USE OF BIOGAS AS AN ALTERNATIVE ENERGY SOURCE IN TUVALU

PRELIMINARY COST-BENEFIT ANALYSIS REPORT

SPREP
Secretariat of the Pacific Regional Environment Programme

The **Pilot Program for Climate Resilience: Pacific Regional Track (PPCR-PR)** is a regional program which aims to strengthen integration of climate change and disaster risk considerations into 'mainstream' policy making and related budgetary and decision-making processes (i.e. 'climate change and disaster risk mainstreaming').

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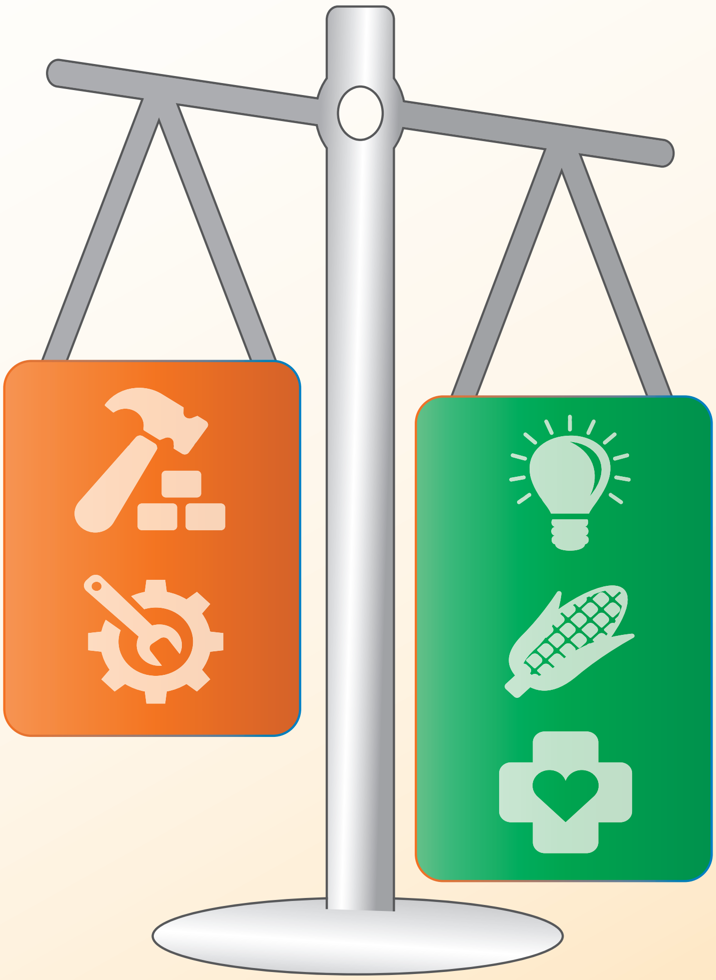

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CONTENTS

EXECUTIVE SUMMARY 1

1. INTRODUCTION AND CONTEXT 3

2. APPROACH, INPUT DATA, AND OTHER PARAMETERS 8

3. COST BENEFIT ANALYSIS RESULTS 15

4. RECOMMENDATIONS, PROJECT DESIGN AND IMPLEMENTATION 29

REFERENCES 35

Executive summary

Energy for cooking is a major cost to households in Tuvalu. Biogas provides a potential means to provide sustainable, affordable, and reliable energy sources for domestic cooking needs.

There are a number of potential technical, economic and social reasons why digesters have not been used extensively in Tuvalu to date. These include the technical efficacy of digesters, awareness of the technology and its benefits for households, the broader benefits and costs of using digesters, and access to appropriate funding to cover the significant up-front establishment costs. A preliminary cost-benefit analysis (CBA) building on the existing knowledge base will enhance the information base for policy development, decision-making, and future investment in biogas.

A major trial is about to commence to install, monitor, and evaluate the use of household-scale biogas digesters in 40 households across Tuvalu. This report summarises the findings from a preliminary CBA of the use of biogas. Three options were assessed:

- Option 1: Household biogas for cooking energy only.
- Option 2: Household biogas for cooking energy and home garden benefits in the form of higher yields and avoided fertiliser costs.
- Option 3: Biogas at the household scale with a compressor to enable the digester to be located with the pig accommodation and not necessarily adjacent to the house. While this option has been assessed in the CBA, the compressor technology requires more development and trial before consideration as a mainstream option.

The CBA found benefits to households related to household costs that would be avoided, specifically:

- reduced fossil fuel energy expenditure of up to AUD 475 to 500 per annum;
- avoided time to collect and prepare firewood worth up to AUD 500 per annum (based on the hourly returns to labour from home production and sales of agricultural output); and
- when output from the digester is used as a substitute for liquid fertiliser, benefits in the form of lower fertiliser costs and increased garden yields are worth around AUD 50 to 75 per annum.

When the costs to households are also included in the analysis (cost of time, cost of water), households could still be better off by around AUD 825 to 900 per annum (assuming similar energy substitution to previous trials). That is, there is a net benefit to the household of up to AUD 900 per annum.

Other benefits include a reduction in the health burden associated with indoor cooking using wood (potentially worth AUD 26 per digester per annum) and marginal reductions in CO_2 emissions (potentially worth around AUD 17 per digester per annum).

Overall, the preliminary CBA over a 30-year period[1] indicates benefits exceed costs by a ratio of around 1.5 to 1 when the mid-point estimates for inputs are adopted (i.e. a Benefit-Cost Ratio [BCR] is 1.5). Sensitivity analysis conducted for the CBA indicates that:

- if the value of time for subsistence activities is ignored (i.e. time has no opportunity cost), the BCR drops to around 1.0;
- if the useful life of a digester is <10 years, the BCR falls below 1 for some options. This reinforces the need to ensure digesters are used and maintained in the long-term;
- overall, the sensitivity analysis found that for the digesters to be economically viable, the household generally needs to have some fossil fuel expenses that are substituted by the biogas.

1 Analysis was conducted over a 30-year period. However, the assumed base-case of the life of digesters is 20 years. We have also run sensitivity analysis of changes in the life of the digesters at 10 years and 30 years (hence the 30-year time frame for the overall analysis).

That is, to be economically viable, a household must displace some fossil fuel use. The benefits of time savings to collect firewood alone are generally not sufficient to make a digester an economically viable option;

- It is important to consider climate variability, climate change, and disaster risks, because the performance and economic viability of digesters is susceptible to extreme drought, cyclones, and storm surge events. These risks can be significantly mitigated through actions including the location and design of equipment and establishing contingencies to ensure continued operation during and after extreme events; and
- while we have assumed an effective life of digesters is 20 years as a base case, similar tanks used in other locations have an expected life of 30 years. If the life of the tanks can be extended to 30 years through proper maintenance, the benefit cost ratios increase significantly (to approximately 1.9).

Of the three broad options considered, the results from the CBA were very similar. However, Option 2 (biogas and garden benefits) had the highest overall NPV and BCR. These values indicate that this option is superior.

The approach used for the CBA is outlined in detail in Section 2 of this report, while the findings from the analysis including sensitivity analysis and climate change risks are outlined in Section 3.

Key recommendations from the CBA project:

1. The use of digesters should proceed as a trial because digesters are economically viable.
2. At the project steering committee meeting on 10 August, key demographic and economic data and the outcomes of the CBA outlined in this report were used to inform the choice of islands for the trial. The demographic and economic analysis found no valid reason to exclude any of the islands being considered. However, a contingency plan should be available if any particular island is undersubscribed.
3. A properly designed monitoring and evaluation (M&E) strategy should be established as part of this trial. The M&E strategy will provide vital information to inform any future business case for the widespread use of biogas in Tuvalu.
4. The implementation phase of the trial should also ensure the proper design and placement of digesters and pig pens and the establishment of contingency for extreme weather events to ensure the continuity of benefits from the digesters.
5. As part of the M&E strategy, cost-sharing options should be assessed, particularly future options for households to contribute to the capital costs of digesters.
6. More detailed recommendations and insights for the design and implementation of the trial are outlined in Section 4 of this report. In addition, Section 3.3 highlights specific climate and climate change risks and implications for the design and implementation of the project.

1. Introduction and context

The lack of access to an adequate, affordable, reliable, safe, and environmentally benign energy source for cooking is a severe constraint on development in Tuvalu. Most households are highly reliant on sources such as bottled gas, kerosene, or more traditional sources such as wood. Energy supplies are significantly more costly and potentially unreliable in the outer islands where transport costs are high, and supply of gas and kerosene can be unreliable due to disruptions in shipping from Funafuti. The Tuvalu Government has an ambitious target of 100% renewable energy by 2020 for all uses excluding transport fuels. The objective of this policy is threefold: reducing energy costs; enhancing reliability and reducing the reliance on imported fossil fuels (particularly diesel, kerosene, and liquefied petroleum gas [LPG]); and reducing Tuvalu's contribution to CO_2 emissions. Major increases in capacity of solar PV technologies in recent years have resulted in progress toward this target, particularly for lighting and refrigeration in the outer islands. However, progress in achieving renewable energy sources for cooking has been more problematic because electricity is generally not used as a source of energy for cooking.

The dominant sources for energy for cooking in Tuvalu are kerosene, LPG gas, and firewood. Kerosene and LPG gas are expensive sources of energy, particularly for lower income households. In addition, transport disruptions to the outer islands can result in occasional shortages of fossil fuels. Firewood takes a significant amount of time to collect and prepare, and the use of firewood for indoor cooking has significant impacts on health.

One option being considered is the use of biogas digesters. Biogas digesters breakdown organic matter in an anaerobic environment and produce various gases (including methane) that can be efficiently combusted for household cooking. Typically, organic material (particularly pig manure) and freshwater are fed into the digester, and gas and digester effluent (a slurry also called digestate) are produced. The gas is captured, stored, and used as a form of energy. Furthermore, the digestate can be used as a natural fertiliser, which will increase crop yields and reduce the need to purchase fertilisers. A simple diagram of a digester is shown below.

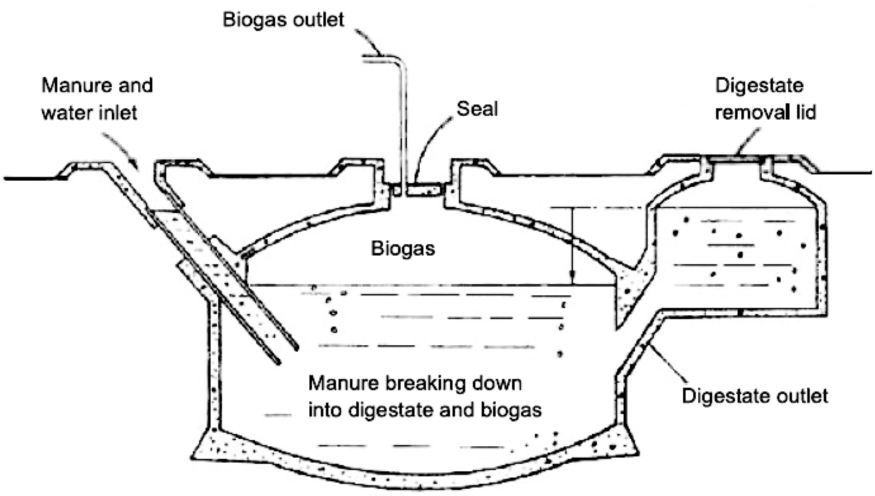

FIGURE 1. DIAGRAM OF A SIMPLE DIGESTER

There are a number of potential technical, economic and social reasons why digesters have not been used extensively in Tuvalu to date. These include:

- The technical efficacy of digesters and the degree to which they can be used to displace fossil fuel sources.
- A lack of awareness of the technology and the net benefits that could be derived by households. Overcoming this information problem is a major step towards the widespread use of biogas.

- The broader benefits and costs of using digesters. Knowledge of the benefits and costs will enhance decision-making and investment at the Government and household scales.
- Access to appropriate funding to cover the significant up-front establishment costs. Once the benefits to households are understood, financing and cost-sharing options for biogas can be established.

A preliminary CBA building on the existing knowledge base will enhance the information base for policy development, decision-making and future investment in biogas.

1.1 Broad objective of this study

The objective of this report is to conduct a preliminary CBA for the use of biogas. This CBA will enhance the awareness and information base for policy development, decision-making, and future investment in biogas. This report will inform a major European Union funded project *Sustainable Community-Based Biogas Schemes for Domestic Energy and Improved Livelihoods* where up to 40 digesters will be installed, operated, and evaluated over the two-year project. That project will provide a real-world trial and demonstration of the applicability of biogas as an affordable and reliable source of energy for cooking across Tuvalu. In addition, this report seeks to enhance available information relating to digesters, reduce investment risk, inform the design and implementation of the monitoring and evaluation of the proposed trial of digesters, and provide a framework within which future economic analysis (including monitoring and evaluation) can be undertaken.

1.2 Households and energy usage for cooking

Tuvalu's population of approximately 11,000 residents is spread across 10 islands. Table 1 shows a selection of key demographic statistics relevant to this analysis.

TABLE 1. KEY HIGH-LEVEL STATISTICS

	ISLAND									
INDICATOR	**NANUMEA**	**NANUMAGA**	**NUITAO**	**NUI**	**VAITAPU**	**NUKUFETAU**	**FUNAFUTI**	**NUKULAELAE**	**NIULAKITA**	**TOTAL / AVERAGE**
Household characteristics										
Resident population	543	478	603	529	1,541	536	5,935	322	27	10,514
Households	115	116	123	138	226	124	845	67	7	1,761
Average household size (persons)	4.7	4.1	4.9	3.8	6.8	4.3	7.0	4.8	3.9	6.0
Household owns land (%)	96%	97%	94%	100%	95%	96%	77%	100%	100%	87%
Households owning pigs (%)	88%	87%	87%	94%	92%	90%	71%	85%	100%	81%
Households with home garden (%)	29%	28%	37%	6%	10%	23%	27%	31%	29%	24%
Estimated average size of gardens (m^2)[2]	11	13	7	9	7	12	9	7	6	9

Source: Government of Tuvalu (2012) Tuvalu national population and housing census

2 This is the weighted average home garden size for each island based on data in the 2012 census.

A number of points are of note:

- The population is highly concentrated in Funafuti and Vaitapu. The majority of the other islands have populations of approximately 300 to 600 people. Persons per household are significantly higher in Funafuti and Vaitapu (7.0 and 6.8 respectively). This compares to a range of 3.8 to 4.9 persons per household across the islands with lower populations.
- The incidence of land ownership is typically greater than 95% of all households, with Funafuti being the exception.
- Typically, over 85% of households own pigs. Again, the exception is Funafuti, where land availability constraints limit ownership.
- The incidence of households with home gardens varies significantly across the islands but is significantly lower than pig ownership. Home gardens are typically relatively small and rarely exceed 20 m^2. We estimate the weighted average size of home gardens is typically between 9 m^2 and 12 m^2 across most of the islands.

The 2004/05 and 2010 Household Income and Expenditure surveys show a significant difference in fuel use between the poor and non-poor and between Funafuti and the outer islands. It also indicates an increase in the use of gas in recent years across all user groups (Table 2).

TABLE 2. COOKING FUEL USE AND CHANGE SINCE 2004/05

	NATIONAL		FUNAFUTI		OUTER ISLANDS	
	POOR	NON-POOR	POOR	NON-POOR	POOR	NON-POOR
2010						
Electricity	3.0%	3.1%	7.0%	5.2%	0.0%	1.5%
Gas	29.2%	49.5%	48.8%	73.6%	14.0%	31.2%
Kerosene	26.4%	17.0%	34.9%	17.8%	19.9%	16.4%
Firewood	39.5%	29.1%	7.0%	1.7%	64.6%	50.0%
Other	1.9%	1.2%	2.3%	1.7%	1.6%	0.8%
Change in % since 2004/05						
Electricity	3.0%	2.0%	7.0%	4.5%	0.0%	0.2%
Gas	26.6%	35.6%	40.2%	46.9%	11.7%	26.3%
Kerosene	**-31.7%**	**-41.2%**	**-53.7%**	**-52.0%**	**-22.4%**	**-32.4%**
Firewood	1.3%	3.0%	4.1%	-0.4%	11.5%	5.8%
Other	0.7%	0.4%	2.3%	1.0%	-0.7%	0.0%

Source: Government of Tuvalu (2014) The poverty lines, the incidence and characteristics of poverty in Tuvalu.

The latest data indicate that the use of gas is significantly higher in Funafuti, particularly among the non-poor. The use of traditional fuels such as firewood is significantly higher in the outer islands. This is particularly true among the poor due to several factors including the price of fossil fuels and also due to a general higher propensity for self-sufficiency of the people in the outer islands.

Change has also occurred in recent times in the mix of fossil fuels, with significant increases in the use of gas in lieu of kerosene.

1.3 Previous use of biogas in Tuvalu

A small trial of 11 biogas digesters has been underway on Nanumea and Nanumaga islands for the past few years. A major consultation exercise was undertaken in 2015 to review the use of digesters and households' views of the digesters (Manuella-Morris 2015). This review included significant interviews and surveys.

The consultation found that households generally found the use of the digesters to be a convenient, reliable, and a cost-effective source of energy for cooking compared to the previous need to purchase fossil fuels.[3] The majority of participants in the consultation indicated that the digester system made it easy to keep pig pens clean; was more convenient than collecting and preparing wood for the fire, and provided an important source of fertiliser for the home garden.

Most importantly for this CBA, households were specifically asked about how much the digester had allowed them to reduce their consumption of expensive fossil fuels. Key findings were:

- Two thirds of the households used both LPG and kerosene as part of their fuel mix. All households used some kerosene.
- On average, households that had previously used LPG as part of their fuel supply mix reduced their LPG use by 4 bottles per year (range of responses was 3 to 5 bottles). Only one of the houses had purchased any LPG in the previous year (1 bottle). Overall LPG use was reduced by 92%.
- On average, households that had previously used kerosene as part of their fuel supply mix reduced their use by 125 litres per year (range of responses was 69 to 208 litres). The overall reduction in kerosene use was 86%.
- One-third of the houses participating in the previous biogas project had been able to completely eliminate the need to purchase fossil fuels.

This information has been used as the more likely level of fossil fuel substitution in this CBA (i.e. 4 bottles of LPG and 125 litres of kerosene). Part of the sensitivity analysis conducted also assessed the changes in the CBA where the substitution was at the low end of the range from the survey.[4]

It should also be noted that the consultation did reveal some potential problems with the digesters, including the occasional smell where digesters were situated very close to the house and occasional shortages of water to mix with the dung, particularly during the recent drought. In addition, one digester was not properly used and maintained in the previous trial and was subsequently moved to another household.

3 It should be noted that participants in the previous trial made no contribution to the capital costs of digesters. Hence, their assessments were based on benefits and costs accruing directly to the household.

4 The proposed project will include a more rigorous monitoring strategy that will enable more reliable data in fuel substitution to be established.

1.4 Overview of options assessed

In this study, three separate options are assessed. The options and their key characteristics are shown in Table 3.

TABLE 3. BIOGAS OPTIONS ASSESSED

OPTION	KEY CHARACTERISTICS
Option 1: Household biogas for cooking energy only	Installation of biogas digesters for the provision of gas for cooking at the household level. The objective is to displace other sources of cooking energy, particularly gas (cylinders) and kerosene.
Option 2: Household biogas for cooking energy and home garden	Installation of biogas digesters for the provision of gas for cooking at the household level. The objective is to displace other sources of cooking energy, particularly gas (cylinders) and kerosene. In addition, the digestate by-product is used as fertiliser on home gardens, removing the need to purchase fertilisers and improving production yields.
Option 3: Biogas with a compressor	The same as Option 2 plus the use of hand-operated compressors to be owned by the Kaupule who would manage the distribution of gas in exchange for raw materials. Note: this option also requires proof of the technical feasibility of compressors as part of the trial.

2. Approach, input data, and other parameters

This section briefly outlines the approach used for the analysis, key input data, and other relevant parameters.

2.1 Analytical approach – cost-benefit analysis (CBA)

Any decision to transition to using digesters will involve economic costs and benefits. These costs and benefits will be unevenly distributed over time and between project households and third parties (project donors, the Tuvalu Government, and broader society).

CBA is one of the main tools used by economists to identify whether projects or policy changes are worthwhile to society overall. CBA assesses the overall outcomes of a proposal by adding up *all* the costs and benefits associated with the proposed change. It can also inform project design, modification, and evaluation through testing underlying assumptions and other relevant parameters used in the analysis.

CBA for an assessment of projects such as those considered in this report is equivalent to a profit-and-loss analysis for a firm. However, there are two critical differences: (1) CBA is a tool for helping to make public decisions, taking the standpoint of society in general rather than a single firm; and (2) CBA is often done for projects, policies, and programs that have non-marketed types of outputs, such as improvements in health or the environment.

If the net result is positive (benefits minus costs exceeds AUD 0), the implication is that the proposed change is worthwhile. This calculation is called the net present value (NPV). In addition, the ratio of benefits to costs can also be calculated. This calculation is called the benefit-cost ratio (BCR). When that ratio is >1, the project is economically viable. Higher ratios indicate better outcomes.

The analysis incorporates discounting calculations to take into account the time value of money, thereby allowing the comparison of projects with different time frames in a consistent manner. In all, CBA has significant potential to inform decision makers on key policy issues, and its use is widely endorsed by government agencies in most developed and developing nations.

Ultimately, the use of CBA in this project is to determine whether the three biogas options outlined in Section 1.4 are economically viable and under which assumptions. In addition, CBA can be used to determine which option is likely to be economically superior. A number of specific questions are answered through the application of the CBA to digesters in this report:

- Is the installation of biogas at the household level economically viable?
- To what extent does the project contribute to cash savings for households?
- To what extent does the project displace fossil fuels used for cooking? (gas, kerosene)
- What factors are important in maximising the benefits of biogas digesters?
- To what extent does the production and the use of digestate contribute to improved household food security? How much does this increase the benefits of the installation of the digester?
- Is the installation of biogas and a compressor by the Kaupule in Nanumaga and Funafuti economically viable?
- What factors are important in maximising the benefits of biogas digester and compressor?
- What factors are likely to influence the level of ownership of the household/Kaupule to the ongoing maintenance and sustainability of the digesters and compressor?
- What information and data should be collected as part of the monitoring process to be able to monitor whether the benefits are being realised?
- What recommendations can be provided to ensure that the benefits are safeguarded from climate risks to the greatest extent possible?

2.1.1 CBA TASKS PERFORMED

The application of CBA to biogas involved a number of systematic tasks, specifically:

1. **Determine the objectives of the CBA.** This is the process of determining what options are being assessed and questions we are trying to answer. In this case, is biogas an economically viable option for cooking energy in Tuvalu? This process also includes specifying the set of options to be assessed (outlined in Section 1.4 of this report). This process was undertaken by the CBA team as part of the broader project design and at the CBA training undertaken by SPREP/GIZ in July. These options were also revisited at a workshop of the CBA team on 29 July 2015.
2. **Conduct a "with and without" analysis** (for identifying costs and benefits). This is the process of identifying what differences will occur with biogas and the benefits and costs of each option. The analysis should consider costs and benefits from society's point of view. This issue was also discussed among the CBA team at the workshop on 29 July.
3. **Collate data** (for measuring costs and benefits). Data on costs and benefits to be used in the CBA must be established. The prediction of the impacts was based on the outcomes of consultation, information and data available from relevant departments, and previous research. CBA team members gathered data relevant to the impacts specific to their department (e.g. Department of Energy sourced, analysed, and provided data on LPG and kerosene). For most impacts, the CBA team were able to readily find monetary information. However, for more complex issues (cost of water, subsistence value of labour, health impacts, and carbon abatement), Jim Binney (CBA consultant) estimated the specific values.
4. **Aggregate costs and benefits.** Annual costs and benefits were aggregated and then discounted to allow streams of benefits and costs with different time frames to be assessed in a common measure (i.e. current dollars). This was done at the CBA model building and training workshop on 7 August. At this workshop, the NPV and BCR of each option were also assessed.
5. **Conduct a sensitivity analysis.** For any major proposal, it is highly likely that there will be uncertainty around many of the assumptions/estimates. A thorough CBA should test the sensitivity of the result. This is done by varying the assumptions/estimates within plausible bounds and recalculating the NPV/BCR. The technical consultant primarily undertook this task. However, CBA team members did practice some sensitivity analysis at the workshop on 7 August.
6. **Rank the options.** The proposal with the largest NPV is the most efficient. When projects are of significantly different scales, the BCR is often used to determine the superior option.
7. **Consider equity and distributional implications.** For this project, consideration of equity and distributional consideration was constrained by data availability. However, the distribution of benefits and costs between stakeholder groups (donors, households, Tuvalu Government) was assessed based on some basic assumptions.

This process has effectively been repeated for each of the three options assessed in this report.

As part of this CBA, two models have been developed in Excel. The first model was a simplified version of the CBA. This model was built at the CBA team workshop on 7 August. Each participant at the workshop built a version of the model on his or her laptop. We then discussed the results and performed some basic sensitivity analysis.

The project technical consultant also built a more sophisticated CBA model that allows for the sensitivity testing of all 32 input parameters relevant to the CBA.[5] This report is based on the outputs from the more sophisticated model, although it should be noted that the results of the simpler model are almost identical.

5 The more sophisticated model has been specifically designed to allow the CBA team to easily test "what if" sensitivity analysis scenarios using "drop-down boxes" in the spreadsheet to assist in the implementation of the broader project. It has also been designed to enable easy updates of input parameters as superior information is gathered through the monitoring and evaluation process. Three of the CBA team and broader project team have also been shown how to use the model (Teuleala Manuella Morris, Bateteba Aselu, and Sarah Hemstock).

2.2 Identification of costs and benefits

Following on from the session to identify benefits and costs held at the CBA training course, the CBA team revisited that process in a meeting on 29 July. At that meeting, we also identified where the potential distribution of the cost or benefit (household or third party such as donor or Government). The outcomes from that session are shown in Table 4.

In this process, we identified two broad sets of costs. First, those costs involved in the establishment of the digesters and associated equipment. For the purposes of the current trial being developed, we assumed that the capital costs would be borne by donors for this demonstration project. However, given the fact that many benefits of biogas accrue directly to households (avoided energy costs, time savings, etc.), we have also considered ways of sharing the establishment costs under any program to mainstream the use of biogas in Tuvalu (see Section 4). Other benefits relate to reduced health costs to government and reduced CO_2 emissions, that we have assumed accrue to broader society. We assumed that householders would contribute labour to the establishment of the digesters and pig pens, etc.

Second, we have assumed that ongoing operations and maintenance costs would be borne by the households. Those costs largely relate to time (filling digester, mixing water, etc.).

TABLE 4. IDENTIFICATION OF COSTS AND BENEFITS

COST OR BENEFIT	APPLICABLE TO OPTION? (Y = YES, N = NO)			DISTRIBUTION
	OPTION 1: HOUSEHOLD GAS	OPTION 2: HOUSEHOLD GAS & GARDEN	OPTION 3: BIOGAS WITH COMPRESSOR	
Costs				
Establishment costs				
Ground preparation	Y	Y	Y	Donor
Ground preparation (labour)	Y	Y	Y	Household
Plastic tanks	Y	Y	Y	Donor
Bio-digesters	Y	Y	Y	Donor
Compressors	N	N	Y	Donor
Gas stoves	Y	Y	Y	Donor
Hardware (pipes, glues, buckets etc.)	Y	Y	Y	Donor
Installation (labour)	Y	Y	Y	Donor
Additional freight / transportation	Y	Y	Y	Donor
Technical oversight/training	Y	Y	Y	Donor
Testing	Y	Y	Y	Donor
Pig pen (sand and gravel)	Y	Y	Y	Donor
Pig pen fencing	Y	Y	Y	Donor
Pig pen labour	Y	Y	Y	Household
Garden fencing	Y	Y	Y	Donor
Garden fencing labour	Y	Y	Y	Household
Tools for maintenance	Y	Y	Y	Donor
Operations and maintenance				
Labour (dung collection)	Y	Y	Y	Household
Water	Y	Y	Y	Household
Annual maintenance	Y	Y	Y	Household
Benefits				
Benefits to households				
Avoided LPG purchase costs	Y	Y	Y	Household
Avoided kerosene purchase costs	Y	Y	Y	Household
Avoided firewood collection costs (time savings)	Y	Y	Y	Household
Increased crop yields	Y	Y	Y	Household
Increased reliability	Y	Y	Y	Household
Benefits to third parties				
Reduced emissions	Y	Y	Y	Community
Health benefits	Y	Y	Y	Community

The benefits will largely accrue to households in the form of avoided fossil fuel costs, avoided time for firewood collection and preparation, and benefits to the home garden (avoided fertiliser costs and increased yields). There will also be some health benefits to households where use of firewood in cooking is reduced, with related avoidance of loss of income during related illness. However, there was insufficient information available to estimate those costs.

However, some benefits will accrue to third parties, specifically reduced health expenditure by the Department of Health relating to smoke-induced illness and reductions in CO_2 emissions that benefit society more broadly.

2.3 Valuation of unit costs and benefits

One of the major complexities in undertaking the CBA was the fact that many benefits and costs attributable to the use of digesters were indirect or non-market in nature. That is, their values cannot be observed directly through market transactions. Therefore, a number of valuation techniques were used:

- **Market values.** For some inputs to the CBA, there are direct market prices. This includes items such as the cost of the digesters, etc.
- **The production function approach.** When a good or service is used as an intermediate input factor in some production process (e.g. fertiliser), and the output of the production process can be sold in a market, the economic value of the input can be defined by the additional value (profit) that the input generates in isolation from other inputs and production technology (e.g. the value of the additional vegetable production when fertiliser is applied to crops).
- **Avoided cost, replacement cost and substitute cost methods.** These are related methods that estimate values of goods and services based on either the costs of avoiding damages due to lost services, or the cost of providing substitute goods. For example, the value of cooking energy provided by the digesters can be determined by the avoided cost to the household for purchasing gas or kerosene.
- **Benefit transfer.** This method employs estimates of economic values from studies undertaken elsewhere to infer values for the project under consideration.

Generally, the members of the CBA team identified and gathered relevant data market values and values estimated using the substitute cost method. The technical CBA consultant determined more complex values.

The table below indicates the valuation technique used and the key source(s) of data for each cost and benefit used in this CBA. Note: because of the uncertainty in some estimates of values, a range was used and tested through the sensitivity analysis process.

TABLE 5. VALUATION TECHNIQUES USED AND INFORMATION SOURCES

COST OR BENEFIT	VALUATION TECHNIQUE	SOURCES OF INFORMATION AND DATA
Costs		
Labour costs	Market values and production function	For technical labour inputs, market rates (AUD/hour) were advised by the Department of Public Works (based on standard local contractor rates). Advice on the range of time required (hours) to complete specific tasks was also provided. Because Tuvalu has no minimum wage (or subsistence wage), this value had to be estimated. The technical CBA advisor established a range of estimates using a production function approach based on subsistence gardening. The data used were monthly estimates of the monthly value of garden produce and subsistence sales (from the Household Income and Expenditure Survey) and estimates of hours spent gardening sourced from a time and motion study conducted for 101 households in Tuvalu (Bernard 2013). By dividing monthly values for subsistence gardening by monthly hours spend gardening, it is possible to estimate an approximate value of subsistence labour.
Establishment costs		
Ground preparation, plastic tanks, bio-digesters, compressors, gas stoves, hardware, pig pen (sand and gravel), pig pen (fencing), garden fencing, and tools for maintenance.	Market values	Direct quotes provided to donor agencies by suppliers. Where quotes are more than 12 months old, amounts were increased using estimates of inflation. Additional information was provided by key departmental staff, particularly relating to local construction and materials costs.
Operations and maintenance costs		
Labour (dung collection)	Production function	Estimates of time required were multiplied by the estimate of the value of subsistence labour.
Water	Replacement cost	The CBA technical advisor developed a separate simple mode to estimate the cost of replacing 1 litre of water. The model includes parameters for the capital costs of tanks (based on market values), tank life, and water production yields. Information was provided by Public Works Department, the Meteorological Office, and previous studies.
Annual maintenance	Production function	Estimates of time required were multiplied by the estimate of the value of subsistence labour.
Benefits		
Avoided LPG use	Market values and avoided cost	Data on market prices gathered by the Department of Energy were multiplied by the estimated reductions in use from the recent consultation report (see Section 1.2 of this report).
Avoided kerosene use	Market values and avoided cost	Data on market prices gathered by the Department of Energy were multiplied by the estimated reductions in use from the recent consultation report (see Section 1.2 of this report).
Avoided time to collect and prepare firewood	Avoided cost	Estimates of the hourly value of subsistence labour were multiplied by estimates of time spent collecting and preparing wood (Bernard 2013).
Health benefits relating to use of indoor fires	Avoided cost and benefit transfer	To estimate a per capital estimate of health benefits, available estimates of the annual % burden to health expenditure in developing countries attributable to indoor fires for cooking (World health Organisation, undated) were applied to the Tuvalu per capita expenditure on health (World Bank 2015). It was assumed each digester would reduce the incidence of health impact for one person (i.e. the person undertaking the cooking duties).
Savings in fertiliser costs	Avoided cost	Estimates of use advised by horticulturalists working on the Taiwanese horticulture project multiplied by fertiliser market costs.
Garden yield	Production function	Potential % yield increases from the use of liquid fertiliser (advised by Department of Agriculture and Taiwanese Horticulture project.
Carbon abatement	Benefit transfer	Values per digester transferred from a previous study in the Solomon Islands (Wilks 2014). Values for Tuvalu were established using exchange rates obtained from the internet.

2.4 Other parameters

2.4.1 REAL DISCOUNT RATE

To conduct a CBA, a discount rate must be used to enable the assessment of all future costs and benefits as present values (today's values). There is no official Government bond rate (or similar) to determine a discount rate in Tuvalu, nor is there any formalised equity market to provide guidance. Therefore, we used a real discount rate based on existing nominal lending rates less inflation.

Both the National Bank of Tuvalu (NBT) and the Tuvalu Development Bank (TDB) offer loan facilities. Interviews conducted with bank management revealed commercial rates charged by the NBT range form 6.5% per annum (secured low risk lending) through to 9.5% per annum (unsecured or more risky lending). The TDB charges higher rates, but has a more risky loans portfolio due to the high proportion of business loans. However, the TDB is charged a rate of 6.0% per annum for capital provided by Government. This rate is similar to a risk-free lending rate. Interviews revealed interest rates do not fluctuate greatly, although rates in recent years have been relatively lower.

Analysis of World Bank implicit price deflators for Tuvalu for the period 2004 to 2013 (latest 10 year period) indicates an annual average inflation rate of 2.2%.

Based on the information above, the range of discount rates used in this report ranges from 3.8 to 7.3% per annum, with a mid-point rate of 5.6%.

2.4.2 ECONOMIC LIFE OF DIGESTERS

The major component of digesters are essentially plastic rainwater tanks. The economic life of these tanks will be dependent on a number of factors ranging from the quality of the tanks (e.g. materials and ultraviolet ratings) to the risks of damage (e.g. from cyclones). While the tanks could be expected to last 30 years[6], for the base-case in this analysis, we have assumed digesters will last 20 years. Sensitivity analysis is also conducted for a shorter life (10 years) and a longer life (30 years).

6 30 years is the typical period used for assessment of rainwater tanks in northern Australia.

3. Cost benefit analysis results

This section briefly summarises the results of the CBA analysis for the three options. First, we summarise and compare the results of the analysis of the three options when the most likely parameters are used. Second, we assess some of the key distributional issues. Finally, we have undertaken significant sensitivity analysis to test how the results change depending on the assumptions and input variables used.

3.1 High level results

Table 6 summarises the key results of the analysis for the three options considered. The table outlines:

- **the cost profile**. Both the total establishment costs (digester, tank, cooker, pig pen, etc.) of each option and the annual estimated operational and maintenance costs;
- **the benefit profile.** This includes a breakdown of the annual estimates of each benefit once the digesters are fully operational. It should be noted that we have reduced the benefits in the first year to account for the fact that the digesters take 2-3 months to become fully operational;
- **CBA decision rules.** This includes the results of the NPV and BCR analysis over the full 30 years of the project; and
- **household budget.** This is the annual average improvement in the household budget for any households that install, use and maintain a digester. This is the estimate of benefits accruing directly to households less the costs borne directly by households.[7]

TABLE 6. HIGH LEVEL RESULTS FOR CBA OF BIOGAS DIGESTERS

COST OR BENEFIT (AUD EXCEPT WHERE NOTED)	OPTION 1: HOUSEHOLD GAS	OPTION 2: HOUSEHOLD GAS & GARDEN	OPTION 3: BIOGAS WITH COMPRESSOR
Cost profile			
Establishment costs	$6,505	$6,711	$6,959
Annual operations and maintenance	$137	$137	$137
Benefit profile (once fully operational)			
Annual fossil fuel savings	$495	$495	$495
Annual time savings (collecting wood)	$466	$466	$466
Annual home garden benefits (increased yield + cost savings of fertiliser)	$0	$72	$72
Annual reduction in health costs	$26	$26	$26
Annual CO_2 reductions	$17	$17	$17
Total annual benefits	$1,004	$1,076	$1,076
CBA decision rules			
NPV	$4,757	$5,511	$5,197
BCR (ratio; unitless)	1.5	1.5	1.5
Household budget			
Annual improvement in household budget	$824	$896	$896

7 For the purposes of this report, this excludes the costs of capital equipment (e.g. the digester). However, Section 4 of this report considers options for cost sharing where the household would also cover part or all of the capital costs of equipment.

The analysis produced several key findings:

- **Establishment costs** are in the range of AUD 6,505 to AUD 6,959 across the options. The differences are due to the inclusion of the costs of garden infrastructure (Options 2 and 3) and the additional cost of compressors and gas bottles for Option 3. These costs would be significantly lower if the costs of pig accommodation could be avoided. It is likely that these costs would be further reduced in future years if the use of digesters becomes widespread, the reliance on international expert advice diminishes, bulk discounts could be achieved from suppliers, and instillation processes become more efficient. We have assumed that the bulk of these costs would be borne by donors for this trial. However, under a broader rollout of biogas, it would be prudent for households to contribute to the costs. This is discussed further in Section 4 of this report. Note: This analysis has been conducted under an assumption that digesters and associated infrastructure will have an effective life of 20 years. Therefore, in the CBA, infrastructure is replaced after 20 years and those costs are incorporated into the long-term analysis.
- **Annual operations and maintenance costs** are estimated at AUD 137 year. This figure almost entirely reflects the costs of a household time to collect manure, add the water, and undertake occasional maintenance. There is likely to be a small cost of water each year (around AUD 8), which reflects the *additional* cost of rainwater infrastructure required. Note: A separate model was developed to estimate the cost of water requirements. That model indicated that under most circumstances, many houses could have sufficient yields available from their existing rainwater tanks without the need to increase the volume of storage capacity.
- **Annual total benefits** are estimated at between AUD 1,004 and AUD 1,076 per year, with the difference attributable to the benefits to home gardening (higher yields and lower costs for purchased fertiliser). The benefits are dominated by two categories. First, avoided fossil fuel costs reach approximately AUD 495 per year (based on an estimated reduction in use of 4 bottles of LPG and 125 litres of kerosene per annum). These cash costs represent a significant cost of living for most families. The second major benefit is the reduction of time required to collect and prepare firewood. For many families, this could be worth around AUD 466 per year. It should be noted that this benefit is not a cash benefit. Benefits to home gardens from slurry bi-product could also be significant (approximately AUD 72 per year). These benefits are in the form of increased yields (more fruit and vegetables from the same area of garden) and savings in the cost of purchasing fertiliser. Benefits will also accrue to third parties in the form of a reduction in the incidence of indoor smoke-related costs to the health budget and a small reduction in the cost of CO_2 emissions.
- **CBA decision rules.** All options considered have a positive NPV over the 30-year project life, ranging from AUD 4,757 (Option 1) to AUD 5,511 (Option 2). Importantly, all options easily meet this NPV decision rule, indicating that the use of digesters is economically viable over the long term. The BCR of each option is also approximately 1.5, indicating that for every AUD 1 of costs, the digesters produce approximately AUD 1.50 of benefits over the long-term. There is very little difference between the options. However, Option 2 is marginally superior in terms of both the NPV and BCR. This is due to the fact that the benefits from gardening are included. Option 3 would appear to be the second-best option based on this analysis. However, this option relies heavily on the use of compressors that are yet to be proven in field trials.
- **Household budget.** The impact on the household budget (benefits to household less costs) is likely to be the biggest economic determinant of participation levels by households. The range of annual benefits to households is between AUD 800 and AUD 900. This benefit is significant when compared to annual household cash incomes. The Household Income and Expenditure Survey conducted in 2010 indicates that average annual salaries per household on the outer islands are approximately AUD 2,030, while on Funafuti they are AUD 9,600.

3.2 Distributional consequences

The major distributional consequences for each option are shown in the table below. Our analysis found that over the useful life of the digesters, approximately 96% of the benefits would accrue to households, particularly in the form of lower costs for fossil fuel and time savings. This was based on an assumption that the capital costs would be covered by donors for the proposed trial.

Approximately 4% of benefits would accrue to third parties, specifically the Tuvalu government (in the form of a lower need for expenditure on smoke-related illness) and the broader international community (in the form of reduced carbon emissions).

TABLE 7. DISTRIBUTIONAL CONSEQUENCES

COST OR BENEFIT	OPTION 1: HOUSEHOLD GAS	OPTION 2: HOUSEHOLD GAS & GARDEN	OPTION 3: BIOGAS WITH COMPRESSOR
Distribution of benefits (%)			
Households	96%	96%	96%
Broader society	4%	4%	4%

Assumptions regarding cost sharing are relayed in Section 4 where we assess potential cost-sharing approaches. Those approaches do move some of the costs to households, which reduced the proportional share of benefits accruing to households.

Ideally the assessment of distributional consequences should include the impacts on households with different demographic circumstances, particularly incomes. There are insufficient data to do this analysis in the present report. However, basic demographic and income data should be collected and analysed as part of the monitoring and evaluation strategy for the proposed trial.

3.3 Sensitivity analysis

The CBA model developed has over 30 physical and economic input parameters. Based on the research conducted by the CBA team, each of these parameters has a range to reflect the variability and uncertainty relating to that parameter. A key part of any CBA is to do sensitivity analysis to determine whether any changes in the inputs or assumptions significantly change the decision to proceed with biogas or change the assessment of the best option (Option 2 biogas plus gardens).

This section outlines the findings for the sensitivity analysis conducted for the project through a structured series of “what if” scenarios where we have changed key values for input parameters. For example, what happens to the analysis is subsistence labour is actually valued at AUD 0? In addition to the base case scenario for each option (outlined in Section 3.1), we also undertook sensitivity analysis by running six alternative “what if” scenarios by changing key parameters. The CBA team discussed the choice of scenarios on 7 August based on the concerns that some assumptions could have a major impact on the outcomes of the CBA. The “what if” scenarios tested were:

- **Labour AUD 0.** We have generally included a subsistence wage to represent the value of a person’s time in this analysis (e.g. reduced time to collect firewood as a benefit, and additional time to operate the digester as a cost). However, during consultation, this assumption was discussed, particularly if a family does not place any monetary value on their time. For this scenario, we set the value of labour to the household at AUD 0. This means that there is no value used to reflect the cost of time required to use digesters, or the value of time savings (particularly collecting and preparing firewood).

- **Digester life is 10 years only.** The major cost of biogas is the costs of establishing the digester and associated capital. While the digester and other equipment should last up to 30 years if it is maintained properly, we have assumed a more conservative life of 20 years as a base case. We have further tested the impact of the useful life of digesters by running a scenario where the digester and other equipment would need to be replaced every ten years.
- **High and low establishment costs.** These scenarios represent the impacts of using the highest or lowest estimates of the establishment costs from our research. Because these costs occur at the beginning of the project, even small movements in costs can have relatively significant impacts on the NPV or the BCR of the project.
- **Low substitution.** The key benefit of the digester is the ability of a household to avoid the cost of purchasing kerosene or LPG. The value of this benefit will largely be derived by the amount of kerosene and gas that household used prior to switching to biogas. The previous trial indicated that the average degree of substitution was 125 litres of kerosene and 4 bottles of LPG per year. Two scenarios were then run to test the impact of a lower level of fossil fuel substitution. Specifically, digesters would substitute for 3 bottles of LPG and 69 litres of kerosene each year which is the lowest level of substitution reported in the previous trial. This scenario was then tested under an assumption that labour has a value, and an assumption that the value of labour is AUD 0.

By running a number of "what if" scenarios, we can test the sensitivity of the results to changes in the input assumptions and parameters. Where the BCR changes significantly from the base case (i.e. 1.5), this indicates that the economic viability of the digesters is very sensitive to the particular input variable that has been changed.

The findings for Option 1 (household gas benefits only) are shown in Table 8. The key points to note are that the overall economic viability of Option 1 is most susceptible to:

- **Changes in labour value.** Where the value of labour provided by the household is valued at AUD 0, the overall BCR declines significantly as a major component of the benefit stream is excluded from the analysis (i.e. the value of avoiding the need to collect firewood). When all other input parameters are held constant with the base case analysis, excluding the value of labour reduces the NPV of the project significantly and the BCR from 1.5 to 1.0.
- **Lower levels of substitution.** When the levels of LPG and kerosene substitution are reduced, the NPV and BCR drop significantly. When substitution levels are lowered *and* household income is set to AUD 0, digesters are no longer economically viable.
- **Digester life.** If the digesters and associate equipment only have a useful life of 10 years, the economic viability of the project becomes more marginal (BCR of only 1.1). This indicates the importance of maintaining and using the digesters in the long-term. This is discussed further in Section 4.

TABLE 8. SENSITIVITY ANALYSIS – OPTION 1. HOUSEHOLD GAS ONLY

COST OR BENEFIT (AUD)	BASE CASE	LABOUR $0	DIGESTER LIFE 10 YEARS ONLY	HIGH ESTABLISHMENT COSTS	LOW ESTABLISHMENT COSTS	LOW SUBSTITUTION 3/69 (WITH WAGE)	LOW SUBSTITUTION 3/69 (NO WAGE)
Cost profile							
Establishment costs	$6,505	$6,505	$6,505	$7,775	$5,841	$6,505	$6,505
Annual operations and maintenance	$137	$8	$137	$137	$137	$137	$8
Benefit profile (once fully operational)							
Annual fossil fuel savings	$495	$495	$495	$495	$495	$313	$313
Annual time savings (collecting wood)	$466	$0	$466	$466	$466	$466	$0
Annual home garden benefits (increased yield + cost savings of fertiliser)	$0	$0	$0	$0	$0	$0	$0
Annual reduction in health costs	$26	$26	$26	$26	$26	$26	$26
Annual CO_2 reductions	$17	$17	$17	$17	$17	$17	$17
Total annual benefits	**$1,004**	**$538**	**$1,004**	**$1,004**	**$1,004**	**$821**	**$355**
CBA decision rules							
NPV	$4,757	$350	$1,202	$3,172	$5,575	$1,765	–$2,642
BCR	1.5	1.0	1.1	1.3	1.6	1.2	0.7
Distribution of benefits							
Households	96%	94%	96%	96%	96%	95%	90%
Broader society	4%	6%	4%	4%	4%	5%	10%
Annual improvement in household budget	$824	$475	$824	$824	$824	$642	$305

The results of the sensitivity analysis are different if you take a more narrow view of the project and only benefits and costs directly accruing to households are considered. Under this circumstance, digesters provide significant annual improvements to household budgets under *all* of the scenarios tested for the sensitivity analysis except where there is a lower level of substitution for fossil fuels *and* a household places a AUD 0 value on their time. Like the broader CBA, the results are most susceptible to the treatment of the value of household labour, and the level of fossil fuel substitution. The household results are not impacted by changes to establishment costs or digester lives as we have assumed that those costs are borne by donors for the duration of the trial. Furthermore, because we have assumed that households do not have to cover the significant establishment costs (see Section 4), even where digesters are not economically viable, they may still be an attractive financial proposition to a household.

Sensitivity analysis for Option 2 is shown in Table 9. The findings are largely consistent with the sensitivity analysis conducted for Option 1 except for the fact that the results are marginally better (due to the additional benefits accruing to home gardening).

TABLE 9. SENSITIVITY ANALYSIS – OPTION 2. HOUSEHOLD GAS AND GARDEN BENEFITS

COST OR BENEFIT (AUD)	BASE CASE	LABOUR $0	DIGESTER LIFE 10 YEARS ONLY	HIGH ESTABLISHMENT COSTS	LOW ESTABLISHMENT COSTS	LOW SUBSTITUTION 3/69 (WITH WAGE)	LOW SUBSTITUTION 3/69 (NO WAGE)
Cost profile							
Establishment costs	$6,711	$6,705	$6,711	$8,084	$5,944	$6,711	$6,705
Annual operations and maintenance	$137	$8	$137	$137	$137	$137	$8
Cost or benefit	Base case	Labour $0	Digester life 10 years only	High establishment costs	Low establishment costs	Low substitution 3/69 (with wage)	Low substitution 3/69 (no wage)
Benefit profile (once fully operational)							
Annual fossil fuel savings	$495	$495	$495	$495	$495	$313	$313
Annual time savings (collecting wood)	$466	$0	$466	$466	$466	$466	$0
Annual home garden benefits (increased yield + cost savings of fertiliser)	$72	$72	$72	$72	$72	$72	$72
Annual reduction in health costs	$26	$26	$26	$26	$26	$26	$26
Annual CO_2 reductions	$17	$17	$17	$17	$17	$17	$17
Total annual benefits	$1,076	$610	$1,076	$1,076	$1,076	$893	$428
CBA decision rules							
NPV	$5,511	$1,110	$1,904	$3,925	$6,329	$2,519	–$1,882
BCR	1.5	1.1	1.1	1.3	1.7	1.2	0.8
Distribution of benefits							
Households	96%	94%	96%	96%	96%	96%	92%
Broader society	4%	6%	4%	4%	4%	4%	8%
Annual improvement in household budget	**$896**	**$559**	**$896**	**$896**	**$896**	**$714**	**$377**

Sensitivity analysis for Option 3 is shown in Table 10. The findings are largely consistent with the other options. The main changes to note are that this option would not be viable unless the digesters, compressors, and associated equipment last for more than 10 years. This is due to the additional capital costs of compressors and gas bottles being incorporated into the analysis, while the benefits remain the same.

TABLE 10. SENSITIVITY ANALYSIS – OPTION 3. HOUSEHOLD GAS, GARDEN BENEFITS AND THE USE OF A COMPRESSOR

OST OR BENEFIT AUD)	BASE CASE	LABOUR $0	DIGESTER LIFE 10 YEARS ONLY	HIGH ESTABLISHMENT COSTS	LOW ESTABLISHMENT COSTS	LOW SUBSTITUTION 3/69 (WITH WAGE)	LOW SUBSTITUTION 3/69 (NO WAGE
ost profile							
stablishment costs	$6,959	$6,953	$6,959	$6,858	$5,987	$6,959	$6,953
nnual operations nd maintenance	$137	$8	$137	$154	$154	$137	$8
enefit profile (once lly operational)							

COST OR BENEFIT	BASE CASE	LABOUR $0	DIGESTER LIFE 10 YEARS ONLY	HIGH ESTABLISHMENT COSTS	LOW ESTABLISHMENT COSTS	LOW SUBSTITUTION 3/69 (WITH WAGE)	LOW SUBSTITUTION 3/69 (NO WAGE)
Cost profile							
Establishment costs	$6,959	$6,953	$6,959	$6,858	$5,987	$6,959	$6,953
Annual operations and maintenance	$137	$8	$137	$154	$154	$137	$8
Benefit profile (once fully operational)							
Annual fossil fuel savings	$495	$495	$313	$495	$495	$313	$313
Annual time savings (collecting wood)	$466	$0	$466	$466	$466	$466	$0
Annual home garden benefits (increased yield + cost savings of fertiliser)	$72	$72	$72	$72	$72	$72	$72
Annual reduction in health costs	$26	$26	$26	$26	$26	$26	$26
Annual CO_2 reductions	$17	$17	$17	$17	$17	$17	$17
Total annual benefits	**$1,076**	**$610**	**$893**	**$1,076**	**$1,076**	**$893**	**$428**
CBA decision rules							
CBA	$5,197	$1,594	**–$1,271**	$3,611	$6,014	$2,205	**–$2,215**
Benefit-cost ratio	1.5	1.2	**0.9**	1.3	1.6	1.2	**0.8**
Distribution of benefits							
Households	96%	94%	96%	96%	96%	96%	92%
Broader society	4%	6%	4%	4%	4%	4%	8%
Annual improvement in household budget	**$896**	**$559**	**$714**	**$879**	**$879**	**$714**	**$377**

There are a number of operational risks and uncertainties relating to the use of digesters that also have economic consequences. Those are discussed in Section 4.2.3 of this report. Providing those risks are managed, they will not materially impact on the findings of the CBA.

3.4 Climate and climate change – assessment of risks

This CBA has been developed under a set of specific assumptions regarding the performance of digesters. However, these assumptions could change under climate variability and climate change. In this section, we have briefly assessed two specific types of risks:

- water availability for digesters; and
- the risks of extreme weather events: cyclones and storm surge.

3.4.1 WATER AVAILABILITY FOR DIGESTERS

The operation of digesters is entirely reliant on the availability of water to mix with pig dung. This water must be added on a very regular basis to ensure the efficiency of the digester.

In our analysis, we have established a simple rainwater tank yield model as an input to estimate the availability and cost of water inputs. The key parameters for that model are monthly rainfall for the period 1945 to 2015[8]; average household roof sizes[9]; and estimated per capital consumption.[10]

Monthly rainfall data (mean, lowest on record, highest on record) for Funafuti is in Figure 2. The 2011 drought is shown by the brown dashed line. In addition, we also calculated the threshold monthly rainfall requirement for an average household rainwater tank to cover both indoor *and* digester demand (i.e. at least 90 mm), shown by the purple dashed line.

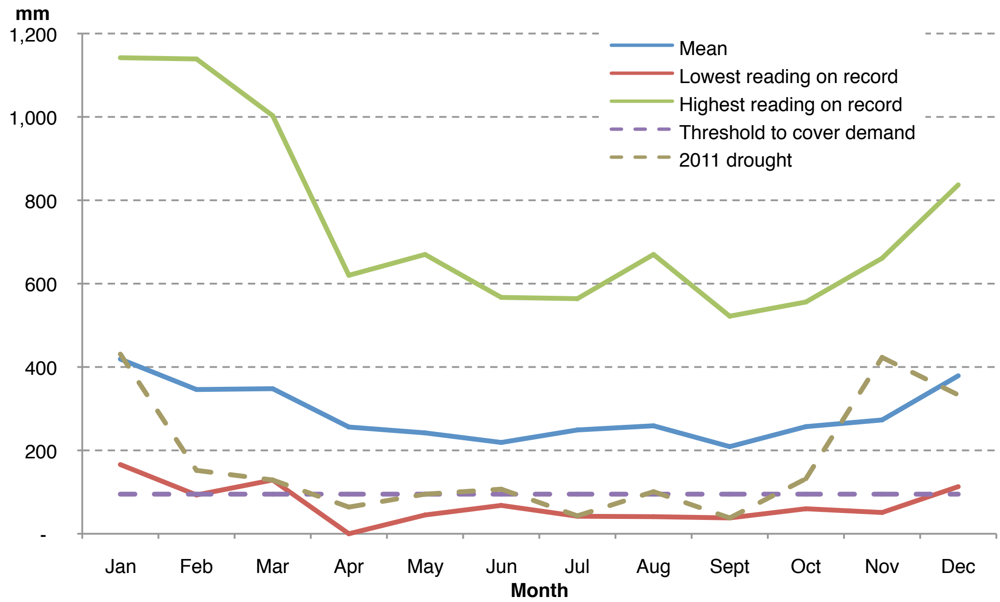

FIGURE 2: MONTHLY RAINFALL – FUNAFUTI

Source: Tuvalu Met Office

8 This was provided by the Office of Meteorology for Funafuti.

9 Based on analysis of census data.

10 Based on Department of Public Works advice.

Under mean rainfall, there should always be sufficient water available from existing rainwater tanks without jeopardising other household uses. However, under severe drought conditions (rainfall less than 30% of the monthly mean for more than two consecutive months), there *may* be some months when competition between water for general household use and water for digesters becomes a material issue[11]. During the major drought of 2011[12], rainfall was below the minimum threshold three months that year (April, July, and September).

The available rainfall data would indicate that a severe drought (insufficient water for households and digesters for two consecutive months) probably has an average return interval (ARI) of approximately 1 in 50 years.[13] We ran the CBA model incorporating the risk of severe drought conditions and there was no material difference in the results.

Given the variability in rainfall and the chance of drought, it would still be prudent to develop contingencies for drought periods. This could include actions such as voluntary restrictions on usage; coordination of water usage at the Kaupule scale; and maximising water stored at any one time at the household scale through spreading usage across all available tanks.[14] Drought risk in general also reinforces the need to properly maintain all existing rainwater tank infrastructure to ensure contingency storage is available when droughts occur.

While the analysis above based on historical rainfall patterns indicates the likelihood of severe water shortages is very low, it is important to understand the potential impact of climate change on *future* yields for rainwater tanks and any subsequent impacts on digesters.

Figure 3 shows the historical and range of simulated annual rainfall for Tuvalu under various climate change assumptions. It generally shows an expectation for a slight increase in annual rainfall, while even under the more pessimistic assumptions and modelled outputs, reductions are relatively minor during the 30-year period of this analysis. Furthermore, the likelihood of droughts is expected to decline.

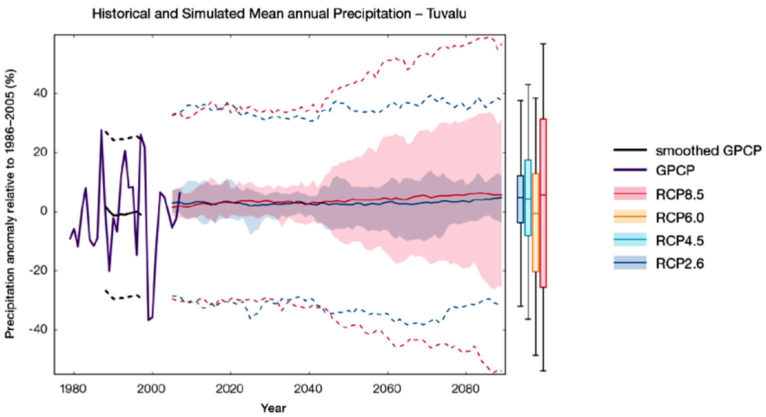

FIGURE 3: HISTORICAL AND SIMULATED ANNUAL AVERAGE RAINFALL TIME SERIES FOR THE REGION SURROUNDING TUVALU

Source: Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2014) Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports 2014

11 Monthly rainfall has only been below the threshold 28 times since 1945 (3% of months), and the longest consecutive period with rainfall below the threshold was for three months (in 1950).

12 It should be noted that rainfall in 2011 was the lowest annual total since recording commenced in the late 1940s.

13 ARI is the measure commonly used in water supply planning to represent reliability based on drought. Because the timing of the drought is not known, and ARI of 1 in 50, is typically incorporated into the CBA as a change in the expected value of water of water available (i.e. an ARI of 1 in 50 translates to a 2% chance that drought will incur in every year, so benefits are reduced by 2% in all years).

14 Consultation revealed that in the 2011 drought, some families used some of their water stored in rainwater tanks for the digester for internal household use.

We also assessed a range of climate change scenarios for Tuvalu sourced from the *Pacific Climate Futures Version 2*. For the period relevant to this CBA (up to 2045), they indicate annual rainfall could increase by approximately 4 to 6% per annum. However, the variability from the models indicates a standard deviation of approximately 4.2%. Again, this suggests that expected changes in rainfall patterns are unlikely to materially impact the availability of water for digesters.

While this analysis is relatively basic, it does generally indicate that providing rainwater tanks are maintained properly and drought contingencies are in place, there should be sufficient water available for digesters under all but the most extreme drought circumstances.

3.4.2 RISKS FROM EXTREME WEATHER: CYCLONES AND STORM SURGE

The other major events that may create risks to the viability of digesters are the potential impact of cyclones and storm surges.

Cyclones

Cyclones and other extreme weather events will create physical risks to biogas infrastructure (digesters, etc.) and operations. Figure 4 shows the frequency of cyclone activity in the Tuvalu Exclusive Economic Zone since 1969. Cyclones are more likely during an El Niño event.

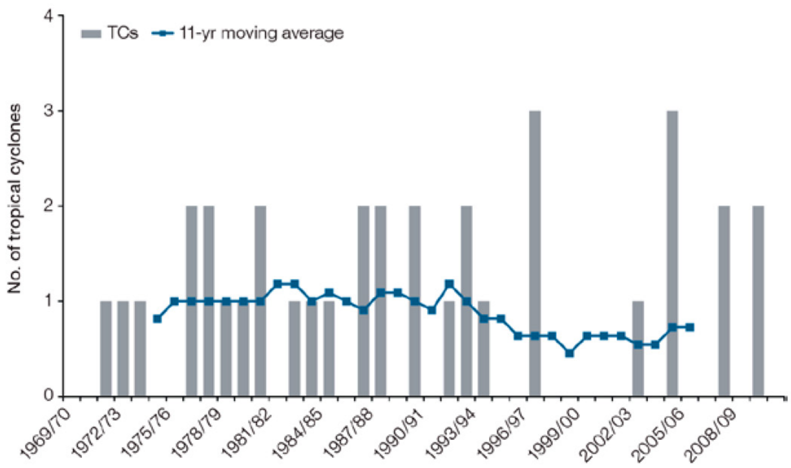

FIGURE 4: TIME SERIES OF THE OBSERVED NUMBER OF TROPICAL CYCLONES DEVELOPING WITHIN AND CROSSING THE TUVALU EEZ PER SEASON. THE 11-YEAR MOVING AVERAGE IS IN BLUE

Source: Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2014) Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports 2014

From 1969 to 2010, 31 tropical cyclones passed within 400 km of Funfuti. However, it would appear that major damage has only occurred on land twice during that period (Cyclone Bebe in 1972 and Cyclone Pam in 2015). While the frequency of cyclones is expected to decrease under climate change, the intensity of cyclones is expected to increase (BOM and CSIRO 2014). These physical risks and changes in risk also have economic consequences in the form of the cost of replacing digester and associated equipment, and disruption to biogas supplies. The impacts of major cyclones reaching landform would be twofold:

- there would be physical damage to the digester, possibly requiring significant repair or complete replacement. However, it could be argued that other alternatives (e.g. fossil fuel or firewood) also face risk from cyclones; and

- there would be a disruption in the supply of gas from the digester because there is a lag attributable to delays in replacing infrastructure and time required for the digester to become operational. This would reduce benefits received for the period immediately after the cyclone as alternative fuels (potentially LPG or kerosene) would be required. It should also be noted that supply disruption risks would also exist for alternative energy sources.

While no specific annual return intervals for cyclones impacting on Tuvalu land are available, it is instructive to assess how the frequency of cyclone damage could impact on the economic viability of biogas. To do this, we have run the CBA model (Option 2 only) to replicate the economic impacts of cyclone frequency (assuming the major impacts are the replacement cost and lost biogas production). The impacts on the NPV and BCR of different cyclone frequencies are shown in Table 11.

TABLE 11. SENSITIVITY ANALYSIS. IMPACT OF CYCLONES

COST OR BENEFIT	BASE CASE (20-YEAR INFRASTRUCTURE LIFE)	CYCLONE FREQUENCY 1 IN 15 YEARS	CYCLONE FREQUENCY 1 IN 10 YEARS	CYCLONE FREQUENCY 1 IN 9 YEARS
NPV (AUD)	$5,511	$4,609	$1,695	–$4,363
BCR	1.5	1.4	1.1	0.8

The key point to note is that where the cyclone frequency is less than one in every ten years, the economic viability of the digesters becomes questionable. However, this analysis may be overly pessimistic because we have not assessed the impacts of cyclone frequency on all alternative energy sources to assess their relative befits and costs. Given the uncertainty of cyclone risk and the fact it cannot be managed, a more prudent approach would be to ensure actions are undertaken to reduce the risk of cyclone damage, if and when, one occurs. This would include operational actions such as:

- fixing digesters into positions where they are partially sunk into the ground to reduce the likelihood of losses under strong weather events;
- ensuring the digester lids are secured during high-wind events to avoid loss or damage (e.g. chained to bottom tank);
- potentially expelling gas from the digester prior to the cyclone to reduce the exposure of the lid to high winds; and
- avoiding the use of pig dung that may have been contaminated by salt water from a cyclone's storm surge.

Sea level rise and increased storm surge risk

Sea level rise scenarios for Tuvalu are shown in Figure 5. It is the inter-annual levels that are of most interest to this analysis because these provide some indication of the extremes that would significantly exacerbate storm surge. These extremes are shown by the grey dashed lines[15].

15 95% confidence intervals based on the modelled outcomes.

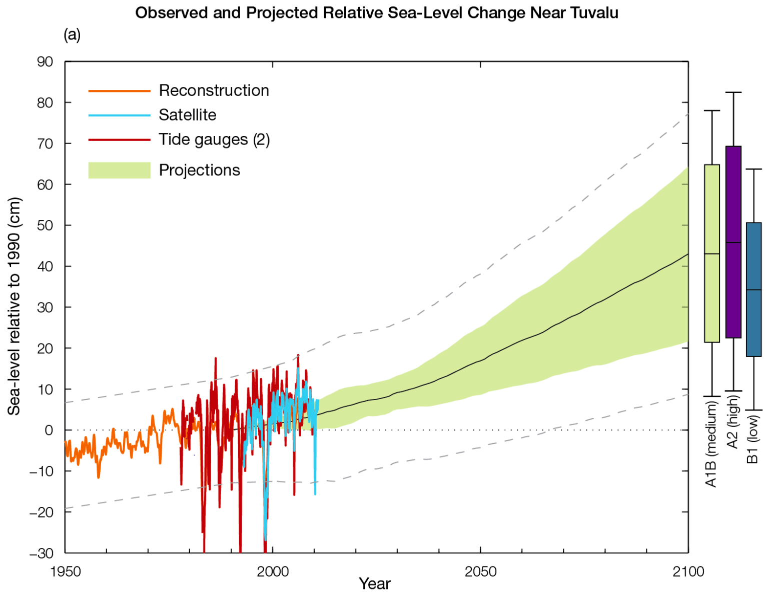

FIGURE 5: TUVALU SEA LEVEL RISE SCENARIOS

Source: Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2014) Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports 2014

The figure above indicates that by approximately 2045, maximum sea level heights could be 30 cm higher than 1990 levels during high tide events. Storm surges are already a problem in some low-lying areas of Tuvalu, and this risk will incrementally increase under climate change. Storm surge creates two key sets of risks to biogas projects:

- salt water inundation in the actual digester. While this was a problem associated with some of the digesters in the earlier trial (where brick digesters were dug into the soil profile), the proposed design of digesters for this trial (polyethylene tanks) should eliminate this risk. Furthermore, digesters can be located in areas with a lower likelihood of loss during a storm surge;[16] and
- the risk of storm surge entering pig pens and contaminating pig dung. Where contaminated pig dung is used, the anaerobic digestion process will not work. The digester will then need to be cleaned out and the process started again (2 to 3 months before usable volumes of gas are produced).

The risks of storm surge can be significantly reduced through two distinct mitigation strategies:

- placing digesters and pig pens outside the storm surge zone; and
- when a pig pen is flooded, avoiding using the dung until the pig pen has been cleaned out. This will also require accessing a contingent supply of uncontaminated dung in the short-term.

It is instructive to examine the potential benefits (avoided costs) of the mitigation strategies. The more likely risk is contamination of the digester through the use of contaminated pig dung. We ran the CBA model (Option 2 only) for two disruption scenarios:

- when the inundation occurs once a year and biogas production is lost for 2 to 3 months, the project NPV reduces from AUD 5,511 to approximately AUD 2,100, while the BCR falls from 1.5 to 1.2; and
- when the inundation occurs twice a year, the project NPV becomes negative (i.e. AUD –1,080), while the BCR falls to 0.9.

Clearly there is a strong economic case for undertaking actions to mitigate the risks of storm surge under current climate patterns. This will become increasingly important under climate change.

16 It should be noted that a functioning digester will contain a significant weight of materials, which should reduce the likelihood of the digester washing away in a surge event.

3.5 Conclusions from CBA

The CBA has found that digesters are economically viable under almost all circumstances assessed. Digesters could provide significant net benefits to families. The findings of the CBA suggest that the use of digesters should proceed.

3.5.1 KEY RESEARCH QUESTIONS ANSWERED

The terms of reference for this CBA included a number of specific questions. These questions and the relevant findings from this analysis are outlined below.

QUESTION. Is the installation of biogas at the household level economically viable?

Yes. Section 3 of this report clearly indicates that biogas is likely to be economically viable. Sensitivity analysis conducted (Section 3.3) shows that biogas is viable under virtually all circumstances except where very pessimistic assumptions are made.

QUESTION. To what extent does the project contribute to cash savings for households?

Based on our analysis and assuming fossil fuel substitution at the same rate as previous trials, households should save in excess of AUD 400 per year in energy costs. Where a household places a cost on their time (e.g. to collect and prepare firewood), these benefits are significantly higher.

QUESTION. To what extent does the project displace fossil fuels used for cooking? (gas, kerosene)

Analysis of the previous trials indicates that households that had previously used LPG as part of their fuel supply mix reduced their LPG use by an average of 4 bottles per year (range of responses was 3 to 5 bottles). Households that had previously used kerosene as part of their fuel supply mix reduced their use by an average of 125 litres per year (range of responses was 69 to 208 litres).

QUESTION. What factors are important in maximising the benefits of biogas digesters?

Benefits of digesters are maximised where a household had previously used either LPG or kerosene as a main source of energy for cooking, and where the digestate from the digester is used to enhance home garden productivity.

QUESTION. To what extent does the production and the use of digestate contribute to improved household food security? How much does this increase the benefits of the installation of the digester?

We estimate that the digestate would increase home garden productivity by up to 15% as well as save households money by reducing the need to purchase fertiliser. Based on a home garden size of 12 m^2, benefits per household are likely to exceed AUD 70 per year.

QUESTION. Is the installation of biogas and a compressor by the Kaupule in Nanumaga and Funafuti economically viable?

While available information relating to compressors is limited, it would appear that the use of compressors does not add significantly to the cost of biogas and the option should be economically viable. However, some degree of coordination will be required at the Kaupule level to ensure digester inputs are coordinated and gas produced is shared fairly across households where digesters are designed to service multiple households.[17]

QUESTION. What factors are important in maximising the benefits of biogas digester and compressor?

17 It should be noted that the size of digesters proposed for the current trial will only produce enough gas for one household.

The most important factor will be to ensure the continued operation, use and maintenance of both the digester and compressor. The use of compressors is likely to provide significant gains in the flexibility for the location of digesters (i.e. no need for pigs to be near the house). It could also overcome a social constraint to the use of biogas (i.e. bottled gas for cooking is seen as a status symbol), although the obvious savings from the use of digesters should be sufficient incentive to use biogas, particularly for lower-income families. In addition, compressors offer a means for lower-income families to move to biogas (either through collecting dung from other households to swap for gas or through the sharing of a digester).

QUESTION. What factors are likely to influence the level of ownership of the household / Kaupule to the ongoing maintenance and sustainability of the digesters and compressor?

Agreement on the use and maintenance of digesters and compressors between households and Kaupule will be vital to the success of biogas where compressors are used. It should be noted that available information suggests that even where a compressor is used, each digester proposed would only provide sufficient gas for one household. It may be prudent to trial a larger digester. See Section 4 for further detail.

QUESTION. What information and data should be collected as part of the monitoring process to be able to monitor whether the benefits are being realised?

There is a suite of physical and economic information that should be collected as part of any M&E strategy got this project. Suggestions are outlined in Section 4.2.2.

QUESTION. What recommendations can be provided to ensure that the benefits are safeguarded from climate risks to the greatest extent possible?

Maintenance of the digester and associated equipment is vital to the long-term success of biogas. Given the significant establishment costs, digesters should be located in areas away from storm surge and potentially secured to avoid loss during tropical storms. This is discussed further in Section 4.2.3.

4. Recommendations, project design and implementation

The CBA has found that digesters are economically viable under almost all circumstances assessed. They provide significant net benefits to families and some limited benefits to the broader community. This section briefly outlines the high-level recommendations from this CBA study and provides insights for the biogas project design and implementation.

4.1 High-level recommendations

Key recommendations from the CBA project are:

1. The use of digesters should proceed as a trial because they are economically viable.
2. At the project steering committee meeting on 10 August, key demographic and economic data and the outcomes of the CBA outlined in this report were used to inform the choice of islands for the trial. The demographic and economic analysis found no valid reason to exclude any of the islands being considered. However, a contingency plan should be available if any particular island is undersubscribed.
3. A properly designed monitoring and evaluation (M&E) strategy should be established as part of this trial. The M&E strategy will provide vital information to inform any future business case for the widespread use of biogas in Tuvalu.
4. The implementation phase of the trial should also ensure the proper design and placement of digesters and pig pens and the establishment of contingency for extreme weather events to ensure the continuity of benefits from the digesters.
5. As part of the M&E strategy, cost-sharing options should be assessed, particularly future options for households to contribute to the capital costs of digesters.

In addition, Section 3.3 highlights specific climate and climate change risks and implications for the design and implementation of the project.

4.2 Project design and implementation

There are a number of insights from this study that should assist in the design and implementation of the biogas trial. These are outlined below.

4.2.1 CHOICE OF ISLANDS AND HOUSEHOLD SELECTION CRITERIA

At the project management meeting on 10 August, there was significant discussion about the choice of islands where the digesters would be located and the potential selection criteria for participating households.[18] The best results from trial are likely to be gained where the following criteria can be met:

- The Kaupule and Fali Kaupule support the project.
- The household wants to trial biogas and has the skills (including record keeping) and time to participate for the duration of the trial.
- The household has at least 5 pigs and preferably can establish pig accommodation quite close to the digester (e.g. <100 meters). This will reduce the likelihood of dropout due to any perceived inconvenience factors.
- The household's current energy use must include some gas or kerosene (e.g. 3+ bottles of LPG and/or 60+ litres of kerosene per annum). Without this condition being met, there are insufficient economic incentives to participate.
- The household is concerned about fossil fuel costs.

18 Note: Nanumea and Nanumaga are not proposed as new sites as part of this trial because they have already participated in previous trials. However, they should be included in future monitoring and evaluation.

Table 12 summarises available data relevant to the suggested selection criteria (by island). While those data cannot be used to estimate the number of households that meet *all* of the suggested criteria, they can be used to identify where there may only be a few households that meet any specific criteria.

TABLE 12. KEY HIGH-LEVEL STATISTICS RELEVANT TO THE SELECTION OF SITES

	ISLAND									
INDICATOR	**NANUMEA**	**NANUMAGA**	**NUITAO**	**NUI**	**VAITAPU**	**NUKUFETAU**	**FUNAFUTI**	**NUKULAELAE**	**NIULAKITA**	**TOTAL / AVERAGE**
Proposed units	0	0	6	6	8	6	6	6	2	40
Physical and home preconditions										
Households	115	116	123	138	226	124	845	67	7	1,761
Household owns land	110	112	116	138	214	119	649	67	7	1,532
Households with home garden	33	32	45	8	22	28	226	21	2	417
Households owning pigs	101	101	107	130	208	111	603	57	7	1,425
Average pigs per household	17	8	6	7	7	5	5	4	6	6
Houses with pig accommodation <50 m from house	7	19	18	6	66	20	137	14	4	291
Houses with pig accommodation 50–100 m from house	4	15	12	2	31	33	89	13	0	199
Energy use preconditions – main source of energy for cooking										
Gas	14	14	9	13	53	33	686	34	1	857
Kerosene	11	6	2	10	27	14	101	6		177
Wood	8	96	109	64	56	72	44	26	2	477
Coconut parts	82	0	3	49	89	1	6	1	3	234
Economic and social preconditions										
Number of poor households	Data not available by island without a special request to statistics office									
Capacity to complete diary	Only basic literacy is required. Data on the highest education attained is available on a population basis per island (but is not tied back to a household).									
Willing to do paid work	122	71	127	171	206	53	841	81	8	3,284

Source: Government of Tuvalu (2012) Tuvalu national population and housing census

The available data suggest there should be sufficient households on each island to fulfil the proposed quota of digesters. The exception may be Nuitao, where census data indicates that there are only 11 households that use gas or kerosene as their major source of energy for cooking. While the data are not conclusive, they do suggest all of the proposed islands are appropriate. However, some form of contingency plan should be put in place to ensure the successful recruitment of households.

4.2.2 MONITORING AND EVALUATION

Given the results of this preliminary CBA, it would appear that the use of biogas could have a major impact on energy use for cooking in Tuvalu. However, the accuracy of the CBA has been constrained by data availability and quality.

The monitoring and evaluation to be conducted over the duration of the trial should provide sufficient information to enhance the accuracy of the CBA and underpin any future business case for widespread adoption of biogas in Tuvalu. At a minimum, the monitoring (through participant household diaries) should collect the information outlined in Table 13.

TABLE 13. DRAFT MONITORING PLAN (DIARY INFORMATION REQUIREMENTS)

DIARY ITEM	INFORMATION REQUIRED, MEASUREMENT UNITS AND SUGGESTED FREQUENCY OF COLLECTIONS	RATIONAL FOR COLLECTION AND EVALUATION APPROACH
Fuel sources and cooking		
1	Use of fossil fuels (LPG bottles and litres of kerosene) (number)	This data would form the basis for estimating the degree to which biogas provides a substitute for fossil fuels.
2	Prices paid for LPG and kerosene (AUD per bottle or per litre)	In conjunction with data on reduction in fossil fuel use, this is required to estimate the key economic benefit from the biogas. This information would also inform any future business case for widespread use of biogas in Tuvalu.
3	Firewood collection and preparation time (hours per week)	This data will provide vital information to underpin the estimates of the value of time savings.
4	Time spent cooking (hours per week)	Provides a measure of demand for energy that is common to all possible fuel types.
	Pig and digester maintenance	
5	Number of pigs (number)	This data will provide vital information on the production of dung as a feedstock for the digesters.
6	Pig dung disposal requirements (hours per week)	This change in time requirement will have an economic value.
7	Digester operation and maintenance (hours per week)	The number of hours per week required to run the digester (adding dung and mixing in water). This additional time will have an economic cost to the household.[19]
8	Compressor use and gas yields (hours per week and bottles per week)	Time spent per week operating compressor and the number of bottles filled.
Home garden		
9	Area of garden (m^2)	This information is necessary to estimate yield gains.
10	Application of purchased fertiliser products (kg/month and AUD/month)	Changes in these measures will enable a better estimate of cost savings available to households from the use of digestate.
11	Garden yields (kg/month)	Data on the types of produce and weights will enable the estimation of changes in yields from the use of the digestate and the economic value of changes.

19 2Note: Where the sum of diary items 5 and 6 indicate a net increase in time requirements, this would be counted as a cost of biogas based on the value of time (as we have assumed in the preliminary CBA). However, it may be the case that time requirements may actually fall. This would provide a further benefit to households.

Basic household demographic and income data should also be collected from participating households at the commencement of the trial.

In addition, it would be prudent to include a broader group of representative households within the monitoring program because this would provide a more representative sample of household data to underpin future investment decision-making.

It is vital that the monitoring and evaluation commence before the digesters become operational to ensure a baseline of data is created against which the performance, benefits, and costs of biogas can be measured.

As part of the establishment process for the 40 digesters and associated equipment, the project team should also collect detailed and disaggregated information on the establishment costs (parts, transport, and labour).

The M&E strategy has significant reliance on participant households and a broader selection of representative households keeping a diary of energy use, etc. This does create a risk from inaccuracies in record keeping. Therefore, part of the M&E strategy will need to cover capacity building and support in keeping accurate records. This could include specific training, the development of a community of practice involved in the trial, local leaders for the project on each island, and potentially involvement of school children on each island (where the household diary is used as a means to teach basic budgeting and data analysis).

4.2.3 REDUCING OPERATIONAL RISKS THROUGH PROPER PROJECT IMPLEMENTATION

There are a number of other risks and uncertainties relating to the economic viability of biogas in Tuvalu. These risks and uncertainties are largely physical in nature and can be mitigated through proper project implementation. These risks and uncertainties are:

- **the importance of maintenance to ensure benefits are derived.** The economic viability of the digesters is very reliant on their continuous use and maintenance. If the digesters are not used, or are not maintained, this will reduce their economic viability. This reinforces the need to ensure careful selection of households for the proposed trial and that households receive adequate training in the use and maintenance of the digesters. This should also include regular checks of the equipment;
- **compressors trial and usage.** The development and use of compressors will be largely experimental during the period of this current trial. However, compressors have the potential to offer some very tangible additional benefits as they enable more flexibility on the choice of digester and pig pen location (being adjacent to the house is no longer vital); while they enable the use of gas from bottles which is sometimes seen as a status symbol. It would be prudent to use compressors as a research component of the initial trial until the technology is proven. Where compressors are used more broadly, the ability to share the compressor equipment across multiple households should be explored; and
- **mitigating the risk of extreme events.** Climate variability, climate change, and extreme weather events create risks to the digesters and associated infrastructure, particularly through loss/damage of infrastructure during cyclones and seawater contaminating dung and digesters during storm events. There risks can be mitigated through the design and location of infrastructure and through the establishment of contingencies to be implemented during and after extreme weather events. These needs are outlined in Section 3.4 of this report.

By implementing these practical actions, the physical risks to biogas production (volume and reliability) should be significantly reduced. This should ensure that the economic benefits of biogas can be realised.

4.3 Potential for cost sharing in the future

In this CBA, we have assumed that donors would cover the establishment costs of digesters, while the ongoing operations and maintenance costs would be borne by households. There are a number of legitimate reasons why households may not risk their own financial capital at this time including:

- lack of knowledge. Households are not aware of the technology;
- **technical and economic risks.** The technology, while proven internationally, is yet to be proven in Tuvalu. This creates technical risks and a disincentive to households to risk their own capital. Furthermore, the degree of fossil fuel substitution is yet to be proven in a scientifically valid trial. Therefore, households are not able to estimate the savings that would be accrued through the use of biogas;
- **limited access to capital.** The major cost of biogas is the establishment cost. Access to significant financial capital is limited, particularly where the cash savings associated with digesters are yet to be proven; and
- **private vs. public benefits and costs.** Biogas produces both private (energy and digestate) and public (health costs and reductions in CO_2 emissions) benefits. It is highly unlikely a household would be prepared to invest private financial resources to achieve public benefits. However, it should be noted that the public benefits are relatively small.

This CBA clearly demonstrates significant cash savings should accrue to households that are able to partially or fully substitute biogas for existing fossil fuel use. This indicates that there is likely to be a financial case for some form of cost sharing between donors and households for the use of the digesters. Theoretically, a household should be prepared to pay to use a digester to the extent that the cash savings (avoided fossil fuel costs) are greater than the cost of the digester.

Providing the M&E of the trial is conducted well and the CBA is repeated using the information from the trial, it should be possible to address many of the risks outlined above and clearly demonstrate the economics benefits of the digesters at the household scale within the next 12 to 24 months. Once this information is available, a robust cost-sharing arrangement could be established.

4.3.1 A HYPOTHETICAL TARIFF FOR DIGESTER RENTAL

Given the current low levels of disposable income on the outer islands in conjunction with difficulties in securing debt financing, rather than households purchasing their own digesters, it may be more feasible to establish a digester rental scheme where households make a regular rental payment (e.g. monthly rental payment). This could be established by the Kaupule or Government or as a commercial enterprise (where a return on investment is also included in rental prices).

While the digester and associated rainwater tank can be relatively easily moved to and between customers, pig pens cannot be easily moved. Therefore, any rental scheme would probably be viable for the digester and associated rainwater tank only.

Below, we have estimated the costs associated with a digester rental scheme. To be viable, any rental scheme would need to recover:

- operational and maintenance costs borne by the business renting the digester. This would include the costs of testing and maintenance and the costs of account administration;
- the capital cost of the digester spread over the life of the digester (i.e. 20 years). This ensures the capital cost of the digester and rainwater tank is recovered over the long-term; and
- where the rental scheme is run as a fully commercial (self-funding) business, the scheme owner would also require a return on their capital invested.

Table 14 shows indicative monthly rental prices for digesters developed using a building blocks approach. This approach is typically used by utilities to estimate revenue requirements and to establish tariffs.[20]

TABLE 4. INDICATIVE DIGESTER RENTAL PRICES (AUD/MONTH)

COST ITEM	COST (INCLUDING A RETURN ON CAPITAL) (AUD)	COST (EXCLUDING A RETURN ON CAPITAL) (AUD)
Capital costs over life of digester		
Return on capital (return on investment)	$9.96	
Return *of* capital (over 20 years)	$8.96	$8.96
Operational costs		
Testing / maintenance (10 hours/year)	$3.33	$3.33
Account administration (12 hours/year)	$4.00	$4.00
Indicative monthly rental price (AUD/month)	**$26.25**	**$16.29**

Based on available information, we estimate that the monthly rental price for a digester would be approximately AUD 16.30 (excluding a return on capital) and AUD 26.25 (including a return on capital). To put this in perspective, the monthly charge (excluding a return on capital) is the equivalent to using approximately 7 litres of kerosene per month or 4 bottles of LPG per year. Even including a return on capital, the monthly charge is the equivalent to using approximately 11 litres of kerosene per month or 6.5 bottles of LPG per year.[21]

While a rental scheme may not be viable for all households, particularly those that use low levels of fossil fuel, a rental scheme will be financially viable for many households.

It should be noted that efficient pricing of any digester service will not be possible until the trial is in operation and the costs (fixed and variable) are better understood. It would be useful to further develop and run consultation on potential cost sharing options as part of the broader evaluation of the trial.[22]

20 The building blocks approach typically includes a return *on capital, a return of capital, and operations and maintenance costs.*

21 These usage levels are lower than those revealed through the consultation of the previous biogas trial.

22 Note: As part of this project, we developed a simple financial tool to enable a household to estimate the economic benefits to them (avoided fossil fuel costs, increased garden outputs, etc.) to assist with the recruitment process for the trial. This could be enhanced to inform future cost sharing and pricing arrangements.

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The **Pilot Program for Climate Resilience: Pacific Regional Track (PPCR-PR)** is a regional program which aims to strengthen integration of climate change and disaster risk considerations into 'mainstream' policy making and related budgetary and decision-making processes (i.e. 'climate change and disaster risk mainstreaming').

The PPCR-PR is implemented by the Secretariat of the Pacific Regional Environment Program (SPREP) and Asian Development Bank (ADB) and is funded through the Climate Investment Funds (CIF).

SPREP
Secretariat of the Pacific Regional Environment Programme