm and water shortages are uncommon in the Choiseul villages (Daniel Farkas, GIZ Development Worker Taro – personal communication May 2014).

Figure 5: Average monthly rainfall (mm) for Taro Island.



Source: Solomon Islands Meteorological Service

During these times, water must be sourced via boat journey to other islands (Daniel Farkas, GIZ Development Worker Taro, personal communication May 2014). It can be expected that during these times the population's preference will be to allocate water to drinking and basic household chores and the cost of traveling to other islands to collect water for the digester will outweigh the desire to keep it running. In addition, livestock will also be allocated less water during these times and may lead to reduced production of manure and even the loss of some livestock.

Given this for the Choiseul case, it can be assumed that, for certain times of the year, the digester will be left unused. Depending on the length of the period, the digester may take time to get up and running again while bacteria are recultivated.

In order to minimise further exacerbating the already stressed water supply, it is recommended that the implementation of digesters takes water availability into account and that rainwater harvesting tanks are included in project designs where necessary.

Cost of time

The results in the illustrative analysis done for the Government farm digester depend heavily on the amount of time that would be needed each day to carry out the daily tasks, such as collecting manure, mixing the digestate and carrying out maintenance. Here, it is assumed this could take an average of an hour per day and that the government farm staff could be using their time productively on other activities if they were not carrying out digester-related tasks. In the villages, the cost of this time each day could be lower as there may be fewer opportunities to carry out productive tasks. This would mean that the hourly cost of labour could be reduced below the minimum wage rate used as the estimated cost of time in this analysis. Given that the maximum quantified benefits accruing from the biogas and carbon emission reduction are SBD 7.16 per day and the daily activities are estimated to take an hour at an hourly cost of SBD 7.69, if the time or hourly cost of labour decreased, it could be possible to create a small net benefit each day by running the digester. Nevertheless, it would still take many years to pay off the minimum of SBD 7,600 it costs to install the digester.

Safe use of digester effluent

A precondition for the success of this approach will be the compilation of health and safety guidelines for the use of digester effluent on crops, and training on how to employ the practices at the community level.

Incorporating climate change

Annual average rainfall is projected to increase over the twenty first century as is the frequency and intensity of days of extreme rainfall. The frequency of droughts is expected to decrease (CSIRO, 2011). This may raise the expected benefits of the digester, by increasing the probability of having enough water to run the digester throughout the year.

Incorporating gender

Given the current cultural roles of men and women in the communities, women are more likely to be using the gas for cooking and perhaps the digestate for fertilisation of garden fruit trees. Whilst traditionally, men have been more involved in building activities so are likely to be interested in constructing and running the digester. This means that women more likely to be involved at the last stage of the process where products are used, and men at the first stage.

As men will not be using the biogas output, their incentive to monitor digester and check may not be as high. Likewise, if the women have not had to spend their labour filling the digester, they may have less incentive to use the products economically and have their burning hobs altered for efficiency.

To increase the likeliness of best practice being used at each stage of the biogas digester process, it is recommended that all of the community, men and women, are trained on the digester, the labour requirements and best practices at each stage, and how this will impact the quality of outputs (benefits) produced.

SECTION 7: SUMMARY OF RECOMMENDATIONS

1. Use of alternate biomass: Even with five swine, the digester is unlikely to produce enough useful products to make the project worthwhile. In fact, manure from 8 to 10 swine is expected to be required for the digester to break even. Making use of plant biomass, such as adding coconut husks and rotting food to the manure input, may increase productivity when swine manure is scarce.
2. Suitability of current technology: While manure digesters are popular in Africa and Asia, adoption is low in the Pacific. The fact that so few digesters have been set up, even though the Taiwan Technical Mission already offers to install digesters and train communities free of charge, might reveal a preference not to use digesters.
3. Learning from the demonstration digester: If the PDF can find a way to make the digester produce overall benefits, through effective use of the digestate fertiliser and/or making use of plant biomass in addition to manure, the team could use this to create awareness of the digester's benefits and potentially increase demand from communities for adopting the technology. To fully value the costs and benefits of a digester system, information detailed in appendix 1should be collected from the outset. This includes data from field trials that can determine the scale of benefits from digestate fertiliser. Such information can inform decisions on whether the technology should be altered to better suit the Choiseul environment.
4. Community ownership: To increase the likelihood that communities will continue to run and maintain digesters, communities would not only need to have enough water and biomass input, but would also need to express an interest in having a digester in the first place, be trained in the technology and contribute to the construction of the digester so that they have incentive to keep it running.
5. Water scarcity: The digester is expected to be less successful in areas that suffer water shortages. In order to reduce risk of digester failure and to minimise further exacerbating the already stressed water supply, it is recommended that the implementation of digesters takes water availability into account and that rainwater harvesting tanks are included in project designs where necessary.
6. Manure and water sourcing: The running of the digester depends on these two principle inputs so structures must be put in place to motivate community members to share their own valuable manure and water resources. As an example, digestate fertiliser might be used to reimburse households for manure for the digester.
7. Gender: To increase the likeliness of best practice being used at each stage of the biogas digester process, it is recommended that both men and women are trained on the digester, the labour requirements and best practices at each stage and how this will impact the quality of outputs (benefits) produced.
8. Making safe use of all benefits: A major benefit produced by the digester is the digestate, which can be used as a crop fertiliser. In order to reap this benefit, communities must be made aware of its value and of how to safely apply it through demonstrations and trainings at the PDF.

9. **Time required to begin digestion process:** A 5 m^3 digester requires around 15 swine and takes between 4 to 6 weeks to fill and to allow the chemical processes to gather momentum before gas can be extracted. With less swine, the fill time will need to be increased.
10. **Hob adjustment:** In order to ensure that the biogas produced can be used efficiently, it is necessary to make alterations to the cooking gas hob. Reductions in the efficiency of the hob could produce significant reductions to the benefits of the system and increase the greenhouse gas emissions it creates.

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APPENDIX 1: Material Construction Costs

Table 15: Material cost table.

Description	Qty	Unit price (SBD)	Total (SBD)
Rejected empty petrol drums (200L)	4	30	120.00
Plywood sheets	2	305	610.00
Screws	28	2	56.00
PVC waste pipes	2	380	760.00
Stainless steel basin	1	120	120.00
Ball Valve	1	80	80.00
Valve connection (assorted polypipes)	4	40	160.00
Polypipe length for connection	1 m	26/m	26.00
Cement(Bags)	15	88	1,320.00
Mix Sand / gravel	10 m^3	\$300/m^3	3,000.00
Timbers	27 ft^2	\$10/ft^2	270.00
Pieces of galvanised metal rods	7.5 m	20/m	150.00
Galvanised security wire mesh	1	850	850.00
Bricks (Inlet &Outlet)	16	12	192.00
Tacks or screws to hold basin to plywood	6	2	12.00
Polypipe for connection to gas stove	5 m	20/m	100.00
Dux	2 m	26/m	52.00
Flat iron	4 m	35/m	140.00
Frame of timbers and plywood	2 ft^2	10/ft^2	20.00
Total Cost (SBD)			**8,038.00**

Source: Nichol Nonga, SPC and Daniel Farkas, GIZ Development Worker Taro - email communication June 2014.

APPENDIX 2: Quantifying Benefits

Two benefits are quantified given the data available; the value of biogas and the value of carbon emission reduction.

1. Value of using biogas for cooking/heating

Calculating the volume of methane produced from a 5-swine digester

According to US Environmental Protection Agency (1999), for each type of system and temperature that the swine manure is broken down in, the production of methane gas is the following:

$$CH4\ (ft^3/lb./day) = TMA\ (lb./day) * VS * MMP\ (ft^3/lb.) * MCF$$

Alternatively, standardising to metric units for methane and manure[16] gives;

$$CH4\ (m^3/kg/day) = TMA\ (kg/day) * VS * MMP\ (ft^3/lb.)(0.028/0.45) * MCF$$

Where:

CH4 = Methane

TMA = Total manure broken down by system A

VS = per cent volatile solids found in adult swine manure (average)

MMP = max methane potential for adult swine manure (average) ft^3/lb

MCF = Methane conversion factor for the system and given temperature

This is equivalent to the revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Zeeman and Gerbens, undated);

$$CH4\ (m^3/year) = B * TVS * MCF$$

Where:

B = Biodegradability of manure (m^3 CH4 produced per kg of VS)

TVS = Total kg of volatile solids produced annually

MCF = Methane conversion factor for the system and given temperature

Pooling the values provided in these two papers provides the following information given

MMP = 5.8ft^3/lb., B = 0.45 for Oceania, VS = 0.09 and the average annual MCF for different systems at or above 30 degrees Celsius displayed in table 16:

Table 16: Methane conversion factors.

System	State	MCF
Liquid slurry (aerobic)	30 degrees	0.65
Dry Corral (aerobic)	30 degrees	0.05
Pasture (aerobic)	30 degrees	0.02
Anaerobic lagoon	30 degrees	0.9
Digester		0.1

[16] 1 cubic foot = 0.028 cubic meter and 1 pound = 0.45 kg.

For the purposes of this assessment, the "Dry Corral" system will be used as representative of the environment where manure is left unused on the ground in the "without scenario" and the "digester" system will be used as representative of the environment in which manure will breakdown in the digester in the "with scenario".

Consequently, the average methane emissions produced by 5 swine, producing a total of 15 kg manure each day would be such as displayed in Table 17 below.

Table 17: Average methane emissions for 5 swine waste.

	US EPA (1999)		IPCC guidelines		Average Methane (m^3/day)
Scenario	Methane (m^3/year)	Methane (m^3/day)	Methane (m^3/year)	Methane (m^3/day)	
Dry Corral (without scenario)	8.89	0.02	11.09	0.03	0.025
Digester (with scenario)	17.57	0.05	22.18	0.06	0.055

Assuming that 5 swine produce 15 kg manure per day and that the digester is functional 365 days/annum.

Quantifying the value of biogas

Biogas is a mixture of methane, carbon dioxide and a small amount of various trace gases with the ratio of methane to carbon dioxide ranging from 55:45 to 70:30. (USDA, 2014). The volume of methane expected to be produced in the "with scenario" (by a 5-swine digester is calculated in the above section) is found to be 0.055 m^3. When biogas is used for heating, the methane combusts and produces energy and the carbon dioxide escapes into the atmosphere. Methane is the "useful" part of biogas and can be quantified.

Given:

- the price of LPG for the PDF is SBD 37.1/kg on average (Andrew Loli, MAL)
- LPG is a mixture of propane and butane
- the net heating value (Btu/kg) butane = 8,989
- the net heating value (Btu/kg) propane = 8,925
- the net heating value (Btu/m^3) methane = 32,500

Based on standard temperatures and pressure (Engineering tool box, 2014).

It is possible to calculate:

- the expected net heating value of LPG is 8,957 Btu/kg
- the price of 1 Btu energy in Choiseul as: SBD 0.004/Btu
- the net heating value of 0.055 m^3 methane produced each day in the digester is 1,788 Btu
- the value of the 0.055 m^3 methane produced each day in the digester is SBD 7.15.

This estimate represents the maximum value of the biogas expected to be produced. It assumes the constant and efficient functioning of the digester all year round, and that the cooking hob is able to efficiently use 100 per cent of the methane produced in the digester.

2. Value of Carbon Equivalent Emission Reduction

Calculating the greenhouse gas emissions

If we take the "Dry Corral" system as a representative system for manure left on the ground around the farm and the "digester" system as a representative system for the breakdown of manure in the digester, we can produce some estimate of the methane, which would be produced with and without a digester[17].

As indicated already, biogas is a mixture of methane, carbon dioxide and a small amount of various trace gases. The ratio of methane to carbon dioxide ranges from 55:45 to 70:30 (USDA, 2014). It is assumed that over the life of the manure degradation, the carbon atoms that make up the volatile solids part of manure will convert either to CH4 or CO_2. It is also assumed that:

- The average methane to carbon dioxide ratio of biogas is 62.5:37.5 (USDA, 2014)
- Greenhouse effect of methane is 72 times that of carbon dioxide (IPCC, 2007)
- A mole of CH4 weighs approx. 16 g
- A mole of CO_2 weighs approx. 44 g
- The complete combustion of methane follows the equation: CH4 + $2O_2$ => CO_2 + $2H_2O$ and so the combustion of 1 mol methane produces 1 mol CO_2.
- 1 mole of a gas occupies 22.4 litres (0.0224 m^3) at standard temperature and pressure (Carbon Dioxide Information Analysis Centre, accessed 2014)

Given these assumptions, the following table can be derived based on the average methane production given in table 18.

Table 18: Emissions produced through manure breakdown in 2 scenarios before combustion of biogas or LPG.

Scenario	CH4 (m^3/day)	CH4 (mol/day)	CH4 (kg/day)	CO_2 (mol/day)	CO_2 (kg/day)
Without digester	0.025	1.116	0.018	2.812	0.124
With digester	0.055	2.455	0.039	1.473	0.065

Table 18 above shows the CH4 and CO_2 produced through the breakdown of manure in the two scenarios (with and without the digester). It does not account for the emissions produced through combusting the methane in the "with digester" scenario or the LPG in the 'without" scenario when using the cooking hob.

In order to calculate the final emissions that are expelled into the atmosphere in the two scenarios, it is necessary to account for the emissions produced through combusting the methane in the "with digester" scenario or the LPG in the "without" scenario when using the cooking hob. Calculations are presented in table 19 below. In order to make a fair comparison of the emissions produced through combusting the methane in the "with digester" scenario and combusting LPG in the "without" scenario, the energy used in each must be the same; i.e. the energy provided in the "with digester" scenario by burning the 0.039 kg methane produced each day in the digester, must be the same as the British thermal unit (Btu) given through using LPG in the "without" scenario. Previously, in the "Valuing the methane produced" section of this report, the calculations for the monetary value of methane production indicated that approximately 1,788 Btu methane would be

[17] Assuming complete digestion.

produced each day in the digester. Given that the expected net heating value of LPG is 8,957 Btu/kg, in the "without" scenario, 0.20 kg LPG are assumed to be used[18].

Table 19: Total emissions in the "with and without" scenarios.

Scenario	Emissions from manure and derivatives[19]		Emissions from combustion of LPG[20]		Total carbon equivalent emissions (kg/day)
	CH4 (kg/day)	CO_2 (kg/day)	CH4 (kg/day)	CO_2 (kg/day)[21]	
Without scenario (Dry Corral)	0.018	0.124	0	0.626	2.046
With scenario (digester)	0	0.173 [22]	Na.	Na.	0.173
Carbon equivalent emission reductions with digester					1.873

The total emissions of CH4 and CO_2 calculated above assume that the methane or LPG is completely combusted (100 per cent efficiency of the gas hob). If the efficiency differs, the amounts of CH4 and CO_2 emitted will also change.

The estimation of the emissions created through the use of LPG in the "without" scenario only include emissions which are directly created during LPG combustion. All the emissions produced during the production and transport of LPG before it is actually used, are ignored. This means that the carbon equivalent emissions estimated in the "without" scenario are underestimating the total carbon equivalent emissions produced and should be taken as a minimum estimate.

Valuing the emissions reduction

The traded monetary value of reducing carbon equivalent emissions by 1 tonne is USD 5.9 or SBD[23] 42.6 (Peters-Stanley and Yin, 2013). Given that the daily reduction in carbon equivalent emissions is 1.873 kg per day, from table 15 above, the daily offset value is equal to SBD 0.08.

This carbon market value may not represent all environmental gains which greenhouse gas reductions produce and should be taken as a minimum estimate[24].

[18] The expected net heating value of LPG is 8,957 Btu/kg.

[19] These emissions are produced through manure decomposing on ground in the "without" scenario, and manure being digested and then completely combusted in the "with digester" scenario.

[20] The combustion of LPG only takes place in the "without" scenario, because in the "with digester" scenario, the cooking gas is supplied from the manure derivatives.

[21] Combustion of 1 kg LPG produces approximately 3,129.66 g CO_2 (MercyCorps, accessed 2014).

[22] The amount of CO_2 increases once the combustion of CH4 occurs. Using values from table 18 for reference; all 2.45 mol CH4 is completely combusted to form an extra 2.45 mol CO_2. In total, the 1.47 mol CO_2 produced in the digester and the 2.45 mol CO_2 produced during CH4 combustion amounts to 3.93 mol CO_2, or 172.8g of CO_2.

[23] Mid-market exchange rate used according to rates at 30-06-2014 from: http://www.xe.com/.

[24] Here, the emissions reductions value is being used as an estimate of the environmental benefit of the digester. Although the CBA is done in terms of the PDF and it is not possible to know how much of the benefit will go to the PDF versus the rest of the planet, the use of this market value was chosen for its simplicity. In addition, if a project was to set up with multiple community digesters, and adhered to the relevant IPCC guidelines, it would be possible to sell the carbon credits in exchange for cash.

APPENDIX 3: Global Warming Potentials

Table 20 and its notes are taken directly (word for word) from the IPCC Fourth Assessment Report (IPCC, 2007) based on data from their 2005 assessments.

Table 20: IPCC Global warming potentials.

				Global Warming Potential for Given Time Horizon			
Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency (W m^{-2} ppb^{-1})	SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See belowa	[b]1.4x10^{-5}	1	1	1	
Methane[c]	CH4	12[c]	3.7x10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03x10^{-3}	310	289	298	153

Notes:

a The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (IPCC, 2007) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

Where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

[b] The radiative efficiency of CO_2 is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).

[c] The perturbation lifetime for methane is 12 years as in the TAR (see also Section 7.4).

The GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour (see Section 2.10.3.1).

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