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An Economic Assessment of Renewable Energy Options for Rural Electrification in Pacific Island Countries

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ACRONYMS

ADB	Asian Development Bank
APACE-VFEG	Appropriate Technology for Community and Environment – Village First Electrification Group
AWEA	American Wind Energy Association
BCA	Benefit-Cost Analysis
CIF	Cost + Insurance + Freight
CIDA	Coconut Industry Development Authority (Fiji)
EIA	Energy Information Administration (US Department of Energy)
ESMAP	Energy Sector Management Assistance Programme (World Bank/UNDP)
FOB	Free on Board
GDP	Gross Domestic Product
IEA	International Energy Association
IMF	International Monetary Fund
IRR	Internal Rate of Return
ITDG	Intermediate Technology Development Group
MDG	Millennium Development Goals
NGO	Non-Government Organisation
NPV	Net Present Value
O&M	Operation and Maintenance
LCC	Life-Cycle Cost
OECD	Organisation for Economic Cooperation and Development
PIC	Pacific Island Country
PIFS	Pacific Islands Forum Secretariat
PIEPSAP	Pacific Islands Energy Policy and Strategic Actions Plan Project (SOPAC)
PREFACE	Pacific Rural Renewable Energy France Australia Common Endeavor
PV	Photovoltaic
REEP	Renewable Energy and Energy Efficiency Program for the Pacific (ADB)
RET	Renewable Energy Technology
SIDS	Small Island Developing State
SOPAC	Pacific Islands Applied Geoscience Commission
SHS	Solar Home System
SPC	Secretariat of the Pacific Community
SPREP	Secretariat of the Pacific Regional Environment Programme
UN	United Nations
UNDP	United Nations Development Programme
UNCTAD	United Nations Commission on Trade and Development
WSSD	World Summit on Sustainable Development

Energy and Power Units

AC	Alternating Current
DC	Direct Current
KVA	Kilo-Volt-Amperes
kWh	Kilo-watt-hour
m/s	Meter per second
MW	Megawatt
RPM	Revolutions per minute
Wh	Watt-hour
W_p	Watts peak power

EXECUTIVE SUMMARY

There is an important and growing economic role for renewable energy systems within the energy sector. This is demonstrated by the fact that over the past few years, the use of renewable energy technologies has expanded rapidly. In 2005, renewable energy technologies, including hydropower, accounted for 17% of global energy production.

Renewable energy technologies provide a cost-effective source of electricity in rural areas where distances are large, populations are small, and demand for energy is low. This is a market that, traditionally, has been very difficult for developing country governments to serve in a cost-effective manner. As a result, a large proportion of households living in rural areas still lack access to modern forms of energy. However, access to basic energy services has been identified as a necessary condition for the achievement of many of the Millennium Development Goals. This is because access to energy can promote improved outcomes in the areas of health, education, and economic development.

Pacific Island Countries face a particularly difficult challenge when it comes to rural electrification. As a result of the unique geographical situation in the region, where long distances separate sparsely-populated areas, and markets are too small to achieve cost savings through economies of scale in electricity production, the costs of supplying electricity to rural areas are enormous. This has resulted in a situation where approximately 70% (or approximately 50% excluding Papua New Guinea) of the region's population still lacks access to electricity. In addition, Pacific Island Countries, despite their abundance of renewable energy resources, remain almost completely dependent on imported fossil fuels for meeting their energy needs. Imported petroleum products account for an average of 40% of countries' gross domestic products. With rising petroleum prices, and growing trade deficits, the current situation is likely to be unsustainable in the future.

As part of this study, four rural electrification projects were selected in order to assess the cost-effectiveness of a particular renewable energy technology option in a rural Pacific Island setting. First, the island of 'O'ua, which is part of the Ha'apai Solar Electrification Project in Tonga, was examined in order to compare the cost-effectiveness of individual solar home systems compared with a village diesel generator for supplying basic household electricity services. Using least-cost analysis, it was determined that solar home systems would provide the most cost-effective means of supplying electricity. Next, again using least-cost analysis, it was determined that micro-hydroelectricity was the least-cost option, compared with diesel generators, for supplying electricity to Bulelavata Village, a rural community located in the Western Province of the Solomon Islands. Benefit-cost analysis was used to assess the benefits, in terms of diesel

savings, associated with a wind-hybrid system on the island of Mangaia, in the Cook Islands, compared with the costs of integrating wind turbines into the current electricity production system. Since the fuels savings envisioned under the project have largely failed to materialise, it was determined that the wind-hybrid system was not a cost-effective option for electricity production on the island. Finally, the biofuel pilot projects on the islands of Taveuni and Vanua Balavu, in Fiji, were examined in order to compare the costs of producing electricity from a generator, using coconut oil versus diesel fuel. It was determined that although, in theory, coconut oil could present a more cost-effective option for powering village generators, supply constraints and high labour costs at the micro-economic level, prevent this from occurring in practice.

It is important to highlight that there is not one technology that is least-cost, and it is very much dependent on local conditions, and renewable resource availability. Also, hours of service and power availability vary considerably between different energy options. The results from the study, which indicate that renewable energy technologies are the least-cost option for rural electrification, depend critically on the fact that shipping costs are high, which makes diesel fuel expensive, populations are small and per capita demand for energy is low, which does not allow for economies of scale in energy production.

Based on the results from this study it is recommended that governments actively promote the use of renewable energy technologies, by developing policies, which require renewable energy options to be adequately considered in energy planning. Also, it is further recommended that Pacific Island Governments focus on developing appropriate models for managing renewable energy projects in order to ensure that systems are adequately maintained and that user fees are collected in full, and set at a level which ensures financial sustainability. Regional cooperation is needed for countries to share their experiences with the successful implementation of renewable energy projects. Finally, since the start-up costs associated with renewable energy technologies tend to be high, it is recommended that policies be introduced, which assist in lowering the initial costs, which is another major barrier to their use. However, given the limited amount of resources available for spending on public investment projects, trade-offs between sectors exist, and so renewable energy investment decisions should be integrated into national development planning processes.

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1. INTRODUCTION

The global use of renewable energy technology options has expanded rapidly over the past two decades as their technological feasibility, reliability and cost-effectiveness has been successfully demonstrated in a number of niche markets. Given the high cost of supplying electricity to isolated rural communities, decentralised renewable energy options often can compete on cost with conventional supply options such as grid extension. However, despite their abundance of renewable energy resources, Pacific Island Countries (PICs) remain almost completely dependent on fossil fuels for meeting their energy needs (World Bank, 1992; Wade and others, 2005).

Improving access to electricity has been made a priority among Pacific Island Countries, where approximately 70% (50%, excluding Papua New Guinea) of the population lacks access to electricity, (SOPAC 2004; Wade and others, 2005). This poses an enormous challenge to a region where most countries consist of a number of dispersed islands with isolated populations, poorly developed infrastructure, and limited financial resources to invest in electrification projects. In addition, with global oil prices rising to over US$70 per barrel, the costs of supplying electricity through conventional means has become unsustainably costly, thereby exerting pressure on the countries' trade balances, government budgets and the incomes of energy consumers. Traditionally in PICs, outside of urban areas, when grid extension is not economically feasible, electricity is supplied by decentralised diesel generators (Cheatham, 1990). Although, initial capital investment requirements are low, diesel generators are very costly to operate and maintain, which often makes this technology option unsustainable in isolated rural communities where household income is low, and skilled labour scarce. Under these circumstances, renewable energy options, which are relatively simple to maintain, and do not require imported fuel inputs, provide an increasingly attractive means of promoting rural electrification (Liebenthal and others, 1994).

The aim of this study is to conduct an economic and financial evaluation of a number of technologically-proven renewable energy projects, which have been implemented in Pacific Island Countries, in order to assess the potential for renewable energy to play a larger role in rural electrification strategies in the region. These include projects that utilise technologies such as solar photovoltaic (PV) home systems, wind-hybrid systems, coconut biofuel-powered generators and micro-hydroelectric systems. Using case studies from various Pacific Islands, the least-cost means of supplying electricity to rural communities is assessed by comparing the life-cycle costs of a particular renewable energy technology with the costs of supplying electricity with a diesel generator over the estimated life of a project. The case studies selected as part of the study were chosen in order to reflect as wide a range of renewable technologies as possible in a variety of different Pacific Island settings. These include O'ua Island, which is part of the Ha'apai Solar Electrification Project in Tonga; the Mangaia Wind Power Project in the Cook Islands; the Welagi and Vanua Balavu Biofuel Projects in Fiji; and the Bulelavata Micro-Hydroelectric Project in the Solomon Islands.

1. 1 The Global Situation

In 2004, about US$55 billion[1] was invested in renewable energy power systems, which is just over one-third the amount that was invested in conventional power plants. In 2005, renewable energy, (including hydropower) supplied 17% of the world's primary energy (World Bank, 2006). Much of this growth in use has occurred in developing countries, which account for 44% of the world's renewable generating capacity and receive half a billion dollars each year to fund investments in this sector (REN21, 2005a; World Bank, 2006). Currently PV systems provide lighting for more than 2 million homes worldwide (REN21, 2005b).

There is an important and growing economic niche for renewable energy systems within the energy sector. Renewable energy competes with conventional energy in four main areas: power generation, hot water and space heating, transport fuels, and rural off-grid energy. The costs of renewable energy have declined significantly over the past 10 to 15 years with improvements in technology and economies of scale in production. For off-grid applications, mini-grid and stand-alone renewable energy systems can be a cost-effective alternative to grid-based rural electrification, which is often too costly for sparsely-populated and remote areas (World Bank, 2006). The future prospects for renewable energy technologies are even more promising due to continually falling prices, and the growing awareness of the environmental and energy security benefits that such technologies provide.

In addition, concerns about global climate change have lead to growing interest in the use of renewable energy technologies for energy production. For example, industrialised countries have made a significant number of investments in developing countries, in areas such as renewable energy, under the Clean Development Mechanism included in the Kyoto Protocol, in order to earn carbon credits by investing in project activities that reduce greenhouse gas emissions and promote sustainable development. There is also an incentive for developing countries, although they are not significant emitters of greenhouse gases on a global scale, to promote the use of renewable energy in order to address climate change, since they are expected to bear many of

[1] US$30 billion excluding hydropower

the negative consequences associated with climate change, including sea-level rise and the increased frequency of storms, floods and droughts.

1.2 The Rural Electrification Challenge

Access to affordable and reliable energy supplies is a necessary prerequisite to economic development and poverty reduction (REN21, 2005b). This is because rural electrification leads to a number of quality of life improvements, such as improved communications, educational attainment and health services. Access to electricity services was explicitly identified by the World Summit on Sustainable Development (WSSD) as an essential for achieving the UN Millennium Development Goals for halving poverty by 2015 in the world's poorest countries (Modi and others, 2006; REN21, 2005b).

Despite the benefits of rural electrification, more than 1.6 billion people living in rural areas worldwide lack access to electricity (Modi and others, 2006). One reason for this is that it is extremely costly to provide electricity to rural areas through conventional means, such as through electrical grid extension or stand-alone diesel generation, due to remoteness and low population densities disallowing for economies of scale in the provision of electricity services (World Bank, 2001). As a result, there is a need to find more cost-effective ways to provide electricity to remote rural areas.

The advantage of many renewable energy technologies is that they are either decentralised, do not require transmission lines, or do not require imported fuel, so that they can be deployed in remote areas, where household demand for energy is low, at a relatively low cost compared to more conventional energy systems.

1.3. Renewable Energy Potential for Rural Electrification in the Pacific

Pacific Island Countries, which are characterised by their small size, long distances between islands, and isolated populations are faced with a unique and difficult challenge in supplying electricity to rural households. Often energy markets on Pacific Islands are fragmented, small and difficult to serve, with little potential for achieving economies of scale in infrastructure planning. On most Pacific Islands, grid-based, publicly distributed electricity is provided only on the main island and supply to rural areas is limited (Wade and others, 2005). However, the proportion of the population with access to electricity in the region varies considerably from country to country, with 100% access to electricity available in Niue, compared to less than 10% in Papua New Guinea, see Table 1. Despite the challenge of supplying electricity services to rural areas, Pacific Island governments do recognise its vital importance in supporting sustainable development (SOPAC, 2004). A statement from the 2004 Pacific Regional Energy Meeting, Madang, Papua New Guinea, provides an overview of the barriers faced by Pacific Island Countries in promoting rural electrification, see Box 1.

Box 1. Statement from 2004 Regional Energy Meeting, Madang, PNG, on the unique energy challenges faced in PICs in promoting sustainable development

- Demographics vary widely between countries, but often feature small, isolated population centers;
- Markets are very thin, difficult to serve, and without significant economies of scale;
- 70% of the regional population is without access to electricity, but access varies widely, from 10% to 100% at the national level;
- Pacific Island countries comprise a wide range of ecosystems, predominantly influenced by marine systems, that make infrastructure development difficult and environmental impacts significant;
- Most Pacific Island countries do not have indigenous petroleum resources and only a minority have hydropower potential;
- Pacific Island countries have special concerns arising from their situation that have motivated the development of this policy;
- Environmental vulnerability through climate change and sea level rise is very high, particularly for small islands and low-lying atolls;
- Environmental damage, habitat loss and pollution resulting from development and use of conventional energy sources have significant effects on fragile island ecosystems;
- Energy supply security is vulnerable, given the limited storage for bulk petroleum fuels, which are sourced over a long supply chain at relatively high prices;
- The development of renewable energy resources has been limited by the availability of appropriate technology, poor institutional mechanisms, and the challenges of developing systems for small remote markets at reasonable cost;
- There is limited scope for market reforms considering the variation in size and density of markets; therefore, appropriate alternatives vary between countries; the region has limited human and institutional capacity to respond to these challenges;
- While women and youths are significant energy users, they are poorly represented in energy policy, planning, and development.

Source: SOPAC (2004, p.34-35)

Table 1. Percent of households with access to electricity in Pacific Island Countries.

Country	Year	Population	Percent of Households with access to Electricity
Cook Islands	2004	18,000	99%
Federated States of Micronesia	2000	107,000	54%
Fiji	1996	844,000	67%
Kiribati	1993	85,000	29%
Marshall Islands	1999	54,600	63%
Nauru	2002	10,100	100%
Niue	2003	1,700	100%
Palau	2004	19,100	97%
Papua New Guinea	2003	5,200,000	< 10%
Samoa	2001	176,100	93%
Solomon Islands	1999	457,000	16%
Tokelau	2003	1,500	100%
Tonga	1999	100,000	80%
Tuvalu	2003	9,300	> 95%
Vanuatu	1999	212,000	19%
Total		7,285,300.00	78%
Total (excluding Papua New Guinea)		2,095,400.00	48%

Source: Wade and others (2005)

1.4 Petroleum Dependence in Pacific Island Countries

Pacific Island Countries are heavily dependent on imported fossil fuel products. On average, petroleum product imports account for approximately 40% of GDP, but the figure is significantly higher in countries such as Kiribati and Palau (Osborne, 1996). Furthermore, with the exception of Papua New Guinea (PNG), Pacific Islands have few indigenous sources of fossil fuel (World Bank, 1992). As a result, imported oil is the primary energy source in all countries, accounting for between 8-37% of total imports, as Table 2 demonstrates.

The high ratio of petroleum imports to total exports for most countries highlights the fact that Pacific Island Countries are vulnerable to world oil price shocks. In addition, Table 2 shows that the export structure of many PICs is such that it is insufficient to even cover countries' oil imports, which may not be a sustainable situation in the long run.[2]

[2] Such a situation is sustainable as long as Pacific Island Countries are able to finance their current account deficits through foreign exchange reserves and/or net inflows from abroad.

Table 2. Pacific Island fuel imports.

Country	Fuel Import Value ($US millions)	Fuel Imports as a Share of Total Imports (%)	Fuel Imports as a Share of Total Exports (%)
Papua New Guinea	358.7	25.1	16.2
Fiji	340.2	23.5	50.0
Solomon Islands	11.7	27.4	15.8
Samoa	22.6	15.1	160.3
Vanuatu	12.8	14.3	64.3
Federated States of Micronesia (FSM)	17.3	13.0	88.3
Tonga	17.6	25.5	293.3
Kiribati	5.7	10.0	172.7
Marshall Islands	20.4	37.3	224.2
Cook Islands	6.2	8.4	86.1
Palau	12.4	13.0	104.5

Source: IMF[3] and ADB (2005)

Given this heavy dependence on imports, and the narrow export base of many PICs, it is not surprising that many countries in the region have faced significant balance of payments problems, where imports greatly exceed exports.[4] For example, since the mid-1980s, Kiribati has had import levels that are ten times greater than export levels (Osborne, 1996). If the current trend of rising oil prices continues, growing pressure will be exerted on the balance of payments of many PICs, as their trade deficits continue to rise.

The size and structure of Pacific Island economies also makes them vulnerable to trade shocks, which can compromise economic stability, by affecting variables such as the exchange rate, inflation and debt levels. For example, oil price increases can exert a large amount of inflationary pressure on PIC economies if the value of oil imports accounts for a significant portion of GDP. Therefore, it is important to look at ways in which these chronic balance of payments problems can be eased, especially through the development of renewable energy technologies.

Another factor that adds to the high cost of petroleum products in Pacific Island Countries is the nature of the fuel supply chain. Small markets have resulted in a lack of economies of scale, which limits the potential for competition between fuel suppliers and ensures that fuel prices remain high. Also, the monopoly position of multi-national oil companies in many countries has allowed companies to earn returns on investment comparable to large rapidly growing economies (Morris, 2005).

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[3] IMF country reports for various years.
[4] With the exception of Papua New Guinea and the Solomon Islands.

Table 3. Breakdown of fuel costs in Pacific Islands.

Location	Fuel Cost Component (excluding taxes)	Percent of Total Cost of Fuel in PICs
Primary Ports	Singapore FOB Freight Costs to Primary Port[5] Insurance and Loss	90-95% 4.5-9.5% 0.5-0.6%
Secondary Ports	Transport, handling and distribution costs to ship to secondary ports	Added 15-30% to total cost at primary ports

Source: Rizer and Tavanavanua (1988)

In addition, infrastructure constraints mean that petroleum products can only be shipped in 200 litre drums to most outer islands of the Pacific. The fixed costs of barrels prevent economies of scale from being achieved, which would be available if fuel was shipped in larger quantities (Morris, 2006).[6] Furthermore, in many cases fuel drums must be 'floated' on to shore due to inadequate port facilities, which also imposes a high potential environmental risk if fuel is released into the coastal environment (Coutrot, 1987).

Figure 1. Oil drums sitting on the wharf in Vanua Balavu, Fiji.

[5] Primary ports include: Vuda Point, Suva, Guam, Port Moresby and Apia

[6] However, Morris (2006) emphasises the importance of considering the negative consequences associated with reducing the volume of diesel being shipped to outer islands. This is because diesel accounts for a significant share of total shipping revenues, and a reduction in diesel shipments may lead to increased freight charges to compensate for lost revenues.

2. ECONOMIC ASSESSMENT OF RURAL ELECTRIFICATION PROJECTS

2.1 Introduction to Economic Evaluation

Rural electrification projects are generally viewed as costly, but are justified on the basis that they yield important social and economic benefits. However, meeting the basic energy needs of rural households places competing demands on limited resources allocated for rural development. Access to electricity is but one essential service needed to meet the basic needs of rural households (other services include water and sanitation, health services, etc.). Ideally, all remote communities would be electrified through electrical grid extension, in order to maximise the quality of energy services and the hours that electricity is available to households. However, this cannot always be justified on economic grounds since the costs of undertaking such a project are enormous compared with the benefits people receive. Also, greater returns to investment might be obtained if resources were invested in projects in order sectors such as health and education. Consequently, it is important that resources allocated to the energy sector are used as efficiently as possible (ESMAP/NRECA, 2000).

Decision-makers must make informed decisions by taking into account all of the different costs and benefits associated with the alternative means of providing electricity to rural dwellers. This involves estimating the total economic benefits and costs associated with each potential project. An investment is desirable from an economic perspective if total benefits exceed total costs. For rural electrification projects, the project with the greatest 'net benefits' (benefits less costs) should be chosen among all technologically feasible options for providing electricity to rural households. In addition, the net benefits should exceed to a sufficient degree, the net benefits to investing in other competing projects for which resources could be used. For example, the returns from investing in an education or public health project in a rural community may exceed the returns from investing in rural electrification.

2.2 Economic versus Financial Project Analysis

Economic analysis considers the costs and benefits associated with a project from the perspective of society, whereas financial analysis considers these factors from the perspective of the investor(s). The scope of economic analysis is much wider compared with financial analysis, since financial analysis considers only the direct, monetary values associated with establishing and operating a project (OECD and IEA, 1991). As a result, a project is considered to be financially viable when a project's revenues exceed its costs. Economic analysis, on the other hand, considers both the monetary and non-monetary, as well as the direct and indirect, costs and benefits of a project. This is because economic analysis takes into consideration the value of all goods and services, including those that are not traded in the market, and therefore have no market price assigned to them. A project is considered to be economically viable when its benefits exceed its costs, including market and non-market values.

Because of this distinction between market and non-market values, a project that is economically viable may or may not be financially viable, and vice-versa. In the first case, it may be desirable from an economic perspective to pursue a solar power service project that provides electricity to homes in a remote community, even if the costs of providing this service exceed the expected revenue streams. This is because a project may yield important non-market benefits such as improvements in health and education. In the second case, there may be non-market costs associated with a project that are borne by society but not a private investor. For example, if a profitable hydro-electricity project results in massive deforestation and erosion, the project would be economically unviable if total costs, including the monetary value of environmental damage, exceeded the benefits.

In economic analysis, unlike financial analysis, economic costs of resources are valued using their 'opportunity cost', in order to ensure that resources are put to their most efficient use. The opportunity cost is cost of not using resources for their next best use. For example, the opportunity of capital used to invest in a particular project, is the commercial interest rate, since the funds could otherwise have been put into a bank account in order to earn interest. When there are no distortions in the market, the market price can be used to reflect the opportunity cost of a particular resource such as labour or capital (e.g. wage rate or interest rate). However, when market distortions exist, 'shadow' prices must be used. For example, when evaluating a project, a shadow exchange rate must generally be used in place of a country's official exchange rate. This even with a free-floating exchange rate regime, if any taxes or subsidies on demand and supply exist, if there are any commodity or factor price distortions; or if the current account deficit is not sustainable (ADB, 2001). Use of the official exchange rate rather than the shadow exchange rate, may affect the economic analysis of a project which uses tradable inputs. This is because if an official exchange is overvalued, then projects which produce non-tradable with tradable inputs are favored relative to projects which produce tradable outputs with non-tradable inputs; and represents a misallocation of resources (Lagman-Martin, 2004).[7]

[7] For guidelines on calculating shadow prices see ADB (2001).

2.3 Identifying and Quantifying Benefits and Costs

Costs and benefits are identified by comparing a 'with' projects situation with the 'without' projects situation (its counterfactual), where the 'without' project situation is the situation which would prevail in absence of the project.[8] The benefits and costs of a project can be measured as the difference between the two situations.

Monetary benefits associated with an electricity project may include cost savings on other forms of energy such as kerosene. Monetary costs would include all the costs associated with designing, installing, operating and maintaining the electricity project. However, in most cases electricity projects will also generate non-monetary costs and benefits. These benefits could provide an important contribution to the broader economic viability of a project, and therefore ideally be considered when conducting an economic analysis. For example a solar electrification project may result in reduced carbon dioxide emissions if it replaces fossil fuel-based forms of energy. In order to measure and quantify the economic value of non-market costs and benefits, several economic valuation techniques exist.

When evaluating the economic viability of a project, costs and benefits must be considered over the entire lifetime of each project. Costs and benefits that do not arise until the future are considered to be worth less than those that arise today, because of the time value of money which leads people to place less value on future costs and benefits. Thus, a 'discount rate' must be used to weigh present and future costs and benefits associated with a project. The discount rate reflects the amount individuals or society are willing to accept as compensation for foregoing benefits. The choice of discount rate will vary from country to country, and is based on factors such as opportunity cost of capital, inflation and risk and uncertainty. For example, the commercial interest rate is often used as the discount rate for private individuals. On the other hand, it is often argued that communities as a whole have lower discount rates, as they are willing to delay benefits longer, compared with private individuals. Discount rates for public projects often vary between 5 and 10% (OECD and IEA, 1991). However, the Asian Development Bank uses a discount rate of 10-12% in the economic analysis of proposed projects (ADB, 2001).

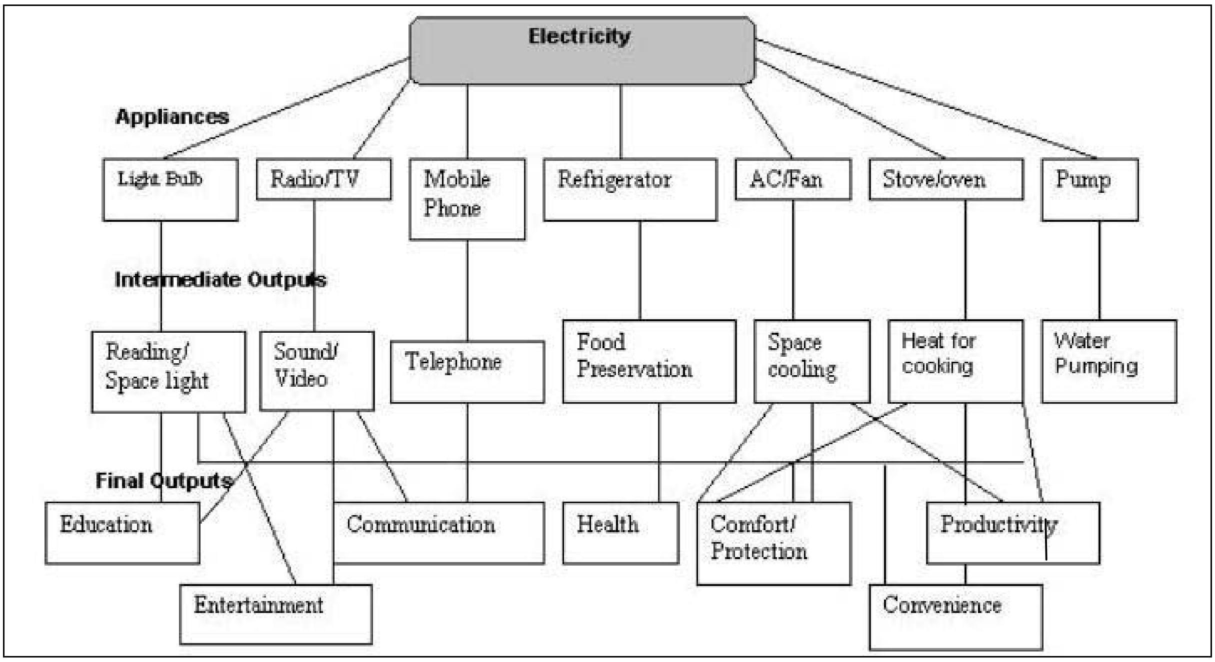
[8] It is important to note that the 'without project' situation is not equal to the pre-project situation, since many variables will change over time, which are not directly attributable to the project.

2.3.1 Benefits of rural electrification

Electricity alone does not produce benefits, rather it is the services provided as a result of electricity, such as lighting and household appliances, which yield benefits to energy users. These benefits are illustrated in Figure 2.

Benefits fall under the following categories:

- Improved Lighting: This may be in terms of better quality of lighting, or greater reliability of lighting. For example, in the case of kerosene, if fuel is not available, it will not be possible to operate lamps.
- Education: improved lighting enables longer hours of study that may lead to improved educational outcomes over time.
- Health: This may come in the form of improved hygiene as a result of being able to store food property or reduction in indoor pollution levels.
- Entertainment and Communication: electricity allows for the use of devices such as radios, mobile phones and video players.
- Improved Productivity Levels: Household members may be able to engage in productive activities for longer hours each day (e.g. weaving handicrafts) as a result of better quality lighting at night; or saving time doing other domestic chores as a result of electrical appliance use.
- Increased Savings: costs avoided if electricity is cheaper than alternative, e.g. kerosene and dry cell batteries[9].
- Improved safety as a result of the reduced risk from fires associated with the use of kerosene lamps and fuel wood.



Source: ESMAP (2002)

Figure 2. Benefits of electricity.

2.3.2 Costs of rural electrification

The costs associated with energy projects are usually assessed using life-cycle analysis, which are also known as levelised costs. This method estimates the total costs of electricity production over the entire lifetime of a project, including both one-off and recurring costs. This allows for a fair comparison between different energy technologies, by taking into account the fact that different costs occur at different times for different energy systems. For example, for many renewable energy systems, the initial costs are high whereas operation and maintenance costs are low. The opposite tends to be true for diesel-powered generators. Lifecycle costs (LCC) are calculated by summing the present value (present worth) of all costs over the lifetime of an energy project as shown in the equation below (Sandia National Laboratories, 2002)[10].

$$\textbf{Life - Cycle Costs (LCC)} = \textbf{CC} + \textbf{OM} + \textbf{R} + \textbf{F}$$

- **Initial capital costs (CC):** This includes initial and up-front costs associated with a project including the costs of any project feasibility studies, system design costs, and equipment purchase, transportation and installation. In other words, all costs incurred up to the point where the project starts running are considered capital costs.

9 Kerosene, however, has the advantage that consumers can choose how much to buy and when to buy it, depending on when income is available whereas renewable energy technologies in many cases require monthly payments to be made regardless of whether or not energy is used or if income is available or not.

- **Operation and maintenance costs (OM):** This includes any costs associated with maintaining and operating the project such as administrative costs, wages and transport costs associated with operating the project.
- **Replacement costs (R):** These are the costs of purchasing spare parts and the replacement and repair of equipment.
- **Fuel costs (F):** These include the market value of the annual costs of any fuel used, (diesel or biofuel).

All costs are converted into present value terms. Also, for an economic analysis, any indirect and non-monetary costs should also be considered.

2.4 Comparing Benefits and Costs

2.4.1 Benefit-cost analysis

When the benefits of a project can be valued, they are discounted and aggregated, and compared with the associated aggregate costs over the lifetime of a project. Comparison between project costs and benefits can be conducted in the following ways (ADB, 2001):

Benefit-cost ratio: compares the total discounted benefits of electrification with total discounted costs, as a ratio, and provides an indication of the scale of return on the investment. This is done by examining the ratio of the present value of benefits to the present value of costs. If the ratio of benefits to costs is greater than one, the project can be viewed as desirable from an economic point of view.

Net present value (NPV): compares the present value of project cost streams with the associated present value of benefit streams. Rather than taking the ratio of benefits to costs, total discounted costs are subtracted from total discounted benefits. If the resulting NPV is greater than zero, then a project is determined to be economically viable.

Internal rate of return (IRR): identifies the discount rate at which the present value of the net benefit stream is equal to the present value of the net cost stream. If the resulting IRR is greater than the chosen discount rate, the project is deemed to be economically viable.

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[10] Note that in the rural Pacific Island context, salvage values are generally irrelevant due to high transport costs between islands. As a result, these are not subtracted from total life-cycle costs at the end of the project life.

2.4.2 Least-cost analysis

Many of the benefits associated with rural electrification are non-market, which makes them difficult to quantify in monetary terms. For example, in order to measure benefits from a rural electrification project such as improved educational outcomes in monetary terms, data would be needed on the earning potential of students, following graduation, living in a rural community before and after the project was implemented; and this would have to be collected over a number of years.

However, if it is assumed that the benefits of an electrification project are equal regardless of the energy technology employed, energy options can be compared on the basis of cost alone. This method, which is known as least-cost, or cost-effectiveness analysis is more straightforward and less time consuming compared with benefit-cost analysis since it avoids the need to collect the large amounts of data needed to identify and enumerate the benefits associated with each energy option.

Least-cost analysis identifies the most cost-effective option for supplying electricity to meet estimated demand. This involves identifying and ranking mutually-exclusive ways of producing identical outputs of equal quality. Since it is assumed that benefits are equal, it is only necessary to compare projects on the basis of the present value of their cost. Alternative project options can be based on different technologies, designs, scales or time phasing (ADB, 2001).

2.4.3 Sensitivity analysis

In order to test the robustness of results obtained from the economic evaluation of electrification projects, all analyses should undergo a sensitivity analysis. This involves varying the values, over which there is some uncertainty, such as the choice of discount rate, the price of diesel, the fuel efficiency of a diesel generator or life of batteries used in solar home systems, in order to assess how robust the results of the analyses are to the underlying assumptions used.

2.5 Methodology Used in this Study

Given the difficulty of identifying all direct and indirect benefits associated with electricity projects and quantifying them in monetary terms, this study uses least-cost analysis to assess the economic viability of solar PV and micro-hydro systems for the Ha'apai Solar Electrification Project and the Bulelavata Community Micro-hydroelectricity Project, respectively, when compared with the conventional option of using decentralised diesel-powered generators to supply electricity to rural areas. For simplicity, this approach compares renewable and conventional energy technologies used for supplying rural households with electricity on the basis of end-use, i.e. basic lighting or entertainment services, rather than the actual quantity of energy, (in kWh) supplied by each type of system. For example, even though, diesel systems can generally support larger loads compared with solar photovoltaic home systems, if both systems are used to supply basic lighting to households in the evenings, the benefits from each system can be viewed as equal. Comparisons between technologically feasible energy options are made on the basis of total lifecycle costs over the estimated life of the project. Where relevant, the non-quantifiable monetary benefits associated with each project are presented in descriptive form.

For a wind hybrid energy system used in the Mangaia Wind Energy Project in the Cook Islands, that combines wind turbines with conventional diesel generators, benefit-cost analysis is used to assess the optimal means of supplying electricity on the island. The costs associated with adding the additional renewable energy generating capacity are compared with the benefits in terms of fuel savings. The main project benefits are easy to measure since it is relatively straightforward to calculate fuel savings in monetary terms.

Following the methodologies used in other economic analyses conducted in Pacific Island Countries, including Greer (2006) and Lal and others (2005; 2006), this study uses a discount rate of 10%.

The lifetime of a particular renewable energy project is assumed to be 20 years, based on the average working life of selected renewable energy technologies. Also, for the purposes of analysis, all values associated with the costs of purchasing, installing, operating and maintaining various energy technologies have been converted into 2005 US dollar terms.

3. CONVENTIONAL OPTIONS FOR RURAL ELECTRIFICATION

3.1 Electrical Grid Extension

Extension of an existing electrical grid, where adequate capacity exists, is generally the preferred option for supplying power to remote areas. In general, this option is preferred because it allows for the provision of 24-hour power, minimises maintenance costs and maximises reliability and efficiency, compared with smaller stand-alone diesel generators (Cheatham, 1990; NRECA, 2000). Unlike stand-alone energy options, there is virtually no limit on power consumption, so enough electricity is provided to supply rural industries in addition to household lighting and appliances (NRECA, 2000; ESMAP, 2000).

However, in the Pacific Island context grid extension to supply rural areas with isolated populations is generally not feasible due to the long distances involved and low population densities, especially in the case of remote outer islands (Cheatham, 1990). For example, most Fijian villages consist of 10-50 homes in isolated areas where the distance to the grid is too far to connect households at a reasonable cost (Wade, 1983). Cheatham (1990) estimated that grid extension in the Pacific costs an average of $12,000/km, which is extremely high when compared to the global average of $7,000/km estimated by NRECA (2000).[11]

Figure 3. Electrical grid.
(Source, NRECA, 2000)

Furthermore, in some countries the quality of power from the grid may be so poor that grid extension is not desirable due to low reliability. Also, given the costs involved, grid-extension may not be the best option in the short- to medium-term since communities may have to wait for years while the government acquires sufficient resources to connect communities to the grid. Consequently, interim measures are still needed to ensure access to electricity.

[11] Cheatham (1990) estimated that the cost of grid-extension ranges from approximately $7,000/km for flat, open areas in the Pacific to 15,000/km in highland bush areas.

3.2 Decentralised Diesel-Powered Stand-alone Generators

When electrical grid extension is too costly, installation of decentralised diesel generators is generally regarded as the next-best option for meeting the energy needs of rural consumers with low energy demands in PICs (Cheatham, 1990; ESMAP, 2000). This is despite high fuel costs and unreliable fuel delivery. For example, under Fiji's Rural Electrification Programme in 2004, of the 48 villages that were electrified, 42 were either supplied with diesel generators or connected to the electrical grid, whereas only 6 villages were supplied solar PV systems (Fiji Department of Energy, 2005).

Table 4. Different types of rural electrification schemes in Fiji 1975-1992.

Electrification method	Number of Schemes	
	1975-1992	1994-2002
Diesel	205	562
Grid Extension	0	260
Solar	0	13
Hydro	0	5
Hybrid	0	2

Source: Matakiviti and Pham (2003)

3.2.1 Diesel generator costs

The initial installed costs of diesel generators are low, typically in the range of US$800-1500/kW, (University of Fairbanks, 2006). Since diesel generators can be operated in most environments, as long as fuel is available, there is no need to conduct costly site feasibility studies as with other technologies such as micro-hydroelectric and wind turbine systems. In Kiribati, Cheatham (1990) estimated that the average cost of purchasing and installing a stand-alone diesel generator, including engine, generator, powerhouse and electrical equipment was US$1000/kW. Operation and maintenance costs of diesel generators, on the other hand, are high due to high fuel costs and maintenance requirements. For example, in the outer islands fuel can account for 60-75% of total life-cycle costs (ADB 2002 cited in Burnyeat, 2004). However, fuel costs are dependent on the efficiency

Figure 4. Generator powerhouse, Welagi Village, (Taveuni), Fiji.

and load of the generator. Efficiency is affected by age and maintenance, and in remote settings, generator efficiency as low as 22% is not uncommon (Prasad, 1997).[12]

In general, diesel-powered generators provide the least-cost option for high, concentrated loads, which are typically found in urban areas.[13] According to Liebenthal and others (1994), the operating costs of a village-scale diesel generator in a remote rural location can be estimated to be approximately US$1-2/kWh, based purely on operating costs. This is about 3-4 times more expensive compared with urban areas.

Decentralised diesel-powered generators are subject to economies of scale, since the marginal cost of connecting additional users to the mini-grid is low, as long as sufficient capacity exists. As a result, average costs tend to decline as the number of households increases and/or demand for energy increases. The latter is due to the fact that generators are more fuel-efficient when the size of the load increases. This is demonstrated by the figures presented in Table 5 for diesel-generated power in French Polynesia.

Figure 5. Diesel generator, Vanua Balavu, Fiji.

Table 5. Cost comparison of diesel generators.

Island	kWh/day	$US/kWh	Number of households
Takakoto	41	3.5	32
Nukutavaka	46	2.1	36
Fakahina	65	2.4	35
Tureia	72	2.7	35
Amanu	123	1.1	45
Makemo	230	1.1	81
Rikitea	452	0.74	100
Mataura	1600	0.56	234

Source: Coutrot (1987)

However, anticipated high growth in demand for power presents particular problems for diesel systems, since if the generator is oversized initially due to anticipated growth in electricity use, there will be poor fuel efficiency when lightly loaded, and maintenance costs will be higher per

[12] The fuel efficiency of a diesel generator can be defined as the amount of power an engine can produce per amount of fuel it burns. The efficiency of a diesel engine can approach forty percent (University of Fairbanks, 2006).
[13] The exception would be where large-scale production of hydro-electricity is possible.

unit. On the other hand an additional diesel generator will be required if demand exceeds the capacity of a single generator, which raises electricity production costs.

3.2.2 Life-cycle costs of diesel generators

To assess the life-cycle costs of diesel generators, the following assumptions based on estimates provided by Wade and others (2002) for various Pacific Islands are used:

- Initial generator purchase and installation costs: US$1000/kW.[14]
- Cost of establishing a distribution system (to connect village of approximately 40 households): US$15,000.
- Operation and Maintenance costs: 5% of initial capital costs annually; engine overhaul costs at 25% of initial capital costs every 5 years; generator and switching system overhaul every 7 years at a cost of 20% of initial capital costs; and major engine overhaul costs at 100% of initial capital cost every 10 years
- Life of generator is assumed to be 20 years.
- Fuel efficiency is assumed to be 0.2 litres/kWh (unless actual data on generator efficiency is available).

3.2.3 Reliability and quality of service:

In rural areas, diesel generators rarely operate for 24 hours per day because noise and high fuel costs associated with lightly-loaded engines in keeping with the low demand for power during night-time hours. Typically they operate 4-5 hours per day in the early morning and evening (Matakiviti and Pham, 2003).

Diesel generators have high maintenance requirements, and reliability tends to be low in remote settings due to a lack of locally-available spare parts and trained technicians (Liebenthal and others, 1994). For example, diesel engines require routine inspections and adjustments, periodic oil changes every 500-2,000 hours and major overhauls every 30-50,000 hours (University of Fairbanks, 2006). A study conducted by the World Bank cited in Liebenthal and others (1994) found the lack of adequately trained operators and mechanics to be a major factor in the poor performance and short life of diesel generators, and that diesel generators generally operated much less reliably, for shorter periods of time, and at higher costs, compared with other energy technologies.

For example, in a remote Pacific Island context, in the event of mechanical failure, it can take up to a month of technician time to repair and return a generator to service (Cheatham, 1990). Often a technician must be brought to the remote site, the spare parts must be ordered, and then the technician must return from considerable distances to install them. The entire process can take months. For example, according to Liebenthal and others (1994), the result of a 1991 survey conducted by Fiji Department of Public Works found that diesel generators were out of service for an average of 77 days per year in remote locations in Fiji. The most common causes for interruption in service were awaiting repairs and unavailability of diesel. Furthermore, often when training is provided to local technicians on how to maintain and repair diesel engines, they are more likely to migrate to urban areas, taking their skills with them.

[14] Based on cost estimate provided by Cheatham (1990)

4. SOLAR ENERGY – PV SOLAR HOME SYSTEMS

Pacific islands have an abundance of solar resources. Solar radiation can be used to generate electricity either through photovoltaic (PV) or thermal technology. This chapter explores the cost-effectiveness of using solar PV systems, as a source of off-grid power, for producing electricity to meet the energy demands of rural households.

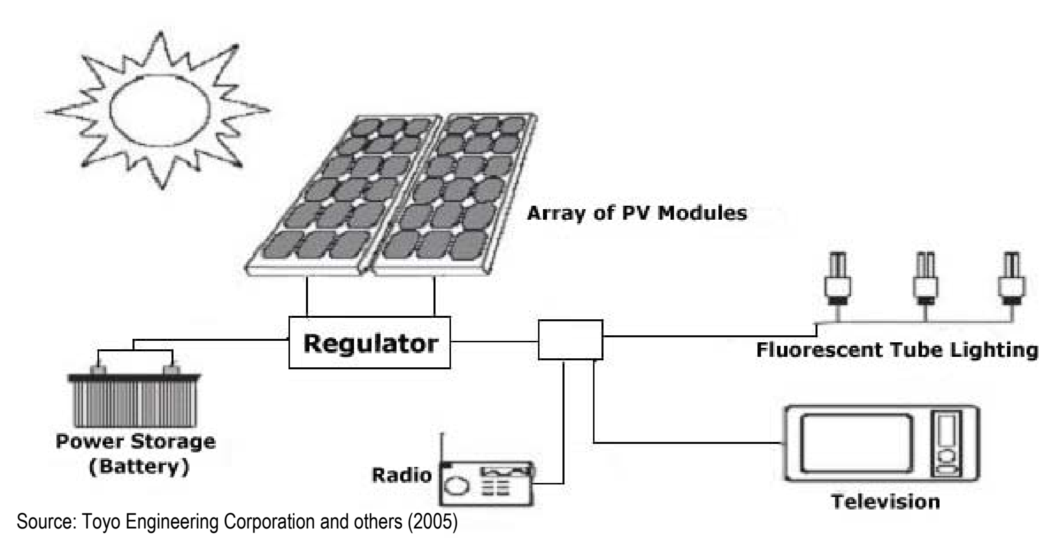
4.1 Experience with Solar Power in the Pacific

Over the past two decades, PV systems have become the most widely adopted renewable energy option for providing electricity to rural areas in the Pacific (Wade and others, 2005). Most countries in the region have experimented with the use of solar PV systems for supplying electricity to rural areas. However, early trials failed to live up to expectations due to short battery life, poor maintenance, lack of financial sustainability and inappropriate institutional structures (Liebenthal and others, 1994). However, more recently the use of PV systems to provide energy services to rural households has been successfully demonstrated in the Pacific, especially by the Kiribati Solar Electric Company, which has installed and maintained over 2,000 systems on eighteen islands since 1984 (Akura, 2006).

4.2 PV System Technology

Solar PV systems convert sunlight directly into electricity using solar cells. On an annual basis, in typical weather conditions, the average solar panel can generate approximately 4-5 hours of peak power per day (Toyo Engineering Corp. and others, 2005). However, the size of the solar PV system and available sunlight determines how much electricity is available for use.

The typical solar home system consists of a 20-100 Wp panel, a battery for storing the energy generated during the day, a battery charge controller (to avoid excessive charging and discharging), several fluorescent lights, and a power-point for connecting low-energy consuming appliances such as a radio or television (Cabraal and others, 1996). A solar system many also include an inverter, which allows AC appliances to be used. The simplicity of the system and low maintenance requirements make PV systems an attractive option for supplying electricity in remote areas (Owens, 2002). The typical setup of a solar home system is illustrated in Figure 6.



Source: Toyo Engineering Corporation and others (2005)

Figure 6. Components of a PV solar home system.

4.3 Costs of PV Systems

With improvements in technology and rising manufacturing levels, the cost of PV systems has fallen significantly over time. For example, the cost of solar PV modules, on an average per peak-Watt (W_p) basis, has fallen from $100 in 1970 to less than $5 in 2006 (Solarbuzz, 2006; Tenesol, 2006). It is expected that the price of solar modules will decline further to approximately US$1.50-2.00/$W_p$ within the next 10 years (Toyo Engineering Corp. and others, 2005).[15]

PV systems, despite their high initial capital costs, have very low operation and maintenance costs. Also, with individual solar home systems, the need to construct costly transmission lines is avoided. Typically, capital costs account for 75% of overall life-cycle costs, whereas annual operation and maintenance costs account for 1% of the initial capital costs, excluding battery and controller replacement costs (Cabraal and others, 1996; Foster and others, 1998). This contrasts with stand-alone diesel generators in rural areas, where the initial purchase cost of a diesel generator is low, but fuel and maintenance costs are significant.

The costs of PV systems increase proportionately with the size of the module and battery. The module, which is the most important component, accounts for approximately 50-60% of total system costs (Cabraal and others, 1996; Toyo Engineering Corp. and others 2005).[16] Also,

[15] This is based on the expectation of further technological improvements and a 20-30% increase in production volume.

[16] Appropriate sizing of the solar system is important. Over-sizing the system can significantly raise costs. However, under-sizing a PV system can also increase overall life-cycle costs. For example if the panel is too small, the battery may be discharged too deeply, and will have to be replaced more often, thereby raising PV system costs.

although the initial capital cost of batteries is not significant, they must be replaced every 5-10 years, which raises the overall life-cycle costs associated with operating PV systems. As a result, unlike diesel-powered systems, PV solar home systems benefit only from very slight economies of scale, and solar rural electrification project costs increase both with the number of households, and electricity demand per household (Reiche and others, 2000).

The costs of PV systems vary widely from country to country, as Table 6 shows, due to factors such as sales volumes, dealer margins, maturity of local manufacturing and marketing infrastructure, duties and taxes, level of competition, etc. For example Indonesia and China have some of the lowest systems costs because of low duties and taxes, high sales volumes and low manufacturing costs (World Bank, 2006; Cabraal, 1996). Also, in the Pacific, local manufacture of batteries in Fiji, and controllers in Kiribati assist in keeping component costs low.

Table 6. Cost comparison of solar home systems by country (US$).

Panel Size (W_p)	China	Philippines	Indonesia	Sri Lanka	India	Kenya	Zambia	Average Cost ($/ W_p)
10	85							8.5
15	120							80.0
20	150	300		302			300	13.2
30	203							6.8
40		520	303	419	307			9.7
50		660	300-408	480	360	822		11.3
75	640	750-1000		686				11.5

Source: World Bank, 2006

Since the cost of energy generated by PV systems tends to be quite high on a per kWh basis, and they do not enjoy economies of scale in energy production, PV systems provide the most cost-effective technology option only under certain circumstances i.e. when demand for electricity is low, the population is isolated, and fuel costs are high (ESMAP, 2000; Cabraal and others, 1996). Typically solar home systems are appropriate for households that currently use kerosene for lighting and batteries to power small appliances such as radios and televisions. The average household tends to consume approximately 0.5-1L of kerosene per day (15-30L per month) and 2-16 dry cell batteries per month (Cabraal and others, 1996). Under these circumstances, switching to PV systems, when capital costs are subsidised, can lead to reduced household energy expenditures (Cabraal and others, 1996).

Liebenthal and others (1994) find that in a remote Pacific context, where fuel transport costs and maintenance requirements for diesel generators are high, PV systems are the least-cost option for supplying electricity to rural areas when household demand for energy is low and load growth is not expected to be significant. Similarly, in a case study of Kiribati, Cheatham (1990) finds that in Kiribati, PV systems were the least-cost option for supplying basic electricity services to 250 households. On the other hand, stand-alone diesel generators were found to be the least-cost option when the population exceeded 500 households.

The cost-effectiveness of PV systems compared with diesel generators for supplying electricity to rural areas is sensitive to a number of variables including the number of households served and the price of diesel. For example, Figure 7 demonstrates that PV solar home systems are the least-cost choice for providing electricity, when the number of households is fewer than 500, after this number is exceeded, a diesel generator becomes the more cost-effective choice.[17]

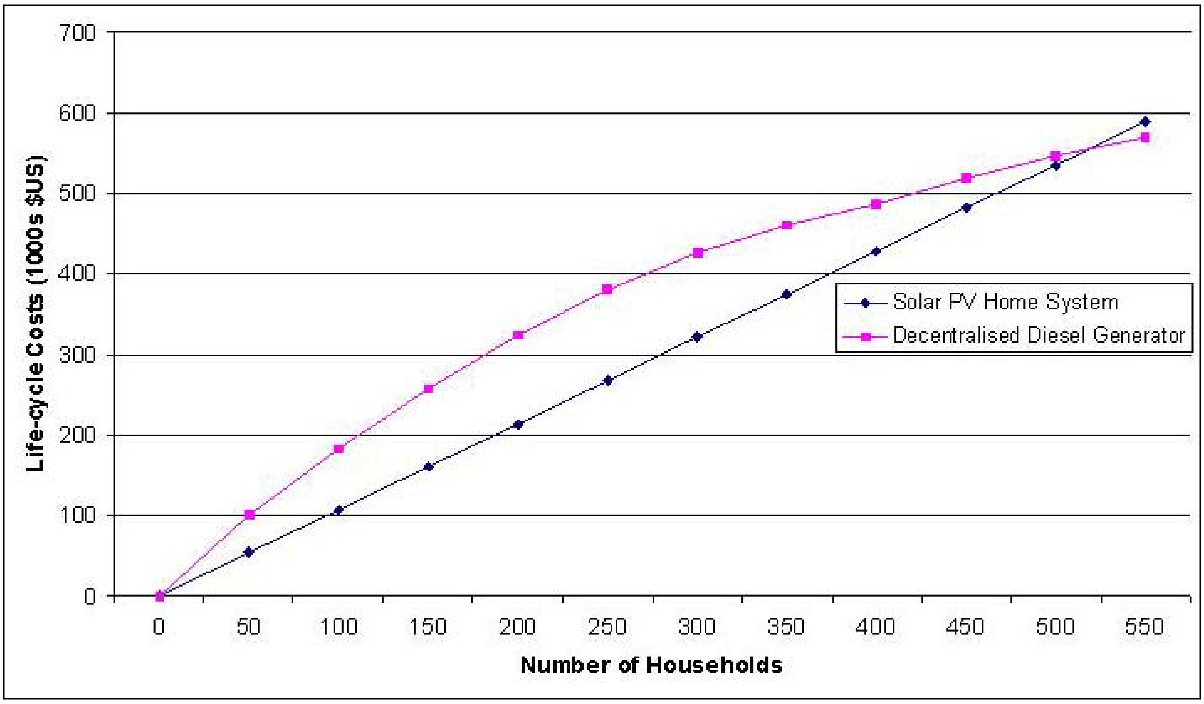


Figure 7. Cost-effectiveness of PV and diesel systems according to the number of households served.

[17] It is assumed that each household consumes 250-watt hours of electricity per day. The capital investment cost of a 75-peak watt panel solar home system is estimated to be US$681 (assuming that the cost of a panel is US$5 per peak watt of power, and that the panel accounts for 55% of the total system cost). Annual PV system operation and maintenance costs are assumed to be 1% of initial capital costs. The life of a PV system is assumed to be 20 years, with battery replacement required every 5 years at a cost of US$200 per battery. The capital investment cost of a diesel generator is assumed to be US$1000/kW of installed power, and annual operation and maintenance costs are assumed to be 5% of initial capital costs. Every 5 years, an engine overhaul costing approximately 25% of initial generator cost will be required, and every 7 years, a generator and switching system overhaul at a cost of 20% of initial generator cost will be required. The life of a generator is assumed to be 20 years, however every 10 years, engine replacement or major overhaul will be required, which will incur a cost equivalent to generator replacement. Generator efficiency is assumed to increase incrementally with the number of households served and engine size. In Figure 7, the price of diesel is assumed to be US$0.70 per litre.

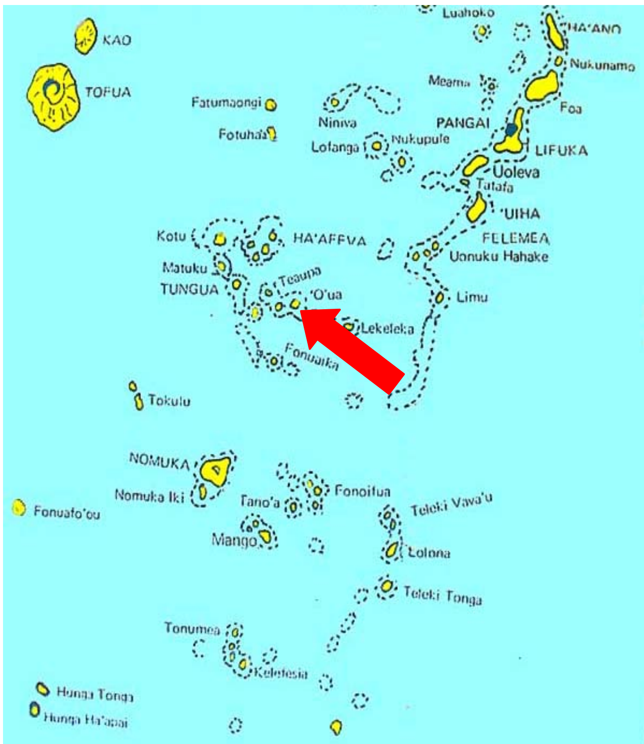
4.4 Reliability of PV Systems

One major advantage that PV systems have over conventional diesel systems is that they do not require imported fuel inputs, which reduces operating costs and improves system reliability where transport is expensive and irregular. In addition, compared with diesel-powered mini-grid, solar home systems are more reliable since only a single household loses power (Liebental and others, 1994). This is an important feature in remote areas of the Pacific where it can take weeks to months to repair a diesel generator when it fails. Also the fact that PV systems need less maintenance compared with diesel generators, which require costly overhauls at regular intervals, makes them more reliable than the latter in remote settings where skilled technicians are scarce.

4.5 Case Study – The Ha'apai Solar Electrification Project, 'O'ua Island, Tonga

In 2002, households on six islands in the Ha'apai Group of Tonga (see Figure 8) gained access to the electricity provided by solar PV home systems. In total 169 systems were installed under the Ha'apai Solar Electrification Project (Wade and others, 2002). The Ha'apai Solar Electrification Project was implemented under the Pacific Rural Energy France Australia Common Endeavour (PREFACE) Project administered by SPC.

The Ha'apai Solar Committee was formed and made responsible for managing the project, including the overseeing of operation and maintenance work, collecting user fees and managing project funds. A technician on each island was made responsible for carrying out routine maintenance and repairs on PV systems (SPC, 2003).



Source: http://www.worldtrip.de

Figure 8. The Ha'apai Group, Tonga.

Households were required to pay an initial US$108[18] fee to have a PV system installed in their homes. Monthly user fees intended to cover routine system maintenance, repair and replacement costs were set at US$6 per month (SPC, 2003).

4.5.1 Background: geography and socio-economic conditions

The six islands that are part of the Ha'apai solar project are remote and only accessible by boat. Weather can be unpredictable which makes transport both costly and unreliable between the islands (SPC, 2000).

At the time that the feasibility study for the project was conducted, incomes per household ranged from US$54 to $108 per week. In addition, ninety percent of households on the islands relied on mat weaving and fishing as sources of income, as well as remittances from relatives. There is a high rate of emigration from these islands, which has led to a population decline in recent years (SPC, 2000).

4.5.2 PV system design

Each solar PV home system consisted of the following components:

- 150 W_p PV array, consisting of two 75 W_p panels.
- A 12 Volt-130 Amp battery.
- Three 13-watt fluorescent tube lights (two indoor and one outdoor).
- ¼ Watt nightlight.
- A 12-Volt power point to which a DC radio can be connected.

Figure 9. Household PV System located on 'O'ua Island, Tonga.

Although the PV systems installed on 'O'ua are able to meet the basic energy needs of households- typically lighting and the use of basic appliances such as a radio- they are unable to cater for larger loads. Overall rates of collection of fees are high, which indicates that user satisfaction with the electricity service provided is high (SOPAC,

Figure 10. PV System battery.

[18] All values in US dollar 2005 terms unless specified otherwise

2006a). However, during interviews on ‘O’ua Island, residents did express a desire to be able to eventually use more appliances such as washing machines and refrigerators. The number of PV systems installed on each project island is listed in Table 7.

Table 7. List of PREFACE project islands and number of systems installed.

Island	Number of Systems
Fonoifua	24
‘O’ua	38
Kotu	35
Tungua	32
Matuku	22
Fotuha’a	18
Total	**169**
Source: Wade and others (2002)	

Some of the benefits which have been realised as a result of the solar energy project in ‘O’ua include:[19]

- **Quality of life:** Previously, the majority of residents on these islands relied on kerosene lamps and batteries to satisfy their energy needs. Households interviewed mentioned several improvements in their quality of life. These included improved lighting, which has allowed children to study more and for women to engage in weaving for longer hours at night.

- **Costs avoided:** In addition, given the subsidised costs of the project, households have also benefited from reduced energy expenditures. In ‘O’ua, the average household previously spent about US$27 per month on kerosene, compared with an average of US$5 and US$6 currently spent on kerosene and PV, respectively.

- **Reliability:** In terms of reliability, the only disruption in service, (until now) has occurred as a result of light bulb failure. Since parts have to be brought from the main island of Pangai, residents must sometimes wait several days to have bulbs replaced. However, this problem could be easily resolved by keeping a stock of spare parts on each island.

[19] This information was obtained during a field visit to ‘O’ua Island where household interviews were conducted.

4.5.3 Least-cost analysis: PV home systems vs. stand-alone diesel generator with mini-grid

A least-cost analysis was conducted as part of the study in order to identify, which of PV or diesel offered the most cost-effective means of supplying electricity to forty households in ‘O’ua, one of the islands included in the Ha’apai Solar Electrification Project.

The initial capital costs of the solar home systems used in the project were estimated to be approximately US$2,000 per system (Tunkunga, 2003). It is assumed that batteries must be replaced after 10 years at a cost of US$243, and that operation and maintenance costs are approximately 1% of the initial system costs per year. The contribution of each component to the overall system cost is presented in Figure 11. For the purposes of analysis, project administration costs and technicians’ wages are omitted from total operation and maintenance costs, since it is assumed that these costs would be similar to a diesel project. The total present value of life-cycle cost of the 150 W_p panel solar home systems was estimated to be approximately US$93,805 over 20 years for the solar PV home systems on ‘O’ua Island (see Appendix 1 for details).

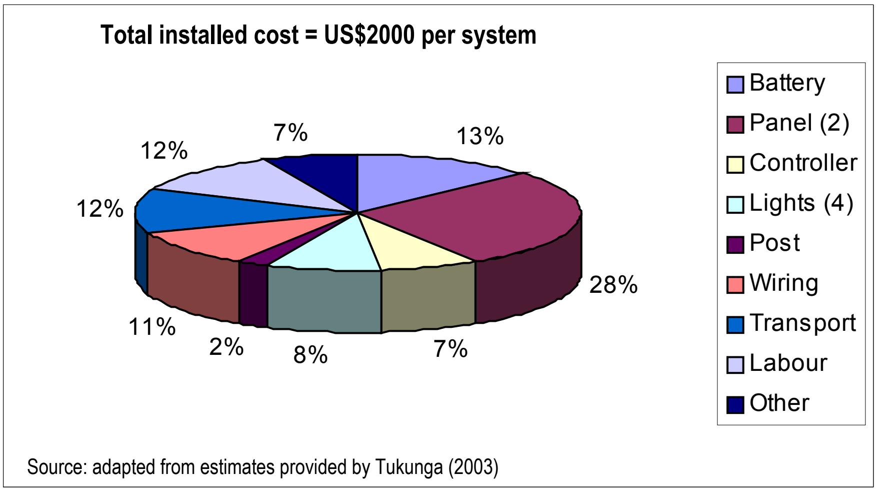


Figure 11. Contribution of each PV system component to overall capital cost.

For the purposes of comparison, the costs of purchasing, installing, operating and maintaining a diesel generator over a 20-year period on ‘O’ua was estimated. It was estimated that it would cost approximately $36,000 to purchase and install a 36 kW diesel generator, and $15,000 to construct a village mini-grid in ‘O’ua. Also, due to the low demand for electricity at night, it is assumed that the generator operates for only 5 hours per day[20]. The cost of diesel in May 2006

[20] The costs of running a diesel generator for a small remote village for 24-hours a day would be prohibitively expensive due to high fuel wastage in lightly-loaded engines.

on Pangai, the main town in the Ha'apai Group was US$1.20 per litre. However, the actual price in 'O'ua is likely to be higher due to high transportation costs. The total life-cycle costs of operating a diesel generator were estimated to be approximately US$97,792 over 20 years (see Appendix 1 for details).

Therefore, the present value of the life-cycle costs of individual solar PV home systems are less than the costs associated with a diesel generator. It is important to note that the level of service would be higher with a diesel generator compared with a PV system, since it would be able to support higher loads. However, for the purposes of analysis, diesel and PV systems are being compared on the basis of end-use i.e. basic lighting and entertainment/communication (from radio) services.

4.5.4 PV system design considerations

As discussed above, the costs of PV systems increase proportionally with the size and number of panels, so that larger PV systems rarely present the least cost option for rural electrification compared with diesel. The Ha'apai solar project PV system design is unusual since a 150 Wp PV array system was installed to provide basic lighting and communications (radio). In theory, a 75 Wp array would meet the basic electricity needs of households on 'O'ua (see Appendix 1 for PV system sizing considerations). The rationale for installing such large panels was to provide an inexpensive means of providing street lighting during the night, by using outdoor lights on houses, and to preserve the life of batteries (SOPAC, 2006a).

However, for the purpose of analysis, given that this end-use would not be available with a diesel system, it will be assumed that each PV system is made up of a 75 Wp panel array, which does not allow street lighting (for PV system sizing see Appendix 1 for details). Furthermore, as a result of having smaller panels, it is also assumed that batteries must now be replaced every 5 years. For 40 solar home systems, each with a 75 Wp panel array, the total life-cycle costs fall to US$87,090 over 20 years.

Table 8. Summary of solar system and diesel generator life-cycle costs.

System Type	Life-Cycle Costs ($US)
Diesel Generator (36 kW)	97,792
150 W_p Solar PV System	93,805
75 W_p Solar PV System	87,090

4.5.5 Sensitivity analysis

It is important to note that the results from the least-cost analysis are sensitive to the assumptions made, regarding the price of diesel, generator efficiency and battery life. Tables 9 and 10 demonstrate how changes in these variables affect the life-cycle costs of each option.

Table 9. Sensitivity of diesel generator life-cycle costs to changes in the price of fuel and generator efficiency.

	Price of Diesel ($US/Litre)				
Generator Efficiency (litres per kWh)	0.80	1.00	1.20	1.40	1.60
0.20	94,934	96,363	97,792	99,222	100,651
0.30	97,792	99,937	102,081	104,225	106,369
0.40	100,651	103,510	106,369	109,228	112,087

Table 10. Sensitivity of PV system life-cycle costs to changes in battery life.

Battery Life (years)	Life-Cycle Cost of 150 W_p Solar System ($US)	Life-Cycle Cost of 75 W_p Solar System ($US)
3	109,006	98,224
5	97,999	87,090
7	93,805	82,849
10	90,311	79,316

In order to further test the robustness of the results, the least-cost analysis was conducted using varying discount rates. The results presented in Table 11 show that the least-cost technology choice (75 Wp panel solar home systems) is not sensitive to the choice of discount rate.

Table 11. Life-cycle cost sensitivity analysis using various discount rates.

Discount Rate	Diesel Generator	150 W_p Solar PV System	75 W_p Solar PV System
5%	$125,994	$100,890	$95,567
7%	$114,097	$97,562	$91,598
10%	$97,792	$93,805	$87,090

4.5.6 Discussion and Conclusions

The results from this case study are consistent with much of the research conducted on the cost-effectiveness of solar PV systems, which find that appropriately-sized PV systems represent the least-cost choice of technology when they are serving remote communities of a small number of households with small demands for electricity. In many rural areas, as per capita demand for energy grows over time, especially as economic development proceeds and household incomes grow, diesel systems usually become the most cost-effective option for electricity supply. However, given the migration patterns from the outer islands in Ha'apai, growth in energy demand may not be large enough to justify installing diesel generators even in the medium- to long-term.

Other factors, which cannot be easily quantified in monetary terms, may also influence the cost-effectiveness of solar PV systems. These include:

i. Increased reliability and energy security (when diesel generators fail or diesel fuel is unavailable), for example, if women are unable to weave at night due to generator failure, they would forfeit opportunities to generate income.

ii. Lower environmental costs such as less noise and pollution associated with the use of solar PV systems.

iii. Longer hours of electricity with PV systems (however this must be weighted against the fact that a diesel generator can support larger household loads).

iv. The use of PV systems for the provision of household electricity services can act as a hedge against any future increase in oil prices.

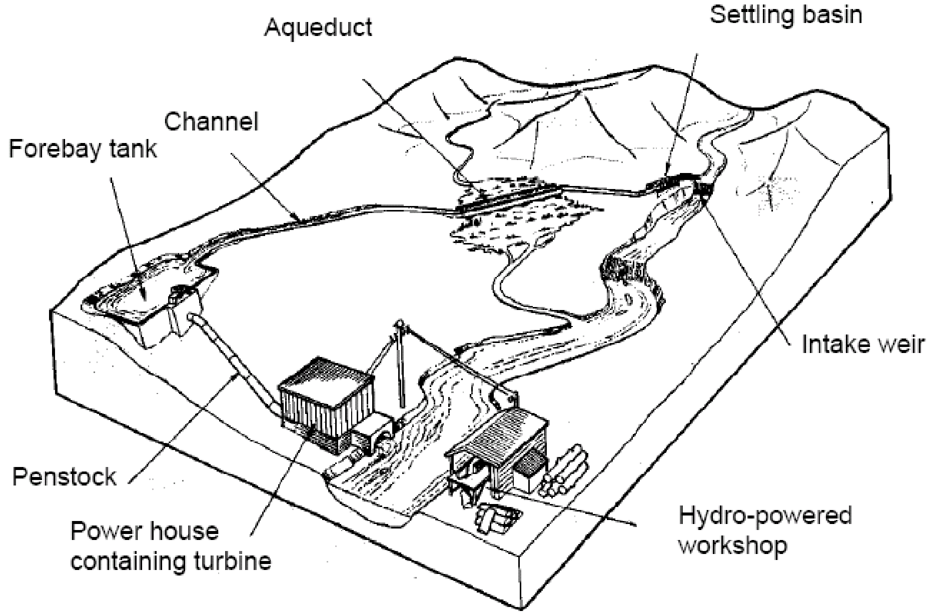
5. MICRO-HYDRO ELECTRICITY

Hydroelectricity is one of the oldest applications of renewable energy, since the use of water wheels for irrigation goes back over 2,000 years (ITDGb, no date). Micro-hydroelectric systems provide a simple, low cost and independent source of electricity for remote rural communities. Also, unlike large hydro schemes, micro-hydro systems do not require water catchments or storage and therefore have no significant environmental impacts.

5.1 Micro-hydroelectricity System Technology

Unlike diesel generators, site-specific conditions that include seasonal variation in water flow, determine the technological feasibility of a given micro-hydro scheme. As a result, detailed hydrological studies must be carried out at the site before a potential project proceeds. In general micro-hydro schemes are generally between 5-100 kW in size, whereas larger hydroelectric schemes are at least 1 MW (ITDGb, no date).

The technology associated with 'run of the river' micro-hydro schemes is straightforward. A weir or small dam is built across a river to trap and raise the height of the water. The water is then diverted to a headrace or power canal, which is either an open canal or a low-pressure pipe. This forces water into a forebay, where sediment and precipitate settle, before it enters the penstock, a high-pressure pipe that carries the water to the turbine, which is generally located in a powerhouse. When water hits the turbines, it forces them to spin, and the energy from falling water is converted into rotational energy. Finally, a generator converts the rotational energy produced by the turbine into electrical energy. The faster the flow of the river, the larger the volume of water, and the higher the drop, the larger the potential for electricity production. The amount of electricity produced by the system will be significantly reduced when water levels are low. A diagram of the setup of a typical micro-hydro system is presented in Figure 12.



Source: ITDG (n.d.)

Figure 12. Typical set-up of a micro-hydro system.

5.2 Micro-hydroelectric Potential in the Pacific

Hydroelectricity is limited in its application in Pacific Islands, since it is generally only suitable for larger, mountainous islands in countries such as Fiji, Papua New Guinea, Solomon Islands, Vanuatu and on some islands in Samoa. There is also limited potential for hydropower in the Federated States of Micronesia, the Cook Islands and Tonga (Wade and others, 2005). Smaller-scale micro-hydro schemes have even greater potential for rural electrification in Pacific Islands where dispersed and isolated populations do not allow for the economies of scale required for larger-scale hydro projects. Initial capital costs are very high and a high threshold level of electricity demand is required for larger-scale hydroprojects to be cost-effective. For a summary of hydroelectric schemes, which have been constructed in various Pacific Islands, see Table 12.

Table 12. Summary of Hydroelectric Schemes in the Pacific.

Country	Size of Hydroelectric System	Location
Papua New Guinea	300 kW 60 kW 100 kW 63 MW 87 MW 12 MW Estimated to be at least 150 micro and pico-hydro schemes	Tari Woitape Telefomin Port Moresby Ramu New Britain Various locations
Fiji	80 MW 0.8 MW 7 small micro-hydro schemes ranging from 3-100 kW	Monsavu Wainikeu Various locations
Samoa	6 run-of-the river schemes ranging from 950-1750 kW 4 MW (2 x2 MW)	Various locations on Upolu Afulilo
Solomon Islands	32 kW 185 kW 75 kW 7 small micro-hydro schemes ranging from 10-50 kW	Malu'u (status unknown) Buala Atolifi Various locations
Vanuatu	2x300 kW turbines	Sarakata

Source: Wade and others, 2005

5.3 Micro-hydroelectricity Production Costs

A micro-hydro system has the advantage that where site specifics are appropriate, it can provide a sustainable, reliable and low-cost source of energy in remote and isolated communities where grid-extension would be cost-prohibitive and fuel transport costs are high.

The initial investment costs associated with micro-hydro systems are large. Since each site is unique, detailed hydrological studies must be carried out before the viability of a micro-hydro project can be determined. As a result, costs remain high since the installation process cannot be standardised as in the case of solar PV systems or diesel technology. Capital costs typically range from US$1000-2000/kW depending on the site, for a community project in a developing country. For example, in Sri Lanka, a 10-13 kW micro-hydro system costs approximately US$15,000 including the distribution network (Martinot, 2001 cited in Greacen, 2004). However, capital investment costs can be significantly higher, as in the 60 kW Woitape Hydroelectric Project completed in 1991, in Papua New Guinea, which cost approximately US$1.4 million or $23,000/kW (Wade and others, 2005). Also, since micro-hydroelectricity is a mature and wellestablished technology, unlike other newer renewable energy systems, its costs have generally not fallen over the past 5 years (Toyo Engineering Corp and others, 2005). The typical component costs for a micro-hydro scheme are presented in Table 13.

One major advantage of micro-hydro compared with conventional alternative sources of power, is that operation and maintenance costs are very low (ITDGb, no date.). This makes electricity very affordable to rural energy users if initial capital costs are subsidised. Also, the approximate life of a micro-hydro system tends to be long compared with diesel-powered generators, which minimises the overall life-cycle costs. The typical lives of 1-kW and 100-kW micro-hydro schemes are 15 and 30 years, respectively (Toyo Engineering Corp. and others, 2005).

Table 13. Typical costs of a micro-hydro system.

Head 5 m – Power 5 kW		
Item	**Percentage of total**	**Minimum Cost $/kW**
Plant	33%	330
Installation and commission	9%	90
Civil engineering	36%	360
Electrical engineering	6%	60
Design and management	7%	70
Contingency	10%	100
Total		1010

Source: Owens (2002)

5.4 Micro-Hydro System Reliability

Since micro-hydro systems require no fuel inputs other than water, when there is low variability in water flows, reliability is higher compared with diesel systems that depend on the delivery of regular fuel supplies to remote areas. Also, although regular inspection and maintenance of micro-hydro systems is necessary, unlike diesel generators, these systems do not require major overhauls every few years. In addition, micro-hydro systems can supply 24-hour power to remote communities, which would be too costly to do using diesel generators in remote locations on Pacific Islands because of high fuel costs. Micro-hydro systems with sufficient capacity are also able to support high loads unlike other renewable energy systems such as solar PV home systems. The micro-hydro technology is more sustainable in the medium- to long-term, since it can meet growing household demand for electricity, and even supply electricity for small-scale industrial activities.

5.5 Case Study – Bulelavata Micro-Hydroelectricity Project, Solomon Islands

Bulelavata is a remote community of approximately 300 people, located in the Western Province of the Solomon Islands (Bryce and Soo, 2004). It is only accessible by sea, which increases the cost and unreliability of fuel supply.

Figure 13. Location of Bulelavata Village, Solomon Islands. (Source: University of Texas)

5.5.1 Project background

The Bulelavata scheme, which was constructed in 1999, is one of a number of community micro-hydro schemes, implemented in the Solomon Islands over the past 20 years, with assistance from the Australian-based NGO, Appropriate Technology for Community and Environment (APACE). The Solomon Islands micro-hydro projects were implemented using the 'Village First' model developed by APACE that was designed to improve project success and sustainability by promoting community ownership of the micro-hydro schemes. Under this model, communities were required to make financial contributions towards carrying out feasibility studies, and donate local materials and labour for the construction of micro-hydro systems. Once construction was completed, the community would then retain ownership of the scheme and be responsible for operating and maintaining the system, by ensuring that revenues received through fee collection were sufficient to cover all project costs (Pio and Tutua, 2004). A list of all of the Village First projects that have been or are being implemented in the Solomon Islands is presented in Table 14.[21]

Table 14. Community Micro-hydro Schemes in the Solomon Islands.

Location	Year Installed	Turbine Capacity	Generation (kW)
Iriri Settlement	1983	10 kW	3-4
Vavanga	1994	10 kW	4-5
Ghatere	1997	12 kW	
Manawai Harbour	1997	50 kW	15-25
Bulelavata	1999	29 kW	14
Raeao	2002	25 kW	14
Nariaoa	2004	25 kW	

Source. Johnston and Vos (2005)

[21] Note that not all of these schemes are currently operating.

The user fees are set at a monthly flat rate, and are determined by the Community Hydro Committee. Fees are collected by the Women's Club and held in the community bank account to cover future expenses such as repairs to the micro-hydro system and parts replacement. Monthly fees are US$0.69 (SB$5) per household for a single light and power point, and US$0.96 (SB$7) for a kitchen light. The village also sells 15 kW of electricity to Beulah Provincial Secondary School at a rate of US$0.03/kWh (SB$0.25/kWh), (Delaka, 2003; APACE, 1997)[22].

5.5.2 Micro-hydro system design

The Bulelavata weir is constructed from concrete and the penstock from PVC pipe. The micro-hydro system consists of a stainless-steel cross-flow Pelena turbine. Currently, the system produces 14 kW of electrical output.

Figure 14. Bulelavata Weir. (Source: Pelena, 2006).

Earlier APACE-supported community micro-hydro schemes encountered problems due to weak system designs, such as the construction of penstocks using wood, which lead to low reliability (Johnston and Vos, 2005). However, many of these problems have been resolved over time through experience, and the Bulelavata system, at the time of its construction, was viewed as being one of the most well-designed community micro-hydro projects in the country (Delaka, 2003).

5.5.3 Benefits from the Bulelavata micro-hydro project

Some of the benefits which have been realised as a result of the project include:

- **Improved quality of Life:** Prior to the implementation of the Bulelavata micro-hydro scheme in 1998, households relied on kerosene lamps, dry cell batteries and fuelwood as sources of energy. As a result of the village micro-hydro system, households have benefited from improved lighting in houses and kitchen buildings (Delaka, 2003). Also, many households have acquired water heaters and radios; and a small number have purchased video machines, refrigerators and electric drills.

[22] Initially Beula Provincial Secondary School was not paying its bills, and it is unclear whether they have begun to pay community for electricity services they receive. Also, user fees that had been collected during the early stages of the project were misappropriated; however, there have been efforts to ensure that this does not happen again.

In addition, the village clinic has been electrified; street lighting installed; and at least 2 community deep freezers have been installed (Paul Bryce, personal communication 2006). This has allowed children to study longer at night, and for women to engage in income-generating activities such as weaving for longer hours (Bryce and Soo, 2004). Also, the local Provincial Secondary School, that is attended by 600 students has also benefited from the electricity provided by the Bulelavata micro-hydro scheme. Previously the school relied on kerosene, fuel wood and two diesel generators, which ran for approximately 4 hours per day (APACE, 1997).

- **Improved Reliability:** Except for four days when the system was overloaded due to abuse of the service, the micro-hydro system has run without any interruption in service for four years (APACE, 2006).

Figure 15. Youth in front of Bulelavata Weir. (Source: Bryce, 2000)

  Previously the generators, which provided power to the local secondary school, which were owned and maintained by the Western Province Government, were unreliable and never operated satisfactorily. By 1997, one of the generators had been non-operational for over a year (APACE, 1997). Now the school has access to a reliable source of energy 24 hours per day.

- **Employment and income-generating activities:** The project has also provided training for 3 village technicians, who perform their duties on a rotational basis. Also income-generating activities have been made possible by allowing fish to be stored in the Bulelavata Community deep freezers. Villagers have also been planning to use the electricity produced by the micro-hydro system to operate a rice mill and open a village trade store (Delaka, 2003).

- **Costs Avoided:** Prior to the implementation of the project, Beula Provincial Secondary School generators were consuming approximately 600 litres of diesel per month (APACE, 1997). Also household expenditures on energy have declined as a result of the project, since monthly user fees are lower than monthly spending on kerosene and dry cell batteries for lamps and radios (Bryce and Soo, 2004).

5.5.4 Least-Cost Analysis: micro-hydroelectricity versus diesel system costs in Bulelavata

In order to determine the least-cost option for providing electricity for the rural community of Bulelavata and the local provincial secondary school, the total life-cycle costs of installing, operating and maintaining the micro-hydro system were compared with the hypothetical costs of operating a diesel generator to supply electricity for Bulelavata Village and the nearby provincial secondary school.

Life-cycle costs for diesel generators and micro-hydro systems

Most households have several basic lights, a number of houses have water heaters, and several homes have refrigerators[23]. With the 24-hour power street lighting and deep freezers provided by the micro-hydro system, it is estimated that total daily energy consumption for an estimated 50 households is 140 kWh, including distribution losses (see Appendix 2 for details). Alternatively, in the absence of the micro-hydro systems, and assuming that electricity were supplied by a diesel generator for only 5 hours daily, demand for electricity is estimated to be approximately 48 kWh per day.[24]

The initial capital costs of the micro-hydro project were approximately US$230,008 (APACE, personal communication, 2006). This included equipment purchase, shipping, distribution system costs, labour, training, and local material costs.[25] Operation and maintenance costs for the micro-hydro system, including the costs of parts replacement, based on current costs, are approximately US$103 per year or approximately 0.04% of initial capital investment costs (Nixon Silas Pio, personal communication, 2006).[26] Furthermore, the life of a micro-hydro system is estimated to be 20 years.

It is estimated that the total initial capital costs of installing generators and distribution lines in the community and the school would be approximately US$85,000[27]. Using data on diesel consumption rates of the Beula Provincial Secondary School generators, and

[23] For the purposes of analysis, it is estimated that 10% of homes have refrigerators, and 30% have water heaters.
[24] This figure is lower compared with the micro-hydro system, since it is assumed street lighting and deep freezers would not be provided.
[25] In order to make a fair comparison with diesel generator costs, in-kind contributions and personnel costs were omitted from the capital investment cost calculations.
[26] Operation and maintenance costs are based on the replacement costs of spare parts, grease and other expenses.
[27] According to APACE (1997), the cost of building a transmission line to the school was $13,000, and it was estimated that constructing a village distribution system was approximately $15,000.

assuming that the village generator had an efficiency of 0.2 litres/kWh, it is estimated that total fuel costs would be approximately US$11, 500 per year (See Appendix 2 for details). [28]

The total life-cycle costs of the diesel generators over 20 years was estimated to be US$267,842 compared with the total life-cycle costs of $229,794 for the micro-hydro system (see Appendix 2 for details).

Table 15. Summary of micro-hydro system and diesel generator life-cycle costs.

System Type	Estimated Total Life-Cycle Costs (US$) over 20 years
Micro-hydroelectric system	229,794
Diesel Generators	267,842

5.5.5. Sensitivity analysis

In order to test the robustness of the results, a sensitivity analysis was conducted by re-estimating the total life-cycle costs of the diesel generators using different generator fuel efficiency levels and fuel costs. Except for the case when diesel costs $0.70 per litre and the generators have a fuel efficiency of 0.20 L/kWh, the micro-hydro system presents the least-cost option for supplying electricity to the community.

Table 16. Sensitivity of diesel generator life-cycle costs to changes in efficiency and fuel price.

	Price of Diesel ($US/Litre)			
Fuel Efficiency of Generator (litres per kWh)	0.70	1.00	1.30	1.60
0.2	222,705	245,274	267,842	290,410
0.3	232,944	259,901	286,857	313,814
0.4	243,183	274,528	305,873	337,217

In addition, the least-cost option for electricity production in Bulelavata Village appears to be insensitive to the choice of discount rate applied in the analysis as demonstrated by the results presented in Table 17.

[28] In May 2006, the price of a litre of diesel in the town of Gizo in the Western Province of the Solomon Islands was US$1.30 excluding taxes (Nixon Silas, personal communication, 2006). In reality, with added transportation costs, the cost of diesel is likely to be even higher in Bulelavata Village. A generator fuel efficiency of 0.35 litres per kWh was assumed.

Table 17. Life-cycle cost sensitivity analysis using various discount rates (US$).

Discount Rate	Diesel Generator	Micro-hydro electric system
5%	$357,415	$230,200
7%	$315,206	$230,008
10%	$267,842	$229,794

5.5.6. Discussion and conclusions

The economic analysis conducted on the cost-effectiveness of energy options in Bulelavata Village indicates that the micro-hydro system provides the least-cost energy option for electricity production compared with diesel generators. In addition, power availability is ideal with the micro-hydro system, compared with diesel generators, since power is produced 24 hours per day. Affordability to users is also higher with micro-hydro systems, especially if initial capital costs are subsidised and since ongoing user costs are low. Continuous expenditures on fuel and major system overhauls every few years are also eliminated with the micro-hydro system.

6. WIND ENERGY

The use of wind to generate power dates back many centuries. In the 7th century AD the Persians built windmills for milling and irrigation. Direct current wind-powered electricity was first developed in 1888, however, it was not until the 1930s that the development of large-scale AC turbines began. During the oil crises in the late 1970 and early 1980s, there was renewed interest in wind energy, which led to the development of modern, highly-sophisticated wind turbines (ITDGa, no date).

The potential for wind energy production is dependent on wind speed, which varies on a global, regional and even local basis, often following seasonal patterns (Owens, 2002). This means that detailed wind resource assessments must be carried out at a potential site before the feasibility of wind energy project can be determined, since the potential for wind production is location specific.[29] Because of the intermittent nature of wind energy, the potential for electricity produced by wind to completely substitute for conventional sources of power such as diesel generators in rural areas is limited, so wind energy is better suited to supplement, rather than replace existing electricity generation. In remote locations isolated from the grid, wind turbines are often combined with PV or diesel systems to create a more reliable hybrid energy systems (ITDGa, no date). However, this also adds to the complexity of the system that is problematic in remote areas where there is highly likely to be a shortage of skilled technicians.

6.1 Wind Turbine Technology

A wind power turbine converts kinetic energy from wind into electric power through rotor blades connected to a generator. Wind turbines can provide power ranging from 50W to more than 1.0 MW (ITDGa, no date). Wind turbines can be classified into two types, those whose blades rotate on a horizontal axis, and those that rotate on a vertical axis, with the former being the most common design (Economist, 2006). Blade lengths increase with the size of the wind turbines and longer lengths result in more energy capture. Small wind turbines can be used for off-grid, mini-grid, and grid-connected applications. On the other hand, larger wind turbines, are used exclusively for grid-connected power supply.

The major components of a (horizontal axis) small wind turbine include (Toyo Engineering Corp and others, 2005):

[29] Because of seasonal variations in wind, surveying must be carried out over at least a one-year, and preferably, a two-year period.

- Alternator that converts the rotational energy into three-phase alternating current (AC) electricity.
- Turbine blades and a rotor system, usually comprising of three fibreglass blades
- Lattice tower and tail assembly. The latter composed of a tail boom and the tail fin which keeps the rotor aligned into the wind at speeds below the limiting, or cut-out, wind speed.
- A power controller unit, which serves at the central connection point for the electrical portion of the system and regulates charging and discharging of the battery bank, and incorporates protection features such as load dumping and turbine protection.

The estimated lifetime of a wind turbine is approximately 20 years (Owens, 2002). Major applications for small wind turbines include charging batteries and supplying small DC loads. When configured with a DC-AC inverter and a battery bank, small wind turbines can provide power for village or mini-grid, usually in a hybrid configuration with diesel or solar PV systems (Toyo Engineering Corp. and others, 2005).

6.2 The PIC Experience with Electricity Production from Wind Energy

There have been wind energy demonstrations and trials on most Pacific Islands. Wind resources in the Pacific range from good in higher latitudes to non-existent in equatorial areas. However, given constraints on land availability, the difficulty in obtaining land leases, and the large risk of damage to turbines posed by cyclones- large-scale wind farms are not feasible on many Pacific Islands.

Wind turbines have been installed to provide power to the electrical grid in Fiji, in Nabouwalu,[30] and Nabua; and a 10-MW wind installation will be commissioned in 2007 in Butoni. Two wind turbines have also been installed on the island of Mangaia in the Cook Islands, which will be discussed in greater detail in the following section. In addition, fifty 0.5-kW wind systems are being tested in Papua New Guinea (Wade and others, 2005).

[30] However, the wind-PV-diesel hybrid installation at Nabouwalu has encountered many problems and is currently not in operation.

6.3 Costs of Producing Wind Energy

Wind energy production costs have been falling with wind turbine technology improvements that has resulted in larger-sized wind turbines, larger blades, improved power electronics and taller towers. The costs of utility-scale wind installations have fallen by 90% over the past two decades, and the costs of wind energy production can be as low as $0.05/kWh (AWEA, 2001; AWEA, 2005).

Wind energy has been demonstrated to be competitive with both conventional sources of energy and solar energy when produced on a large-scale, e.g. wind farms (Economist, 2006). However, available wind resources, size of wind turbines and wind-speed are critical factors in determining the amount of electricity produced by turbines, and therefore directly affect the cost-effectiveness of wind energy. To be cost-effective, generally, an average annual wind speed of 6 meters/second (m/s) at 10 m height is required from large-scale wind turbines, and 5 m/s for smaller wind turbines. The average cost of a wind turbine is about US$1000 per kW of capacity, while the tower cost is approximately US$1500 per m. Installation costs vary with soil conditions and the distance to the power grid, but are typically US$15,000 or less (Owens, 2002). Wind energy can also be combined with PV or diesel systems, which may result in lower energy production costs.

6.4 Case Study – Mangaia Grid-Connected Wind Farm, Cook Islands

Mangaia is the most southerly, and second largest island in the Cook Islands. In October 2003, two 20-kW wind turbines were installed in Mangaia under the Pacific Renewable Energy France Australia Common Endeavor (PREFACE) Project. The turbines are connected to the electrical grid, and are operated and maintained by the Mangaia Power Utility (Cloin and Mario, 2004). The purpose of installing wind capacity on the island was to utilise wind resources in order to reduce the dependence of diesel-powered electricity (SOPAC, 2006a).

Figure 16. Location of Mangaia, Cook Islands. (Source: Cloin and Mario, 2004)

Approximately 700 people reside on the island of Mangaia (Wade and others, 2002). Despite out-migration, it is estimated that demand for energy is growing by approximately 6% per year (Cloin, 2006a).

Figure 17. Two 20-kW turbines on Mangaia. (Source: Cloin and Mario, 2004)

6.4.1 System design

Prior to the installation of the wind turbines, electricity was produced exclusively by diesel generators and distributed through an 11-KV power grid. Electricity is supplied for 24 hours per day on the island. The energy base load is met by two 100-kW diesel generators, and the peak load by one of the 20-KW or 30-KW generators. However, these generators are aging and derated (Cloin, 2006a)[31]. In 2003, two 20 kW turbines, with 10 metre blades were installed and connected to the power grid. It was estimated that at a height of 30 meters, potential wind resources could be up to 7.5 m/s, and that the wind turbines could potentially generate between 95,000 and 100,000 kWh per year (Vergnet, 2001). The feasibility study estimated that the total electricity production system, including both wind turbines and diesel generators, could produce 15-20 kW of wind power at night, and 35-40 kW during the day. When winds are strong, it was estimated that the turbines could generate up to 40 kW (Vergnet, 2001). The power configuration in Mangaia is detailed in Figure 18.

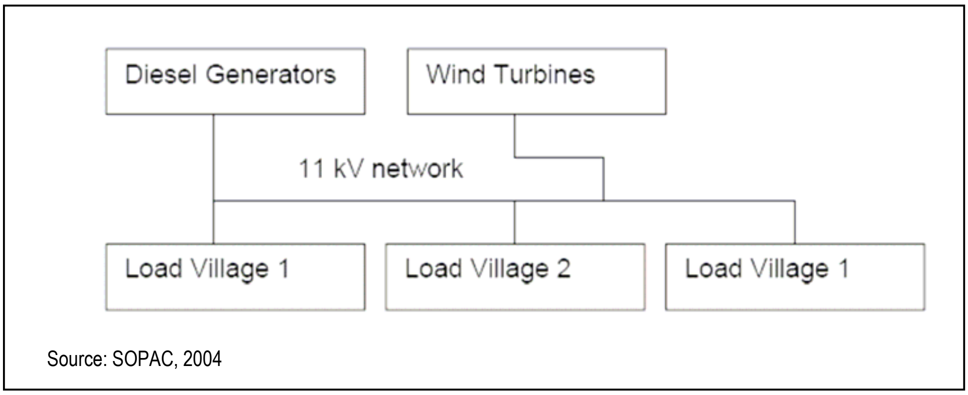


Figure 18. Electricity production system set-up on Mangaia.

The integration of electricity from wind into the system must be limited to 25% of actual demand to prevent destabilisation of the electricity generation system (Wade and others, 2002). This is because the diesel generators require a minimum load of at least 50% of their rated power (Cloin,

[31] According to Vergnet (2001), the rated power range of the generators can operate from 25 to 100% of their nominal power.

2006a). Therefore, in order to avoid destabilising the system, one of the turbines must be disconnected at night when the demand for electricity is low (less than 30 kW). Figure 19 presents the electricity demand profile on Mangaia for the 30th of December 2004, which illustrates the maximum allowable contribution of wind energy to total production throughout the day. The demand profile demonstrates that it is only for five hours per day (between 19.00 and 24.00 hours), that the wind turbines can contribute energy to the system up to their full potential of 40 kW.

6.4.2 Benefits of wind energy

The main benefit of installing wind turbines in Mangaia is the significant diesel savings that this project could potentially yield. Like other Pacific Islands, the Cook Islands are heavily dependent on petroleum imports. The production of wind energy helps not only to reduce this dependence on diesel fuel imports, but it also allows for hedging against future increases in the price of oil. The increased contribution of wind power to overall production of electricity in Mangaia also represents reductions in carbon dioxide emissions. Vergnet (2001) estimated that 240 tonnes of greenhouse gas emissions would be saved over the life of the project, if the anticipated diesel savings materialised.

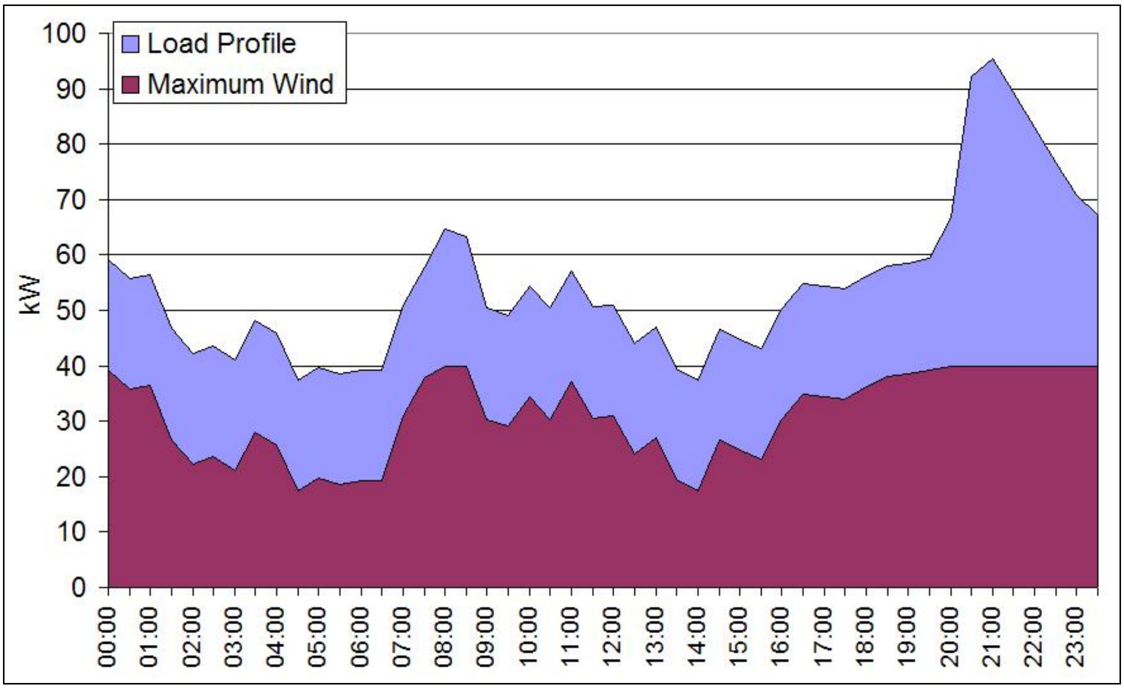


Figure 19. Maximum allowable energy produced from wind in the Mangaia electrical grid.
(Source: Cloin, 2006a)

6.4.3 Life-cycle costs

Capital investment costs were estimated to be US$164,000, and operation and maintenance costs approximately us$7,000 per year[32]. Thus, the total present value of the cost of the project over its assumed 20-year life is estimated to be US$237,000 (Vergnet, 2001; see Appendix 3 for details).

6.4.4 Actual diesel savings

Total energy requirements in Mangaia are approximately 1,149 kWh per day, with a peak demand of about 128 KVA (Cloin, 2006a). During the period 2004-2005, the Mangaia Power Utility sold approximately 386,472 kWh of power to its customers.[33] Load profiles have only increased slightly compared to what was expected at the time when the feasibility studies for this project were being carried out. Diesel savings realised by the addition of the two wind turbines are dependent on the energy actually produced by the turbines, which is determined by the amount of wind resources available, the configuration of the power grid, and the capacity to integrate the maximum amount of available wind energy produced by the turbines. During the feasibility stage of this project, it was estimated that 30,000 litres of diesel could be saved with the addition of the two wind turbines (Wade and others, 2002).

The contribution of the wind turbines to total energy production on Mangaia has been lower than expected due to a sub-optimal power configuration, explained in the next section that has reduced potential diesel savings (Cloin, 2006a). For example, using 2004-2005 data on energy production, it is estimated that wind turbines produce an average of 2,317 kWh per month (see Table 18 for details). As Figure 20 illustrates, the contribution of wind to total energy production has been minimal. It is estimated that wind energy contributes approximately 6% to total energy production, however it is important to note that there is significant variation in monthly contribution rates.

[32] Cost data was obtained from the Vergnet (2001) project feasibility study.
[33] Mangaia wind and diesel energy production and sales data provided by Anthony Whyte.

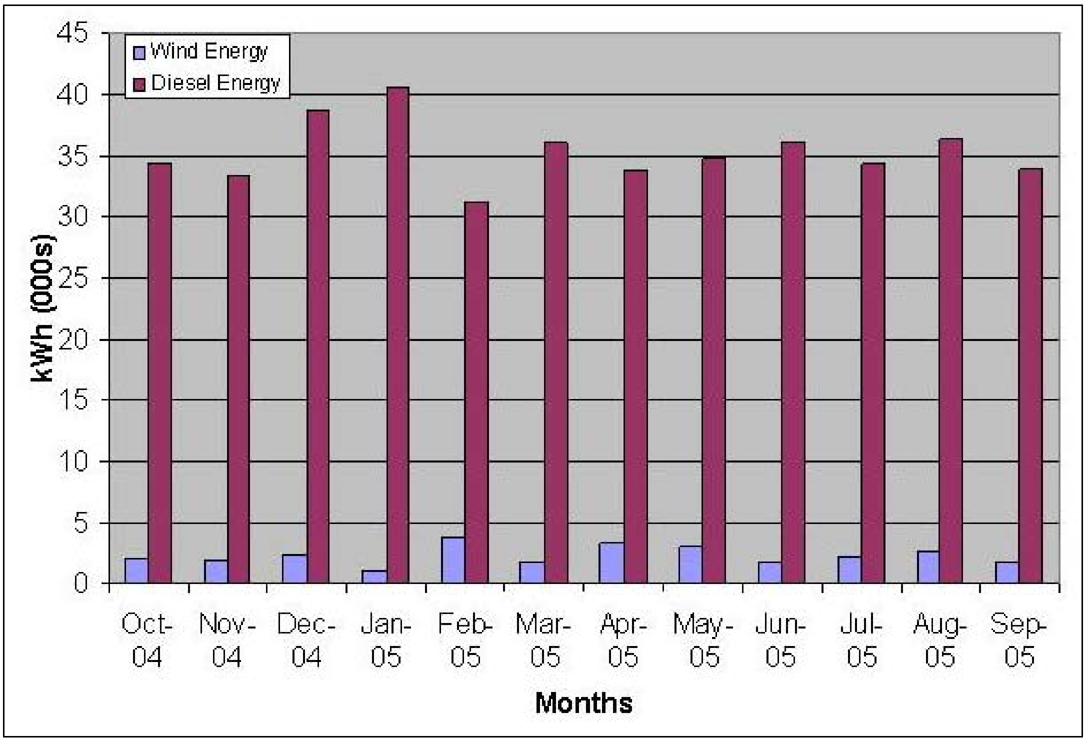


Figure 20. *Wind and diesel power contribution to total energy production.*

Table 18. *Wind energy production in Mangaia.*

Date	Total Wind Energy Production (kWh)	Percent of Total Electricity Production (%)	Theoretical Volume of Diesel Saved (Litres)
October 2004	2,020	5.55	687
November 2004	1,918	5.45	652
December 2004	2,405	5.87	818
January 2005	1,031	2.48	351
February 2005	3,809	10.90	1,295
March 2005	1,868	4.93	635
April 2005	3,338	8.99	1,135
May 2005	3,008	7.96	1,023
June 2005	1,866	4.90	634
July 2005	2,117	5.81	720
August 2005	2,584	6.64	879
September 2005	1,835	5.14	624
AVERAGE PER MONTH	**2,316.58**	**6.22**	**788**

Source: Energy data provided by Anthony Whyte

6.4.5 Benefit-cost analysis of wind turbine installation in Mangaia

Over the period from October 2004 to September 2005, the wind turbines produced a total of 27,799 kWh of electricity. Assuming that the diesel generators would otherwise have produced this energy, an estimated 9,452 L of diesel was saved over this period.[34] The real price of diesel in Mangaia (excluding taxes and duty) is US$1.02 per litre. Thus, the monetary benefits of producing wind power, in terms of diesel savings, are estimated to be approximately US$9,641 per year, if wind energy production is assumed to be constant over time.

Based on current wind production estimates, the costs associated with installing and maintaining the wind turbines exceed the benefits they yield in terms of diesel savings, since the net present value (assuming a discount rate of 10%) of the investment was estimated to be US$-140,279 (see Appendix 3 for details). In order for the net present value (present value of benefits – present value of costs) of wind project to exceed zero, either the price of diesel would either have to rise above $2.77 per litre or wind production would have to increase to 75,350 kWh. However, in the near future, more than doubling of either fuel prices or wind production rates seems unlikely.

Table 19. Present value of costs and benefits associated with the Mangaia Wind Project.

Indicator	Value (US$)
Present Value of Benefits	82,077
Present Value of Cost	222,356
Net Present Value	−140,279

6.4.6 Sensitivity analysis

The economic analysis, which indicated that the costs of the investment outweigh the benefits, (in terms of diesel fuel savings), appear to be insensitive to the choice of discount rate as shown in Table 20.

Table 20. Sensitivity analysis using various discount rates (US$).

Discount Rate	Net Present Value (US$)
5%	−129,324
7%	−134,507
10%	−140,279

[34] A fuel efficiency rate of 0.34 litres/kW for the generators was assumed based on data calculations.

6.4.7 Optimisation of the Mangaia wind hybrid system

According to Cloin (2006a), the wind installation on Mangaia could be substantially improved in order to yield greater diesel savings. The modifications to the system include installing storage to absorb excess energy when demand for electricity is less than wind power production, and installing an electric control (bi-directional converter) to utilise the different supply components. According to the optimisation analysis carried out by SOPAC (2006), diesel savings could be increased by 13% if the proposed modifications of the system were made. However, the extra cost of the investment would be approximately US$120,000 plus maintenance costs of 10%. According to diesel savings estimated in this study, optimisation (13% increase in diesel savings) would lead to a total savings of 10,680 litres of diesel or US$10,894 per year at current diesel prices.

In order to assess whether such an investment is desirable from an economic perspective, another benefit-cost analysis was carried out, to determine whether the optimised system would increase the cost-effectiveness of the wind-hybrid system. However, even with the optimisation of the system, estimated project costs exceed estimated project benefits to an even greater extent compared with the original system design as shown in Table 21.

Table 21. Present value of costs and benefits associated with the optimised Mangaia wind-hybrid system.

Indicator	Value (US$)
Present Value of Benefits	10,670
Present Value of Cost (excluding maintenance costs)	120,000
Net Present Value	− 109,330

6.4.8 Discussion and conclusions:

The results from the cost-benefit analysis indicate that the wind-hybrid system does not present the least-cost option, compared with diesel systems alone, for producing electricity in Mangaia. The reason for this is that the diesel savings envisioned under the project have not materialised, and this is most likely due to a sub-optimal power configuration. One proposal has been to consider moving one of the turbines to a different location in order to reduce operation and maintenance costs. Also, it is important to note that the results of the analysis cannot be generalised for other locations in the Cook Islands or other Pacific Islands, since the economic viability of wind-hybrid systems for providing electricity to remote locations, are for the most part, dependent on site-specific conditions.

7. COCONUT BIOFUEL


Figure 21. Coconut trees.

The coconut tree is a vital component of island ecosystems and economies, and traditionally copra has been an important source of rural income on many Pacific islands. In recent years, another important use of coconut resources has been identified, which is the use of coconut oil as a biofuel substitute for diesel fuel. Although the technology has been around for many years, it has only been in the last 10 years, that there has been renewed interest in using coconut oil as a biofuel in the Pacific (Cloin, 2005). The development of coconut oil as a renewable energy in the region not only provides the opportunity to reduce reliance on imported fossil fuels but also to provide rural communities with a cost-effective source of energy, and to stimulate rural development by creating markets for locally-produced coconut oil.

7.1 Coconut Biofuel Technology

Compared with other renewable energy technologies such as PV systems, the use of coconut oil in modified and unmodified diesel engines has the advantage that the technology is familiar, since diesel engines used in generators and vehicles are commonly found in remote areas of the Pacific.

7.1.1 Use of pure coconut oil

The use of un-modified vegetable oils as fuels, including copra oil, has been proved to be technologically viable in short-term trials. Some trials have demonstrated that it is technically possible to use pure coconut oil as a 100% substitute for diesel fuel in unmodified direct injection engines. However, problems generally occur, especially when the generator load is below 60%, because of the viscosity of coconut oil and incomplete combustion that results in carbon deposits on pistons, valves and combustion chambers.[35] Thus, when vegetable oil content in fuel blends exceeds 20%, the long-term durability of engines is questionable (Cloin and others, 2005). As a result, it is generally not recommended to use coconut oil/diesel blends without special supervision.

[35] With indirect injection engines, however, it is argued that such problems are avoided (Vaitilingom, 2006).

Diesel engines can be modified by making adaptations to the fuel supply system and injectors, by installing a dual fuel tank system and a fuel heater, in order to avoid the problems encountered using pure coconut oil as discussed above (CocoGen, 2005). This allows an engine to be started on diesel fuel, and switched to coconut oil, once it has been heated to a temperature of 70-80 degrees Celsius and its viscosity has been reduced.[36]

7.1.2 Production of biofuel

It is important to note that the energy content of coconut oil is lower than diesel since it requires approximately 1.08 litres of coconut oil to produce the same amount of energy as 1 litre of diesel. As a result, a larger volume of the former is required to produce an equivalent amount of energy as the latter.

Figure 22. Biofuel generator, Vanua Balavu, Fiji.

Coconut oil can either be produced using labour-intensive or capital-intensive production processes. Coconut oil can also be produced on a small-scale in rural areas with high labour inputs, where copra is cut and dried manually, and is then heated, pressed and filtered to produce oil. The entire coconut oil production process can be mechanised from the initial dehusking of whole coconuts stage, through to the end product, where the only labour required is for the collection of coconuts.

Figure 23. Coconut pile, Sawana Village, Vanua Balavu, Fiji.

One potential barrier to the development of coconut oil as an alternative energy source, is the limited availability of copra, since in many Pacific Islands, the copra industry has been in decline for many years, due to a combination of volatile prices, weak management, limited investment, natural disasters and rising labour costs (CocoGen, 2005). As a result copra production in many countries like Samoa, Tonga, Papua New Guinea and Fiji, has virtually ceased, despite the existence of abundant coconut resources. Therefore, the feasibility of using coconut oil as a renewable energy in the region may depend not only on the viability of current technology, but also on the revitalisation of the copra industry.

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[36] Also, as the engine is about to switch off, the system again switches to diesel fuel to ensure that there is no coconut oil in the system when the engine is started again.

7.2 Experience in the Pacific

Interest in using coconut oil as a biofuel in Pacific Island Countries only began recently, and successful trials in Fiji, Vanuatu and New Caledonia have shown this to be technologically viable. However, experience with using coconut oil as a diesel substitute in rural electrification projects in the Pacific to date remains limited. Rural electrification projects that have demonstrated the use of coconut oil as a diesel substitute have been implemented in New Caledonia and Fiji. While the New Caledonia experience with using coconut oil in adapted diesel generators has generally been viewed as a success, Fiji's experience, which is discussed in more detail in Section 7.4, has been a mixed success (Courty 2000; SOPAC, 2006b). SOPAC and UNDP have recently initiated biofuel projects in Samoa, Marshall Islands and Kiribati. Also, a feasibility study for using coconut oil as a diesel substitute in Rotuma, as a follow-up to the ADB Renewable Energy and Energy Efficiency Programme, was carried out in 2006 by the PIEPSAP.

7.3 Economic Impact

7.3.1 Macroeconomic impact of biofuel production

As already noted, fuel imports exert a large amount of pressure on the trade balances and the foreign exchange reserves of many Pacific Island Countries, since they account for a significant portion of total imports. The development of coconut oil as a viable substitute for diesel could assist in addressing these macroeconomic imbalances.

At the same time, the widespread use of coconut oil as a fuel substitute could promote rural economic development in Pacific Islands by creating a stable market for locally-produced copra. At the moment, there is little incentive for copra production in Pacific Island Countries, except in countries with low labour costs, since the world price of copra oil is very volatile as Figure 8 illustrates. For example, the halving or doubling of coconut oil prices within the period of one year is not unusual, which discourages production since potential returns are very uncertain (Etherington, 2005). In addition, Pacific Island producers only account for a small share of total world coconut oil production, and are therefore 'price-takers' since they have no influence on world price.

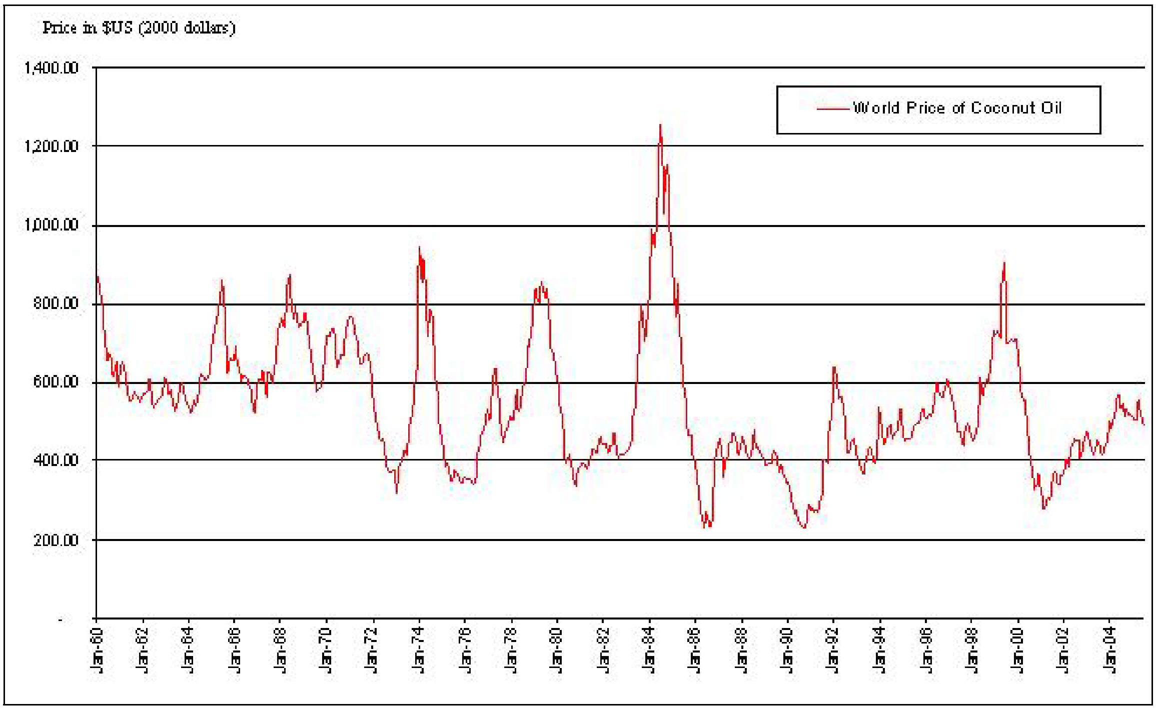

Figure 24. World coconut oil prices (1960-2005). (Source: UNCTAD commodity price database).

Also, under the current situation of heavy dependence on imported diesel and on international markets for domestically-produced coconut oil, Pacific Island Countries face a ‘double freight penalty’ since high shipping costs mean that countries pay more for imported fuel, and receive lower earnings on coconut oil and copra exports. For example, if the world price of coconut oil is US$500 per tonne, producers in Fiji receive approximately US$410 per tonne, since the cost of shipping coconut oil from Suva to Rotterdam, including handling costs, is approximately $90 per tonne of oil (CIDA, 2004). This problem is even more acute in remote areas, away from urban shipping centers, where shipping costs to and from outer islands are even higher. See Figure 25 from Etherington (2005), which shows how transport costs can raise the price of imported fuel and copra exports.

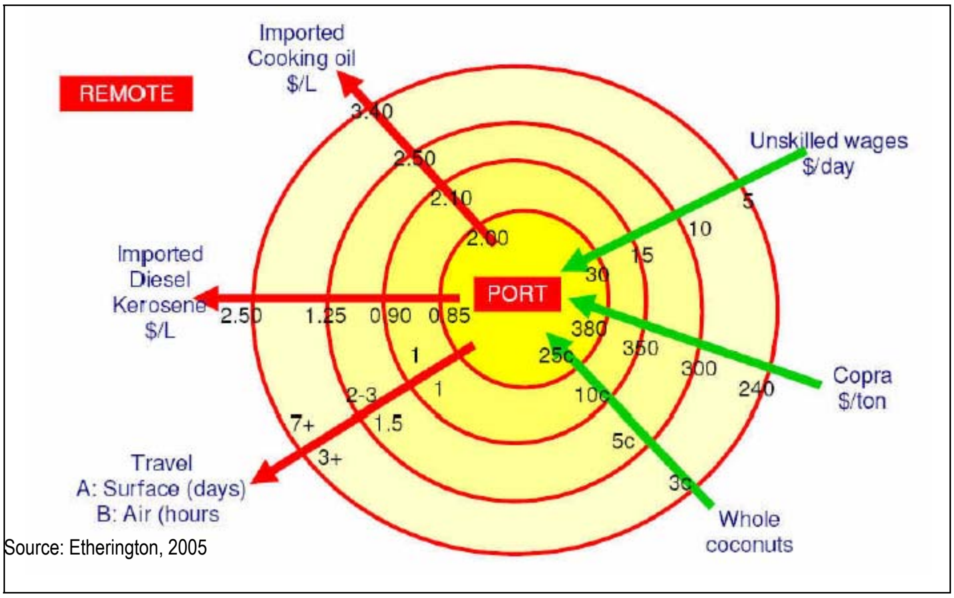

Figure 25. The effect of remoteness on fuel and coconut product prices.

For example, in Vanua Balavu, located in the outer islands in Fiji, energy consumers pay approximately US$0.22 per litre extra to ship diesel from the main port of Suva. In addition, they must pay approximately $57 per tonne of dry copra in shipping charges (Tevita Fotofili, personal communication, 2005). The substantial price differentials between the cost of imported diesel and price of coconut oil in PICs is illustrated in Figure 26.

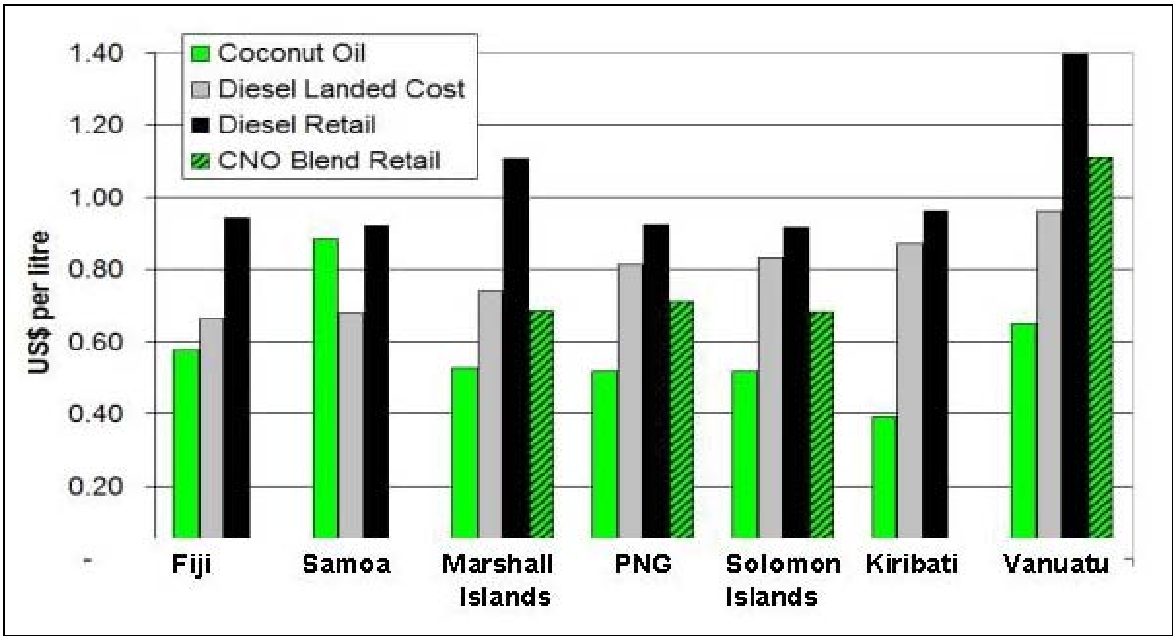

Figure 26. Price comparison of diesel and local coconut oil prices in selected PICs.
(Source: Cloin, 2006b)

Therefore, there is a large potential for the substitution of diesel for coconut oil given abundant coconut resources, and the price differentials between these commodities.

7.3.2 Micro-economic impact of biofuel production

However, at the local level, although there is a large potential for copra oil production in many countries, such opportunities are not being exploited due to poor economic incentives. Copra production in the Pacific has been regarded as a last-resort source of income, in the absence of alternatives, because of the hard work involved and low returns (Etherington, 2005). With advancing development in PICs, along with an expansion in economic opportunities, and increasing remittance flows to rural areas, copra production has been abandoned in many places in the Pacific, because of the increasing cost of labour. Coconuts are now used mainly to meet household needs and for livestock (Etherington, 2005). Also, due to the relatively high value that many people place on leisure time, relatively high returns must be offered in order to induce individuals to spend time producing copra. However, if a local market for biofuel was created, this could result in a rise in domestic demand for copra, leading to increased returns to copra producers. Also, as an alternative to high-cost, labour-intensive production of coconut oil, centralised production facilities have been created in several Pacific Islands to produce coconut oil using industrial processes. Since labour inputs are minimised, it is possible to make a reasonable profit. Therefore, the main challenge to the viability of using biofuel as a substitute for imported diesel is to ensure that returns to copra producers are high enough to guarantee a steady supply; while keeping coconut oil production costs low enough for biofuel to be price competitive. If this can be achieved, coconut oil could present the least-cost option for rural electrification when used in adapted diesel generators.

7.4 Case Study − The Fiji Biofuel Programme

7.4.1 Background

In order to promote rural electrification and sustainable livelihoods, and demonstrate the use of biofuel as a substitute for diesel, the Fiji Department of Energy, with support from the Secretariat of the Pacific Community and the French Government, installed specially adapted generators in Welagi Village located on Taveuni Island in 2001, and in Sawana Village on the island of Vanua Balavu, in the Northern Lau group, in 2000 (Courty, 2000).[37]

[37] The biofuel generator installed in Vanua Balavu, although located in Sawana, is intended to supply electricity to the villages of Lomaloma, Sawana, and the settlement of Naquara.

The rationale behind the two demonstration projects was that by using locally-produced coconut oil as a fuel for electricity generation, these communities could reduce their dependence on costly diesel imports (Courty, 2000). Village committees were made responsible for overseeing the operation and maintenance of the generators, as well as setting and collecting user fees in order to promote project sustainability (Fiji Department of Energy, 2001). In Welagi, it was intended that the village would produce its own coconut oil from its vast coconut resources, using the crusher provided under the project to power the generator. In Vanua Balavu, it was expected that coconut oil for the generator would be supplied from the local mill. Villages were required to cover 10% of the initial capital costs, while the French Government provided funds for the generators and coconut oil presses, and the Fiji Government covered the local and logistical costs associated with the project setup.

Figure 27. Defunct Coconut oil mill in Vanua Balavu, Fiji.

7.4.2 Project design

Welagi was provided with a 45-kVA adapted generator and mini-grid intended to supply electricity to 57 households; while a 95-kVA generator was installed on Vanua Balavu to supply power to 198 households, plus the hospital, the junior/secondary school and government quarters (Khan, 2005). Each household participating in the projects was supplied with two tube lights and a power point.

7.4.3 Costs of coconut oil versus diesel

Given that biofuel and diesel employ virtually the same technology for electricity production, they can be compared on fuel price differences alone, rather than on the basis of system life-cycle costs. Since coconut oil is an exportable good, its economic price is equal to the price received by the producer (world price) minus the costs of transport, handling and distribution, minus any net taxes.

The figures below present the economic price trends for both wholesale automotive diesel, and coconut oil over a 10-year period on Taveuni and Vanua Balavu, in Fiji (Jared Morris, Import Management Adviser, PIFS, personal communication, 2005; UNCTAD commodity price database).[38] Figure 28 illustrates the fact that, on Vanua Balavu, where the cost of diesel is approximately $0.22 higher per litre than at the main port of Suva, except for a brief coconut oil price 'spike' between mid-1998 and 2000, coconut oil enjoys a clear price advantage over diesel fuel.

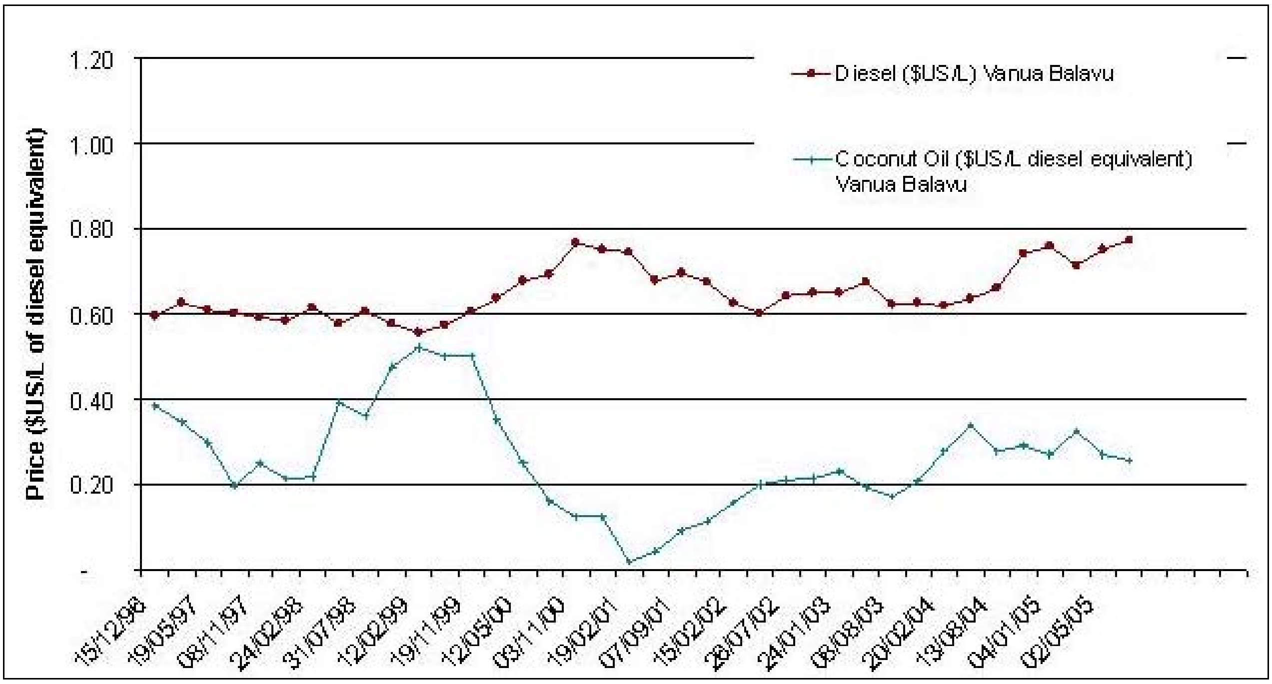

Figure 28. Coconut oil and diesel fuel price comparison for Vanua Balavu, Fiji.

Similarly, in Welagi, on the island of Taveuni, coconut oil has a slight price advantage over imported diesel as shown in Figure 29. However, since the cost of transporting diesel to the island are much lower (US$0.04 per litre) compared with Vanua Balavu, the price difference between the two commodities is narrower, and as a result coconut oil does not always have a clear price advantage over diesel fuel.

[38] Due to data availability, data is not taken at regular intervals. All prices have been adjusted for inflation; taxes and transport costs have also been subtracted from diesel and coconut oil prices. Fuel prices have been converted into US$ using the official FJ$/$US exchange rate, rather than the shadow exchange rate. However, given that the shadow exchange conversion factor for the $FJ/$US official exchange rate in recent years, (on average) has been approximately 0.95 (Lagman-Martin, 2004), the results from the analysis should not be significantly affected.

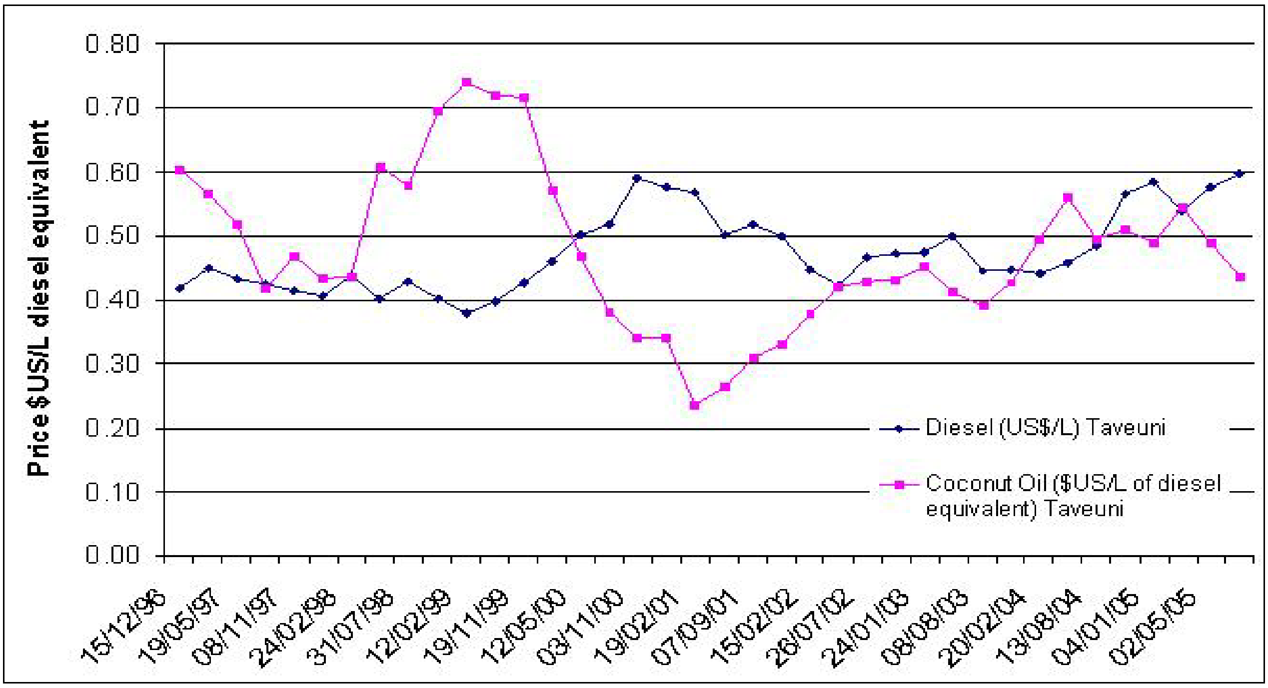

Figure 29. Coconut oil and diesel fuel price comparison in Taveuni (Welagi), Fiji.

In theory, rural communities served by stand-alone diesel-powered generators could switch between using diesel and coconut oil depending on which fuel was less expensive. For example, when diesel prices are low, locally-produced coconut oil could be sold for other uses. However, supply contracts, which effectively commit buyers and sellers to purchasing a given quantity of diesel or coconut oil at a certain price, may make it difficult to enjoy this flexibility.

7.4.4 Impact of the Fiji biofuel programme[39]

Access to electricity: Prior to the implementation of the biofuel project, residents in Welagi relied on kerosene, benzene and small gasoline generators to meet their energy needs. This did lead to quality of life improvements such as allowing children to study longer hours at night, and allowing households to use refrigerators for food preservation.

Costs avoided: In Vanua Balavu, prior to the installation of the biofuel generator, the villages of Sawana, Lomaloma and Naqara enjoyed access to electricity supplied by the diesel generator operated by the now defunct coconut oil mill. However, it was hoped that with the implementation of the biofuel project, substitution of diesel for locally-produced coconut oil would reduce the costs of operating the generator.

[39] This section is based on observations and conclusions from SOPAC (2006b)

To date neither of the project generators are running on coconut oil. The Welagi generator currently runs on diesel and the Vanua Balavu generator, at the time of writing, was non-operational (only for a brief initial period, did either the Welagi or Vanua Balavu generators run on coconut oil). The reasons for the demonstration projects not operating as intended include both economic and non-economic factors.

Obstacles to the use of locally-produced coconut oil for electricity production

i. High opportunity cost of labour*:* the returns to copra production, which is processed into coconut oil, are very low. Currently residents in Welagi can earn much higher returns producing dalo for sale, and using the proceeds to purchase either diesel or commercially-produced coconut oil; rather than using this time to produce coconut oil themselves for use in the biofuel generator (for details see SOPAC, 2006b). In Vanua Balavu, remittances from Suva and abroad reduce the incentives for copra production.

ii. Supply constraints*:* there is no longer a local supply of coconut oil available on Vanua Balavu, due to the closure of the coconut oil mill in 2000; and as a result, shipping costs from Vanua Levu make coconut oil more expensive than diesel, which was sold at approximately F$1.80 per litre at the time the research for this study was being conducted. Also, in Welagi, the local coconut oil producer, who produces mostly for niche export markets is apparently reluctant to supply fuel for the village generator (Intiyaz Khan, personal communication, Senior Scientific Officer, Fiji Department of Energy, 2006).

It is vital that a local supply of coconut is available for these projects to be viable. Otherwise imported coconut oil from other islands can become more costly than importing diesel due to weak distribution networks. However, there seems to be a fundamental trade-off between ensuring returns to copra production are high enough to induce an adequate local production of copra, while maintaining the price of coconut oil at a low enough level to compete with diesel.

7.4.5 Discussion and conclusions

In theory, coconut oil presents the least-cost choice compared with diesel in Fiji's remote outer islands, where transport costs are very high. At the micro-level in the villages that were examined as part of this study, the high opportunity cost of labour and other supply constraints reduce the economic feasibility of using locally-produced coconut oil for electricity production. However, similar biofuel projects for rural electrification could be feasible if a certain set of conditions held. First, if labour costs were low, production costs would be minimised, which would keep the price of coconut oil competitive with diesel. Second, if coconut oil production was centralised and mechanised, economies of scale could be achieved, and labour inputs minimised, thereby increasing its price competitiveness. Third, the location of a biofuel project would have to be isolated enough so that transports costs would make diesel imports very costly.

On the other hand, the introduction of coconut oil production subsidies, which would assist in making locally-produced biofuel more competitive with diesel, may be justified on public goods grounds, since switching from the use of diesel to coconut oil would not only have environmental benefits, but would also reduce dependence on imported fossil fuel and help to hedge against future oil price increases.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Pacific Islands face an enormous challenge in supplying electricity to rural areas, particularly in remote areas, where electrical grid extension is not economically feasible due to the high costs involved. At the same time, access to basic electricity services is regarded as a necessary condition for sustainable development. In the Pacific Region, many rural households lack access to modern forms of energy, although the proportion of the population with access to electricity varies considerably from country to country.

Currently, Pacific Islands are heavily dependent on imported fossil fuels for meeting the bulk of their energy needs. However, this situation is likely to be unsustainable in the long run with rising fuel costs and the growing trade deficits faced by many Pacific Island Countries. Renewable energy technologies, used in a number of demonstration projects, including solar, wind, hydropower and coconut biofuel have proven to be technically feasible options for electricity production in remote locations in recent years,. Furthermore, the results from this study indicate that renewable energy technologies can provide a cost-effective means of supplying electricity to rural areas, where distances are high, and population densities and per capita demand for energy is low.

It is important to highlight that there is not one technology that is least-cost, and it is very much dependent on local conditions, and renewable resource availability. Also, the hours of service, and energy loads that can be supported at any point in time, vary considerably between different energy options

In addition to the direct energy cost savings associated with renewable energy technologies, other benefits, which are not measured in this study, may include increased reliability of energy services, longer hours of daily service, reduced noise and pollution, and increased energy independence. Also, with more widespread use of renewable energy technologies in place of conventional fossil fuel-based alternatives, Pacific Island Countries can assist in addressing global climate change by limiting their green house gas emissions.

8.2 Recommendations

Although, renewable energy technologies have been demonstrated to offer a cost-effective source of energy for rural electrification, the greatest barriers to their wider use in rural electrification strategies are institutional in nature. It is critical to develop effective models for managing renewable energy projects in order to ensure their long-term sustainability. In particular, projects should be designed to ensure that equipment is properly maintained, and that user fees are both collected and set to a level, which ensures that projects are financially sustainable. It is important that experiences with different institutional models applied to renewable energy projects in Pacific Island Countries are shared between countries, so that successful models can be replicated and adapted to local conditions in future projects, and the repetition of past errors avoided.

Also, in order to promote the use of renewable energy technologies, countries should develop policies, which ensure that renewable energy technologies are adequately considered as options in energy planning. For example, only Palau requires the utility to consider renewable energy options in the development of energy plans (Wade and others, 2005).

Finally, since the start-up costs associated with renewable energy technologies tend to be high, it is recommended that policies be introduced, which assist in lowering the initial costs. This is another major barrier to their use. Lowering initial costs can be achieved in a number of ways such as through the use of cost-sharing schemes, import tax exemptions, the provision of soft loans, or increasing users' ability to pay for energy, through the introduction of income-generating schemes in conjunction with electrification projects. It is important to ensure that rural electrification strategies are integrated into national development plans because of the investment trade-offs between sectors, given the limited availability of resources.

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APPENDIX 1

Life-Cycle Costs of PV and Diesel Systems in Ha'apai and Least-Cost Analysis

a) Sizing the PV system

The Ha'apai solar project provides households with three 13-Watt lights and a power point for using a small appliance such as a 10-Watt radio.

Assume that the typical household energy requirements are as follows:

2 lights used for 5 hours per day (2 x 13 x 5)	= 130 Wh
1 light used for 2 hours per day (1 x 13 x 2)	= 26 Wh
1 radio used for 3 hours per day (1 x 10 x 3)	= 30 Wh
Total	= 186 Wh
Total (including 30% system loss[40])	= 241.8 Wh of electricity demanded

Energy provided by the PV system:

According to Wade (2002), the average panel generation factor is 3.43 Wh/day in a typical Pacific Island setting (assuming a tropical coastal climate with most days partly cloudy, and fully cloudy periods no longer than 5 days long).

Therefore, if the panel generation factor is assumed to be 3.43 Wh/day,

A 75 Wp panel produces:	75 Wp x 3.43 Wh/day	= 257 Wh/day
A 150 Wp panel produces:	150 Wp x 3.43 Wh/day	= 514.5 Wh/day

In reality, more energy would probably be produced from the PV system, given Tonga's sunnier tropical climate, the generation factor is more likely to be around 3.86 Wh/day (Wade, 2002). As s result, 290 Wh would be available from a 75 Wp system, and 579 Wh/day from a 150 Wp system.

Therefore, if household energy consumption patterns follow the assumptions above, a 75 Wp panel would be sufficient to meet the current demand for energy.

b) Solar home system cost assumptions

CAPITAL INVESTMENT COSTS

Component	**Cost ($T)**
Modules	940
Batteries	450
Controller	245
Lights	280
Post	70
Wire	360
Transport	400
Labour	400
Other	230
Total	3,375
Total ($US 2005) per system	2,001.28

[40] According to Wade (2002), energy produced by solar panels is always lost in the battery, wires and controller, and it can be assumed that for every 100 Wh needed by electrical appliances, and in order to compensate for this loss, at least 130 Wh must be provided by the panels.

OPERATION AND MAINTENANCE COSTS

Annual operation and maintenance costs are assumed to be 1% of initial system capital investment cost.

Batteries life is assumed to be 7 years for a 150 Wp panel system, and 5 years for a 75 Wp panel system.

c) Diesel mini-grid cost assumptions

CAPITAL INVESTMENT COSTS

Installed generator cost: US$36,000 (36 kW generator @ $1,000/kW, assumed life of 20 years)

Construction of distribution network: $15,000

OPERATION AND MAINTENANCE COSTS

Fuel costs are based on energy consumption of: 10 kWh per day for 40 households
Distribution losses: 15%
Total Energy Consumption = 11.5 kWh per day
Fuel efficiency of generator: 0.2 Litres/kWh
Total annual fuel consumption = 839.5 litres
Cost of fuel: US$1.20/litre
Annual Fuel Costs = US$1,007.40
See Section 3.2.2 for other diesel cost assumptions
Discount rate: 10%

Table A1. Life-Cycle Cost Analysis: Diesel Mini-grid versus Solar Home Systems on 'O'ua, Tonga

	VILLAGE DIESEL MINI-GRID SYSTEM				SOLAR HOME SYSTEMS (150 WP)			SOLAR HOME SYSTEMS (75 WP)		
Year	Capital Investment Costs (2005$US)	Fuel Costs (2005$US)	Operation and Maintenance Costs (2005$US)	Total Discounted Costs (10% discount rate)	Capital Investment Costs (2005$US)	Operation and Maintenance Costs (2005$US)	Total Discounted Costs (10% discount rate)	Capital Investment Costs (2005$US)	Operation and Maintenance Costs (2005$US)	Total Discounted Costs (10% discount rate)
0	51,000.00			51000.00	80,051.00		80,051.00	69882.00		69,882.00
1		1007.40	1750	2506.73		800.51	727.74		698.82	635.29
2		1007.40	1750	2278.84		800.51	661.58		698.82	577.54
3		1007.40	1750	2071.68		800.51	601.44		698.82	525.03
4		1007.40	1750	1883.34		800.51	546.76		698.82	477.30
5		1007.40	9000	6213.81		800.51	497.05		9736	6,045.29
6		1007.40	1750	1556.48		800.51	451.87		698.82	394.47
7		1007.40	7200	4211.69		9,736	4,996.11		698.82	358.61
8		1007.40	1750	1286.35		800.51	373.44		698.82	326.00
9		1007.40	1750	1169.41		800.51	339.49		698.82	296.37
10		1007.40	36000	14267.95		800.51	308.63		9736	3,753.65
11		1007.40	1750	966.45		800.51	280.57		698.82	244.93
12		1007.40	1750	878.59		800.51	255.07		698.82	222.67
13		1007.40	1750	798.72		800.51	231.88		698.82	202.42
14		1007.40	1750	726.11		9,736	2,563.79		698.82	184.02
15		1007.40	9000	2395.69		800.51	191.64		9736	2,330.72
16		1007.40	1750	600.09		800.51	174.21		698.82	152.08
17		1007.40	7200	1623.79		800.51	158.38		698.82	138.26
18		1007.40	1750	495.94		800.51	143.98		698.82	125.69
19		1007.40	1750	450.86		800.51	130.89		698.82	114.26
20		1007.40	1750	409.87		800.51	118.99		698.82	103.88
Present Value				**97,792.40**			**93,804.51**			**87,090.48**

APPENDIX 2

Least-Cost Analysis: Diesel versus Micro-Hydro in Bulelavata, Solomon Islands

VILLAGE LOAD CALCULATIONS

a. Diesel

Appliance	Unit Power Level	Number	Hours	Total kWh	Number HH	Total Wh
Domestic Lighting	28	2	5	280	50	14,000
Radio	10	1	5	50	50	2,500
Water heater	1000	1	1	1000	15	15,000
Refrigerator	400	1	5	2000	5	10,000
						41500 Wh/day
Distribution loss (15%)						47,725Wh/day
						47.73kW/day
TOTAL						1,431.75 kW/month

b. Micro-hydro

Appliance	Unit Power Level	Number	Hours	Total kWh	Number HH	Total Wh
Domestic Lighting	28	2	6	336	50	16,800
Radio	10	1	5	50	50	2,500
Water heater	1000	1	1	1000	15	15,000
Refrigerator	400	1	12	4800	5	24,000
Street lighting	28	50	11	15400	n/a	15,400
Deep Freezer	2000	2	12	48000		48,000
						121,700 Wh/day
Distribution loss (15%)						139,500Wh/day
						139.96 kWh/day
TOTAL						4,198.65 kWh/month

A. DIESEL SYSTEM COSTS

Capital Investment Costs

It is assumed that one 35-kW generator would be required by Beula Provincial Secondary School and that a 35 kW generator would be required by the village, at a total cost of US$70,000 (assuming installed costs of US$1000/kW). It is estimated that a village distribution system would cost approximately $15,000. Total estimated capital costs for electricity provided by diesel generators are as follows:

2 x 35 kW diesel generators	US$70,000
Transmission and Distribution System	US$15,000
TOTAL CAPITAL COSTS	US$85,000

Operation and Maintenance Costs

Diesel Consumption Estimates:

Based on previous studies, it was estimated that Beula Provincial Secondary School consumed approximately 600L of diesel per month before joining the micro-hydro scheme (APACE, 1997). Given that the school generators were old and as a result, likely very inefficient for the purpose of analysis, it is assumed that fuel consumption is 75% of this figure, or 450 litres per month (this is likely to be an underestimate of fuel consumption in the absence of micro-hydro system since kerosene and fuel-wood were also used in addition to diesel generators).

Total Village Energy Consumption	1,431.75	kWh/month
Assumed diesel generator efficiency	0.2	litres/kWh
Total Village Fuel Consumption	286.35	litres
Total School Fuel Consumption	450	litres
Total Fuel Consumption	736.35	litres/month
	8,836.2	litres/year
Diesel Fuel Cost per Litre	$1.30	US
Total Diesel Fuel Cost	$11,487.06	US/year

Price of diesel in Gizo	SB$9.80/litre (SB$1,750 per 200 litre drum)
Sales tax	SB$0.10/litre
Excise tax	SB$0.22/litre
Actual Cost	SB$9.48
US$/SB$ exchange rate	0.137
Actual cost of diesel	= US$1.30/litre

B. MICRO-HYDROELECTRICITY SYSTEM COSTS

Capital Investment Costs

Capital cost estimates provided by APACE (project design, equipment purchase, installation, transport and labour): US$228,919

Operation and Maintenance Costs

The life of the micro-hydroelectric system is assumed to be 20 years.

Annual costs of operation and maintenance estimated by the technician: US$102.75 (includes costs of replacing minor parts such as belts every few years).

Table A2. Total Life-Cycle Costs of Diesel and Micro-hydro Systems.

	DIESEL MINI-GRID SYSTEMS				MICRO-HYDRO SYSTEM		
Year	Capital Investment Costs (2005$US)	Annual Fuel Costs (2005$US)	Operation and Maintenance Costs	Total Discounted Costs (10% discount rate)	Capital Investment Costs (2005$US)	Operation and Maintenance Costs (2005$US	Total Discounted Costs (10% discount rate)
0	268,857			85,000.00	228,919.58		228,919.58
1		11,487.06	4,250.00	14,306.42		102.75	93.41
2		11,487.06	4,250.00	13,005.83		102.75	84.92
3		11,487.06	4,250.00	11,823.49		102.75	77.20
4		11,487.06	4,250.00	10,748.62		102.75	70.18
5		11,487.06	21,250.00	20,327.14		102.75	63.80
6		11,487.06	4,250.00	8,883.16		102.75	58.00
7		11,487.06	17,000.00	14,618.37		102.75	52.73
8		11,487.06	4,250.00	7,341.45		102.75	47.93
9		11,487.06	4,250.00	6,674.05		102.75	43.58
10		11,487.06	70,000.00	31,416.79		102.75	39.61
11		11,487.06	4,250.00	5,515.74		102.75	36.01
12		11,487.06	4,250.00	5,014.31		102.75	32.74
13		11,487.06	4,250.00	4,558.47		102.75	29.76
14		11,487.06	4,250.000.00	4,144.06		102.75	27.06
15		11,487.06	21,250.00	6,819.58		102.75	24.60
16		11,487.06	4,250.00	3,424.84		102.75	22.36
17		11,487.06	17,000.00	6,476.85		102.75	20.33
18		11,487.06	4,250.00	2,830.45		102.75	18.48
19		11,487.06	4,250.00	2,573.14		102.75	16.80
20		11,487.06	4,250.00	2,339.21		102.75	15.27
TOTAL ($US)				**267,842.07**			**229,794.35**

APPENDIX 3

Cost-Benefit Analysis of the Mangaia Wind Project

Diesel Costs

Components of diesel price in Mangaia	$NZ	$US
Bulk price diesel Rarotonga (incl. Tax)	1.93	1.22
Taxes		
VAT (12.5%)	0.24	0.15
Levy	0.22	0.14
Freight to Mangaia	0.15	0.10
Nominal price (bulk price + transport)		1.31
Real price (bulk price + transport – tax)		1.02

Actual wind production Oct 2004 − Sept 2005: 27,799 kWh.

Assumed efficiency of diesel generators: 0.34 litres/kWh.

Total annual diesel savings (based on real price of diesel): US$9,640.69.

It is assumed that demand for energy is increasing 6% per annum.

Cost estimates were obtained from the Vergnet (2001) Mangaia pre-feasibility study.

CAPITAL COST ESTIMATES		**$NZ** Total Price ($NZ)	% of Total
2 Wind turbines	20 KW	90,000.00	24.0064
Control connection box (2)		12,000.00	3.200854
Remote control system		10,000.00	2.667378
Transformer		13,500.00	3.60096
Freight		16,700.00	4.454521
Taxes		136,200.00	36.32969
Civil works		13,100.00	3.494265
Levelling		1,200.00	0.320085
Technical building		1,200.00	0.320085
11 KV grid connection		13,000.00	3.467591
Telephone		4,000.00	1.066951
Assembly and wiring		44,000.00	11.73646
Consulting and commissioning		20,000.00	5.334756
TOTAL	(incl duty)	374,900.00	100
	duty free	238,700.00	
		163,898.84 $US 2005	(NZ$1=US$0.63)

ANNUAL OPERATION AND MAINTENANCE COSTS

Site visit	7,500.00	
Servicing	1,500.00	
Parts replacement	1,000.00	
TOTAL	**10,000.00**	**Per year**
	6,866.31	**$US 2005**

Table A3. Costs and benefits of adding wind turbines to the Mangaia electricity production system.

Years	Capital Cost of Total System ($US)	Electricity Supplied (kWh)			Diesel Fuel Used (litres)			Price of Fuel ($US/litre)	Cost Effects of Wind		Net Benefit (10% discount rate)
		Energy Supplied Total System	Net Wind Supply to Load	Net Diesel Supply to Load	Fuel Consumed without Wind	Fuel Consumed with Wind	Fuel Saved with Wind		Value of Fuel Saved	O&M	
0	163,898.84										–163,898.84
1		458,640.00	27,799.00	430,841.00	155,937.60	146,485.94	9,451.66	1.02	9,640.69	6,866.31	2,522.17
2		486,158.40	27,799.00	458,359.40	165,293.86	155,842.20	9,451.66	1.02	9,640.69	6,866.31	2,292.88
3		515,327.90	27,799.00	487,528.90	175,211.49	165,759.83	9,451.66	1.02	9,640.69	6,866.31	2,084.43
4		546,247.58	27,799.00	518,448.58	185,724.18	176,272.52	9,451.66	1.02	9,640.69	6,866.31	1,894.94
5		579,022.43	27,799.00	551,223.43	196,867.63	187,415.97	9,451.66	1.02	9,640.69	6,866.31	1,722.67
6		613,763.78	27,799.00	585,964.78	208,679.68	199,228.02	9,451.66	1.02	9,640.69	6,866.31	1,566.07
7		650,589.61	27,799.00	622,790.61	221,200.47	211,748.81	9,451.66	1.02	9,640.69	6,866.31	1,423.70
8		689,624.98	27,799.00	661,825.98	234,472.49	225,020.83	9,451.66	1.02	9,640.69	6,866.31	1,294.27
9		731,002.48	27,799.00	703,203.48	248,540.84	239,089.18	9,451.66	1.02	9,640.69	6,866.31	1,176.61
10		774,862.63	27,799.00	747,063.63	263,453.29	254,001.63	9,451.66	1.02	9,640.69	6,866.31	1,069.64
11		821,354.39	27,799.00	793,555.39	279,260.49	269,808.83	9,451.66	1.02	9,640.69	6,866.31	972.40
12		870,635.65	27,799.00	842,836.65	296,016.12	286,564.46	9,451.66	1.02	9,640.69	6,866.31	884.00
13		922,873.79	27,799.00	895,074.79	313,777.09	304,325.43	9,451.66	1.02	9,640.69	6,866.31	803.64
14		978,246.22	27,799.00	950,447.22	332,603.71	323,152.05	9,451.66	1.02	9,640.69	6,866.31	730.58
15		1,036,940.99	27,799.00	1,009,141.99	352,559.94	343,108.28	9,451.66	1.02	9,640.69	6,866.31	664.17
16		1,099,157.45	27,799.00	1,071,358.45	373,713.53	364,261.87	9,451.66	1.02	9,640.69	6,866.31	603.79
17		1,165,106.90	27,799.00	1,137,307.90	396,136.34	386,684.68	9,451.66	1.02	9,640.69	6,866.31	548.90
18		1,235,013.31	27,799.00	1,207,214.31	419,904.53	410,452.87	9,451.66	1.02	9,640.69	6,866.31	499.00
19		1,309,114.11	27,799.00	1,281,315.11	445,098.80	435,647.14	9,451.66	1.02	9,640.69	6,866.31	453.63
20		1,387,660.96	27,799.00	1,359,861.96	471,804.72	462,353.06	9,451.66	1.02	9,640.69	6,866.31	412.39
									Present Value		**– 140,278.96**

APPENDIX 4

Glossary

Definitions of the following energy terms were obtained from EIA (2006) and the California Energy Commission (2006).

Alternating Current (AC): An electric current that reverses its direction at regularly recurring intervals, usually 50 or 60 times per second.

Biofuels: Liquid fuels and blending components produced from biomass (plant), used for electricity production and transportation.

Ampere: The unit of measurement of electrical current produced in a circuit by 1 volt acting through a resistance of 1 Ohm.

Diesel: Fuel for diesel engines obtained from the distillation of petroleum. It is composed chiefly of aliphatic hydrocarbons. Its volatility is similar to that of gas oil.

Diesel fuel system: Diesel engines are internal combustion engines that burn diesel oil rather than gasoline. Injectors are used to spray droplets of diesel oil into the combustion chambers, at or near the top of the compression stroke. Ignition follows due to the very high temperature of the compressed intake air, or to the use of "glow plugs," which retain heat from previous ignitions (spark plugs are not used). Diesel engines are generally more fuel-efficient than gasoline engines but must be stronger and heavier because of high compression ratios

Direct Current (DC): Electricity that flows continuously in the same direction.

Distribution System: The substations, transformers and lines that convey electricity from high-power transmission lines to ultimate consumers.

Economy of scale: The principle that larger production facilities have lower unit costs than smaller facilities.

Efficiency: The fuel efficiency of a diesel generator can be defined as the amount of power an engine can produce per amount of fuel it burns.

Emissions: Anthropogenic releases of gases to the atmosphere. In the context of global climate change, they consist of radiatively important greenhouse gases (e.g., the release of carbon dioxide during fuel combustion)

Gross domestic product (GDP): The total value of goods and services produced by labor and property located in the United States. As long as the labor and property are located in the United States, the supplier (that is, the workers and, for property, the owners) may be either U.S. residents or residents of foreign countries.

Kerosene: Certain colorless, low-sulfur oil products that burn without producing much smoke.

Kilowatt (kW): One thousand (1,000) watts. A unit of measure of the amount of electricity needed to operate given equipment.

Kilowatt-hour (kWh): The most commonly-used unit of measure telling the amount of electricity consumed over time. It means one kilowatt of electricity supplied for one hour.

Life-Cycle Cost (LCC): The present value of the total cost of purchasing, installing, operating, maintaining and repairing a energy generating system over its economic life.

Levelised cost: see life-cycle cost

Load: The amount of electric power supplied to meet one or more end-user's needs.

Megawatt (MW): One million watts of electricity.

Peak watt: A manufacturer's unit indicating the amount of power a photovoltaic cell or module will produce at standard test conditions (normally 1,000 watts per square meter and 25 degrees Celsius).

Peak Load: The highest electrical demand within a particular period of time. Daily electric peaks on weekdays occur in the late afternoon and early evening.

Petroleum: A broadly-defined class of liquid hydrocarbon mixtures. Included are crude oil, lease condensate, unfinished oils, refined products obtained from the processing of crude oil, and natural gas plant liquids.

Petroleum products: Petroleum products are obtained from the processing of crude oil (including lease condensate), natural gas, and other hydrocarbon compounds. Petroleum products include unfinished oils, liquefied petroleum gases, pentanes plus, aviation gasoline, motor gasoline, naphtha-type jet fuel, kerosene-type jet fuel, kerosene, distillate fuel oil, residual fuel oil, petrochemical feedstocks, special naphthas, lubricants, waxes, petroleum coke, asphalt, road oil, still gas, and miscellaneous products.

Photovoltaic cell (PVC): An electronic device consisting of layers of semiconductor materials fabricated to form a junction (adjacent layers of materials with different electronic characteristics) and electrical contacts capable of converting incident light directly into electricity (direct current).

Power: Electricity for use as energy.

Renewable Energy: Resources that constantly renew themselves or that are regarded as practically inexhaustible. These include solar, wind, geothermal, hydro and wood. Renewable resources also include some experimental or less-developed sources such as tidal power, sea currents and ocean thermal gradients.

Solar energy: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.

Volt (V): The volt is the International System of Units (SI) measure of electric potential or electromotive force. A potential of one volt appears across a resistance of one ohm when a current of one ampere flows through that resistance. Reduced to SI base units, 1 V = 1 kg times m^2 times s^{-3} times A^{-1} (kilogram meter squared per second cubed per ampere).

Watt (W): The unit of electrical power equal to one ampere under a pressure of one volt. A Watt is equal to 1/746 horsepower.

Watt-hour (Wh): The electrical energy unit of measure equal to one watt of power supplied to, or taken from, an electric circuit steadily for one hour.

Wind energy: Energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators. Wind pushes against sails, vanes, or blades radiating from a central rotating shaft.