# A Least Cost Analysis of Electricity Generation Options for Kiritimati Island

Kiribati Ministry of Public Works & Utilities

July 2013

*With technical assistance provided by the Deutsche Gesellschaft fuer Internationale Zusammenarbeit (GIZ) GmbH and the Secretariat of the Pacific Community*

SPC
Secretariat of the Pacific Community

giz
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

# Table of Contents

# List of Tables



# List of Figures

# Abbreviations

| | |
|---|---|
| ADB | Asian Development Bank |
| AoSIS | Alliance of Small Island States |
| AUD | Australian Dollar |
| AusAID | Australian Agency for International Development |
| GH | Garrad Hassan |
| IPCC | Intergovernmental Panel on Climate Change |
| IRENA | International Renewable Energy Agency |
| KNEP | Kiribati National Energy Policy |
| KOIL | Kiribati Oil Company |
| KSEC | Kiribati Solar Energy Company |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| kWp | Kilowatt peak |
| LCA | Least Cost Analysis |
| LCOE | Levelised Cost of Electricity |
| MLPID | Ministry of Line and Phoenix Islands Development |
| MPWU | Ministry of Public Works & Utilities |
| NZMED | New Zealand Ministry of Economic Development |
| NZMFAT | New Zealand Ministry of Foreign Affairs and Trade |
| O & M | Operation & Maintenance |
| PUB | Public Utilities Board |
| UK DECC | United Kingdom Department of Energy and Climate Change |
| UNFCCC | United Nations Framework Convention on Climate Change |
| US EIA | United States Energy Information Administration |
| USD | United States Dollar |

# Preface & Acknowledgements

A training workshop on Cost-Benefit Analysis (CBA) for decision-makers, economists and project managers in relation to climate change was conducted at the Kiribati Institute of Technology in January 2013 with support from SPC, SPREP and GIZ.

An objective of the training workshop was to develop work plans for proposed CBAs to assist with real decisions to be taken in the area of climate change adaptation and mitigation. The planned CBAs would then be undertaken by Kiribati government departments with external assistance where requested. At the end of the workshop, participants from the Energy Planning Unit (EPU) of the Ministry of Public Works and Utilities presented a draft work plan for a CBA of electricity supply options for Kiritimati Island.

Following the workshop the EPU requested technical assistance from the SPC/GIZ Coping with Climate Change in the Pacific Islands Region (CCCPIR) programme to finalise the work plan and carry out the CBA. The present report is the output of the assessment undertaken, which upon further consultation between the EPU and the CCCPIR was changed to a Least-Cost Analysis (LCA) to assist in identifying the least cost electricity generation technology for Kiritimati Island.

This report was prepared by Mr. Julian Tollestrup, SPC/GIZ CCCPIR Consultant, Ms. Katerina Syngellakis, SPC/GIZ Sustainable Energy Management Adviser and Mr. Kireua Bureimoa, EPU Energy Planner.

The authors would like to acknowledge the assistance of the following in providing valuable inputs for the preparation of the original work plan for the CBA, the facilitation of a fact-finding mission to Kiritimati Island and the preparation and finalisation of this report:

| | |
|---|---|
| Debwe Kanono | Secretary, Ministry of Line & Phoenix Islands Development (MLPID) |
| Faioa Mikarite | Accountant & Officer in Charge, MLPID |
| Beraina Teirane | Senior Resource Economist, MLPID |
| Kaeka Erieru | Power Foreman, MLPID |
| Timon Iuta | Electrical Superintendent, MLPID |
| Mikarite Temari | Mayor Kiritimati Island |
| Fr Bwebwenta | Catholic Development Committee - Kiritimati Island |
| Teauoki Tonako | General Manager, KOIL Kiritimati Island Branch |
| Herb Wade | Independent Consultant |
| Neil Allison | Energy/Transport Economist, SPC |
| Aaron Buncle | Resource Economist, SPREP |
| Hanna Sabass | Kiribati Country Manager, SPC/GIZ CCCPIR |
| Marita Manley | Climate Change Adviser, SPC/GIZ CCCPIR |

# Executive Summary

Typical of remote Pacific islands, Kiritimati Island in Kiribati experiences a high cost of electricity production. Compared to a regional average of between AU$0.35 and AU$0.55 (IRENA 2012a), the cost of producing electricity on Kiritimati Island is estimated to be as much as AU$0.67 per kilowatt-hour (kWh).

The reasons for this are varied and are likely to include some degree of administrative and technical inefficiencies. Nevertheless, items which have been identified as the primary contributors are the increasing price of diesel and the high cost of shipping to the isolated atoll, which are both necessary costs in the operation of the island's diesel generators.

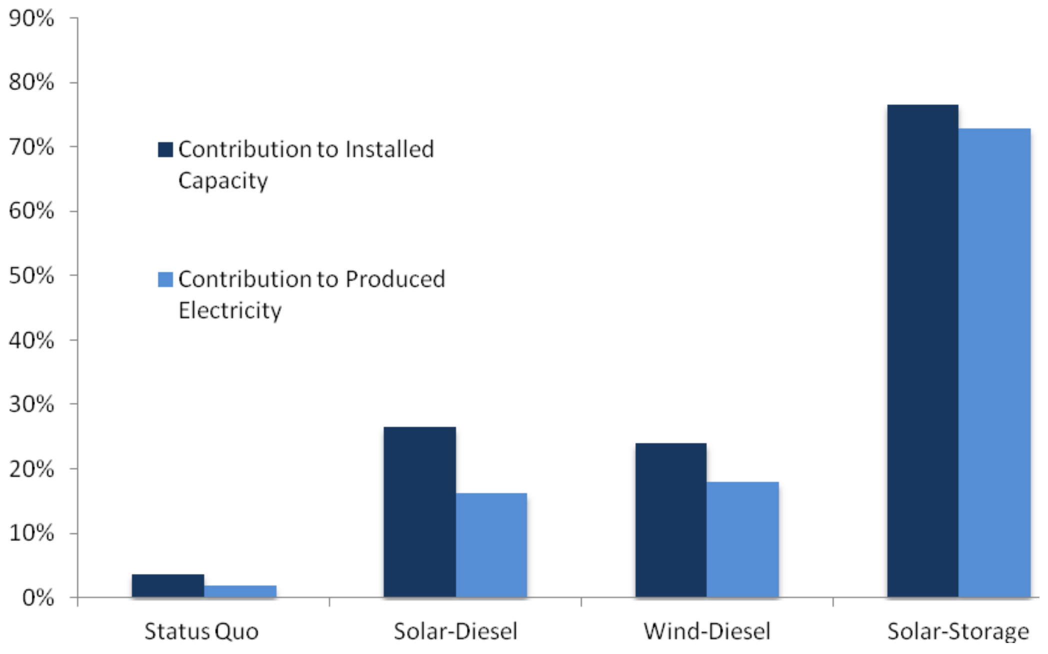
While generous electricity subsidies of up to 55 percent have mostly sheltered consumers from the effect of increasing prices, the Ministry of Line and Phoenix Islands Development (MLPID) has felt them to their full extent. As the responsible ministry for the provision of electrical services, they have been required to cover the full costs of production and thus are devoting an increasing proportion of their budget to cover fuel costs for electricity production creating pressure on budgets for other sectors.

In light of these challenges and the co-benefits of reducing Kiritimati Island's reliance on imported fuel, the government has taken an interest in the feasibility of utilising renewable alternatives to conventional generators. In both the Kiribati National Energy Policy and the Kiribati Development Plan, the development of renewable energy is outlined as a key priority due its ability to reduce costs, improve energy security, and minimise the country's environmental impact. As such, the Government of Kiribati has also outlined as a strategic objective a target of 100 percent renewable energy on Kiritimati Island.

This report undertakes a least cost analysis (LCA) of electricity supply options on Kiritimati Island, with a goal to assist decision makers in achieving renewable energy targets for Kiritimati Island. In particular, the report examines options for supplying electricity to the extended grid network that has been proposed by the MLPID which seeks to inter-connect the existing load centres in London, Tabwakea, and Tennessee.

Looking at both a solar-diesel and wind-diesel hybrid that would raise the installed capacity of renewable energy on this network to approximately 40 percent, and a solar-storage configuration, capable of raising the installed capacity to 90 percent, this study compares the competiveness of these renewable alternatives to that of the status quo diesel generation.
As is illustrated in Figure 1, each of the options would make a significant, although varied contribution towards the government target of reaching 100 percent renewable energy on Kiritimati Island.

*Figure 1.* **Contribution of RE to Installed Capacity & Total Production on Kiritimati**




*Source: Author's Analysis*

The analysis finds that from a financial viewpoint, it would be in the MLPID's interest to utilise a solar-diesel or wind-diesel hybrid to generate electricity on the inter-connected network proposed for Kiritimati Island. As is illustrated in Figure 2, these options would be capable of achieving a $0.03/kWh and $0.01/kWh saving, respectively, compared to the status quo diesel generators. In contrast, it was found that the solar-storage option would not be competitive at current prices, being estimated to cost approximately AU$0.17/kWh more than a continuation with the existing practices.

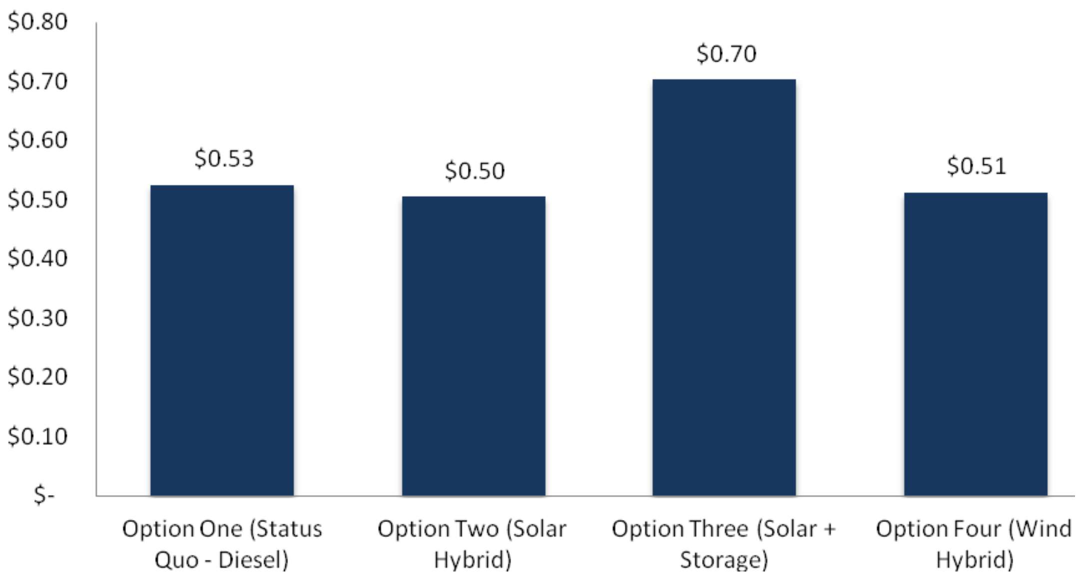
With financial characteristics aside, there were also other important points of difference found to exist between each of the alternatives investigated in this analysis. Two particular issues were the emission of $CO_2$ and the consumption of fuel, both of whose reduction has been cited by the Kiribati Government as key policy priorities. With regard to these two criteria, the solar-storage alternative was the most attractive option, followed by the wind-diesel hybrid, solar-diesel hybrid, and status quo respectively. In light of the balance of payment gains of reducing fuel imports and the strategic benefits of reducing emissions, such factors should be taken into account alongside each of the options' financial characteristics.

In addition to this, it is important that decision makers give due consideration to the expected growth in Kiritimati Island's load. This study found that based on historical growth trends and proposed developments, it is likely that demand for electricity on Kiritimati Island will grow to between three and seven times that of current levels by 2032. For this reason, there may be a justification for utilising more economically modular technologies, whose capacity could be incrementally expanded as necessary, at a similar unit cost to that of the initial installation. In this regard, solar technologies would have the advantage.

Ultimately, the most suitable technology for Kiritimati Island will depend on the priority decision makers place on economic, environmental, political, and strategic characteristics. While these are matters that will need to be decided by the national and Kiritimati stakeholders and decision-makers, whatever the case, it is clear that significant improvements can be made in all areas by a shift away from the continued use of diesel generators.

The present least-cost analysis shows that a solar-diesel hybrid would achieve the lowest costs for the MLPID, while still at least partly addressing $CO_2$ emission and fossil fuel import reductions. However, further feasibility studies and consultations on Kiritimati Island will have to be undertaken to confirm these findings and plan the way forward.

*Figure 2.* **LCOE of the four options examined**




*Source: Author's Analysis*

# 1 Introduction

As is true of many areas in the Pacific, the cost of producing electricity on Kiritimati Island is high. Recent estimates suggest that compared to a regional average of between AU$0.35 and AU$0.55 (IRENA 2012a), the cost of producing electricity on Kiritimati Island is as much as AU$0.67 per kilowatt hour. While the island's heavily subsidised tariffs, on average just AU$0.32 / kWh, have largely sheltered consumers from the impact of these costs, this has not been the case for the Ministry of Line and Phoenix Islands Development (MLPID). As the Ministry is responsible for the provision of electrical services on Kiritimati Island, they have been burdened with the shortfall between the subsidised tariffs paid by consumers and the actual cost of production. This has resulted in a significant reduction of the Ministry's available budget and has diverted funds from other uses such as housing and education.

While Kiritimati Island's rising costs are likely to be in some capacity a function of administrative and technical inefficiencies, their primary source has been the increasing operational costs of the existing electrical infrastructure. Due to the MLPIDs complete reliance on conventional generators, the rising price of diesel has had a direct impact on the cost of electricity on Kiritimati Island - a trend that has been compounded by the high cost of shipping to the isolated atoll which is itself a function of fuel prices.

With this issue in mind, as well as others such as energy security, the MLPID and Kiribati Government have become increasingly interested in reducing their reliance on diesel generators. Indeed, while such a move would offer a means to dampen the impact of rising fuel prices, it would also deliver a number of significant co-benefits that have been recognised in the country's energy policy framework. In both the Kiribati National Energy Policy and the Kiribati Development Plan, the development of renewable energy is outlined as a key priority due its ability to reduce costs, improve energy security, and minimise the country's environmental impact. As such, in the IRENA Kiribati Renewables Readiness Assessment, the government specifically outlines as an action to address these key policy areas, an investigation into, and intention to develop, alternative technologies on Kiritimati Island[1].

This study seeks to assist the development of such projects and provide a resource for decision makers, by analysing the cost of wind, solar, and energy storage technologies that could replace the existing use of diesel generators on Kiritimati Island. In particular, this analysis is focused on the hypothetical network that has been proposed by the MLPID that would connect the existing mini-grids between London and Tabwakea, and carry approximately 82 percent of Kiritimati Island's cumulative load. Looking at this network, with an emphasis on the unit cost of electricity production, this study undertakes a least cost analysis with a primary aim to identify the most

[1] See "Action 5: Determine the best roles for the available renewable energies in Kiritimati's power development", p.70, Kiribati Renewable Readiness Assessment, IRENA, 2012

financially competitive alternative to existing practices, from the perspective of the MLPID. The objective of this report is not to provide an in-depth technical appraisal of the alternatives, but instead to provide a balanced financial comparison and to provide guidance for more detailed feasibility studies to be undertaken.

As a part of this analysis, four theoretical options are assessed that would be capable of satisfying the requirements of the expanded London to Tabwakea network. Importantly, to provide an accurate baseline for comparison, the first of these options is the status quo, which would represent the continued use of a single 400 kW diesel generator. The remaining options, however, make use of renewable technologies, with the second option being a solar-diesel hybrid that would utilise a 233 kWp solar PV installation and a 350 kW diesel generator, and the third being a wind-diesel hybrid that would utilise a 200 kW wind turbine and a 350 kW diesel generator. The fourth option assessed in this analysis is a 1500 kWp solar installation, paired with a battery stock with capacity of 13.2 MWh, and a small backup diesel generator. Options 2 and 3 would increase the installed capacity of renewable electricity on the extended London network to approximately 40 percent, while option 4 would have an installed renewable capacity of up to 95 percent.

In the second instance, this report is also concerned with the key non-financial considerations and co-benefits of each of the alternatives. For this reason, particular emphasis is placed on the environmental implications, impact on energy security, and congruency with national development plans of each of the four options. These issues are considered separately from the alternatives' financial characteristics, and are intended to provide context to the findings of the least cost analysis.

The first section of this report provides an overview of Kiritimati Island, its electrical infrastructure, and the key characteristics of the existing utility market. The report then goes on to provide a detailed methodology outlining the approach and assumptions of the report's analysis, before highlighting its key findings and limitations. The final part of this report evaluates the robustness of this study's conclusions by means of a sensitivity analysis, and discusses the key non-financial merits of each of the four alternatives.

# 2 Kiritimati Island Background

## 2.1 Location and Geography

Kiritimati Island is a part of the Line Islands group and lies some 3000 km east of Kiribati's capital, Tarawa. It sits at a longitude of 157 degrees to the west and a latitude of 2 degrees to the north. At 320 square kilometres, the island is the world's largest coral atoll and the largest of the 33 Islands that make up Kiribati, accounting for approximately 70 per cent of the country's total landmass.

Within the 150-kilometre perimeter of the island, there is a large lagoon that covers approximately 160 square kilometres, which opens to the sea in the north west of the island. To the south east of the lagoon, the island comprises a network of subsidiary lagoons, tidal flats, partially hypersaline brine ponds and saltpans, which together have roughly the same area as the main lagoon.

## 2.2 Weather and Climate

Temperatures on Kiritimati Island are typical of those experienced in the tropics, ranging from 24 to 34 degrees Celsius. Fluctuations throughout the year are minimal with variations in temperature typically being more diurnal than seasonal.

Despite lying in the tropics, Kiritimati receives low levels of precipitation and has an effectively arid climate. The average rainfall on the island is 873 mm a year, and in dry years, such as in 1978, can be low as 177 mm. Correspondingly, and in comparison to other areas of Kiribati, Kiritimati Island has a higher number of sunlight hours and a particularly high average solar radiation, at 6.5 kW/m2/day (NASA Atmospheric Science Data Centre 2013).

Kiritimati Island's dry climate has made it susceptible to regular droughts that are made worse by the island's lack of vegetation and geological structure that consists of porous rock and thin soil. The consistently high levels of evaporation also make retaining fresh water on or within the atoll difficult, further contributing to the intensity of the island's frequent water shortages.

The Island lies in the trade winds region and as such experiences a prevailing northeasterly wind. Throughout the year wind speeds average approximately 27 km/h (Garrad Hassan 2012).

## 2.3 History and Politics

For all but a few years, Kiritimati Island has been continuously occupied since its European discovery in the early 1880's when first attempts were made to establish commercial coconut plantations. Since this time, the island has served multiple purposes including as a military base for both the US and British militaries and as a base for the Allied Forces during the Second World War. In the 1950s and 1960s, Kiritimati was then famously used as the base for a number of atmospheric nuclear tests conducted by the United Kingdom.

In 1979 the Treaty of Tarawa was signed between the governments of the US and Kiribati which formally established Kiribati's sovereignty over Kiritimati. The Island is now managed by the Kiribati Ministry of Line and Phoenix Islands Development and is represented in the Kiribati parliament by three elected members.

## 2.4 Demographics

As of 2010, Kiritimati Island had a population of 5586 people, which comprised 5 per cent of Kiribati's total population. Of this number the overwhelming majority have relocated from elsewhere in Kiribati, with only 8% of the population having been born on the island.

The majority of those living on Kiritimati are i-Kiribati of Micronesian descent. However, there is also a small population of Polynesians, originally from Tuvalu, as well as several expatriates.

Catholicism and Protestantism are the predominant religions by a large margin, however there are also a small number of Mormon and Baha'i followers.

## 2.5 Economy

While commerce on Kiritimati Island is limited, the main source of income has traditionally been the export of copra. Indeed, there still remains a 51 square kilometre state owned coconut plantation in the island's east, though the plantation's output has dropped significantly in recent decades and is in need of replanting.

Other sources of income on the island include the export of aquarium fish and seaweed, as well as a growing production of salt. Kiritimati is also endowed with large crayfish and fish stocks, however infrequent transport and poor infrastructure has made exporting these goods difficult.

More recently, tourism on Kiritimati Island has begun to generate a key source of revenue for locals, with the majority of visitors travelling to the island for its excellent fishing. Over the past few years, surfers have also discovered that the island receives good waves during the northern hemisphere's winter months, and there has been some interest in further developing this market. Infrastructure on the island supporting tourism includes several small hotels, equipment and rental facilities, and a restaurant.

# 3 Electricity on Kiritimati

## 3.1 Grid & Generation Infrastructure

Currently, electricity on Kiritimati Island is supplied to each of the 5 main villages through a series of isolated mini grids. The Ministry of Line and Phoenix Islands Development (MLPID), who are responsible for the generation and delivery of electricity to the island's customers, utilise a collection of diesel generators that range in size from 60 to 400 kW (please see Table 1 for a detailed inventory of the island's generators). The operation and maintenance of the village mini-grids is carried out by the Power and Electrical Sections of the MLPID, while the ministry's administration section is responsible for their management and financial matters.

Recently, to address the growing population between London and Tabwakea, a proposal has been developed by the MLPID to connect the currently isolated London, Tennessee, and Tabwakea distribution networks. Given the likelihood that this development will proceed, this analysis focuses on the proposed interconnected grid that would be created, which would carry approximately 82 percent of Kiritimati Island's cumulative load (316 kW maximum and 236 kW average).

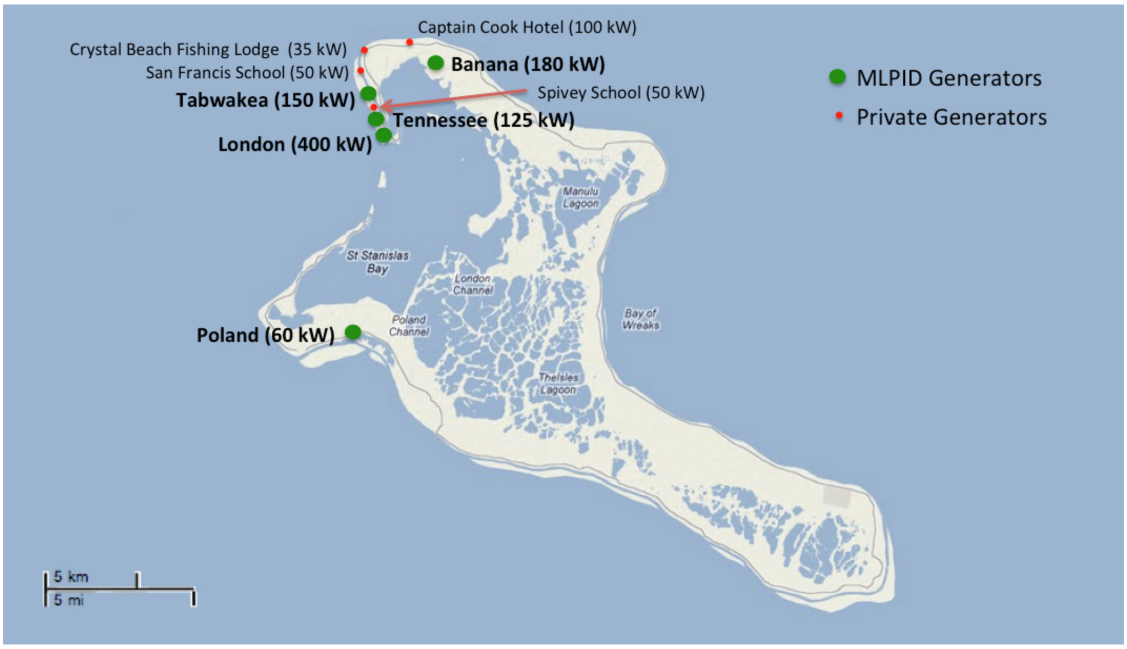
Both Poland and Banana have been omitted from the hypothetical network due to their distance from the corridor and small load that would make it uneconomical for them to be connected at this point in time. Furthermore, the EU has already committed to funding a 10 kW solar installation in Poland that will satisfy the renewable energy contribution without the need for storage.

In addition to the government's infrastructure, privately owned generators are operated at the San Francis and Spivey secondary schools as well as at the Crystal Beach Motel on the outskirts of Tabwakea village. Closer to Banana, there are two additional private generators that are owned and operated by the Captain Cook Hotel and JMB enterprises, respectively. Given the heavily subsidised price of electricity on Kiritimati Island, where possible, this study assumes that entities currently operating private generators would also choose to source their electricity from the central grid if provided the opportunity.

In addition to the privately operated diesel generators, there are two private 10 and 20 kWp solar installations on the island that provide electricity to the ANZ Bank and the Church of Latter Day Saints respectively. While the installations offset the owners' consumption of public electricity, both the bank and church remain connected to the government-operated grids in London and Tennessee.

The size and location of the power stations on Kiritimati Island are shown in Figure 3.

*Figure 3.* **Kiritimati Island Powerhouse Locations and Size**




*Source: GIZ (2013)*

## 3.2 Annual electricity Generation

Detailed information regarding the electricity production of the island's power stations is not available. However, through independent measurements of the generators' daily loads, it is estimated that the total electricity generation of the London, Tabwakea, and Tennessee powerhouses, as well as the nearby private generators that would together comprise the extended grid, is approximately 2,098,368 kWh per annum.

Across the remainder of the island, which includes the Banana and Poland powerhouses, JMB enterprises and the Captain Cook Hotel, annual generation is estimated to be 566,352 kWh.

These figures are estimates calculated by projecting the recorded generation of a typical week in April 2013. While there is therefore a significant limitation to this data, these independent estimates are in the order of other approximations reached by earlier studies (Garrad Hassan 2012; Zieroth 2012). A summary of the electricity generation on Kiritimati Island estimated for 2013 is presented in Table 1.

*Table 1.* **Plant Characteristics & Annual Generation Estimates (2013)**

| Plant | Generator Size (kW) | Maximum Load (kW) | Minimum Load (kW) | Annual Generation (kWh) |
|---|---|---|---|---|
| **Proposed Extended Network** | | | | |
| **London** | 400 | 229 | 176 | 1541901 |
| **Tabwakea** | 150 | 50 | 25 | 297940 |
| **Tennessee** | 125 | 25 | 16 | 140160 |
| **Spivey Secondary School** | 25 | 4 | 3 | 22683 |
| **St Francis School** | 25 | 6 | 4 | 30999 |
| **Crystal Beach Lodge** | 35 | 7 | 4 | 32343 |
| **Rawanibakoa** | 35 | 5 | 4 | 32343 |
| | 845 | 400 | 140 | 2098369 |
| **Rest of Island** | | | | |
| **Banana** | 180 | 50 | 20 | 219000 |
| **Captain Cook Hotel** | 100 | 65 | 20 | 219000 |
| **JMB** | 100 | 25 | 10 | 36372 |
| | 380 | 140 | 50 | 474372 |
| | | | | |
| **Total** | 1225 | 540 | 190 | 2572741 |

*Source: Author's Analysis*

## 3.3 Revenue and Expenditure

There are currently two electricity tariffs on Kiritimati Island which are set at AU$ 0.30/kWh for residential accounts and AU$ 0.33/kWh for business and commercial accounts. The tariff is set by the MLPID's administration unit and, as such, is politically sensitive; something evidenced by the tariff being set at a lower level than in Kiribati's Capital, Tarawa.

As of April 2013 the MLPID managed a total of 647 accounts, excluding those located in Poland. Of these, 156 were commercial and business accounts, while 491 were residential. A full summary of the electricity accounts held with the MLPID is provided in Table 2.

*Table 2.* **Summary of accounts by type and location**

| | Residential | Business | Commercial | Total Accounts |
|---|---|---|---|---|
| **London** | 187 | 68 | 44 | **299** |
| **Tennessee** | 26 | 14 | 6 | **46** |
| **Tabwakea** | 186 | 6 | 0 | **192** |
| **Banana** | 92 | 12 | 6 | **110** |
| **Total** | 491 | 100 | 56 | **647** |

*Source: Ministry of Line and Phoenix Islands Development 2012*

For 2012, the total revenue collected from these accounts was approximately AU$187,435. This is despite the MLPID supplying a total of 1,800,000 kWh of electricity to its customers. Accounts that are exempt from payment, including all MLPID facilities, and those account holders that defaulted on their payments, explain the discrepancy between the number of kWh consumed and the MLPID's received income. It is also suspected that some debts are written off in return for commercial services provided to the MLPID by account holders.

For the same year, the MLPID recorded fuel expenditure of approximately AU$810,000 for its generators in London, Tabwakea, Tennessee, and Banana. Based on this information, electricity generation cost the MLPID approximately AU$0.55/kWh in fuel costs alone. However, the actual budget for all activities related to electricity generation in 2012 was AU$1,229,345, which indicates the total price of electricity on Kiritimati Island is closer to AU$0.67/kWh. By these figures, it appears the MLPID is heavily subsidising the consumption of electricity on Kiritimati Island.

While this falls outside the scope of this analysis, it appeared during consultations that the MLPID may benefit from a more holistic approach to estimating the costs of electricity generation. Many of the costs incurred in the provision of electricity and the collection of revenue seem to be currently attributed elsewhere. It is believed that a more thorough analysis of the tariff structure required by the Ministry to ensure full cost recovery may assist with targeting the MLPID's existing financial shortfalls.

## 3.4 Current Projects

There are currently several projects underway aimed at improving the existing electrical infrastructure on Kiritimati Island. Given the limited capacity and budget of the MLPID's electrical section, it is important that decision makers consider these projects when planning further developments. The most notable of these projects that are either proposed or underway on Kiritimati Island are outlined below to provide context to the island's electrical activities.

The key project currently in progress is the upgrade of the distribution network in London, which is hoped to mitigate the severe voltage drops that have become increasingly frequent on the network as demand for electricity has increased. As these problems have been attributed to the existing low voltage specifications (415 v) of the distribution infrastructure, this project has laid a new, higher voltage, 4 kV cable through the village of London and has also installed two new 112-kVa step down transformers. The final stage of this project will be completed in mid-April 2013, when Gen-Serve are scheduled to connect the new cabling and transformers to the existing distribution boxes.

It was also revealed during a consultation with the MLPID Electrical Section, that a prospective development is soon to be underway that will install separate switches for the two feeder lines into the Tabwakea grid. As it currently stands, there exists only one switch for the two feeder lines that cover the village, which has prohibited the selective delivery of load and resulted in significant efficiency losses. As a short-term solution, the MLPID has replaced the existing 180 kW generator with a larger 250 kW generator from the London powerhouse. The replacement of the switches has now gained parliamentary approval and is currently awaiting funding.

The extension of the grid in Tabwakea to electrify the approximately 200 unconnected households, is also at a similar stage. Since people moved into the new settlement north of the main village, the MLPID has been awaiting funding to install the required distribution boxes and cabling. However, the MLPID's resulting revenues from the project cannot be utilised for funding, as electrical bills are paid directly to the Ministry of Finance in Tarawa. At the current time, it is unknown when the necessary funds will be allocated for this project.

As mentioned earlier in this report, there are also plans to connect the distribution networks between London and Tabwakea. The first stage of this project, which was the laying of the 4kV cable in London, has already been completed. Parliamentary approval and funding are now being sought to extend this cable through Tennessee to London, which would enable the connection and electrification of the corridor between the existing grids in each of these villages. As of yet, however, there is still little indication of when the required funds will be acquired despite there being a general belief that the project will gain approval before the end of 2013.

## 3.5 Challenges

Electricity generation and distribution on Kiritimati Island currently face a number of challenges. While this analysis is in the first instance concerned with addressing rising costs, it has also been motivated by the environmental, and to a lesser extent, technical challenges that persist on the island. The following section highlights the key challenges associated with current electrical activities on Kiritimati Island that may be alleviated through the use of alternative technologies.

### 3.5.1 Financial

Arguably the largest challenges to producing electricity on Kiritimati Island at the current time are financial. Even by regional standards, Kiritimati Island has very high operational and maintenance costs that have made the provision of electricity at the present level of subsidisation difficult. In 2012, the generation of electricity cost the MLPID approximately

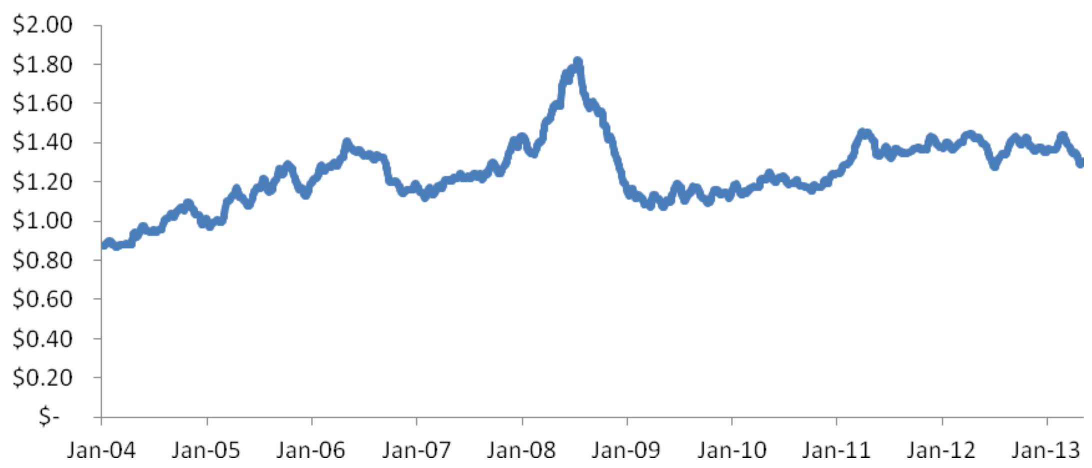
AU$0.67/kWh, which suggests the Ministry is paying up to 50% more than other islands in the region. According to the International Renewable Energy Agency (IRENA) the average production cost for diesel generators among Pacific Island countries is between AU$0.35 - $0.55/kWh (IRENA 2012a).

This high generation cost is partly explained by the significant cost of transportation to Kiritimati Island, which inflates the price of imported diesel. Due to the island's remote location and distance from usual supply routes, Kiritimati pays a premium for fuels that amounts to approximately AU$0.25/litre or 20% of the fuel's landed cost. For comparison, shipping contributes only 2% of diesel's landed price in New Zealand (NZ Automobile Association 2013).

In addition to this, the added costs of freight to Kiritimati Island have been compounded by the increasing price of diesel over recent years. As can be seen in Figure 4, the real cost of diesel has risen by almost AU$0.40/litre since 2004 and has varied throughout this period by as much AU$1.00/litre.

As diesel accounts for approximately 66 percent of the MLPID's generation costs, the ministry's expenditure is highly sensitive to changes in the price of the commodity. For this reason, as the price of fuel continues to rise, increasing financial pressure will be placed on the MLPID and their ability to provide electrical services at the current rates of subsidisation.

*Figure 4.* **Historical Wholesale Diesel Prices in Australia (2004 – 2013)**




*Source: (Australian Institute of Petroleum 2013)*

### 3.5.2 Technical

The key technical challenge that faces Kiritimati Island's existing electrical infrastructure is the supply of electricity through the low voltage distribution system. As a result of Kiritimati Island's predominantly 415-volt distribution networks, brownouts and voltage drops have become increasingly frequent as demand for electricity has grown. In the case of London, this problem is being addressed through the network upgrades that were discussed in section 3.4 of this report. However, for the island's other villages, this remains a serious problem and there are currently no projects or funding proposed to address these issues.

The second major technical challenge that is faced on Kiritimati Island is the lack of supporting generators to supply the load during periods of maintenance and breakdowns. As most of the villages have only one functioning generator, there is no supply of electricity when the primary generator is out of operation. For scheduled maintenance, this problem results in four hours of service interruptions each week at each of the island's powerhouses. For unscheduled breakdowns, the lack of supporting generators is reported to result in power outages approximately once a month, which last for varying amounts of time. While for most of the island's residents such disruptions are merely a nuisance, for consumers such as Kiritimati Island's hospital, who are heavily reliant on electricity, the consequence of interruptions has the potential to be much more serious.

### 3.5.3 Environmental

In addition to financial and technical difficulties, electricity practices on Kiritimati Island are also challenged by their environmental impact. The carbon emissions released from the island's diesel generators are the best documented of these, which by rough calculations amount to approximately 1390 t/CO2 a year[2] [3] and account for some 3.5% of the country's total. While strong trade winds ensure these emissions have little local effect in the short term, they nonetheless contribute to global CO2 emissions and their subsequent affects on climate.

While harder to measure, the use of diesel generators also poses an environmental challenge due to the risk of fuel spillage during the transportation and storage of the required diesel. Given the close proximity of all of the island's powerhouses to the ocean, a spill could have serious effects on the island's marine environment. The risk of this is partially controlled by the various powerhouses' limited storage capacity, however a spill at the island's main port or KOIL storage facility would have more serious repercussions. Given the islands economic reliance on the ocean for both produce and tourism, any risks to its marine environment should be of high concern.

---

[2] Based on IPCC Adjusted Guidelines for National Greenhouse Gas Inventories (1996)

[3] Assumed diesel fuel density of 1kg=0.85 litres

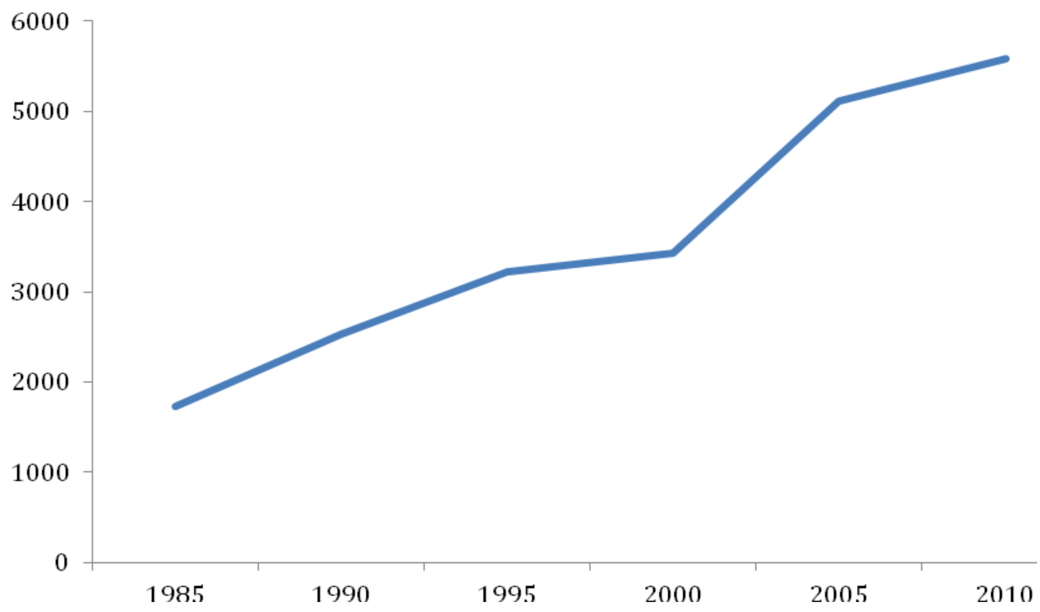
# 4 Future Load Demand

While the analysis in this report is conducted for a fixed level of demand, actual demand for electricity on Kiritimati Island is likely to rise considerably over the next 20 years. This should be of interest to decision makers, as it will dictate the required growth in the island's generation capacity, and may indicate whether preference should be given to more modular technologies whose capacity could be incrementally expanded as necessary.

There are numerous factors that will influence how the consumption of electricity will grow. In addition to the increased demand that will result from the island's growing population, the construction of new developments and a shift towards increasingly energy intensive consumer preferences will also have an impact on the amount of electricity that is required.

In the case of population, recent trends suggest that the number of residents on Kiritimati Island will continue to grow strongly over the coming years. As is illustrated in Figure 5, the island's population has experienced consistent growth of around 5 per cent since 1989, and for the period spanning 2000-2005 this rate exceeded 8 per cent, making it the fastest growing island in Kiribati. Given the availability of land on Kiritimati Island and the growing population density in the country's capital, Tarawa, it seems likely that a trend of migration will continue.

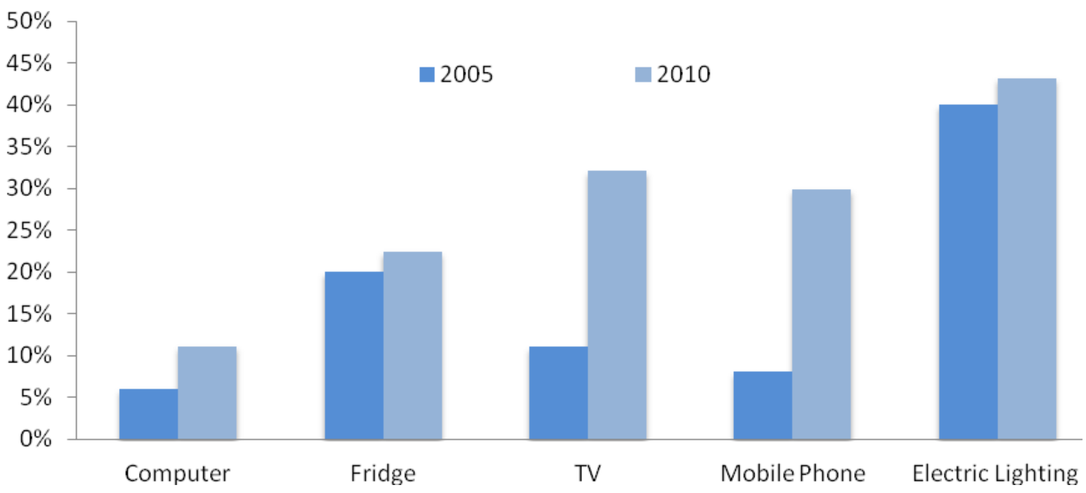
*Figure 5.* **Kiritimati Island Population 1985 -2010**




*Source: (Govt. Kiribati 2010)*

In addition to a growing population, there has also been an increasing trend in the energy intensity of the population's preferences, which is likely to continue over the coming years. While data on this is limited, it appeared clear from field consultations that the number of appliances and electricity usage per person was increasing on Kiritimati Island. This is also supported by the nationwide census data that shows there have been increases in the percentage of the nation's households that own electrical appliances. As is illustrated in Figure 6, the percentage of households owning a cell phone, TV, and computer more than doubled between 2005 and 2010, and there were also observable increases in the ownership of refrigerators and electrical lighting.

*Figure 6.* **Household Appliance Ownership as Percentage of Total Households**




***Source:*** *(Govt. Kiribati 2005, 2010)*

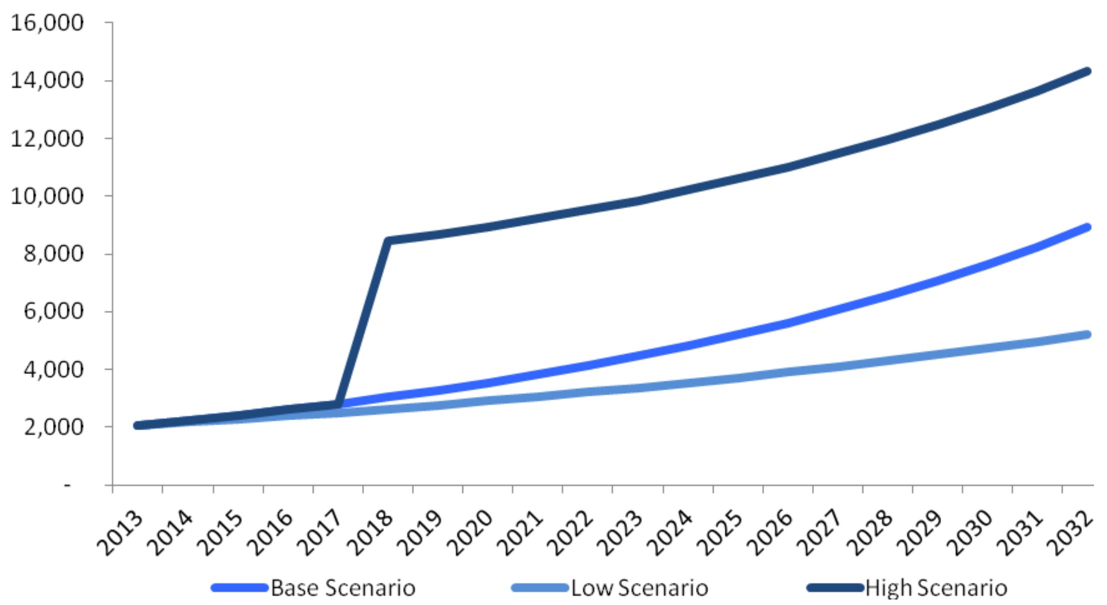
The combination of such changing preferences and the growing number of households, suggests that electricity demand will likely outpace population growth in coming years. This conclusion is also supported by the limited historical data that is available, which shows electricity generation on Kiritimati Island has increased by approximately 8% p.a. over the past two years.

In view of this evidence, what should also be considered are the opportunities for the MLPID to implement electricity demand side management (DSM) measures to reduce the expected increases in consumption, reduce operating (subsidy) costs and to increase energy efficiency. Were such policies implemented, the actual consumption growth realised may be reduced below the historical trend, without curbing the socio-economic development of the island. DSM policies and actions may include education campaigns, restrictions on imports of inefficient electronics, or the imposition of consumption restrictions (as is currently practiced in Tokelau). This may also enable the MLPID to delay necessary expansions in the island's supply capacity and thus avoid significant capital costs which can then be used for maintenance and improvements on the distribution grid.

In addition to population growth and changing tastes, one particular development that warrants consideration due to the significant impact on electricity consumption it would have, is the proposed fisheries processing plant that is currently being discussed for London. Based on the electricity requirements of the similarly specified plant in Tarawa, such a facility would have a minimum and maximum demand of 200 kW and 650 kW respectively. This would nearly triple the current maximum load of the extended network that has been proposed. While it is unknown whether the plant would operate a private generator, it is understood the project developers have expressed a preference for being connected to the public grid.

Based on the above information, three growth scenarios can been constructed: A low scenario, where demand would grow at the same rate as the population; a base scenario, where demand would continue to grow at the observed rate as a product of preference changes and continued population growth; and a high scenario, where the base scenario would be realised in addition to the proposed fisheries processing plant in London. These three scenarios are illustrated in Figure 7, and show that demand may reach levels as high as 14,000 MWh per annum by 2033.

*Figure 7.* **Kiritimati Island Demand Growth Scenarios (MWh)**




***Source:*** *Author's Analysis; (Govt. Kiribati 2010)*

# 5 Least Cost Analysis

## 5.1 Methodology

The analysis component of this report employs the least cost analysis method, which compares options based on the sum total over their lifetime costs. In contrast to cost benefit analyses, least cost analyses do not consider or attempt to quantify the associated benefits of the alternatives. While the merits of each option are given consideration in this report, they are discussed qualitatively, separate from the financial analysis, as quantifications of these characteristics are particularly speculative.

As a part of the analysis, four electricity supply options that would be capable of satisfying the requirements of an extended network between London and Tabwakea are considered. These four options are:

1. Status Quo – 400 kW Diesel Generator
2. Solar/Diesel Hybrid – 233 kW Solar PV System & 350 kW Diesel Generator
3. Solar with Battery Storage – 1.52MW Solar PV System and 13.2 MWh battery stock
4. Wind/Diesel Hybrid – 200 kW Enercon E33 Wind Turbine & 350 kW Diesel Generator

The basis of comparison for these alternatives is the levelised cost of electricity (LCOE), which measures the cost of generating one unit of electricity based on the lifetime costs of each particular option. The LCOE provides an even platform for comparison, as it remains fixed over each of the projects' useful period of operation.

This LCOE is calculated by first adjusting each of the project's costs for inflation, then discounting them to their present day value and dividing by their lifetime electricity production. By definition, the sum of the present value of the LCOE multiplied by the energy generated should be equal to the present valued net costs, as is shown in equality 1 (Branker, Pathak, and Pearce 2011). By rearranging this equation one can derive the LCOE formula, which is equation 2, where $C_t$ is the costs incurred by the project in year t, $\pi$ is the inflation rate, $d$ is the discount rate, and $e_t$ is the total number of kWh generated in year t. Note, that while it looks although electricity production is being discounted, it is just an arithmetic result of rearranging equation 1.

$$\sum_{t=0}^{T}\left(\frac{LCOE_t}{(1+d)^t} \times e_t\right) = \sum_{t=0}^{T}\frac{C_t\,(1+\pi)^{t-1}}{(1+d)^t} \qquad (1)$$

$$LCOE = \frac{\sum_{t=0}^{T}\frac{C_t\,(1+\pi)^{t-1}}{(1+d)^t}}{\sum_{t=0}^{T}\frac{e_t}{(1+d)^t}} \qquad (2)$$

## 5.2 Assumptions & Limitations

### 5.2.1 Discount & Inflation Rate

Due to the time value of money, costs and benefits that do not arise until the future are considered to be worth less than those that arise today. For this reason, a discount rate must be used to appropriately value the costs associated with the projects in this analysis, depending on when they are incurred. The discount rate is representative of the amount that individuals or society are willing to accept as compensation for forgoing benefits, and is typically based on such factors as the opportunity cost of capital, inflation, risk, and uncertainty. While discount rates thus vary from country to country, typical values used for public projects tend to vary between 5 and 10% (IEA 1991). However, many entities use discount rates that are higher than this, such as the Asian Development Bank, who believe values between 10 and 12 % should be used (ADB 2012).

As a base scenario, this analysis assumes a discount rate of 8 percent, which is the same for each of the four alternatives. This was chosen to ensure consistency and comparability with previous least cost analyses that have been conducted in the Pacific (Empower Consultants 2008; Garrad Hassan 2012; NZMFAT 2013) and to reflect the views of available literature, despite there being widely varying opinions on the matter.

In regard to cost and income inflation, these are assumed to be equal at 2% and to remain constant over the project's lifetime. This is roughly consistent with the historical inflation rate that has been experienced in Kiribati (ADB 2012) and is also in line with the values that have been used in similar analyses in the Pacific (Garrad Hassan 2012).

### 5.2.2 Carbon Cost

The cost of carbon in this analysis is assumed to be AU$40/t and is held constant over the lifetime of the projects. While the cost of carbon is a matter of fierce debate, the value chosen in this study reflects an average of the values used by the US and UK governments in their own policy analyses (UK DECC 2011; US GOVT 2010). In comparison to values used by others, such as the LSE Grantham Research Institute and The Stern Report, AU$40/tCO2 is relatively conservative, and does not consider arguments that the cost of carbon should grow with time to reflect the increasing marginal cost of emissions (Bowen 2011; Stern 2006). The Grantham Research Institute states that by 2033 - the end of the specified project period – a more appropriate price for carbon based on global targets would be closer to AU$125/t (Bowen 2011).

### 5.2.3 Constant Demand

The level of demand used in this analysis is based on that estimated for the extended distribution network outlined in section 3.1. For this network, demand is assumed to be fixed throughout the 20-year project lifetime at the 2013 level of 2,098,369 kWh a year. This figure takes into account the demand of the London, Tennessee, and Tabwakea villages, and also includes the demand of those entities currently operating private generators.

The villages of Poland and Banana have not been included in the estimation of demand as their isolation makes it unlikely they would be integrated into the extended network in the foreseeable future. In addition, the EU has already signed on to fund a grid connected solar project in Poland, which is expected to satisfy the full extent of the village's electricity requirements.

### 5.2.4 Full Consumption of Renewable Electricity

To calculate the LCOE, this analysis has also assumed that all solar and wind generated electricity, after efficiency losses, will be fed into to the distribution network. Given the capacity of the proposed renewable generators and the minimum daily load, this is likely to be a reasonable assumption as it is unlikely that output would at any time exceed demand. While this would not be the case for the larger solar installation, the utilisation of batteries in this configuration would enable excess output to be smoothed across the daily load.

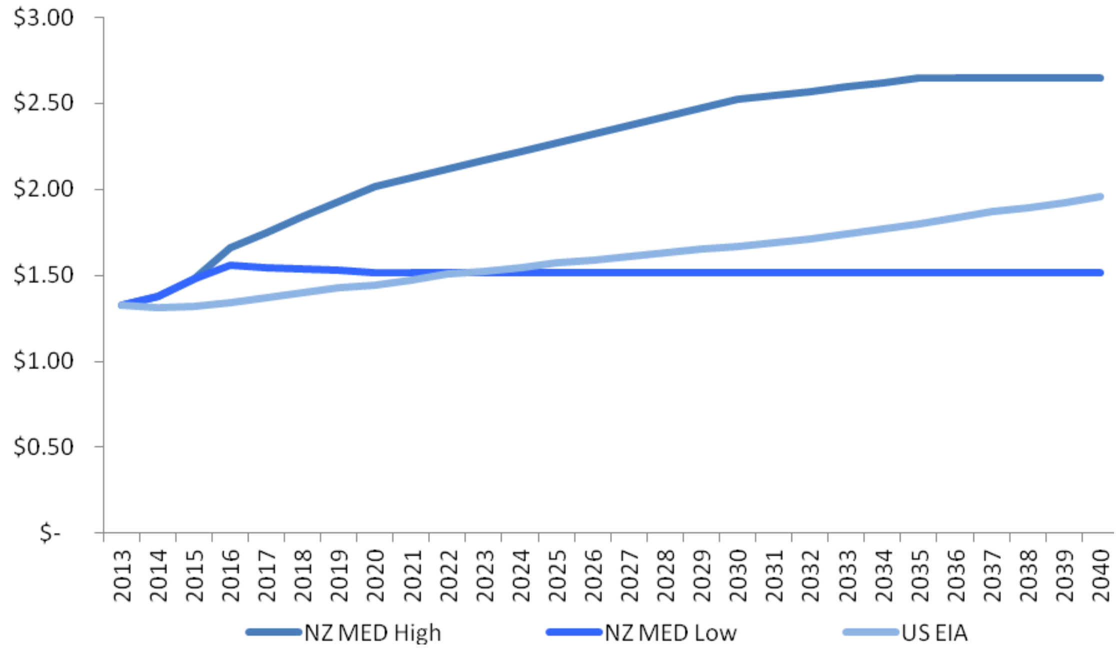
In the case of the 233 kW solar installation, the minimum demand during sunlight hours is estimated to be 208 kW, while maximum output based on peak radiation values is not expected to exceed 133 kW. For this reason, at all times, at least some contribution from the complementary diesel generator would be required.

This would also be the case for the proposed wind turbine, whose maximum expected output based on the wind speed recordings undertaken by *Garrad Hassan*, is 200kW. While the network load has been recorded at levels as low as 180kW between 12am and 5am, the requisite wind speeds to generate an output greater than this have been predicted to occur only 0.01 percent of the time (Garrad Hassan 2012). It is thus unlikely that winds of this speed would coincide with the absolute minimum load for any significant period of time.

### 5.2.5 Diesel Prices

Given the fixed nature of diesel prices in Kiribati, it is difficult to predict how they will change in response to the wholesale rate. Figure 8 illustrates 3 possible growth scenarios that have been estimated based on scenarios formulated by the NZ Ministry for Economic Development (MED) and the US Energy Information Administration (EIA). The 3 scenarios follow the predicted percentage change in the wholesale price, applied to the current fixed rate of diesel in Kiritimati Island. While there is a great deal of uncertainty attached to any long range diesel forecasts, this analysis assumes that real diesel prices will grow in accordance with the modest forecasts provided by the US EIA.

*Figure 8.* **Diesel Price Forecasts for Kiritimati Island (2013 – 2040)**




***Source:*** *(NZ MED 2011; US Energy Information Administration 2013)*

### 5.2.6 Sunk Capital & Installation Cost of Diesel Generators

For each of the four options assessed in this analysis, it is assumed that one, or a combination of the existing diesel generators located on Kiritimati Island could be configured to deliver the necessary capacity. For this reason, the capital and installation cost of the diesel generator in each of the alternatives is considered to be sunk and is thus omitted from the total costs of each option. Nevertheless, the maintenance, operational, and replacement costs of the generators are still factored into the analysis. Table 1 provides an inventory of the diesel generators currently owned and operated by the MLPID that would be available to be used.

# 6 Option 1 - Status Quo – Diesel Generator

To establish a robust baseline, this first option in this analysis is representative of the scenario in which the MLPID continues with their existing electrical practices. However, to reflect the efficiency gains of connecting the utility grids between London and Tabwakea, this configuration is assumed makes use of a single generator. Based on this assumption, option one would utilise the recently purchased 400 kW generator in London, which would be capable of satisfying the load requirements of the extended network that has been proposed.

## 6.1 Prevalence of diesel generators in the Pacific Islands

For remote Pacific communities, diesel generators have traditionally been the default option for electrification. Despite the increasingly high price and unpredictable supply of diesel, their low capital cost has made them an attractive option compared to alternatives such as solar or wind, which have typically required a significant upfront investment.

This fact has contributed to diesel becoming the major source of electricity in most Pacific Island countries (IRENA 2012a), with several notable exceptions, including Fiji and Tokelau where hydro and solar are the primary electricity sources respectively. Approximately 95 percent of electricity in Kiribati is currently generated using diesel generator sets (IRENA 2012a).

## 6.2 Suitability for Kiritimati

As is evidenced by the operation of the existing diesel generators on Kiritimati Island, their continued use would be capable of satisfying the island’s electricity requirements. Despite this, several issues make their current and continued use less than ideal.

A key disadvantage of using diesel generators on Kiritimati Island is their reliance on imported fuel. Given the island’s isolation, residents pay a premium for the required diesel due to high shipping costs, which contribute approximately 20 percent of the fuel’s landed value. This makes the operation of generators on Kiritimati Island more costly than in less remote areas of the Pacific. Furthermore, Kiritimati Island’s continued reliance on diesel generators maintains the risk that the price of diesel may experience greater inflation or be more volatile than what is currently expected. These risks were illustrated in 2008, when the price of the fuel rose unexpectedly by nearly 50 percent over a period of two months.

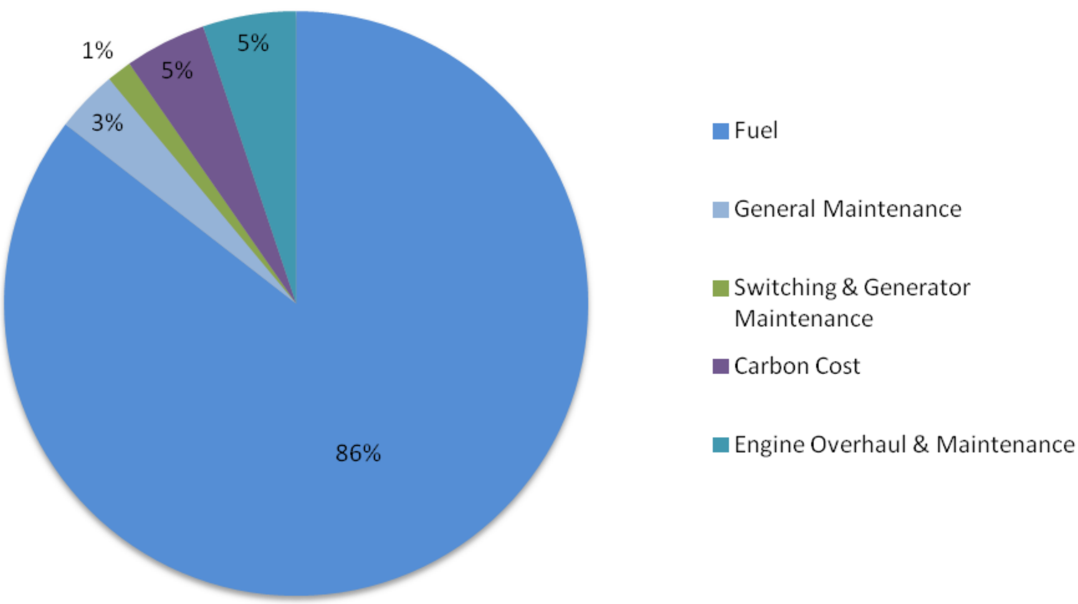
In contrast, one advantage that diesel generators do have is their relative simplicity. Given the difficulty in accessing external support from Kiritimati Island, the ability of local technicians to repair diesel generators and undertake basic maintenance is a desirable attribute.

Unfortunately, diesel generators tend also to be more prone to mechanical failure and often require more maintenance than other technologies such as solar PVs or wind turbines (SELF 2008).

## 6.3 Lifetime Costs and Analysis

The cost estimates of purchasing, installing, and operating a diesel generator in this analysis are representative of the actual costs reported by the MLPID and are supported by previous literature and analysis undertaken in the Pacific. As the requisite generator has already been purchased, the initial capital investment on Kiritimati Island would be relatively low, however the cost of maintenance and fuel throughout the generator's useful life would be considerably higher than that of the renewable alternatives.

*Figure 9.* **Status Quo/Diesel Generator NPV breakdown (20-Year Analysis)**




*Source: Author's Analysis*

For the purpose of calculating the LCOE of the status quo, the capital, installation, and balancing cost of the requisite generator have been estimated to be AU$1098/kW. This is based on the MLPID's 2012 purchase and installation of the 400 kW Cummings diesel generator that is currently located in the London powerhouse, and on which this option is configured. However, as the generator has already been purchased, its costs are considered to be sunk and have thus been omitted from the final estimation of costs. Nevertheless, the operational and maintenance cost of the generator must still be taken into account, which, in line with the assumptions of Wade (2002) and Woodruff (2007), are assumed to be 5 percent of the generator's capital value and to remain constant over the generator's useful life. Furthermore, it is assumed that an engine overhaul once every 5 years and a complete engine replacement every 10 years would be required at a cost of 25 and 100 percent of the project's initial capital value respectively, and that the engine switching gear and generator would require maintenance every 7 years at a cost of 20 percent of the generators' value.

For the estimation of diesel consumption, fuel efficiency is assumed to be 0.27 litres/kWh of electricity. This is consistent with the limited consumption data that is available on Kiritimati Island and the findings of consultations that were held with the MLPID. It is also in line with data available for similar generators, such as those operated in Funafuti by the Tuvalu Electricity Corporation.

Based on this information and the parameters detailed in section 5.2, it is estimated that the net present value of operating a 400 kW diesel generator on Kiritimati Island would be AU$10,821,161, with a LCOE of AU$0.53/kWh. This is calculated over a 20-year lifetime and is based on the US EIA's diesel price scenario that is presented in section 5.2.5. **Error! Reference source not found.** shows a breakdown of the project's net present value, while Table 3 provides a summary of the option's costs and financial analysis.

Note, that the listed LCOE estimate differs from the estimate of AU0.67/kWh discussed earlier in this report, which was based on the MLPID's budgeted expenditure for all activities related to the supply and generation of electricity.  The estimates presented here consider only direct capital, operational, and maintenance expenditure.

*Table 3.* **Option 1 Diesel Generator Financial Analysis**

| | Frequency | Amount | |
|---|---|---|---|
| **Generator Costs** | | | |
| ***Capital & Installation Cost (Sunk Cost)*** | | *$439,425.00* | AUD |
| **Engine Overhaul Cost** | Every 5 years | $109,856.25 | AUD |
| **Switchgear and Generator Overhaul** | Every 7 years | $87,885.00 | AUD |
| **Diesel Engine Replacement Cost** | Every 10 Years | $439,425.00 | AUD |
| **Operational & Maintenance Costs** | Annual | $21,971.25 | AUD |
| **Diesel** | Annual | $853,533.87 | AUD |
| **Carbon Cost (AU$40/tCO2)** | Annual | $60,055.32 | AUD |
| | | | |
| **Discount Rate** | | 8% | |
| **Cost and Income Inflation Rate** | | 2% | |
| **Project Lifetime** | | 20 | Years |
| **Electricity Generation** | Annual | 2098369 | kWh |
| **NPV** | | **$10,821,161.35** | **AUD** |
| **LCOE** | | **$0.53** | **AUD** |

*Source: Author's Analysis*

# 7 Option 2 - 233 kWp Solar and 300 kW Diesel Generator

## 7.1 Overview of solar technology and prevalence in pacific Islands

An alternative to the use of a diesel generator on Kiritimati Island, and the second option considered in this analysis, is solar photovoltaics. Solar PV systems generate energy by converting the heat emitted from solar radiation into electricity. Such technology could work well on Kiritimati Island due to its abundant solar resource and infrequent cloud cover.

Over recent decades solar technology has become the most widely adopted renewable energy for providing electricity to rural areas in the Pacific, and is particularly prevalent in Kiribati. Initially, trouble with short battery life, poor maintenance, and a lack of financial sustainability led to a slow uptake of the technology. However, following the success of several solar projects in remote communities, interest in the technology has grown considerably.

Much of the Pacific's growth in solar installations has been driven by the Kiribati Solar Energy Company (KSEC), which was established through UNDP funding in 1984. Since its inception, the government-managed utility has installed over 2200 solar home systems in Kiribati, of which approximately 98 percent serve rural communities. This has led to around 20 percent of Kiribati's rural population receiving basic electrical services from household solar systems.

While the majority of solar systems in Kiribati are small-scale, there have been steps taken recently to develop several larger, utility scale installations. In 2009 the EU signed on to develop a grid connected solar plant for the remote village of Poland on Kiritimati Island, and in 2013 the World Bank and Kiribati Government committed to a 516 kWp installation on Tarawa, to be funded by AusAID.

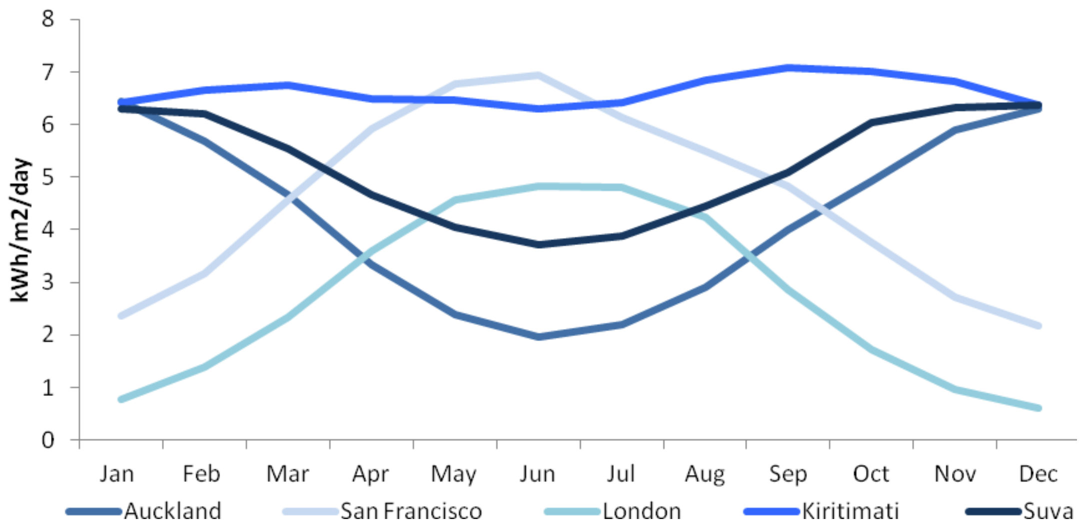
The country of Tokelau has also recently installed 3 large-scale systems, which together provide over 90 percent of the country's electricity. The 930 kWp installation is now one of the largest in the Pacific region and has provided savings of approximately NZ$0.15/kWh over the previously installed diesel system (NZMFAT 2013).

## 7.2 Suitability for Kiritimati

Kiritimati Island has an excellent solar resource that would make it a particularly suitable location for solar energy. Based on the past 22 years of NASA readings, Kiritimati Island has received an average solar radiation of approximately 6.5 kWh/m2/day (NASA, 2013). A comparison of Kiritimati Island with other locations is shown in Figure 10, which also illustrates the island's seasonal variation.

Due to Kiritimati Island's location just north of the equator, seasonal variation in radiation and cloud cover is minimal. However, unknown longer-term variations may exist due to oscillations of El Nino/El Nina weather cycles and the longer-term effects of climate change.

*Figure 10.* **By global standards Kiritimati has an excellent solar resource**




*Source: (NASA Atmospheric Science Data Centre 2013)*

## 7.3 Option Configuration

With a goal to reach an installed capacity of 40 percent renewable electricity on Kiritimati Island, this option proposes a hybrid configuration, making use of a 233-kWp ground mounted solar installation and a 350kW diesel generator. This configuration would not require the use of storage as the generator would be capable of supplying the full maximum load if this ever occurred in the absence of solar radiation. Such a configuration also allows for significant savings as the batteries and charge controllers, required for storage, typically account for around 40 percent of a solar installation's total costs, and usually need to be replaced at least once over the project's lifetime.

In calculating the output of such a configuration, this analysis has assumed that the effective level of solar radiation would be 4.74 kWh/m2/day. This is the based on the recorded average of 6.5 kWh/m2/day after factoring in a 15% loss due to the temperature being significantly higher than the optimal 25 degrees Celsius; 5% due to the likely non-optimal orientation of the panels; 5% due to uncompensated glass reflection; and 5% due to the accumulation of dirt. In addition to this, it is assumed that there will be an annual system output degradation of 0.8%.

Based on these technical specifications and the adjusted solar radiation, the solar component of this system could be expected to generate approximately 389,773 kWh of electricity annually, or just under 19 percent of the London-to-Tabwakea-corridor's requirements. To ensure an accurate estimation, this figure takes into account a 10 percent loss attributable to the inversion of the electricity from DC to AC.

## 7.4 LCOE and NPV

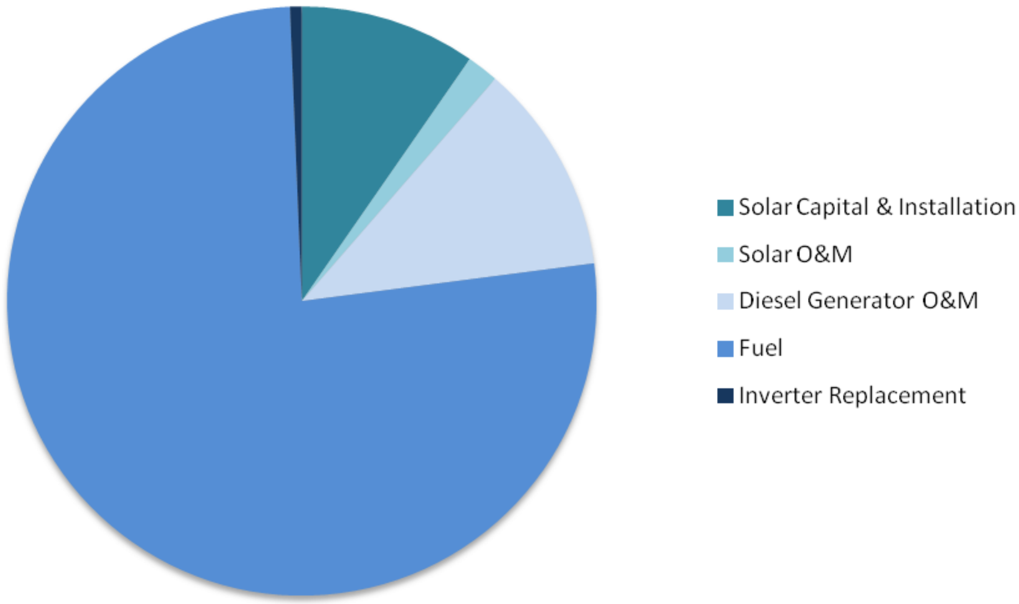
The costs of this solar hybrid option have been based on the reported costs of existing solar installations in the Pacific. Specifically, the per-kilowatt capital, installation, and maintenance costs, as well as the inverter replacement schedule, are based on the 3 solar installations that were recently completed in Tokelau. However, with the exclusion of batteries, the cost of a photovoltaic system on Kiritimati Island is estimated to be significantly less expensive, at AU$4.32 per-kilowatt. This is consistent with the findings of a separate analysis of solar costs that was undertaken in Tokelau (Empower Consultants 2008), and also reflects the average regional price levels estimated by IRENA (IRENA 2012b).

The cost of the accompanying 350 kW diesel generator are based on the per-kW purchase and installation costs of the 400 kW Cummings generator that was purchased by the MLPID in 2012. However, as it is likely one or more of the existing diesel generators on Kiritimati Island could be used, the capital and installation cost of the generator has ben sunk. Similar to option 1, the operational and maintenance costs of the generator are based on previous literature (Wade, 2002; Woodruff, 2007) and data collected on Kiritimati Island. They are assumed to be:

- Maintenance costs of 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 a major engine overhaul every 10 years at 100% of the initial capital cost.

- Fuel efficiency is assumed to be 0.27 litres/kWh.

*Figure 11.* **Solar-Diesel Hybrid NPV Breakdown (20-Year Analysis)**




*Source: Author's Analysis*

Based on this information, it is estimated that the net present value of a solar-diesel hybrid generation system on Kiritimati Island would be AU$10,400,482, and that it would have a LCOE of AU$0.50/kWh. This is calculated over a 20-year lifetime and is based on the US EIA's diesel price scenario presented in section 5.2.5. **Error! Reference source not found.** provides a summary of the project's costs, analysis parameters, and key financial characteristics, while Figure 11 provides a breakdown of the project's NPV.

*Table 4.* **Option 2 Solar-Diesel Hybrid Financial Analysis**

| | Frequency | Amount | |
|---|---|---|---|
| **Solar Costs** | | | |
| **Solar Panels** | | $237,108 | AUD |
| **Inverters** | | $200,430 | AUD |
| **Civil Works** | | $186,299 | AUD |
| **Engineering, Project management, Labour** | | $135,490 | AUD |
| **Ground Mounting for Array** | | $101,618 | AUD |
| **BOS** | | $84,681 | AUD |
| **Freight and Logistics** | | $60,000 | AUD |
| **Operational & Maintenance Costs (labour)** | Annual | $14,400 | AUD |
| **Operational & Maintenance Costs (consumables)** | Annual | $1,550 | AUD |
| **Inverter Replacement** | Every 10 Years | $135,490 | AUD |
| | | | |
| **Generator Costs** | | | |
| ***Capital & Installation Cost (Sunk Cost)*** | | *$384,469* | AUD |
| **Engine Overhaul Cost** | Every 5 years | $96,124 | AUD |
| **Switchgear and Generator Overhaul** | Every 7 years | $76,899 | AUD |
| **Diesel Engine Replacement Cost** | Every 10 Years | $384,496 | AUD |
| **Operational & Maintenance Costs** | Annual | $19,224 | AUD |
| **Diesel** | Annual | $853,533 | AUD |
| **Carbon Cost (AU$40/tCO2)** | Annual | $50,743 | AUD |
| | | | |
| **Annual Electricity Generation** | Annual | 2098369 | kWh |
| | | | |
| **Discount Rate** | | 8% | |
| **Cost and Income Inflation Rate** | | 2% | |
| **Project Lifetime** | | 20 | Years |
| | | | |
| | | | |
| **NPV** | | **$10,400,482** | AUD |
| **LCOE** | | **$0.50** | AUD |

*Source: Author's Analysis*

# 8 Option 3 – 1.52 MWp Solar & 13.2 MWh Battery Storage

## 8.1 Overview of large scale solar installations and prevalence in pacific Islands

A second solar alternative that would also be suitable for Kiritimati Island, is a larger installation that makes use of batteries for storing excess electricity, and a small backup generator. Such a system would be more complex than that discussed in the previous section, however it would enable the island to produce near 100 percent of its electricity from renewable sources.

The use of solar installations of this nature has been much more limited than smaller household systems in the Pacific. Recently, however, with current diesel prices and the declining cost of solar technology, larger utility scale installations have begun to gain popularity. This has been particularly true of areas in the Pacific with little cloud cover, where strong solar resources have enabled solar installations to challenge the economic efficiency of small to medium scale diesel generators, without the need for incentives or subsidisation.

Even within Kiribati, several large-scale solar projects are currently being developed. In 2009 the EU signed on to fund a grid connected solar plant for the remote village of Poland on Kiritimati Island, and in 2013 the World Bank and Kiribati Government committed to developing a 516 kWp installation to be connected to the grid in Tarawa.

To date, however, there have been few large-scale installations that have provided the primary source of electricity for communities in the Pacific. A notable exception to this is the 930-kWp solar installation that was recently completed in Tokelau, which utilised a considerable stock of batteries to provide approximately 90% of the country's electricity requirements. Interestingly, despite the project having an upfront cost of NZD 8.45 million, an analysis of its lifetime costs has shown that its LCOE is in fact 10 percent lower than that of the previous diesel system that was in operation (NZMFAT 2013).

## 8.2 Suitability for Kiritimati

As is illustrated in Figure 10 (section 7) Kiritimati Island is an excellent candidate for solar energy given its strong solar resource. The general suitability of photovoltaics for Kiritimati Island is discussed in greater detail in section 7.2, however, in contrast to the solar/diesel hybrid discussed in the previous section, this option includes the use of batteries, which generates additional implications.

In general, the lifespan and efficiency of batteries have proven poorly suited to tropical climates, which was evidenced by the significant problems early household systems in Kiribati faced (Woodruff 2007). Despite this, improvements in technology have mostly remedied these problems, and with appropriate precautions taken, including housing and cooling facilities, there is little reason why this should pose an issue to the use of batteries on Kiritimati Island.

One issue that would require further consideration, however, is an appropriate disposal and handling process for the batteries. Tsoutsos et al. (2005) points out that a life cycle analysis of batteries for photovoltaic systems shows they can be responsible for a number of environmental problems due to their short life, non-degradable construction, and heavy metal content. As there are currently no established processes on Kiritimati Island for dealing with such materials, this would need to be addressed. However, while it would clearly be a priority to ensure their environmental impact was minimised, it is believed that a well-designed module-recycling scheme could greatly reduce any negative impacts (Fthenakis 2000).

## 8.3 Option Configuration

With a goal to maximise the contribution of renewable electricity on Kiritimati Island, this option would utilise a 1.52 MWp ground mounted solar array, batteries with a combined storage capacity of 13.2 MWh, and a small 100 kW diesel generator to provide backup support. This is based on the theoretical requirements to provide 100 percent of Kiritimati Island's electricity in the first year of operation, taking into consideration a 15 percent inverter loss and a battery efficiency of 85 percent.

In calculating the output of such a configuration, this analysis has assumed that the effective level of solar radiation would be 4.74 kWh/m2/day, after factoring in a 15% loss due to the temperature being significantly higher than the optimal 25 degrees Celsius; 5% due to the likely non-optimal orientation of the panels; 5% due to uncompensated glass reflection; and 5% due to the accumulation of dirt. In addition to this, it is assumed that there would be an annual system output degradation of 0.8%.

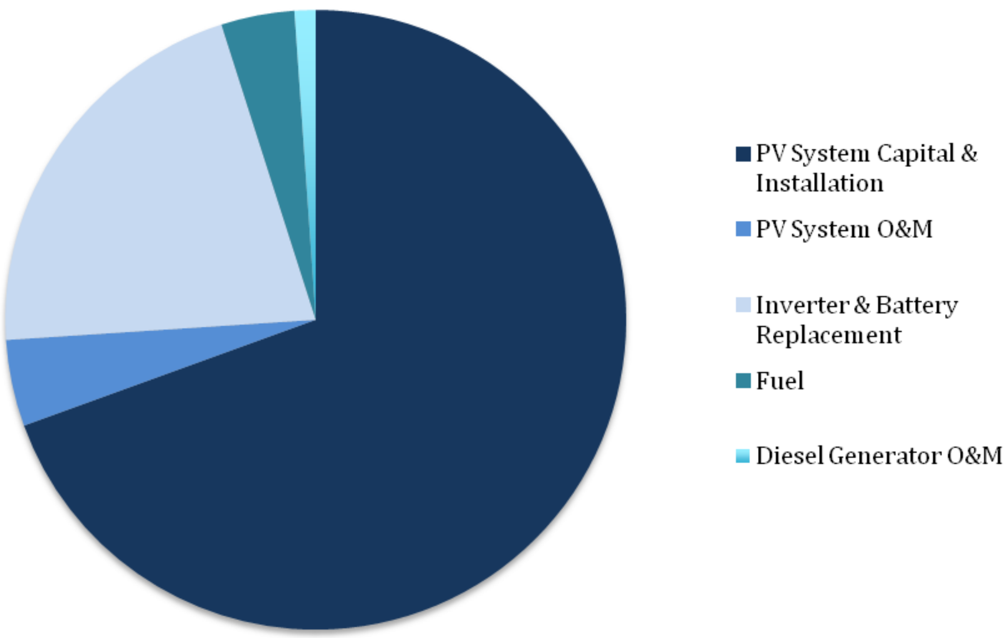
Based on the identified technical specifications and the adjusted solar radiation, the solar component of this system would generate approximately 2220000 kWh of electricity annually. However, due to the specified system losses and battery efficiency, it could be expected that such an installation would provide an average of around 93 percent of the London-to-Tabwakea-corridor's annual requirements, which are approximately 2098369 kWh. This is based on the winter solar fraction achieved by the practically identical system in Tokelau (NZMFAT 2013). A small back up diesel generator would make up the remaining shortfall in electricity.

## 8.4 LCOE and NPV

The costs in this analysis are estimated from the costs of existing installations in the Pacific and those discussed in available literature. Specifically, the per-kilowatt capital, installation, and maintenance costs, as well as the inverter and battery replacement schedule, are based on the 3 solar installations that were completed in Tokelau in 2012. The Tokelau project was very similar to the sort this configuration proposes for Kiritimati Island, and, as such, provides an accurate indication of price.

From this information, the installed cost of a 1.52MW Solar PV System and 13.2 MWh battery stock, is estimated to be AU$7.27 per kilowatt. This cost is consistent with the findings of a separate analysis of solar costs that was undertaken in Tokelau by Empower consultants (Empower Consultants 2008). The maintenance and operational costs of approximately 2 percent also reflect those estimated by IRENA (IRENA 2012b), and are also in line with the costs incurred by the 40 kW PV installation in Tuvalu (e8 2009).

*Figure 12.* **Solar-Storage Net Present Value Breakdown (20-Year Analysis)**




*Source: Author's Analysis*

The cost of the supporting 100kW diesel generator is based on the per-unit capital and installation cost of the recently purchased 400 kW diesel generator in London. However, as it is likely that one of the existing diesel generators currently in operation on Kiritimati Island could be used, this cost has been considered sunk.

Operational and maintenance costs are still taken into account and are assumed to be line with the assumptions of Wade (2002) and Woodruff (2007) at 5 percent of the generator's initial capital value, remaining constant over the generator's useful life. Furthermore, it is assumed that an engine overhaul once every 5 years and a complete engine replacement every 10 years would be required at a cost of 25 and 100 percent of the project's initial capital value respectively, and that the engine switching gear and generator would require maintenance every 7 years at a cost of 20 percent of the generator's value.

Based on these costs, it is estimated that the net present value of a solar installation with storage on Kiritimati Island, would be AU$16,043,409, and that its LCOE would be AU$0.70/kWh. This is calculated over a 20-year lifetime and is based on the US EIA's diesel price scenario presented in section 5.2.5.

Table 5 provides a summary of this project's costs, analysis parameters, and key financial characteristics, while Figure 12 above provides a breakdown of the project's expected NPV.

*Table 5.* **Option 3 Solar-Storage Financial Analysis**

| | Frequency | Amount | |
|---|---|---|---|
| **Solar Costs** | | | |
| **Batteries** | | $4,168,666.67 | AUD |
| **Solar Panels** | | $1,577,333.33 | AUD |
| **Inverters & Charge Controllers** | | $1,577,333.33 | AUD |
| **Civil Works** | | $1,239,333.33 | AUD |
| **Engineering, Project management, Labour** | | $901,333.33 | AUD |
| **Ground Mounting for Array** | | $676,000.00 | AUD |
| **BOS** | | $563,333.33 | AUD |
| **Freight and Logistics** | | $563,333.33 | AUD |
| | | | |
| | | | |
| **Operational & Maintenance Costs (labour)** | Annual | $40,860.00 | AUD |
| **Operational & Maintenance Costs (consumables)** | Annual | $4,100.00 | AUD |
| **Inverter Replacement** | 10 Yearly | $1,333,332 | AUD |
| **Battery Replacement** | 12 Yearly | $4,999,973 | AUD |
| | | | |
| ***Backup Diesel Generator (Sunk Cost)*** | | *$109,800* | AUD |
| **Engine Overhaul Cost** | Every 5 years | $27,450 | AUD |
| **Switchgear and Generator Overhaul** | Every 7 years | $21,960 | AUD |
| **Diesel Engine Replacement Cost** | Every 10 Years | $109,800 | AUD |
| **Operational & Maintenance Costs** | Annual | $5490 | AUD |
| **Diesel** | Annual | $67,974 | AUD |
| **Carbon** | Annual | $4,100 | AUD |
| | | | |
| **Annual Electricity Generation** | Annual | 2098369 | kWh |
| | | | |
| | | | |
| **Discount Rate** | | 8% | |
| **Cost and Income Inflation Rate** | | 2% | |
| **Project Lifetime** | | 20 | |
| | | | |
| | | | |
| **NPV** | | **$16,043,409** | **AUD** |
| **LCOE** | | **$0.70** | **/kWh** |

*Source: Author's Analysis*

# 9 Option 4 - 250 kW Wind Turbine and Diesel Generator

## 9.1 Overview of wind technology and prevalence in pacific Islands

A further alternative to the status quo and use of solar photovoltaics on Kiritimati Island, and the fourth option assessed in this analysis, is the use of a wind turbine. Wind turbines generate electricity by capturing kinetic energy from the wind and converting it into electricity. This process is achieved through the use of a turbine that rotates around a horizontal axis parallel to the wind, with the generator and drive chain supported some 20 – 100 metres above the ground.

The potential for wind energy production is dependent on prevailing wind speeds that vary both globally and locally. Because of the intermittent nature of wind, the potential for wind energy to replace conventional sources of electricity is limited. However, when used to supplement the electricity production of another technology, such as solar or diesel, wind energy has been shown to be highly efficient.

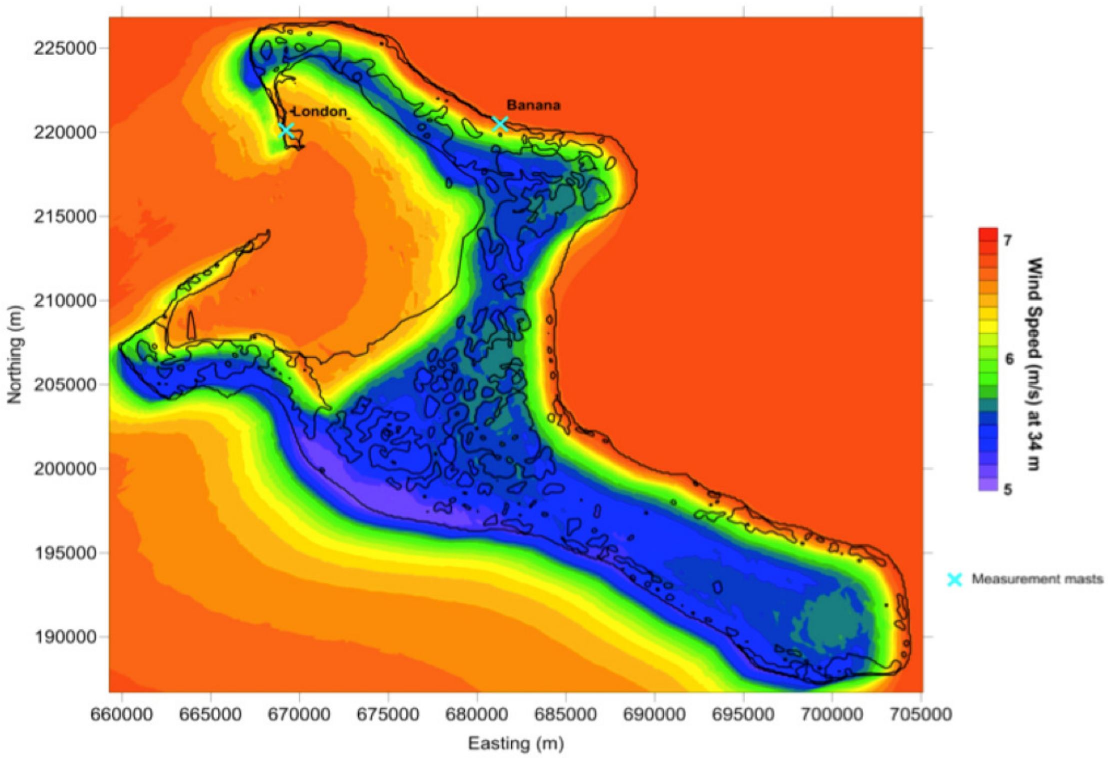
Throughout the Pacific, wind resources vary from very good in the northern latitudes to non-existent in some areas around the equator. Due to this fact, while most Pacific Islands have had wind energy demonstrations or trials, there are still only a small number of islands that utilise the technology as a main source of electricity (Woodruff 2007).

Fiji is one of the largest users of wind energy in the Pacific with a 72 kW and 20 kW wind installation in Nabouwalu and Nabua respectively. The country also has a 10 MW plant in Butoni that consists of 37 Vergnet 275 kW turbines. In addition to the wind energy plants in Fiji, the Cook Islands have also utilised the technology, installing two 20 kW turbines on the island of Mangaia with successful results, while Vanuatu also sources a considerable percentage of its electricity from wind.

## 9.2 Suitability for Kiritimati Island

In 2012, the Energy Planning Unit of the Kiribati Ministry of Public Works, commissioned the Australian consultancy *Garrad Hassan* to undertake a wind feasibility study of Kiritimati Island. The report found that Kiritimati Island has an excellent wind resource and would be a good candidate for utilising wind energy, with an average wind speed in several areas exceeding 7.5 m/s. Figure 13 illustrates the varying wind strengths across Kiritimati Island as recorded by GH, and also highlights the locations GH recommended for the positioning of a turbine.

*Figure 13.* **Kiritimati Island Wind Speed Map**




***Source:*** *(Garrad Hassan 2012)*

While Kiritimati Island has a particularly strong wind resource, one issue that has affected the suitability of wind turbines elsewhere in the Pacific is the risk that cyclones can pose. As Kiritimati Island is located outside of the cyclone belt, such is unlikely to pose a significant barrier to one's use on the island. However, the island does on occasion experience strong gusts and high wind speeds that would require appropriate consideration to be give to the style of turbine and foundation selected (Garrad Hassan 2012).

Another issue that can in some instances affect a turbine's suitability, is its impact on the surrounding fauna. Due to the large and diverse bird population on Kiritimati Island, the ecological impact and risk of accidental bird strikes must be considered. Many of Kiritimati Island's birds travel to sea to feed on a daily basis and exit the island from a range of locations depending on the speed and direction of the wind. The GH wind feasibility study raised this issue with local conservationists and found that a turbine would most likely pose little or no problem, however a more thorough assessment may need to be conducted once a turbine site has been finalised.

Lastly, the suitability of a wind turbine on Kiritimati Island may in some instances be affected by its noise generation in high winds. If the turbine was to be placed behind the MLPID offices in London, as was suggested by the GH consultants, the issue of noise would be of little concern due to its distance from residential settlements. However, depending on one's final location, the issue of noise may need to be investigated in greater depth, particularly if it was to be located closer to one of the island's 5 main villages.

## 9.3 Proposed system configuration

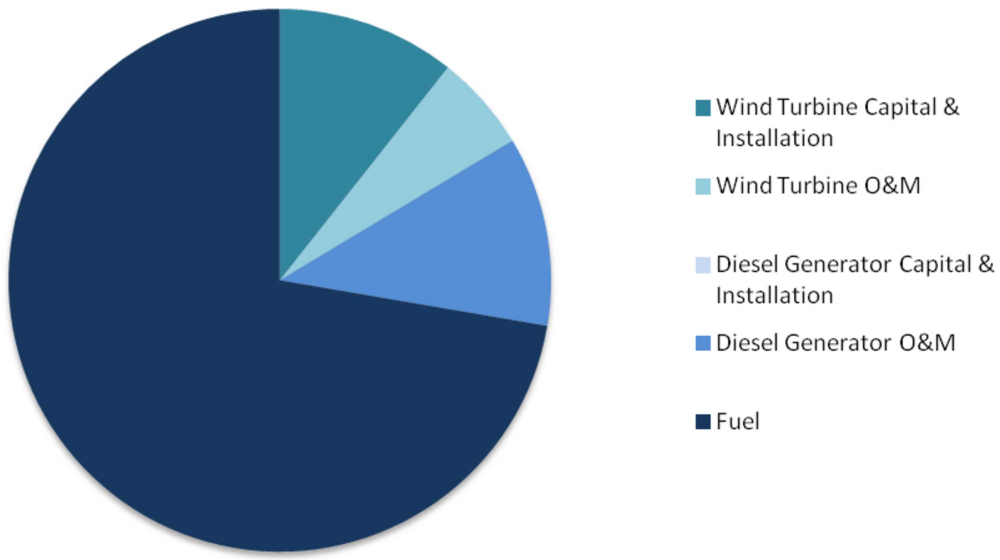
As for option two, this configuration would seek to maximise the contribution of wind electricity without the use of storage technology. It would thus utilise a 200 kW wind turbine, as recommended in the wind feasibility study undertaken by GH, and a 350 kW diesel generator, which would ensure that the maximum network load of 318 kW could be satisfied during a period of low or no wind.

Based on the average recorded wind speed of 7.5 m/s, a 200 kW wind turbine located behind the MLPID offices has been estimated to generate approximately 720,000 kWh/year (Garrad Hassan 2012).However, in the interests of being conservative and in keeping with the cautious radiation predictions used to calculate the solar estimates in this analysis, an output of 438,000 kWh/year has been assumed. This is based on the expectation of a 25 percent capacity factor which would be in line with the performance wind turbines elsewhere in the Pacific.

## 9.4 LCOE and NPV

The costs used to estimate the LCOE for the wind-diesel hybrid configuration are based on the specific financial assessment that was undertaken as a part of *Garrad Hassan's* 2012 wind feasibility study. In their assessment, they estimate that the capital and installation cost of a 200 kW turbine on Kiritimati Island would be approximately AU$1,100,000. In addition, the GH analysis assumes annual operational and maintenance costs of $AU64,000 or around 5 percent of the projects capital value, which is roughly consistent with the global O&M estimates provided by IRENA (IRENA 2012b).

*Figure 14.* **Wind–Diesel Hybrid Net Present Value Breakdown (20-Year Operation)**




*Source: Author's Analysis*

The costs of the 350 kW diesel generator used in this configuration are based on the actual purchase price and installation costs of the 400 kW Cummings generator that was acquired by the MLPID in 2012. However, as one of the existing generators owned by the MLPID could likely be used, the capital and installation costs have been considered sunk. Nevertheless, as with the other options, the operational and maintenance costs of the generator are included and are based on the estimates used by Wade (2002) & Woodruff's (2007) economic assessment of renewable energy in the Pacific. From these analyses, the generator's lifetime costs are assumed to be:

- 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 at 100% of initial capital cost every 10 years.

- Fuel efficiency is assumed to be 0.27 litres/kWh.

Based on these costs, it is estimated that the net present value of a wind-diesel hybrid installation on Kiritimati Island, would be AU$10,541,892 and that it would have a LCOE of AU$0.51/kWh. This is calculated over a 20-year lifetime and is based on the US EIA's diesel price scenario presented in section 5.2.5. Table 6 provides a summary of this project's costs, analysis parameters, and key financial characteristics, while Figure 14 provides a breakdown of the project's expected NPV.

*Table 6.* **Option 4 Wind-Diesel Hybrid Financial Analysis**

| | Frequency | Amount | |
|---|---|---|---|
| **Wind Turbine Costs** | | | |
| **E33 - 200kW Turbine** | | $600,000 | AUD |
| **Foundation & Transformer** | | $70,000 | AUD |
| **Grid Connection** | | $30,000 | AUD |
| **Shipping** | | $30,000 | AUD |
| **Spare Parts** | | $50,000 | AUD |
| **Control System** | | $100,000 | AUD |
| **Installation** | | $100,000 | AUD |
| | | | |
| **Technical Operations** | Annual | $20,000 | AUD |
| **Electrical Components Maintenance** | Annual | $2,000 | AUD |
| **Misc. Operational Costs** | Annual | $22,000 | AUD |
| **Turbine Maintenance** | Annual | $20,000 | AUD |
| **Capital injection (2% CAPEX)** | Annually (years 11 - 18) | $22,000 | AUD |
| **Generator Costs** | | | |
| ***Capital & Installation Cost (Sunk Cost)*** | | *$384,469* | AUD |
| **Engine Overhaul Cost** | Every 5 years | $96,124 | AUD |
| **Switchgear and Generator Overhaul** | Every 7 years | $76,899 | AUD |
| **Diesel Engine Replacement Cost** | Every 10 Years | $384,496 | AUD |
| **Operational & Maintenance Costs** | Annual | $19,224 | AUD |
| **Diesel** | Annual | $692,126 | AUD |
| **Carbon Cost (AU$40/tCO2)** | Annual | $48,642 | AUD |
| | | | |
| | | | |
| **Annual Electricity Generation** | Annual | 2098369 | kWh |
| | | | |
| **Discount Rate** | | 8% | |
| **Cost and Income Inflation Rate** | | 2% | |
| **Project Lifetime** | | 20 | |
| | | | |
| | | | |
| **NPV** | | **$10,541,892** | **AUD** |
| **LCOE** | | **$0.51** | **/kWh** |

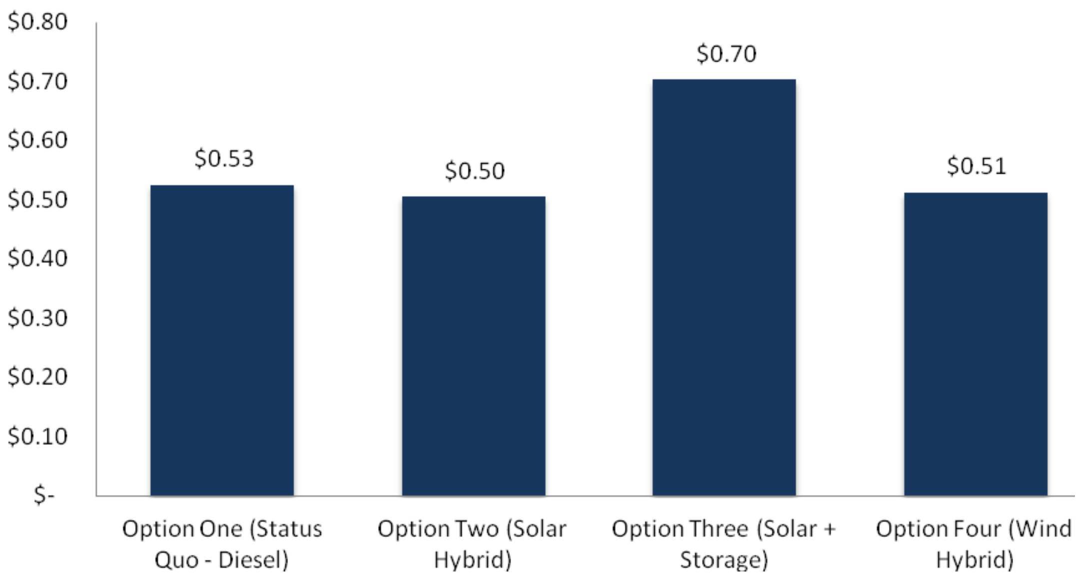
*Source: Author's Analysis*

# 10 Findings and Sensitivity

## 10.1 Overview

The findings of this analysis suggest that it would be in the MLPID's financial interest to use a solar-diesel hybrid or wind-diesel hybrid to generate electricity on Kiritimati Island. Compared to the status quo, which was found to have a LCOE of AU$0.53/kWh, savings of AU$0.02 and AU$0.03/kWh could be achieved by switching to a wind or solar hybrid respectively. In contrast, it is found that a solar-storage configuration would be more expensive than existing practices, with a LCOE of AU$0.70/kWh.

*Figure 15.* **Option 2 has the most competitive LCOE under standard assumptions**




*Source: Author's Analysis*

## 10.2 Sensitivity of Results

It is important to note that the results of this least cost analysis are sensitive to the assumptions that are made regarding diesel prices, generator efficiency, the discount rate, and the timeframe of each of the projects. In order to test the robustness of the analysis, it is thus necessary to assess the impact of changes in these parameters on the analysis' findings. Figures 16 to 19 illustrate the sensitivity of each of the alternative's LCOE to changes in the stated assumptions.

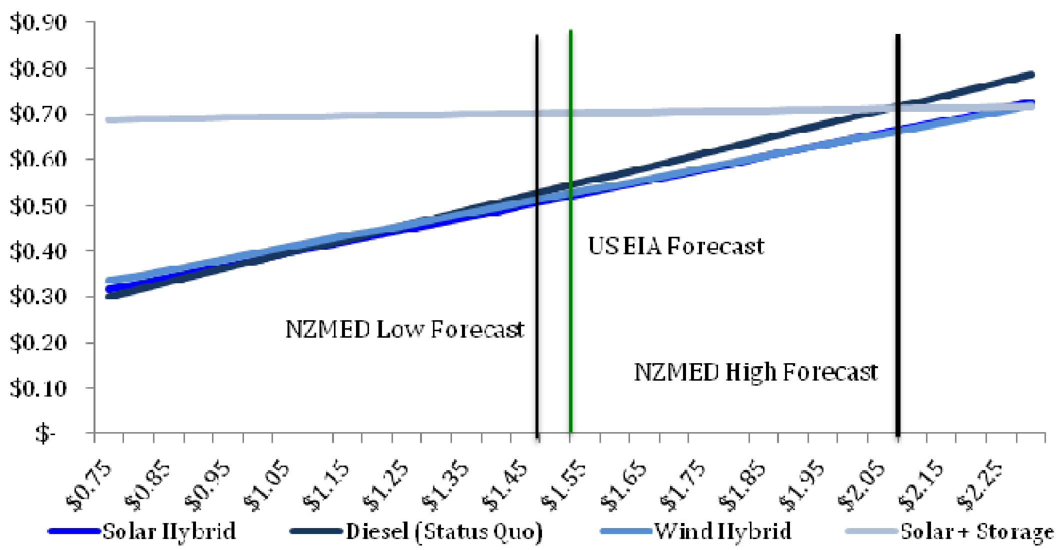
### 10.2.1 Diesel Prices

Figure 16 highlights the sensitivity of the results to changes in the price of diesel. This should be of interest to decision makers, as it illustrates the level of price uncertainty that is associated with the configurations that make greater use of conventional generators. As the status quo is that most reliant on diesel for the provision of electricity, it is also the most sensitive to changes in the commodity's price. In contrast, the LCOE of the solar-storage configuration is practically indifferent to diesel's cost.

In general, the sensitive analysis shows that the solar-hybrid option as the least expensive is only moderately sensitive to changes in the prices of diesel. Thus for a wide range of values from AU$1.15 to AU$1.65/litre the solar-hybrid option remains the most competitive.

However, if the price of diesel were to average over the period of analysis a price below AU$1.00/litre, the status quo would then have a lower LCOE than the solar hybrid. In contrast, if the price of diesel exceeded an average of AU$2.25/litre over the period of analysis, the solar-storage configuration would then have the lowest LCOE, at AU$0.71/kWh. Each of these theoretical scenarios, however, falls outside of the price band predicted by the high and low NZMED forecasts, which predict an average price of between AU$1.50 and $2.10/litre over the period of analysis.

*Figure 16.* **Real Average Diesel Price (2013 – 2033) versus LCOE**



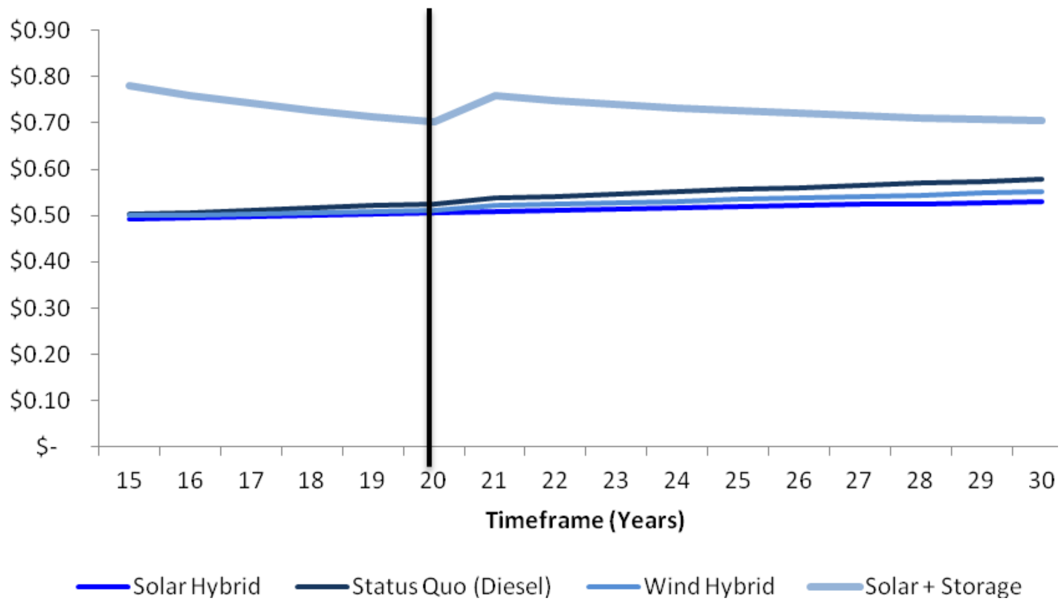

*Source: (NZ MED 2011; US Energy Information Administration 2013); Author's Analysis*

### 10.2.2 Timeframe

Figure 17 illustrates the relationship between the alternatives' LCOE and the length of their useful life, taking into account all necessary replacement, maintenance, and capital injection costs. As can be seen, the alternatives with the greatest upfront investment costs are those most sensitive to changes in the length of the timeframe. While a change from 20 to 30 years leads to a reasonable reduction in the LCOE of the solar option, it has a lesser impact on the status quo. This is due to the relatively even spread of costs across the lifetime of a diesel generator compared to the large upfront investment required of solar installations, which are relatively inexpensive to operate thereafter.

Overall, the results of the analysis could be considered to have only a low level of sensitivity to the timeframe. While the solar option is noticeably affected by the timeframe over certain intervals, the cost of battery and inverter replacements mostly dampen these short-term gains. The LCOE of the other options show little movement under a reasonable range of values, and, for all possible timeframes between 15 – 30 years, the solar-hybrid remains the most competitive.

*Figure 17.* **Project timeframe versus LCOE**

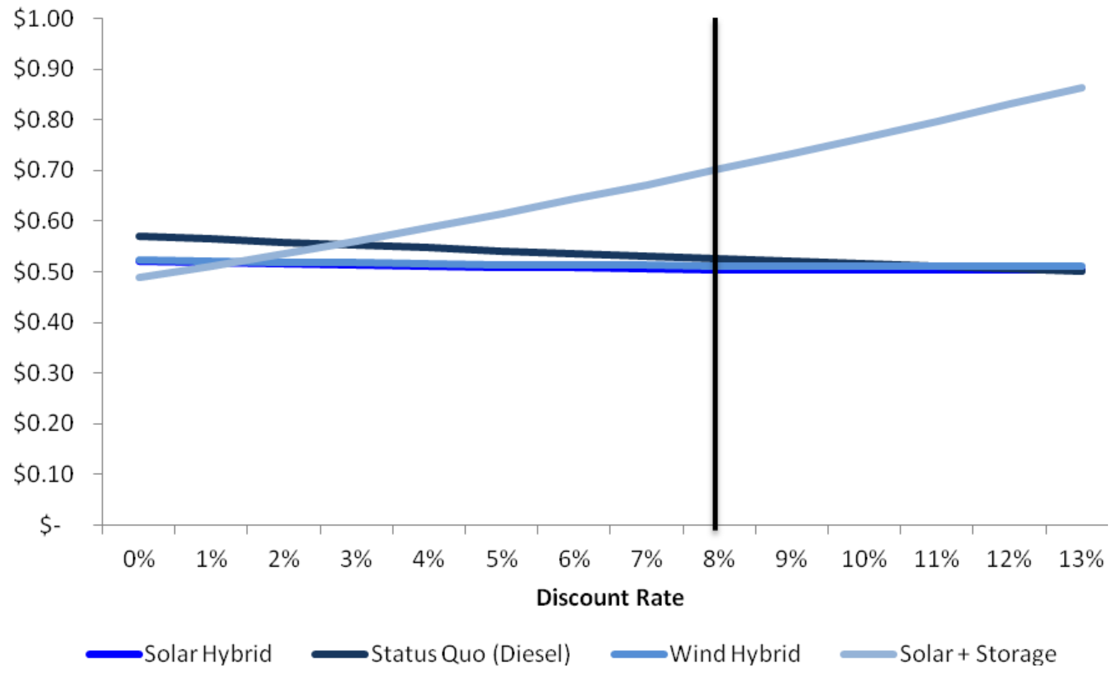



*Source: Author's Analysis*

### 10.2.3 Discount Rate

Each of the options has a unique relationship to the discount rate. Due to the nature of the LCOE calculation (see section 5.1), alternatives that incur the bulk of their lifetime costs at an early stage become less expensive as the discount rate is reduced. However, for alternatives with an even spread of lifetime costs, or a bulk of expenditure later in their life, reductions in the discount rate serve to make them less competitive. For this reason, at lower discount rates the full solar alternative becomes comparatively more economical, while the diesel option becomes increasingly expensive. While the discount rate at most levels has no affect on the conclusion that the solar-hybrid is the most economical option, if it was to be set at a rate equal to or less than 1 percent, the full solar alternative would then have a lower LCOE than all other options.

*Figure 18.* **The LCOE is particularly sensitive to the chosen discount rate**

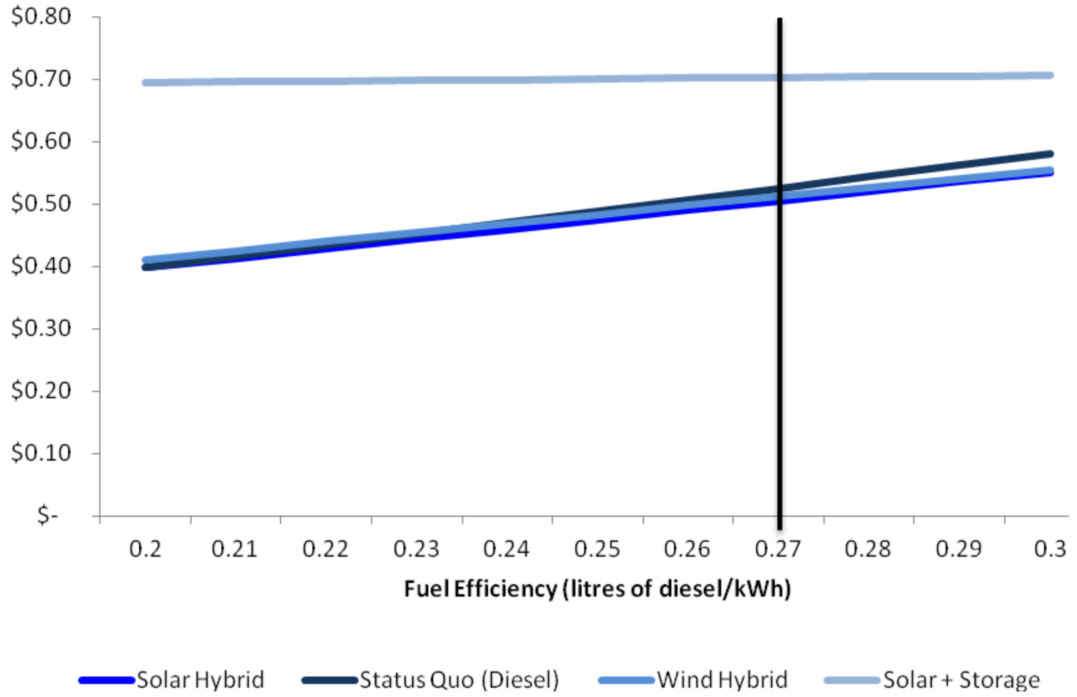



*Source: Author's Analysis*

### 10.2.4 Fuel efficiency

Intuitively, fuel efficiency has the greatest impact on the price of options that are most reliant on diesel. It is therefore the case that the full solar option is practically indifferent to changes in the rate of fuel efficiency, whilst the status quo is highly impacted. Despite this, what can be seen in Figure 19 is that no reasonable level of fuel efficiency significantly changes the relative competiveness of each of the 4 alternatives. Across all values between 0.2 litres/kWh and 0.3 litres/kWh, the solar-hybrid configuration remains the most cost efficient.

*Figure 19.* **The LCOE versus Fuel Efficiency of Generator**



# 11 Additional Considerations

In addition to the financial characteristics assessed in this analysis, there exists a range of broader considerations that should also be taken into account. Indeed, while the LCOE could be considered a good indicator of the direct costs of each of the options, it fails to evaluate a number of indirect costs such as negative environmental externalities, or the risk of price increases. In addition to this, the LCOE is unable to value non-financial aspects such as political favorability, or congruency with government priorities, which may in some instances be capable of outweighing higher project costs. The following sections evaluate some of these key areas that should be considered alongside the financial findings of this report.

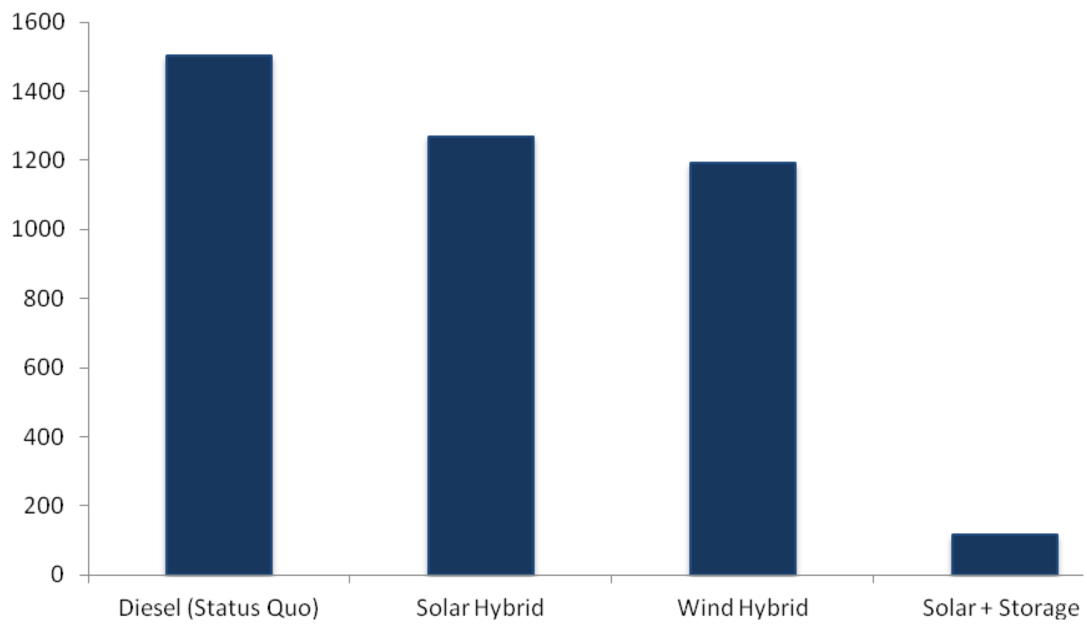
## 11.1 Environment

A particular characteristic that should be taken into account is the environmental impact of each of the options and their ability to improve upon that of the status quo. This is an issue that is highlighted as a key priority in the Kiribati National Energy Policy (KNEP), and as such should be given due consideration.

In particular, one area that should be given considerable thought is the emission of CO2. Existing electrical practices on Kiritimati Island are currently responsible for approximately 1400 tCO2 annually, or some 3 percent of Kiribati's total. While in a practical sense, strong trade winds ensure these emissions have little noticeable effect on Kiritimati Island itself, there may be a strategic incentive to reducing the island's emissions. As a signatory to the Kyoto protocol, a UNFCCC member state, and a member of the Alliance of Small Island States (AoSIS), a reduction in CO2 would enable Kiribati to substantiate their commitment to these organisations and treaties.

As is illustrated in Figure 20, the solar-storage configuration would be capable of reducing the current emissions attributable to electricity generation by approximately 90 percent. And, even under the solar and wind hybrid alternatives, reductions of 30 and 45 percent could be achieved respectively.

*Figure 20.* **CO2 emissions of proposed generation configurations (tCO2/year)** [4]

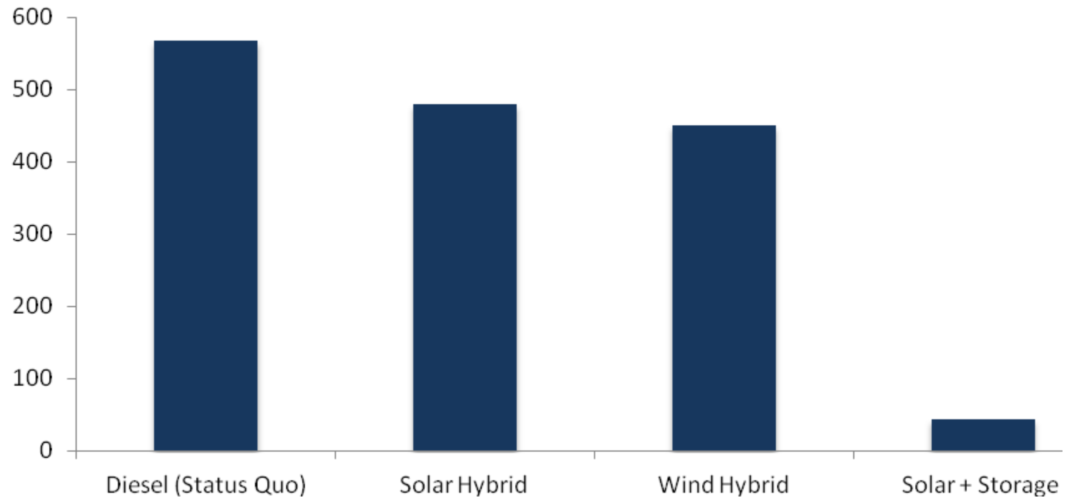



*Source:* (IPCC 1996)*; Author's Analysis*

An additional consideration that applies to each of the four alternatives and which should be factored into decisions alongside financial characteristics, are the risks of transporting and storing diesel. Each of the alternatives requires a differing quantity of fuel, and, as such, has a varying risk of an accident with environmental implications. While this risk is partly limited by the availability of fuel storage at the island's powerhouses, their close proximity to the sea means even a small spill could be serious. Quantifying this factor is difficult, as it may be the case that such an event never occurs. However, given the economic and cultural importance of the sea to Kiritimati Island, any activities that risk pollution of the island's surrounding coastline or lagoons should be carefully considered. The annual fuel requirements of the four alternatives are presented in Figure 21.

[4] Assumed diesel fuel density of 1kg=0.85 litres

*Figure 21.* **Annual diesel consumption of the four proposed options (000 litres)**




*Source: Author's Analysis*

## 11.2 Energy Security & Balance of Payments

In addition to the environmental value of reducing Kiritimati Island's consumption of imported diesel, such would also secure broader strategic and economic benefits. By reducing the island's reliance on the commodity for the production of electricity, Kiritimati would improve their energy security by reducing their current exposure to fluctuations in the price and supply of diesel. This is something that was raised as a key priority by the Government of Kiribati in both the Kiribati National Energy Policy and the country's Renewable Readiness Assessment.

Furthermore, reductions in Kiribati's reliance on imported fuel would also have a positive impact on the country's balance of payments. While Kiribati's use of the Australian Dollar precludes the possibility of any exchange rate benefits from such a shift, a positive movement in this key development indicator would signal progress towards greater economic stability and independence.

The respective diesel requirements for each of the four alternatives are presented in Figure 21.

## 11.3 National Development Considerations

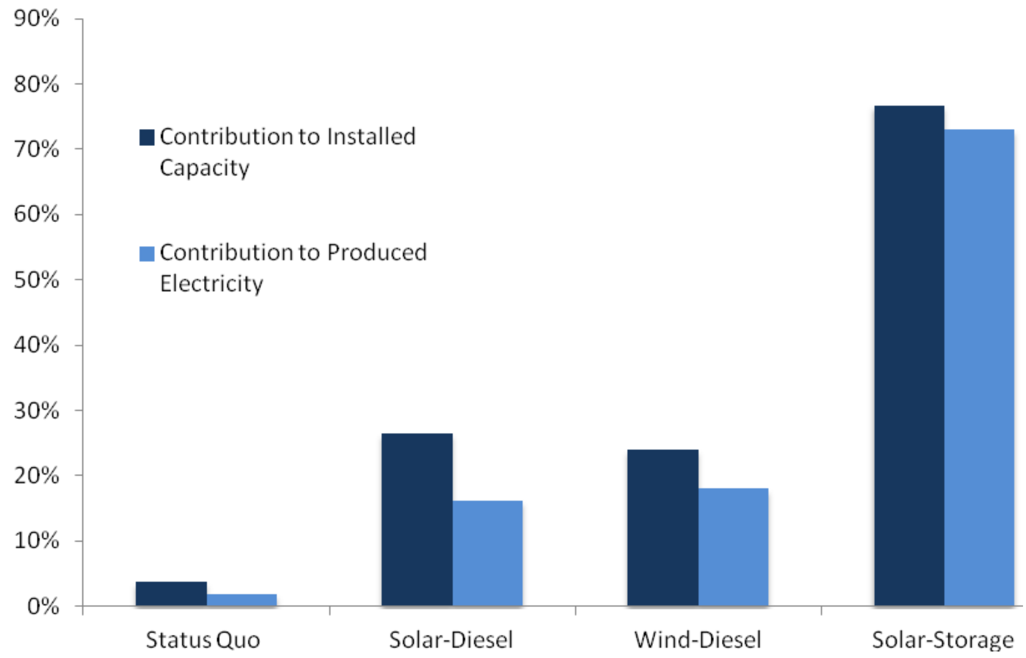
Another important issue that should be to be taken into consideration, is the development priorities of the national government as well as the plans of other sectors and industries in Kiribati. Such an integrated approach is necessary to avoid problems caused by path dependency at a later stage, and to factor in future developments that may impact on the energy sector in Kiritimati Island.

In this regard, a key area for consideration is the government's commitment to developing renewable energy and reducing emissions. In the Kiribati National Energy Policy, which was designed to provide a guiding framework for energy decisions makers, the government outlines as key priorities the development of renewable energy, the reduction of energy related emissions, and the reduction of the environmental impacts associated with electricity generation. These objectives are also highlighted in the Kiribati Development Plan for the period spanning 2012 to 2015. Developments on Kiritimati Island should thus make progress in these key policy areas, or at the very least, be sure not to restrict the ability of future developments to do so.

In the IRENA Renewables Readiness Assessment (RRA), the goals of the government in regard to Kiritimati Island are detailed more specifically. Action 5 of this report highlights the government's plan to determine the most cost effective and sustainable approach to converting Kiritimati Island's diesel mini grids to 100 percent renewable energy (IRENA and Govt. Kiribati 2012). While this report is hoped to contribute to such analysis, it is important that all sources of information that surface within the action's 24-month timeframe are taken into account. Furthermore, it is important that decisions regarding electricity on Kiritimati Island are made with consideration for the eventual goal of achieving 100 percent renewable energy that is highlighted in the RRA. The contributions the different options could make to a 100% renewable energy target are illustrated in Figure 22 below.

In a more general sense, and in addition to the above, decision makers on Kiritimati Island must also ensure that the development plans of other relevant sectors are congruent with their own. Good examples of this are the fisheries and copra industries' development plans on Kiritimati Island, which may augment electricity demand and consumption patterns in coming years. Particularly in regard to the large fisheries processing plant that has been discussed for London, an integrated approach to planning would ensure that its electricity requirements could be met if necessary. Such considerations may also help to identify which renewable technologies are most suitable, as more economically modular alternatives such as solar may be seen as the best suited to respond to changing capacity requirements.

*Figure 22.* **Contribution of RE to Installed Capacity & Total Production**




*Source: Author's Analysis*

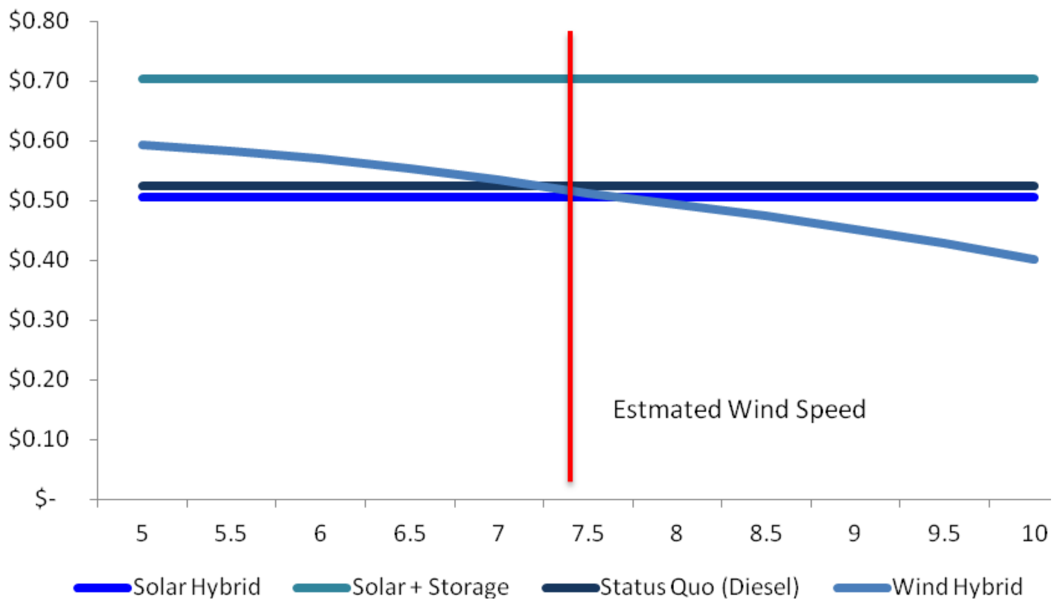
## 11.4 Price Uncertainty

A final issue that should be weighed against the financial characteristics of each the alternatives presented in this analysis, is the uncertainty attached to future costs. For the options that incur costs at a later stage in their project life, there is a greater uncertainty around what their present day value will be, as it is unknown whether prices will be as predicted due to unforeseen market developments or inflation. In the case of option 3, over 70 percent of the lifetime costs are incurred in the initial capital investment phase, and, as such, there are fewer costs with an uncertain value following the project's commencement. In contrast, only 1 percent of the status quo's costs are incurred in the initial capital expenditure, leaving a greater deal of uncertainty around what the option's actual lifetime costs will be.

Diesel is one cost that is particularly variable and has been shown in the past to be highly unpredictable. Consequentially, for the more fuel intensive options such as the status quo, and to a lesser extent the solar and diesel hybrid configurations, the risk of price exposure should be duly considered against the comparatively fixed nature of option 3's lifetime costs.

The reliability of intermittent natural resources could also have an impact on the actual cost of each of the four alternatives. As 22 years of data are available for solar radiation, the solar resource can be forecasted with relative confidence. In the case of wind, however, data exists for only 3 years for the period spanning 2009 to 2012. As the output of a wind turbine is proportional to the cube of the wind, a small deviation from the predicted average wind speed could have a significant impact on the option's LCOE. Solar output on the other hand, while being the function of numerous inputs, is typically related to solar radiation in a more linear manner. Figure 23 illustrates the impact on the LCOE that varying levels of average wind speed would have. As shown, if the average wind speed realised was 7 m/s, or 7 percent slower than the estimated 7.5 m/s, the wind-hybrid option's LCOE would rise to AU$0.54/kWh, higher than that of the status quo.

*Figure 23.* **Average Wind Speed (m/s) Versus LCOE (AUD)**




*Source: Author's Analysis*

# 12 Conclusions

The findings of this report suggest that it would be in the MLPID's financial interest to use a solar-diesel hybrid or wind-diesel hybrid to generate electricity on Kiritimati Island. In assessing the costs of the possible generation technologies to electrify the proposed grid extension between London and Tabwakea, it was found that the existing generation practice of using diesel generators would not be the most cost-effective option. Compared to the status quo use of a diesel generator, which was found to have a LCOE of AU$0.53/kWh[5], savings of AU$0.02 and AU$0.03/kWh could be achieved by switching to a solar or wind hybrid configuration respectively. In contrast, it was found that a solar PV installation with storage, capable of replacing all but a backup generator, would be more expensive than existing practices, with a LCOE of AU$0.70/kWh.

These findings were found to be only moderately sensitive to changes in the fixed parameters, which in most instances had little effect on the analysis' conclusions. Both the timeframe and discount rate, when moved within a reasonable band, did not impact the finding that the solar-diesel hybrid was the least cost alternative. Reasonable changes in the average price of diesel, however, were shown to have some influence on the results of the analysis. If the diesel price was to reach an average value over the analysis period greater than AU$2.15/litre, the LCOE of the full solar with storage alternative would then be the lowest of all the options. Nevertheless such a price level is currently seen to be unlikely and falls outside of the range predicted by the NZMED.

It was also found that the results of the analysis are moderately sensitive to the estimated average wind speed. The limited availability and questionable accuracy of the wind data makes this a point of interest. Compared to 22 years of solar data, only 3 years of wind data exist which may be inadequate to accurately estimate the strength of the island's resource. This report found that if the actual average wind speed was only 7 percent slower than that predicted, the wind hybrid alternative would then have a higher LCOE than the status quo, while if it was 6 percent greater than that estimated, it would have the lowest LCOE of all four alternatives.

What was also highlighted in this report, and which should be considered by the island's decision makers, is the expected growth in Kiritimati Island's demand for electricity. Looking at historical demand trends and proposed developments on the island, it was shown that the load of the proposed network between London and Tabwakea could be expected to grow to between three and seven times its existing level over the next 20 years. This should be of interest to the MLPID as it suggests a preference should be given to more economically modular

[5] Note, this estimate differs from that of AU$0.67/kWh that was discussed in chapters 1 and 3 of this report. The estimate presented here is based only on capital and operational costs, while the former takes account of all activities associated with MLPID's production and distribution.

technologies, whose capacity can be incrementally expanded as necessary, at prices similar to initial installations that are likely to have been larger. In this sense, solar has an edge over the use of a wind turbine as it generally considered a more modular technology.

In addition to this, other important differences were also found to exist between each of the options. The emission of $CO_2$ and reliance on imported diesel were two particular examples, which were shown to be lowest for the full solar option. While the hybrid alternatives also appeared able to make a considerable improvement on the status quo in these areas, the wind diesel hybrid showed a marginal edge on the solar hybrid alternative, requiring less diesel and causing fewer emissions. $CO_2$ emission reductions and decreased reliance on imported diesel are highlighted as key policy areas in the Kiribati National Energy Policy, not only for their environmental implications, but also due to their impact on energy security and economic performance.

In a general sense, the most suitable technology for Kiritimati Island will therefore depend on the importance decision makers place on economic, environmental, political, and strategic characteristics of the different options. While the solar diesel hybrid would be the least expensive, the full solar option could be justified under particular circumstances, despite a significantly higher LCOE, depending on how the government valued the environmental, political, and broader economic benefits that could be expected to eventuate from its development.

The future direction of electricity generation on Kiritimati island will need to be decided on by the national and local responsible stakeholders after due consideration of the options. This assessment is a first step in providing information to decision makers and presents preliminary results that show significant improvements can be made in priority areas targeted by the Kiribati government by a shift away from the continued use of diesel generators on Kiritimati Island.

However, further feasibility studies and consultations on Kiritimati Island will have to be undertaken to confirm these findings, assess other parameters such as training and capacity building requirements and plan the way forward.

# References


ADB. 2012. “Kiribati Key Indicators 2012.” 1–6.

Australian Institute of Petroleum. 2013. “Terminal Gate Prices - Historical Averages for Petrol and Diesel (Raw Data).”

Bowen, Alex. 2011. *The case for carbon pricing*.

Branker, K., M.J.M. Pathak, and J.M. Pearce. 2011. “A review of solar photovoltaic levelized cost of electricity.” *Renewable and Sustainable Energy Reviews* 15(9): 4470–4482. http://linkinghub.elsevier.com/retrieve/pii/S1364032111003492 (May 23, 2013).

e8. 2009. “The Tuvalu Solar Power Project.”

Empower Consultants. 2008. “Hybrid Photovoltaic / Coconut based Power Systems in Tokelau - Consultancy for the Feasibility , Environmental Impact Assessment , System Design and Specifications of Major Components and Financing Strategy Report on Feasibility , Environmental Impact Ass.” (March): 1–84.

Fthenakis, Vasilis M. 2000. “End-of-life management and recycling of PV modules.” 28: 1051–1058.

Garrad Hassan. 2012. “WIND ENERGY FEASIBILITY STUDY FOR KIRITIMATI ISLAND, REPUBLIC OF KIRIBATI.”

Govt. Kiribati. 2005. “2005 Census of Population and Housing.”

———. 2010. *2010 Census of Population and Housing*.

IEA. 1991. “Guidelines for the economic analysis of renewable energy technology applications.”

IPCC. 1996. “IPCC Adjusted Guidelines for National Greenhouse Gas Inventories.”

IRENA. 2012a. “Policy Challenges for Renewable Energy Development in Pacific Island Countries and Territories.”

———. 2012b. “Renewable Power Generation Costs in 2012 : An Overview.”

IRENA, and Govt. Kiribati. 2012. “Kiribati Renewables Readiness Assessment 2012.”

NASA Atmospheric Science Data Centre. 2013. “Surface meteorology and Solar Energy Location Data.”

NZ Automobile Association. 2013. “How Petrol Prices are Calculated.” http://www.aa.co.nz/cars/maintenance/fuel-prices-and-types/how-petrol-prices-are-calculated/ (May 30, 2013).

NZ MED. 2011. *Summary of 2011 Modelling Results - Energy Prices*.

NZMFAT. 2013. “Tokelau Renewable Energy Project Case Study.” (March).

SELF. 2008. “A Cost and Reliability Comparison Between Solar and Diesel Powered Pumps.” (July): 1–13.

Stern, Nicolas. 2006. *Stern Review: The Economics of Climate Change*.

Tsoutsos, Theocharis, Niki Frantzeskaki, and Vassilis Gekas. 2005. “Environmental impacts from the solar energy technologies.” *Energy Policy* 33(3): 289–296. http://linkinghub.elsevier.com/retrieve/pii/S0301421503002416 (March 11, 2013).

UK DECC. 2011. “A brief guide to the carbon valuation methodology for UK policy appraisal.” (October).

US Energy Information Administration. 2013. *Annual Energy Outlook 2013 - With Projections to 2040*.

US GOVT. 2010. “Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.” (February).

Woodruff, Allison. 2007. “An Economic Assessment of Renewable Energy Options for Rural Electrification in Pacific Island Countries.” (February).

Zieroth, Gerhard H. 2012. “Kiritimati Biofuel Feasibility Report.”