Cost-benefit analysis of solar hybrid system in Alfred Sadd Memorial College

Solar Boarding Schools Project, Kiribati
Pacific Community (SPC)
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EUROPEAN UNION PACIFIC ISLANDS FORUM SECRETARIAT german cooperation giz

1 Table of Contents

Executive summary

The Kiribati Solar Boarding Schools Project is part of the Adapting to Climate Change and Sustainable Energy (ACSE) Programme funded by the European Union (EU). The project aims to provide solar photovoltaic (PV) systems to two boarding schools. This is an economic appraisal of one of the schools Alfred Sadd Memorial College (ASMC) on Abemama. A solar PV system with a diesel generator backup sized at 20-25 kW is found to be the best option. However, even this option falls short of targeted economic feasibility. About a 10 per cent reduction in estimated capital costs would make the project just feasible. Otherwise the low economic return needs to be accepted or other project alternatives considered. The project appears to be well targeted with the students receiving a large share of the net benefit.

1 Introduction

The Government of Kiribati has set a target for 100 per cent of boarding schools in rural areas to have renewable energy technology by 2025. The two remaining boarding schools without a solar photovoltaic (PV) system are Meleang Taabai Secondary School (MTSS) on Tabuaeran (Fanning Island) and Alfred Sadd Memorial College (ASMC) on Abemama. These two schools have been selected for assistance in acquiring solar PV systems by the Adapting to Climate Change and Sustainable Energy (ACSE) Programme. The project is named Kiribati Solar Boarding Schools Project and it is funded by the European Union (EU) and implemented by the Deutsche Gesellschaft für Zusammenarbeit (GIZ).

The objective of the project is to help achieve the government target of establishing renewable energy systems in 100% of boarding schools across Kiribati[1]. Expected outcomes for the project are:

- Students have access to light, water, internet etc throughout both the days and nights;
- School/island technicians' skills are upgraded and able to operate and maintain the systems;
- Reduced use of imported fuels and generated energy savings;
- Uses of environmental friendly clean and safe energy promoted in the outer islands and fossil fuel reduction target achieved in rural public and private communities.

As part of the design phase of the project a cost benefit analysis of the solar hybrid system installation was carried out on both sites. This is a report of the analysis for ASMC.

2 Methodology

This methodology of this cost benefit analysis follows common economic appraisal principles as described in Belli et al. (1998) and HM Treasury (2003). The approach applied is using consumer and producer surplus to estimate welfare changes in the society. The following sections explain the applied

[1] For more information on the project see GIZ (n.d.) or visit http://acsepacific.org/project/kiribati-solar-schools.

principles for valuation of costs and benefits. This methodology chapter contains detailed technical explanation of the methodology. Non-technical readers are advised to skip directly to chapter 3.

2.1 Discount rate

It was not possible to find a discount rate used by Kiribati government or other alternative projects in Kiribati. According to Belli et al. (1998) the World Bank has used a notional economic discount rate of 10-12 per cent for projects they finance. They also state that a discount rate of less than 10 per cent might be difficult to justify. On the other hand, the UK government recommends a rate of 3.5 per cent (HM Treasury 2003). While a higher discount rate may be justifiable in less developed countries due to shortage of capital and other factors compared to the UK, the difference between these two recommendations is significant and has a clear influence on the feasibility of projects.

The government of Kiribati has low debt and high reserves. Public debt was AUD 48.65 million in 2015 and the Revenue Equalisation Reserve Fund (RERF) was valued at AUD 678.97 million in December 2015 (MFED 2015). No information was available on the interest rate of public debt or the return on investment of RERF, which could have been used to define the opportunity cost of public funds. The Vanuatu Ministry of Finance and Economic Management has in two recent appraisals of infrastructure investment used 5 per cent and 5.5 per cent (Mele Trief & Busai 2013; August & Tagaro 2013). As a compromise, 5 per cent is applied in this study. However, this figure is arbitrary which needs to be taken into account in the interpretation of the results.

2.2 Shadow exchange rate

Most traded goods in Kiribati are applied a 12.5 per cent VAT when imported with no excise duty. Although excise duty is applied on some goods such as alcohol, vehicles, and some fuels, for simplicity a uniform import duty of 12.5 per cent is assumed for estimating the shadow exchange rate (SER) in Kiribati. As an approximation of the SER, price elasticities of supply and demand of foreign exchange are assumed equal. Thus, SER is estimated as:

$$SER = (1.125 \times w_i + 1 \times w_x)\ OER$$

Where OER is official exchange rate and:

$$w_i = \frac{I}{I + X}$$

And

$$w_x = 1 - w_i$$

Total merchandise imports are denoted by I and total exports by X. Table 1 shows the values of these variables for Kiribati. Using these figures SER is approximately 1.114 × OER.

TABLE 1. VARIABLES FOR CALCULATION OF SER. SOURCE: MERCHANDISE TRADE FIGURES FROM KIRIBATI NATIONAL STATISTICS OFFICE

	Price of foreign exchange	Merchandise goods
Imports	1.125 × OER	AUD 118,990,000
Exports	1 × OER	AUD 11,254,000

2.3 Cost categories

For the purposes of this analysis the costs of have been group into categories shown in Table 2. This also shows which costs are included in the appraisal.

TABLE 2. COSTS AND CATEGORIES INCLUDED IN THE APPRAISAL.

Category	Contents
Capital costs	Initial, replacement, and residual value of solar panels, inverter, batteries, wires, fues, mounting structures, diesel generator, and buildings (power house, fuel storage, and battery storage) ; Installation work and project design costs.
Fuel and lubricants	Diesel fuel and lubricant
Non-fuel costs	Oil and fuel filters, diesel generator and PV system spare parts
Wages	Labour costs of generator operator, and PV system operation, maintenance, and repairs
Land	Cost of land (as rent)

2.4 Tradeable goods

Tradeable goods are valued net of taxes and subsidies. The value of imports is estimated using the CIF (cost, insurance, freight) price plus internal transport costs. Exports are valued at the FOB (free on board) price. The same method is applied for lubricant fuel.

2.4.1 Diesel fuel

The cost of diesel fuel has been estimated as cost recovery price[2]. Table 3 shows the estimation of the cost recovery price.

TABLE 3. ESTIMATION OF DIESEL COST RECOVERY PRICE. FIGURES MAY NOT ADD UP DUE TO ROUNDING.

	AUD per litre
International price	0.60

[2] The approach follows the one used by SPC (2017) for the review of fuel subsidies in Kiribati.

International transport margin	0.41
Distribution margin	0.24
Internal transport[3]	0.08
Wholesale expenditure	0.17
Greenhouse gas emissions	0.12
Total	**1.61**

2.4.2 Generator equipment

The current imported diesel generator in use by ASMC was bought second hand in the end of 2015. It was four years old when purchased. The generator is assumed to have had 8 years remaining lifetime at the time of purchase, i.e. 6 years remaining at the time of project appraisal. The value of the generator is linearly depreciated with zero residual value. At the time of project appraisal (end of 2017), the generator is already located in Abemama. Because of this it's economic price is assumed the same as financial price and shadow exchange rate is not applied on the imported value.

2.5 Non-tradeable goods

2.5.1 Land

Since no active market for land exists in Abemama the imputed rent for land has been set equal to the estimated annual income from land. Annual income from land is derived from growing breadfruit trees based on interviews during the site visit. Breadfruit can be harvested twice a year with 40-50 fruit per tree each harvest. One tree is assumed to cover 225 m^2 and the local price of a fruit is AUD 2.00. It is assumed that harvesting the breadfruit takes 2 hours per tree per year which is valued at AUD 6.00/h (see valuation of labour). Thus, estimated income per m^2 is $(2\times45\times2\text{AUD}-2\times6.00)/225\text{m}^2\approx0.75$ AUD/m^2.

2.5.2 Buildings

The value of the buildings involved which already exist, the power house, fuel storage buildings[4], and battery storage buildings has been derived by estimating the cost of a new building. This consists of required construction materials and labour. The value of buildings excludes the land they are built on. Since these buildings already exist the value of a new build is multiplied by 2/3 to estimate the remaining value of these buildings.

2.5.3 Labour

Abemama does not have a modern labour market with formal employment and many people live in subsistence farming. Shadow wage rate for non-skilled labour is estimated as the reservation wage. In Abemama this is considered to be the earnings from copra drying which is an occupation accessible to most people. Women also participate in this activity. According to interviews during the field visit, the school staff purchase 300 coconuts for AUD 60. After cutting and drying them they sell the copra

[3] Estimated based on Kiribati Shipping Services Ltd listed price of AUD 78.00 per cubic metre from Kiritimati to Tabuaeran, i.e. AUD 0.078 per litre of diesel.

[4] Fuel is sometimes stored outside, sometimes inside a storage building.

for AUD 120. This takes one person about one day of work and 3 days of drying. Assuming a total workload of ten hours the hourly income is AUD 6.00, which is the shadow wage rate for non-skilled labour.

ASMC staff receive benefits such as free housing and electricity. If the actual ASMC wages were used for unskilled labour instead of the shadow wage rate, the cost of these free services should be added to the wage rates. When using copra drying earnings as the opportunity cost of labour, this implies that the value of the free services provided to staff are already included in the rate.

Skilled labour is valued as the average ASMC teaching staff salary including non-staff costs and housing benefit. Due to the absence of a well-functioning housing rental market in Abemama, the value of housing, which is provided to ASMC staff free of charge is estimated based on rental rates in Kiritimati using AUD 30 per fortnight. Operation and maintenance labour is valued at twice the cost of skilled labour to reflect additional travel costs since suitable labour may not be locally available in Abemama.

2.6 Estimating benefits to consumers

The benefit from the project to the consumers is estimated using the consumer surplus approach (see Belli et al. 1998). This means the demand function for electricity in ASMC has to be estimated in order to calculate the consumer surplus. Limited information exists on the demand of electricity in ASMC. First of all, electricity in ASMC has been provided for free revealing little information about willingness to pay. The size of the project did not also warrant a detailed survey to find out about the willingness to pay. Since many of the beneficiaries are non-income earning students and the residents have been used to not paying for electricity getting reliable willingness to pay information is challenging.

Estimation of the demand function of the economic appraisal is based on a few reference points. First is the estimated current use of electricity (86.8 kWh per person per year at zero price) and the second point is the forecasted demand based on wishes expressed by the project beneficiaries (268.8 kWh per person at zero price). Both points are derived from interviews of the households and students during the field visit. The third point of reference is the electricity provided by Public Utilities Board (PUB) in South Tarawa (277.3 kWh per person at a price of AUD 0.40[5], according to Pacific Power Association (PPA) Benchmarking Questionnaire 2012 data). While South Tarawa may have different socioeconomic and lifestyle characteristics compared to Abemama it was the closest available point of reference. It can also be assumed that in the long-run, over the project's 30 year horizon, demand would increase and shift towards the present day South Tarawa demand. The functional form of the demand function used is:

$$\ln q = \alpha + \beta p$$

Where *ln* is natural logarithm, *q* is the quantity of electricity, *p* is electricity price, α is a positive constant and β is price elasticity of demand for electricity.

This follows the approach of Choynowski (2002) and addresses some of the limitations of using a constant elasticity demand function such as infinite demand at zero price.

[5] This figure is based on the old tariff structure with a fixed tariff of AUD 0.40 to all households. Tariffs were changed in 2017.

The mean prices estimated by the South Tarawa demand function and the ASMC demand function are taken. This is under the assumption that at the start of the project, demand would be at the level taking into account people's current wishes on electricity use and would then increase and gradually reach the upper bound of current demand function in South Tarawa. However, in the estimation of consumer surplus over time the shift is not accounted for instead a constant demand function is used for simplicity. At Tarawa price of AUD 0.40, the price elasticity of demand is assumed to be -0.365 (Labandeira et al. 2016).

The estimated demand has some restrictions. The benefit from the project does not take into account the increase (or change) in reliability of electricity supply. It also ignores the time of the day and the duration electricity is supplies, i.e. 24 hour supply and 3 hour supply are treated the same as long as the total quantity of kWh supplied is the same. Furthermore the estimated benefit does not take into account of students and islands technicians in operation and maintenance of solar PV systems. Nevertheless this can be an additional benefit of the project.

3 Appraised options

3.1 Option 1

This is the 'business-as-usual' option where the project will not take place and ASMC will continue to produce electricity with the current diesel generator. Electricity is not provided for 24 hours, but only for about four hours per day[6].

3.2 Option 2

In this option a 31.5 kW solar PV system is installed to meet in full electricity needs identified during the energy needs assessment for both students and staff households. The diesel generator is kept for backup purposes only and is assumed to run on average about 9 hours per month.

3.3 Option 3

In option 3 the diesel generator setup is kept but the generator is running for 24-hours on every day. The estimated electricity supply is the same as option 2 meeting all the identified needs of students and staff households. Solar PV system is not installed.

3.4 Option 4

Options 4 and 5 are similar to option 2 using a solar PV system with diesel backup but with a smaller system sizes. For option 4 a 20 kW system was chosen.

[6] Actual estimate used is 1400 hours per year or on average 3.8 hours per day. This is based on current generator running hours.

3.5 Option 5

Options 4 and 5 are similar to option 2 using a solar PV system with diesel backup but with a smaller system sizes. For option 5 a 25 kW system was chosen.

4 Data

Prices data used in the estimation of project costs is shown in Appendix 1. The data used to estimate ASMC electricity demand function and consumer surplus under different scenarios is shown in Table 4.

TABLE 4. DATA USED FOR ESTIMATION OF ECONOMIC BENEFIT.

		Source
The total electricity billed to customers under domestic tariff in MWh.	7060	PPA Benchmarking questionnaire. 2012 data
Electricity tariff (AUD/kWh)	$0.40	PPA Benchmarking questionnaire. 2012 data
Combined number of domestic connections across all grids, taken at end of benchmarking period	4108	PPA Benchmarking questionnaire. 2012 data
Electricity billed per customer (household) (kWh)	1718.6	Calculated
Electricity consumption per customer (AUD/year)	$687.44	Calculated
Average number of people per household	6.2	Kiribati National Statistics Office. 2015 Population and Housing Census, Volume 1: Management Report and Basic Tables.
Electricity billed per person (kWh)	277.3	Calculated
Number of beneficiaries in MTSS	107	ASMC Cashier
Baseline total yearly load per capita (kWh)	86.8	Gender and Energy Assessment Report
Forecast total yearly load per capita (kWh) - option 2	268.8	Gender and Energy Assessment Report
Forecast total yearly load per capita (kWh) - option 4	170.6	Gender and Energy Assessment Report
Forecast total yearly load per capita (kWh) - option 5	213.0	Gender and Energy Assessment Report

5 Results

The basic results of the economic appraisal are shown in Table 5. The table shows the social net present value (SNPV), economic rate of return (ERR), and benefit cost ratio (BCR). The analysis is incremental, i.e. costs and benefits are identified in relation to option 1, which would result in a nil SNPV and BCR.

The results show that none of the options are feasible at 5 per cent discount rate and receive a negative NPV. The best options are options 4 and 5 which have an economic rate of return above 4 per cent. Option 3 with diesel generator running for 24-hours is the least feasible option. The results mean that the project should not go ahead unless a 4 per cent economic rate of return is acceptable.

TABLE 5. ECONOMIC APPRAISAL RESULTS

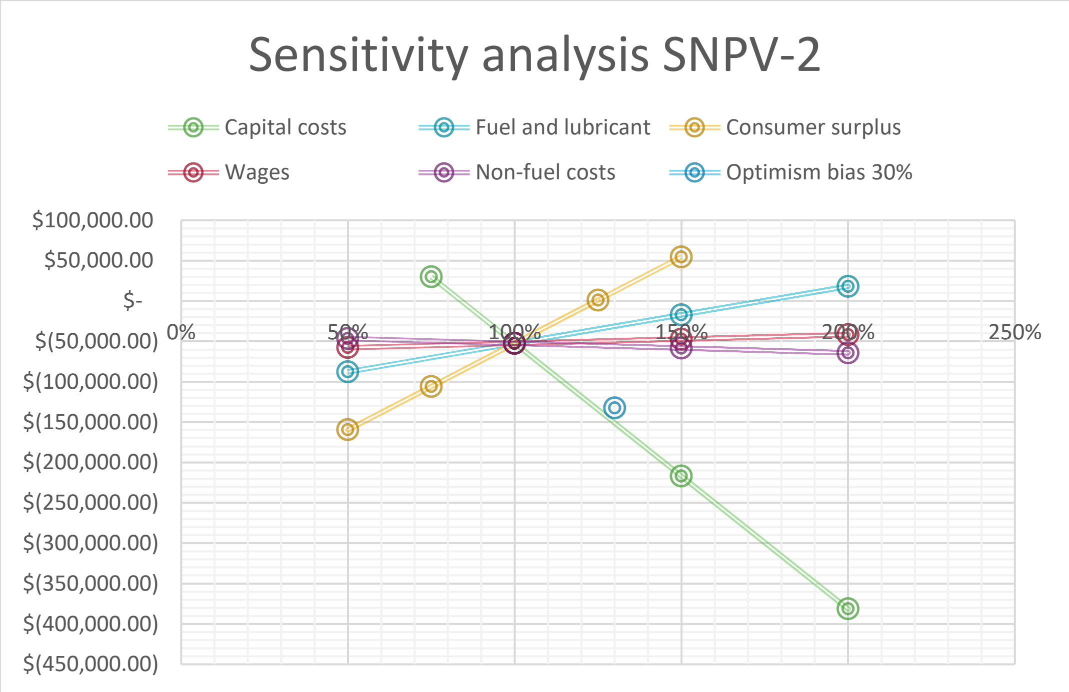
				SNPV	ERR	BCR
Option 2	Hybrid system	31.52	kW	-$ 52,379.02	3.23%	0.82
Option 3	24-hour diesel			-$150,358.51	n/a	-179.26
Option 4	Hybrid system	20	kW	-$ 19,292.09	4.12%	0.91
Option 5	Hybrid system	25	kW	-$ 23,999.16	4.06%	0.90

5.1 Sensitivity analysis

The sensitivity analysis of SNPV for options 2 to 5 is shown in Figure 1. These graphs show how the SNPV result for each option changes with relative changes in the associated costs and benefits. Options 2, 4, and 5 have a similar sensitivity pattern. For these options, capital costs, cost of fuel and lubricant, and the estimated consumer surplus are the biggest sources of uncertainty regarding economic feasibility. At 5 per cent discount rate, these options would be feasible if the actual capital costs were 10-20 per cent lower than estimated, or fuel and lubricant, costs were between 25 and 125 per cent higher depending on the option. Options 2, 4, and 5 become more feasible with higher oil prices. One would generate more savings with higher oil prices. Consumer surplus would have to be 10-25 per cent higher than estimated. This is possible since estimating the consumer surplus involves a high amount of uncertainty. On the other hand, this may also mean that consumer surplus has been overestimated. Wages and non-fuel costs have less impact on the overall result. Sensitivity of ERR of option 4 is shown in Figure 2.

Option 3 has a different pattern of sensitivity due to low capital costs, but high fuel costs. For option 3, capital costs are not very relevant to the feasibility. Instead, fuel costs and consumer surplus are the most important factors. Compared to other options fuel costs in option 3 have the opposite effect with lower fuel prices making the option more feasible. It would require around 40 per cent drop in fuel prices to make this option feasible.

All these options were run under an optimism bias option in accordance with UK government guidelines (HM Treasury 2003). Optimism bias is estimated by increasing all costs by 30 per cent. When including optimism bias the options 4 and 5 fall clearly below 3 per cent ERR.


Sensitivity analysis SNPV-2
Capital costs
Fuel and lubricant
Consumer surplus
Wages
Non-fuel costs
Optimism bias 30%
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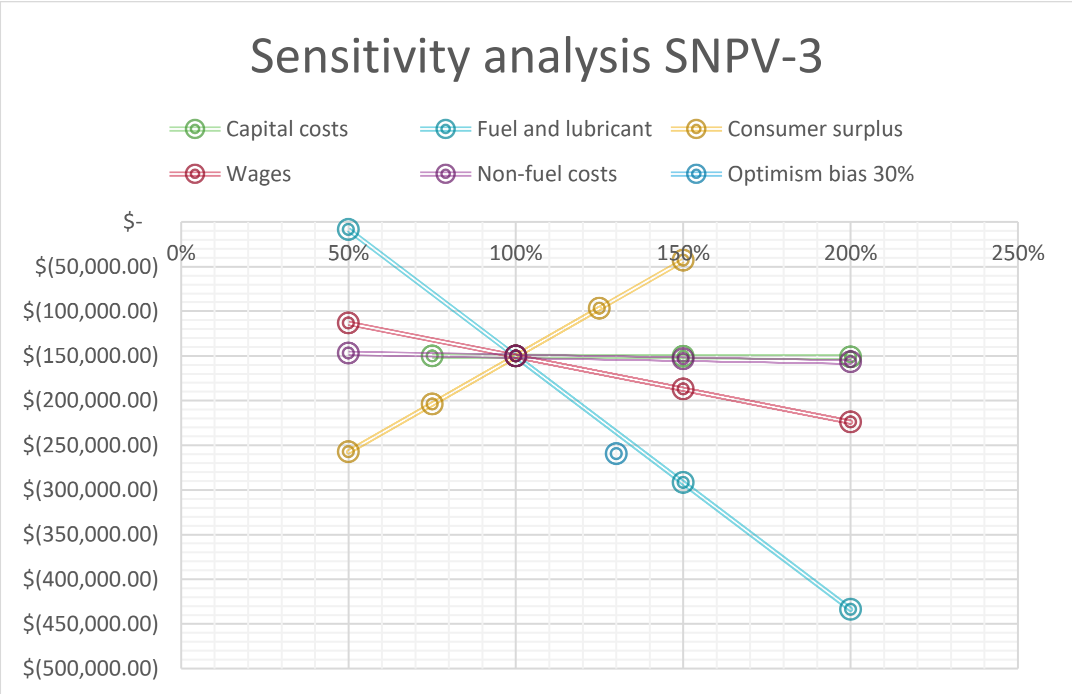
Sensitivity analysis SNPV-3
Capital costs
Fuel and lubricant
Consumer surplus
Wages
Non-fuel costs
Optimism bias 30%
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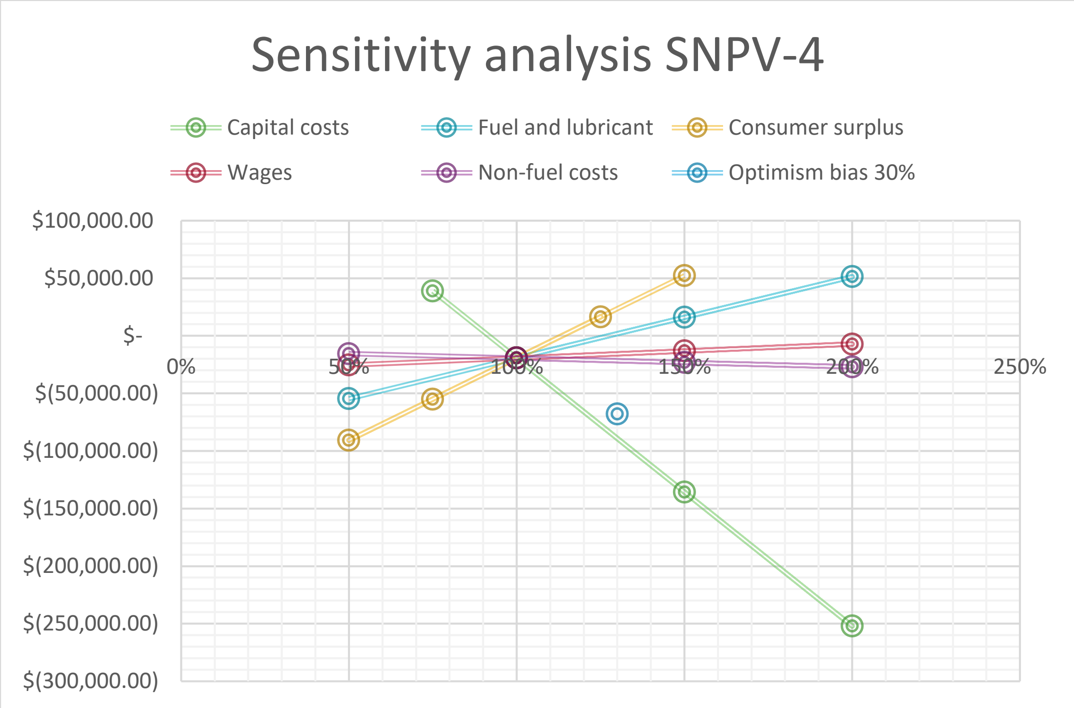

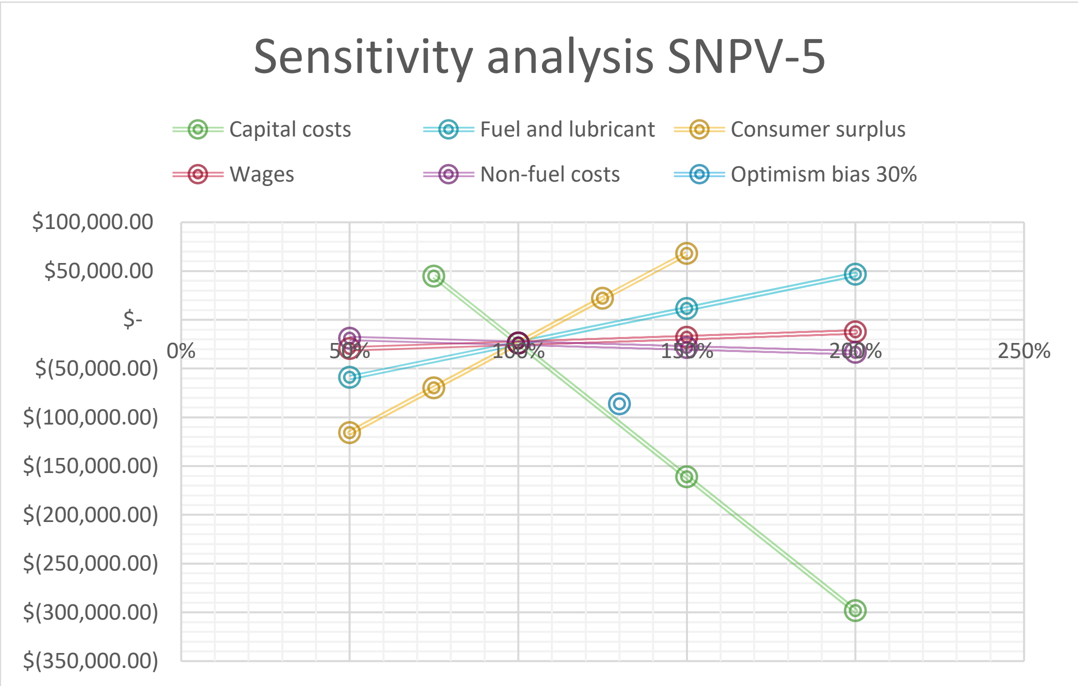

Figure 1. SNPV sensitivity analysis of project options.

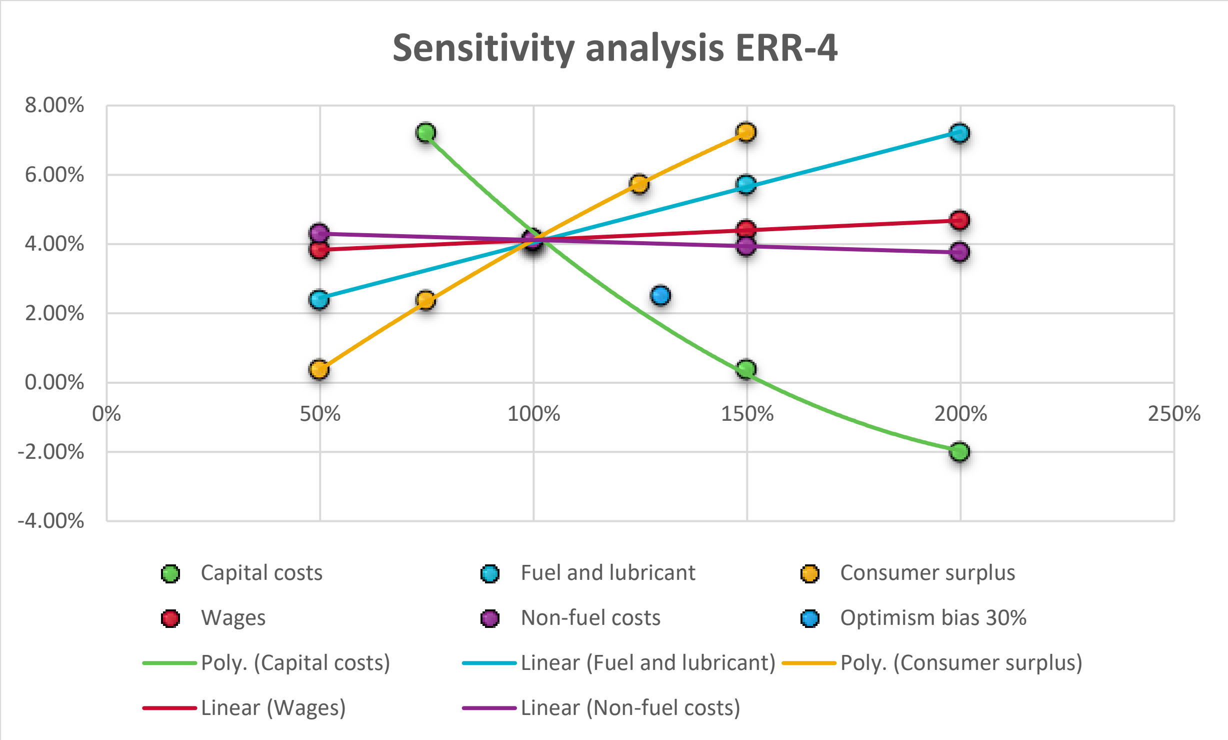

FIGURE 2. ERR SENSITIVITY ANALYSIS OF OPTION 4.

The results of the different scenarios used for sensitivity analysis for each option are listed in appendix II. Figure 3 shows the variance of SNPV under all the scenarios. Although statistically biased and based on subjectively defined scenarios, it is a simple way to summarise and compare the uncertainty regarding each option. The variance of options 2, 4, and 5 increases with increased capital costs which is expected.

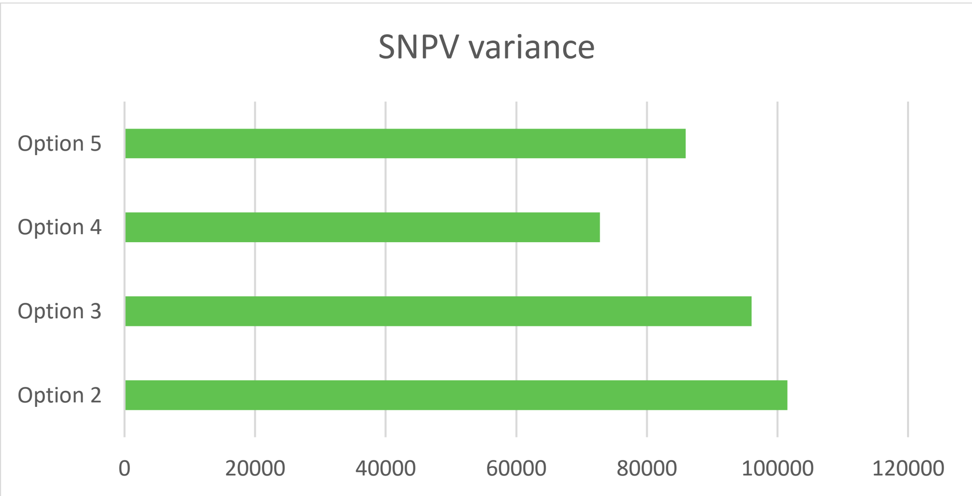

FIGURE 3. SNPV VARIANCE OF PROJECTS UNDER ALL SCENARIOS.

5.2 Financial affordability

The estimated incremental capital costs of the project options are shown in Table 6. Apart from the beginning of the project there are also additional costs when batteries (Project year 11 and 21) and inverter (Project year 16) needs to be replaced. The costs in the table are incremental but there are also non-incremental costs of replacing the generator which are common to all options 1 to 5 and thus shown as zero. At the end of the project, the generator also has residual value, which is common to all options. The capital costs of project year zero are expected to be paid by the donor but it is important to ensure that there is budget available for the replacement costs to guarantee the financial sustainability of the project.

TABLE 6. INCREMENTAL FINANCIAL CAPITAL COSTS (IN AUD)

Project year	Option 2	Option 3	Option 4	Option 5
0	$223,496	$0	$141,809	$177,261
11	$35,465	$0	$22,500	$28,125
16	$27,593	$0	$17,508	$21,885
21	$35,465	$0	$22,500	$28,125
Total	**$322,018**	**$0**	**$204,317**	**$255,396**

Incremental annual financial operating costs are shown in Table 7. Negative values mean that there are savings in relation to option 1. As can be seen when use of the diesel generator is reduced to backup role only savings in fuel and lubricant can be over AUD 4,000. On the other hand this gain is partially outweighed by other cost such as spare parts for the PV system. These changes in operating costs are to be covered directly from the ASMC budget. There is considerable uncertainty in estimating the cost of maintenance and repairs. These costs may be underestimated and ASMC should be prepared overall savings to be less than the estimates here.

TABLE 7. INCREMENTAL ANNUAL FINANCIAL OPERATING COSTS (IN AUD)

	Option 2	Option 3	Option 4	Option 5
Fuel and lubricant	-$4,131	$16,581	-$4,131	-$4,131
Non-fuel costs	$769	$429	$503	$634
Wages	-$216	$2,371	-$311	-$270
Operating costs total	**-$3,578**	**$19,381**	**-$3,939**	**-$3,767**

5.3 Gainers and losers

Distributional analysis of project option 5 is shown in Table 8 and Figure 4. This shows how the benefits and costs are distributed among the project stakeholders, i.e. who gains and who loses as a result of the project. At the left of Table 8 are donor and ASMC, which reflect the financial costs of the project.

At the right is the society reflecting the total of all costs and benefits and the project SNPV. Donor costs include only the initial capital costs of the project. The replacement costs of equipment are assigned to ASMC. Consumer surplus benefits are distributed between households based on how much electricity is supplied to the school and how much to the households. Men and women are assumed to consume an equal amount of electricity. This can be an underestimation of the benefit to women since electrical goods can assist in household work normally done by women.

As can be seen there are no real losers as a result of the project (apart from the financial loss to the donor). The students benefit the most with more benefits to male students due to their larger numbers. In per capita terms the net benefit to students is AUD 1,825. The school also benefits mainly due to savings in fuel costs although these are partially offset by increases in other costs. Men and women in staff households receive a roughly equal benefit which is AUD 891 in per capita terms.

TABLE 8. DISTRIBUTIONAL ANALYSIS OF OPTION 5 (THOUSAND AUD). FIGURES MAY NOT ADD UP DUE TO ROUNDING.

	Donor	ASMC	Female students	Male students	Staff households - female	Staff households - male	Government	Suppliers	Environment	Society
Consumer surplus	0	0	47	55	21	20	0	0	0	143
Total Benefits	0	0	47	55	21	20	0	0	0	143
Capital costs	-205	-29	0	0	0	0	1	0	0	-233
Fuel and lubricants	0	64	0	0	0	0	0	2	5	71
Non-fuel costs	0	-8	0	0	0	0	0	0	0	-8
Wages	0	5	0	0	4	4	0	0	0	12
Land	0	0	-1	-2	-1	-1	0	0	0	-5
Total costs	-205	31	-1	-2	3	3	1	2	5	-162
Net benefit	**-205**	**31**	**46**	**53**	**24**	**23**	**1**	**2**	**5**	**-19**

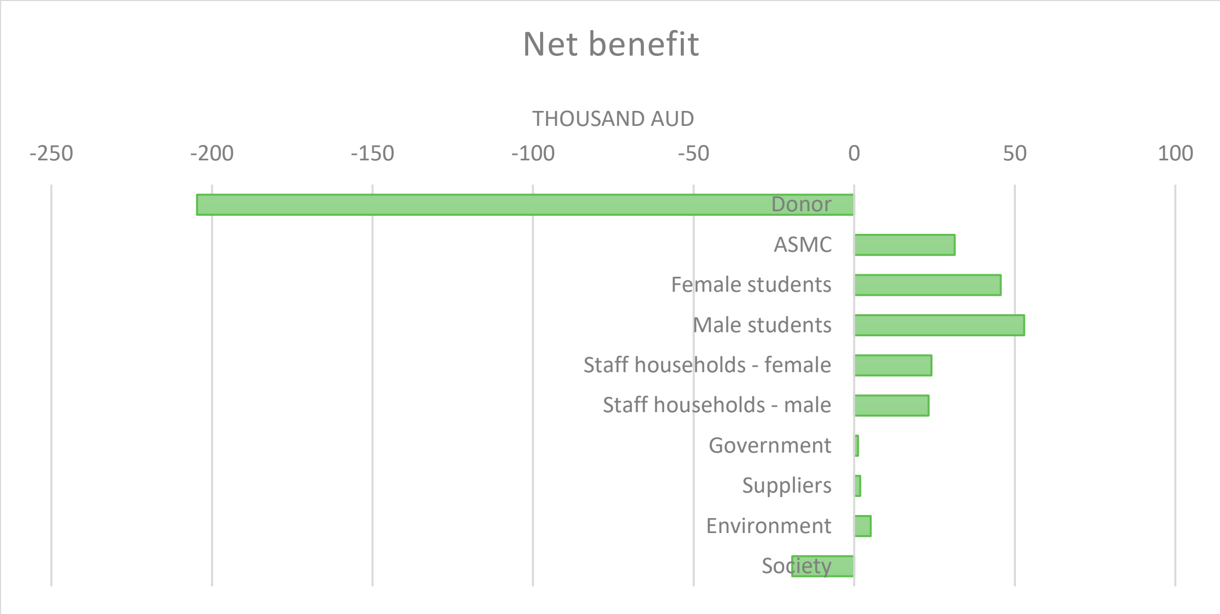

FIGURE 4. DISTRIBUTION OF OPTION 5 NET BENEFIT

5.4 Dependency on diesel fuel and environmental impact

Currently, electricity production at ASMC uses about 3,080 litres of diesel fuel a year. Project options 2, 4, and 5, all reduce dependency on diesel fuel. For these options it is estimated that only 240 litres per year is required to use the generator as a backup. However, if the size of the PV system is set lower than the identified need, there may be pressures to use the generator more to supplement the solar PV output.

Reducing the amount of diesel consumed means some financial savings for ASMC from reduced fuel purchases (see Table 7) but part of the savings is likely to be offset by additional costs from operating a solar PV system. There is also an environmental benefit due to reduced greenhouse gas emissions. Thus, the project is expected to have positive impacts on the environment. This environmental benefit, however, is not as substantial as other welfare and economic benefits of the project. For example, for option 4 the total benefit from reduced use of fuel is estimated at around AUD 70,620. This includes a reduced fuel bill worth AUD 63,500 in present value to ASMC and AUD 5,150 from reduction of greenhouse gas emissions.

5.5 Optimisation

In order to find an optimal size of a PV system the estimation of ERR for option 5 was run using different size parameters. This tells the optimal size of a system when running the diesel generator as a backup only. These results are shown and compared to other options (see Figure 5). The highest ERR values are obtained from sizes ranging from option 4 (20 kW) to option 5 (25 kW).

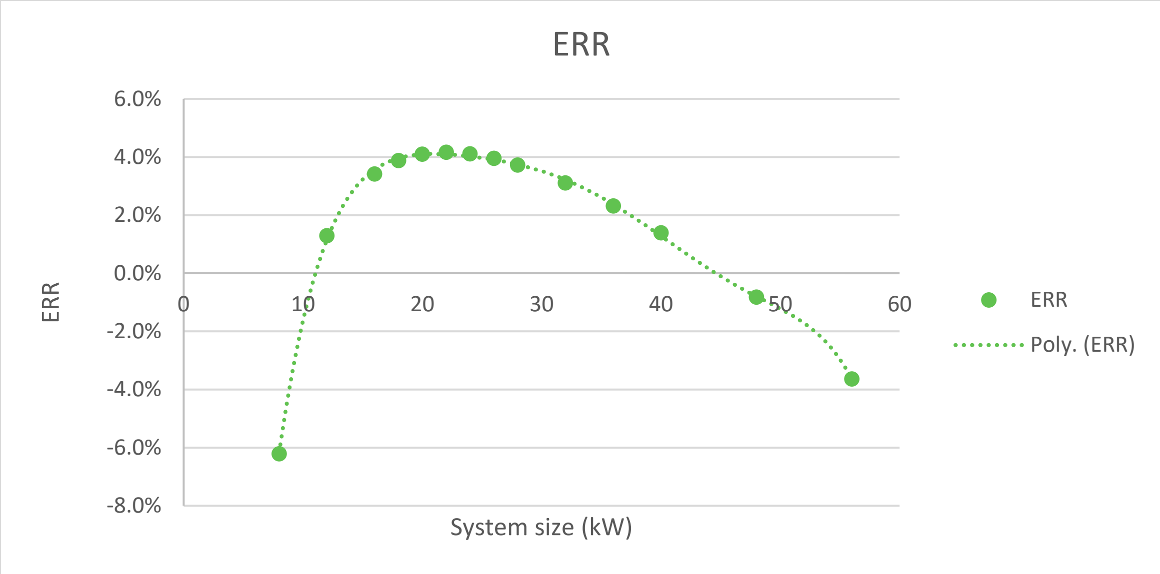

FIGURE 5. RELATIONSHIP BETWEEN SYSTEM SIZE AND ERR FOR OPTION 5.

6 Conclusion

The results of the analysis show that none of the appraised project options are feasible at a 5 per cent discount rate. The best options are 20 kW or 25 kW PV systems with diesel backup which have an ERR around 4 per cent. Capital costs would need to be about 10 per cent lower to make these options feasible. Accurately estimating the project benefit is also difficult. For the best option 10-15 per cent higher benefits than estimated would make the project feasible. Otherwise the low 4 per cent economic rate of return needs to be accepted or the project may need to be altered or even rejected. When adjusting for optimism bias the best ERR is at 2.5 per cent. The results of options using PV system with diesel backup are sensitive to estimated project benefit, capital costs, and fuel costs. On the other hand, the estimated benefit does not take into account the benefit from students learning to operate and maintain solar PV systems.

The optimal size of a solar PV system with diesel backup is determined to be around 20-25 kW. For ASMC an option where a smaller PV system is combined electricity supplied by a diesel generator was not run. For MTSS this proved to be an option worth considering. ASMC runs a smaller and less expensive generator which might make this option relatively less interesting than at MTSS. If time permits it might still be worth considering.

There are some high fixed costs involved in the project, particularly around technical assistance, site surveys, the feasibility study, and design of the system. These fixed costs explain why the feasibility of the project initially increases with an increase in system size. Some of these costs are sunk costs at the time of the analysis and thus excluded since they have no relevance to decision-making regarding this project. However, incorporating these costs fully in the analysis would make the project less feasible, considering the small size of the project. A lesson learned for future projects is that with a considerable technical assistance component an attempt should be made to either capture larger number of beneficiaries or reduce the fixed costs.

After reaching a certain point the net benefit of the project starts to decrease as the cost of providing an additional unit of electricity exceeds the benefit derived from it. Since electricity is provided to the beneficiaries for free, they have an incentive to consume in excess of this point. This can be avoided by not oversizing the project.

The option 3 with a diesel generator running 24-hours a day and no solar PV system is shown to be not feasible in the base case. It would require a considerable drop in fuel prices to make it feasible. In addition fluctuations in fuel prices make this option relatively more uncertain. The results support having a solar PV system to meet the electricity needs of ASMC instead of relying solely on the diesel generator.

The appraised solar PV based project options would results in a reduction in the use of diesel fuel. This would in turn reduce the carbon footprint of ASMC. The value of this benefit is estimated to be relatively small compared to other project benefits. Monetary savings from reduced diesel fuel consumption are estimated to be at most around AUD 4,000 a year. These savings are estimated, to some extent, be outweighed by increased costs related to the operation, maintenance, and replacement parts of the solar PV system.

Distributional analysis was run only for option 4, which is a 20 kW system with diesel generator backup. It shows that the biggest winners of this option would be the students themselves. Since there are more male than female students, the overall net benefit is little higher to male students. Both men and women in staff households also benefit but clearly to a lesser extent. There are no clear losers as a result of the project. The project is well targeted to reach the students as intended beneficiaries.

In comparison with the economic appraisal of MTSS, the overall feasibility of the ASMC site is lower. The results suggest that it is feasible to invest a larger share of project funds into MTSS and a lower share to ASMC in order to maximise programme outcome.

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I. Appendix 1 – Price data

Item	Unit	Financial/cash price (AUD)	Shadow price	Lifetime (years)	Source (financial price)	Notes
Generator equipment, used	generator	$ 3,500.00	$ 3,500.00	8	ASMC Mechanic	Bought 4 years old in the end of 2015; ASMC paid 1500 but market price estimated as 3500 by the mechanic
Generator equipment, new	generator	$ 5,250.00	$ 5,250.00	12	Calculated	
Diesel fuel	litre	$ 1.45	$ 1.61		ASMC Accounts	Based on price $289.40 per drum from KOIL, when KOIL is out of diesel pay $1.90 per litre to other suppliers.
Oil 30	litre	$ 10.00	$ 9.90		ASMC Cashier	
Oil filter	filter	$ 5.00	$ 4.95		MTSS Tradesman interview	Ordered from Tarawa
Fuel filter	filter	$ 5.00	$ 4.95		MTSS Tradesman interview	Ordered from Tarawa
Average ASMC salary	year	$ 6,785.62			KUC. ASMC paysheet	
Average ASMC non-salary labour cost	year	$ 416.67				Excludes free housing and electricity
ASMC Staff housing cost	year		$ 300.00			Housing is provided for free to staff; no housing market in Abemama; one thached house assumed to cost $3000 and have a lifetime of 10 years
Generator operator salary	year	$ 5,512.00			KUC. ASMC paysheet	
Construction worker wage	year	$ 5,928.67			Calculated	based on generator operator, includes non-salary costs but excludes housing
Unskilled labour	hour	$ 6.00	$ 6.00		ASMC Cashier	Assumed as copra drying income
Skilled labour	year		$ 8,482.95		Calculated	
Labour - generator operator	year	$ 5,928.67	$ 12,000.00			Assuming 40 hours per week, 50 days per week for shadow wage rate (unskilled labour wage), implicitly includes housing, electricity and other benefits
Installation labour	W	$ 0.25	$ 0.13		KSEC	for shadow price assuming four people, twice the cost of skilled labour to adjust for travel expenses, assuming 40 hours per week, 5 days per week
O&M labour	hour	$ 8.18	$ 8.48			Assuming twice the cost of skilled labour to adjust for travel expenses, assuming 40 hours per week, 50 weeks per year
Project design	Site		$ 125,650.74		Project budget	Assuming budgeted cost is the same as economic cost. Includes: cost of material and equipment, cost to third party services, personnel, travel expense, operating and

						administrative costs, workshops and training, 7 % overhead. Excludes construction. Converted using 1 EUR = 1.48 AUD
Power house building	building	$ -	$ 5,610.16	30	Calculated from MTSS data	Based on MTSS cost for a 5m x 10m building. The size is estimated as 4x5m
Petrol house building	building	$ -	$ 1,564.00	30	Calculated from MTSS data	Petrol is stored in open air, or inside the storage building. Based on MTSS cost for a 2.5m x 5m building. The space reqruiment is estimated as 2x2m
Battery storage building	building	$ -	$ 2,805.08	30	Calculated from MTSS data	A size of 2x5m. The building already exists.
Land, rent (breadfruit)	m2	$ -	$ 0.75		MTSS and ASMC interviews	Breadfruit tree harvested twice a year with 40-50 fruit each time, $2 each, tree area 15x15m; labour is valued at copra harvesting rate for 2 hours
Freight Tarawa - Abemama	m3	$ 78.00	$ 78.00		KSSL	Prices effective 7/7/14, shadow price assumed equal, though price possibly subsidised
42.5 kW PV system	system	$ 351,094.34			Reference project	Includes equipment only (panels, battery, inverter)
12.69 kW PV system	system	$ 105,437.28			Reference project	Includes equipment only (panels, battery, inverter)
Panel 140W in Tarawa	panel	$ 512.30	$ 507.29	30	KSEC	Local price in Tarawa, imported, includes VAT
Panel 140W in ASMC	panel	$ 517.99	$ 512.98	30	Calculated	Assuming 0.073 m3 dimension
Panel	W	$ 3.70	$ 3.66	30	Calculated	
Inverter 800W/12V in Tarawa	inverter	$ 699.00	$ 692.17	15	KSEC	Local price in Tarawa, imported, includes VAT
Inverter 800W/12V in ASMC	inverter	$ 700.33	$ 693.49	15		Assuming 0.017 m3 dimension
Inverter	W	$ 0.88	$ 0.87	15	Calculated	
Battery bank	Ah	$ 1.50	$ 1.49	10	Reference project	Includes VAT, MTSS price
PV spare parts	kW	$ 26.20	$ 25.95		EPRI 2015	EPRI estimate is USD2-20 /kW-year

II. Appendix 2 – Results summary

	SNPV	ERR	BCR
Option 2 (incremental)	101508.3471		
Standard case	-$ 52,379.02	3.23%	0.82
Optimism bias 30%	-$132,373.34	1.36%	0.64
CAPEX 150%	-$216,897.39	-0.49%	0.49
CAPEX 200%	-$381,415.75	-2.92%	0.33
CAPEX 75%	$ 29,880.17	6.25%	1.14
Fuel 150%	-$ 17,068.93	4.44%	0.94
Fuel 200%	$ 18,241.17	5.58%	1.06
Fuel 50%	-$ 87,689.11	1.92%	0.69
Consumer surplus 125%	$ 1,188.16	5.04%	1.00
Consumer surplus 75%	-$105,946.20	1.19%	0.63
Consumer surplus 50%	-$159,513.38	-1.22%	0.44
Consumer surplus 150%	$ 54,755.34	6.70%	1.19
Wages 150%	-$ 47,055.40	3.42%	0.83
Wages 200%	-$ 41,731.79	3.60%	0.85
Wages 50%	-$ 57,702.63	3.04%	0.80
Non-fuel costs 150%	-$ 58,234.77	3.02%	0.79
Non-fuel costs 200%	-$ 64,090.52	2.81%	0.77
Non-fuel costs 50%	-$ 46,523.27	3.43%	0.84
Option 3 (incremental)	96058.5573		
Standard case	-$150,358.51	n.a.	-179.26
Optimism bias 30%	-$259,746.67	n.a.	-238.54
CAPEX 150%	-$150,775.57	n.a.	-119.50
CAPEX 200%	-$151,192.64	n.a.	-89.63
CAPEX 75%	-$150,149.97	n.a.	-239.01
Fuel 150%	-$292,050.74	n.a.	-349.12
Fuel 200%	-$433,742.98	n.a.	-518.99
Fuel 50%	-$ 8,666.27	n.a.	-9.39
Consumer surplus 125%	-$ 96,791.32	n.a.	-115.04
Consumer surplus 75%	-$203,925.69	n.a.	-243.48
Consumer surplus 50%	-$257,492.87	n.a.	-307.70
Consumer surplus 150%	-$ 43,224.14	n.a.	-50.82
Wages 150%	-$187,252.39	n.a.	-223.49
Wages 200%	-$224,146.27	n.a.	-267.72
Wages 50%	-$113,464.62	n.a.	-135.03
Non-fuel costs 150%	-$153,623.02	n.a.	-183.17
Non-fuel costs 200%	-$156,887.54	n.a.	-187.08
Non-fuel costs 50%	-$147,093.99	n.a.	-175.34
Option 4 (incremental)	72815.61777		
Standard case	-$ 19,292.09	4.12%	0.91
Optimism bias 30%	-$ 67,940.86	2.50%	0.74
CAPEX 150%	-$135,672.27	0.38%	0.56

CAPEX 200%	-$252,052.45	-2.01%	0.38
CAPEX 75%	$ 38,898.00	7.21%	1.25
Fuel 150%	$ 16,018.00	5.70%	1.08
Fuel 200%	$ 51,328.09	7.19%	1.25
Fuel 50%	-$ 54,602.18	2.38%	0.73
Consumer surplus 125%	$ 16,425.53	5.72%	1.08
Consumer surplus 75%	-$ 55,009.71	2.36%	0.73
Consumer surplus 50%	-$ 90,727.33	0.36%	0.55
Consumer surplus 150%	$ 52,143.15	7.22%	1.26
Wages 150%	-$ 13,217.35	4.40%	0.94
Wages 200%	-$ 7,142.61	4.68%	0.96
Wages 50%	-$ 25,366.83	3.83%	0.88
Non-fuel costs 150%	-$ 23,116.85	3.94%	0.89
Non-fuel costs 200%	-$ 26,941.60	3.76%	0.87
Non-fuel costs 50%	-$ 15,467.33	4.30%	0.92
Option 5 (incremental)	85944.3853		
Standard case	-$ 23,999.16	4.06%	0.90
Optimism bias 30%	-$ 86,320.90	2.26%	0.72
CAPEX 150%	-$161,270.57	0.28%	0.55
CAPEX 200%	-$298,541.99	-2.15%	0.37
CAPEX 75%	$ 44,636.55	7.18%	1.25
Fuel 150%	$ 11,310.94	5.43%	1.05
Fuel 200%	$ 46,621.03	6.72%	1.20
Fuel 50%	-$ 59,309.25	2.57%	0.75
Consumer surplus 125%	$ 21,935.84	5.83%	1.09
Consumer surplus 75%	-$ 69,934.15	2.10%	0.71
Consumer surplus 50%	-$115,869.14	-0.17%	0.51
Consumer surplus 150%	$ 67,870.83	7.47%	1.28
Wages 150%	-$ 18,250.43	4.29%	0.92
Wages 200%	-$ 12,501.70	4.51%	0.95
Wages 50%	-$ 29,747.89	3.82%	0.88
Non-fuel costs 150%	-$ 28,821.04	3.86%	0.88
Non-fuel costs 200%	-$ 33,642.92	3.67%	0.86
Non-fuel costs 50%	-$ 19,177.27	4.25%	0.92