Kiribati Integrated Energy Roadmap: 2017–2025

International Renewable Energy Agency

Pacific Community
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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy in the pursuit of sustainable development, energy access, energy security and low carbon economic growth and prosperity.

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The Pacific Community (SPC) is the principal scientific and technical organisation supporting development in the Pacific region. It is an international organisation established by treaty in 1947 and is owned and governed by its 26 members including all 22 Pacific Island countries and territories. SPC works across more than 25 sectors and is the lead Pacific regional agency for the pursuit of an energy secure Pacific.

About PPA

Pacific Power Association (PPA) is an association of electricity utilities, organisations, and individuals who have an interest in the operations and development of the power industry in Pacific Island Countries (PICs). PPA is an inter-governmental regional organisation founded by the electricity utilities operating in PICs. The PPA was established in 1992 and has a Secretariat Office located in Suva, Fiji. Currently it has a membership of 25 electricity utilities operating in 22 Pacific Island Countries and 93 Allied Members world-wide with interest in the development of the power industry in the Pacific region.

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Cover image: 500 kWp Solar PV system in South Tarawa, Kiribati (Source: Masdar)

FOREWORD

Kiribati's dependence on imported oil to meet the majority of its energy needs creates vulnerability to oil price volatility and results in high energy costs, which place a burden on local development. As a collection of low-lying, isolated islands, Kiribati is particularly vulnerable to rising sea levels, increasing storm strength, disruptions to rainfall that supplies fresh water, and other dangers of climate change. To address these challenges and support economic and social development, the Government of Kiribati is dedicated to finding energy solutions and climate change mitigation measures that are sustainable, reliable and affordable.

The Kiribati 2009 National Energy Policy calls for access to sustainable, reliable and affordable energy services. In 2011, Kiribati joined Pacific Island leaders to agree on developing credible, comprehensive energy roadmaps that improve energy security, reduce dependency on fossil fuel and increase access to electricity. In 2012, Kiribati worked with the International Renewable Energy Agency (IRENA) to conduct a Renewables Readiness Assessment (RRA) and has adopted the renewable energy targets defined in the RRA. In September 2014, Kiribati joined the IRENA Lighthouses Initiative and completed a Quickscan, which provided a comprehensive assessment of the enabling conditions for the accelerated deployment of renewables and identified specific needs for targeted support from development partners.

The 2012-2015 Strategic Plan for Kiribati's infastructure and sustainable energy development, together with the Quickscan, highlighted the need for a long-term roadmap covering the energy sector. In response to these calls for action, Kiribati has co-operated with IRENA, the Pacific Community (SPC) and the Pacific Power Association (PPA) to develop the Kiribati Integrated Energy Roadmap (KIER).

The KIER comprises a policy framework, with specific targets, and a prioritised action plan, including cost estimates and timelines. The KIER covers institutional, policy, regulatory, technical, financial and capacity-building actions. Collectively, these will enable the Government of Kiribati to achieve its vision of an energy sector that contributes to energy independence and sustainable development. The KIER also demonstrates Kiribati's commitment to deploying renewable energy and addressing the challenges of climate change.

Kiribati has already taken action to put in place the recommendations of the KIER, and I am confident that the dedicated efforts of the government and people of Kiribati, and the co-ordinated support of the international development community, will let us realise of our dream of becoming an energy-independent nation.

Honourable Ruateki Tekaiara
Minister for Infrastructure and Sustainable Energy
Republic of Kiribati

CONTENTS

List of figures

List of Tables

ACRONYMS

AUD	Australian Dollar
BAU	business as usual
CFL	compact fluorescent lights
CNO	Coconut Oil
DPK	Dual Petroleum Kerosene
DSM	Demand Side Management
EE	Energy efficiency
EPU	Energy Planning Unit
GJ	Gigajoule
HV	High Voltage
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
KCFL	Kiribati Cooking for Life
KHC	Kiribati Housing Corporation
KOIL	Kiribati Oil Company
KSEC	Kiribati Solar Energy Company
KUSRP	Kiribati Utilities Services Reform Programme
kV	kilovolt
kW	kilowatt
kWh	Kilowatt hour
kWp	kilowatt peak
LED	light emitting diode
LPG	liquefied petroleum gas
LTL	linear tube lights
MIS	Management Information System
MISE	Ministry of Infrastructure and Sustainable Energy
MV	Medium Voltage
MW	megawatts
MWh	megawatts hour
NZMFAT	New Zealand Ministry of Foreign Affairs and Trade
OTEC	Ocean Thermal Energy Conversion
PALS	Pacific Appliance Labelling Standards
PEC	Pacific Environment Community
PPA	Pacific Power Association
PRDR	Pacific Regional Data Repository
PUB	Public Utilities Board
PV	Photovoltaic
RO	Reverse Osmosis
SFC	specific fuel consumption
SOC	State of Charge
SPC	Pacific Community
SSM	Supply Side Management
STSISP	South Tarawa Sanitation Improvement Sector Project
TJ	Terrajoule
UAE	United Arab Emirates
WB	World Bank

EXECUTIVE SUMMARY

In 2015 the Government of Kiribati requested assistance from IRENA, SPC and the PPA for the development of a comprehensive energy roadmap, which would take into account renewable energy and energy efficiency potential in all sectors by the year 2025. The findings of this roadmap show that power sector is a key area, where the ongoing efforts from deployment of solar PV should be continued and complemented with and improvement of efficiency in Kiribati's entire energy system, including electricity use, heating, cooling and transport.

The outer islands have an ongoing successful solar home systems (SHS) program, which should be expanded and supported going forward.

The potential for the development of coconut oil as an alternative fuel to diesel, for both power generation and transport, is also a key element that requires further development for a truly sustainable energy supply from renewable and local sources, complementing the important role of solar PV and – for Kiritimati – wind in the electricity sector. Specific measures need to be put in place for making best use of solar and wind resources, as well as for deploying the necessary water desalination capacity using renewables after minimizing water losses. These issues have been assessed in two separate, in-depth studies, one on grid integration of solar PV in south Tarawa, the other on options for water desalination using renewables. The key findings from these studies, developed in support of the KIER, are integrated as part of the KIER, in chapters 5 and 11 respectively.

This executive summary highlights some of the key challenges identified in the analysis and presents the solutions to overcome them. These solutions represent the core of the roadmap for the improvement of the energy sector in Kiribati, the Kiribati Integrated Energy Roadmap (KIER).

Challenges for the sustainability of Kiribati energy sector

- **Supply:** As a remote small island state, Kiribati is highly dependent upon energy imports. In 2014, 63% of the national energy supply came from imported petroleum products while indigenous renewable energy sources (mainly bioenergy, then solar) accounted for the remaining 37%. The KIER shows that renewable energy has the potential to greatly reduce or even eliminate Kiribati's energy import dependence.
- **Demand:** The KIER business as usual (BAU) estimate is that Kiribati's total energy demand will likely remain stable through 2025. The KIER also identifies numerous energy efficiency measures that could lead to a decline in electricity demand in South Tarawa.
- **Government expenditures:** Electricity represents one of the Government of Kiribati's highest expenditures, in terms of cost for supporting electricity supply across the country as well as electricity bills. To reduce these costs, energy efficiency recommendations for the demand side (EE-DSM) focus on improvements in cooling loads, lighting in government buildings, state-owned companies and industries, and office equipment.
- **Cost recovery:** The significant loss in revenue for the Kiribati's Public Utilities Board (PUB) between 2010 and 2014 confirms that there is ample room for improvement in the performance of the electricity system. PUB faces a number of challenges; in particular, insufficient cash flow led to deferred or complete absence of maintenance of its diesel generators. A 2014 re-assessment of PUB power system losses showed that they were unacceptably high and work needed to be done to reduce total losses from 20.63% to less than 5%.

» **Non-technical losses:** Measures should be taken to eliminate significant non-technical electricity losses. This would help with cost recovery and could also result in a significant reduction in demand when unbilled electricity is accounted for and billed. Non-technical losses amount to 10.36% of total energy generation, roughly half for unmetered services like water pumping and street lights, half being unbilled electricity.

» **Need for change:** The current fossil fuel-based power system is inadequate to meet future demand. Kiribati's readily available renewable energy resources (*e.g.* solar, wind, bioenergy) could be systematically exploited to move away from expensive and environmentally adverse overdependence on fossil fuels.

» **Modernisation:** As the level of variable renewable energy generation increases, PUB must ensure that operations of the power grids of South Tarawa and Kiritimati are improved, also accounting for the variability in the output from solar and wind through the use of modern control systems, storage and improved operational practices.

Solutions

Looking towards 2025: Table 1 defines the 2025 policy targets that drive the KIER analysis. This are the official targets adopted by the Government of Kiribati prior to the development of the KIER.

Table 1: KIER targets

Location	2025 fossil fuel reduction goal	of which	
		renewable energy	energy efficiency
South Tarawa	45%	23%	22%
Kiritimati	60%	40%	20%
Outer Islands	60%	40% (100% in rural public/private institutions)	20%

1. Optimise and reduce current fossil fuel use

» ***Enhance*** the existing petroleum-related infrastructure and ensuring that Kiribati Oil Company (KOIL) staff is fully and regularly trained in all aspects of fuel terminal operations and management.

» ***Implement*** the proposed conversion from kerosene use to liquefied petroleum gas (LPG) for cooking. This would lead to savings at all levels: from cleaner, cheaper, more efficient and more environmentally-friendly fuel to health benefits resulting from switching to LPG. Government of Kiribati stands to accrue the greatest benefits — gross subsidy savings of close to 1 million Australian Dollars (AUD) — from the new LPG subsidy programme.

» ***Achieve*** significant savings on electricity—estimated at AUD 475,482 by 2025—through the Government's full implementation of all recommended EE-DSM measures.

» ***Introduce*** PUB structural reforms, as recommended in the Kiribati Utilities Services Reform Programme (KUSRP) *i.e.* its separation into *two* new state-owned enterprises: "Kiribati Power" to manage electricity generation and transmission, and "Kiribati Water and Sewerage".

» ***Replace*** Kiritimati's currently fragmented generation systems with three independent grid systems or "zones".

» ***Reduce*** the use of fossil fuels for power generation by 22% through energy efficiency improvements on both the supply and demand side.

2. Expand the efficient use of indigenous renewable energy resources

There are numerous options to increase the renewable energy share in Kiribati's energy mix, with solar PV being the most recently proven and reliable of the newer technologies and wind for marine vessels (*i.e.* sailboats) being the most traditional. Kiribati could focus on the following renewable energy options:

- **More solar deployment for the electricity grid and for desalination in South Tarawa**, including deployment of properly-sized battery systems as key enablers for further deployment of solar PV. Renewable energy desalination is already cost-competitive with fossil-driven desalination and advances in technology allow for direct use of solar PV to drive reverse osmosis systems, without the need for battery storage or connection to the grid system.
- **More PV, wind and battery storage for Kiritimati**. The least-cost future solution for Kiritimati presents the highest share of renewable energy, exceeding 55% in the larger zone and 80% in the smaller one, thanks to the combination of PV, battery storage and wind power.
- **More renewable energy and ice plants** for fish preservation on the Outer Islands.

3. Introduce new technologies to the Kiribati energy sector

- **For variable renewable energy:** increase PV penetration levels by reducing electrical demand, retaining levels of service through advanced control systems and energy storage. Options to integrate VRE include: controllable and deferrable loads, ice storage; load shifting; electric vehicles; specialised diesel generators; battery storage; automatic curtailment of excess PV and wind; VRE generation forecasting; and geographical distribution of PV generation. Some of these measures require detailed engineering studies for assessing the potential, cost and feasibility, but they can all facilitate the introduction of VRE in South Tarawa.
- **For bioenergy:** Support the use of renewable energy sources for transportation; in particular, liquid biofuels for land and marine transport. Investigate the incremental introduction of coconut oil (CNO) into the supply chain to replace diesel for power generation as priority. Replacement of traditional use of bioenergy for cooking with improved cook stoves.
- **For road transportation:** Introduce electric vehicle pilot projects to assess their feasibility for Kiribati and, if viable, support their adoption. Government of Kiribati should spearhead the adoption of more energy efficient vehicles, such as hybrid cars and electric vehicles that use solar PV for charging.
- **For marine transportation:** Explore clean renewable energy applications in ships of all sizes, including options for primary, hybrid or auxiliary propulsion, as well as on-board and shore-side renewable energy uses. The best of multiple options, including wind (soft sail), hybrid solar and liquid biofuels (*i.e.* CNO) should be explored, introduced and refined between now and 2025.
- **Renewable energy desalination:** Before any investment in desalination takes place, the high rates of fresh water leakage and other issues with the water supply and sanitation system should be fully address. Once these issues are addressed, and rainwater collection potential is fully implemented, if a supply gap for fresh water is still present, reverse osmosis (RO) desalination powered by PV or wind (without battery storage) is the most suitable option. However, RO desalination plants previously installed in Kiribati failed due to lack of proper maintenance. Any future use of desalination needs to be accompanied by a comprehensive and well-funded plan covering the long-term maintenance.
- **Ocean Thermal Energy Conversion (OTEC):** A 1 MW OTEC plant is planned for deployment in Kiribati in 2020. A simple analysis presented in the Annex of this report indicates that the plant could increase the 2025 RE share from 35% to 59%. However a detailed study base on the performance of the OTEC plant is required to determine its full potential.

1 INTRODUCTION

Kiribati, officially the "Republic of Kiribati", is an island state in the central Pacific Ocean comprising 33 coral atolls that straddle both the equator and the International Date Line. The capital, Tarawa, is truly remote, being located about halfway between Hawaii and Australia. Together, these islands have a total land area of only 800 square kilometres (310 square miles). However, they are dispersed over 3.5 million square kilometres (1,351,000 square miles) of open ocean.

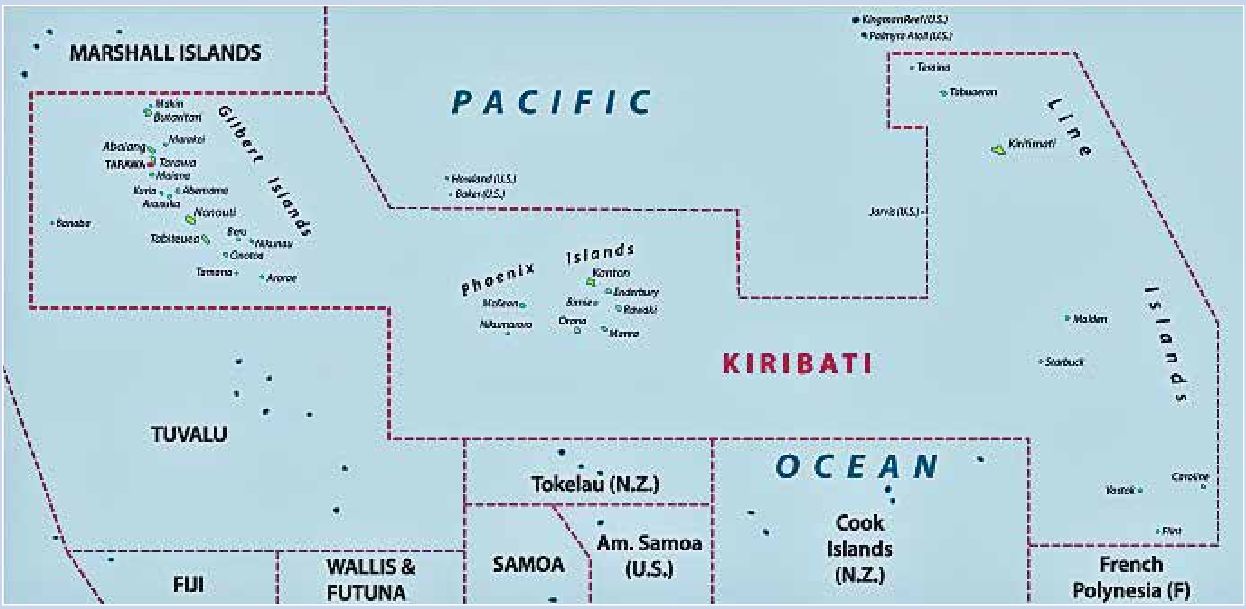
Kiribati's permanent population numbered just over 100,000 in the 2011 census, half of whom lived on Tarawa Atoll. In 2015 the CIA World Factbook described 44.3% of Kiribati's population as "urban" while a significant portion—38.23%—fell the into the "productive" 25-54 age group.

As a result of these formidable geographic and demographic factors, according to the World Bank, "Kiribati faces many challenges that are unique to small island nations, including remoteness from markets, a widely dispersed population, and vulnerability to economic shocks" (World Bank, 2013). Environmental and climatic vulnerability have also come to the forefront of island energy concerns. Hence, the value of this integrated energy roadmap, produced by a government-led team involving the International Renewable Energy Agency (IRENA), the Pacific Community (SPC) and the Pacific Power Association (PPA) in close consultation with regional and national stakeholders.

1.1 Rationale for developing the KIER

Kiribati, like other Small Islands Developing States (SIDS), depends on imported oil products to meet the vast majority of its energy needs. This dependence makes Kiribati extremely vulnerable to oil price volatility. As shown in Figure 1, Kiribati is composed of numerous small islands scattered across the vast expanse of the Pacific Ocean. The remoteness and wide dispersal of these islands engenders high energy costs that place a burden on local development.

Figure 1: Map of the Republic of Kiribati



Source: Shutterstock

Figure 2: Damage to key infrastructure resulting from rising sea levels

Source: © Nick Wardrop 2015

As a collection of some three dozen low-lying, isolated islands, Kiribati is also at the forefront of climate change, with its vulnerability exacerbated by rising sea levels, increased storm strength and frequency, and unpredictable precipitation (rainfall being the main source of fresh water). Figure 2 provides direct evidence of the impacts of climate change, showing extensive damage to the main road in Banraeaba, South Tarawa after a spring tide with high winds and waves in July 2015.

To address these challenges and support economic and social development, the Government of Kiribati is officially committed through its 2009 National Energy Policy (MISE, 2009) to finding improved energy solutions, climate change mitigation and adaptation measures that are sustainable, reliable and affordable.

Despite continuous work at the global, regional and national levels to raise awareness of the need for sustainable energy, a variety of technical, regulatory and financial barriers continue to hinder the government from increasing access to affordable modern energy services in many parts of Kiribati. In 2011, Kiribati joined the Pacific Islands Leaders in collectively agreeing on the value of developing credible, comprehensive energy roadmaps to overcome these barriers. In its three-year Strategic Plan (2012 – 2015), Kiribati's Ministry of Infrastructure and Sustainable Energy (MISE) highlighted the need to have a long-term plan (roadmap) for the energy sector.[1] In response to these calls for action, Kiribati is developing a comprehensive plan—the Kiribati Integrated Energy Roadmap (KIER)—to support the country's transition to renewable energy and efficient use of resources.

1 The Ministry of Infrastructure and Sustainable Energy (MISE) was known until recently as the Ministry of Public Works and Utilities (MPWU).

1.2 KIER Purpose and Scope

The KIER comprises a policy framework with specific targets and a set of priority actions, with associated cost estimates and specific timelines. The KIER presents a packaged plan of institutional, policy, regulatory, technical, financial and capacity-building actions that, collectively, will enable the Government of Kiribati to achieve its energy objectives, in line with the Kiribati Development Plan 2012-2015 (Government of Kiribati, 2012). The importance of renewable energy for the national development is also reaffirmed in the latest Kiribati Development Plan 2016-2019 (Government of Kiribati, 2016). The KIER provides a comprehensive, holistic overview of the Kiribati energy sector, including:

- Renewable energy options for power generation (e.g. solar, wind, bioenergy, ocean);
- Energy efficiency in electricity supply, including supply side management (SSM);
- Energy efficiency in electricity consumption, including demand side management (DSM);
- Supply of petroleum products;
- Bioenergy, including solid bioenergy, liquid biofuels and biogas;
- Renewable energy for transport (e.g. road and sea);
- Energy efficiency and conservation for transport (e.g. road and sea);
- Renewable energy-powered seawater desalination; and
- Cleaner cooking fuels and more efficient cooking technologies.

The KIER focuses on the affordability of energy services in Kiribati through an integrated approach to energy sector development. In addition, the KIER is aligned to the United Nations' Sustainable Energy for All (SE4ALL) objectives to be achieved by 2030 of: ensuring universal access to modern energy; doubling the share of renewable energy in the global energy mix; and doubling the global rate of improvement in energy efficiency.

The following renewable energy targets have been adopted by Kiribati as official policy goals. The KIER analysis has established how these goals are to be achieved and their estimated costs.

- **The goal for Tarawa is a 45% reduction in fossil fuel use by 2025.** 23% of this goal will be achieved through deployment of renewable energy and 22% through improvements in energy efficiency.
- The goal for Kiritimati is a 60% reduction in fossil fuels by 2025. 40% is to be achieved through deployment of renewable energy and 20% through improvements in energy efficiency.
- The goal for the Outer Islands is a 60% reduction in fossil fuel use in all rural public infrastructure, including Southern Kiribati Hospital and ice plants, (40% through deployment of renewable energy and 20% through improvements in energy efficiency) by 2025. The goal for rural public and private institutions (e.g. Boarding schools, the Island Council, private amenities and households) is to meet of 100% electricity demand with renewable energy by 2025.

The KIER provides a summary of coordinated, realistic, achievable and integrated institutional, policy, regulatory, technical, financial and capacity-building actions to meet the national renewable energy and energy efficiency. It will also assist with setting national targets for other energy sectors, including road, air and sea transport, petroleum and other interrelated energy issues. The KIER will be used as an implementation plan for the Kiribati National Energy Policy that was endorsed in 2009 (MISE, 2009). In addition, the Government of Kiribati will benefit from the KIER as it can be used as a tool to focus funding for the energy sector and possibly leverage additional support for the priority activities identified.

To develop insights into the key areas affecting the Kiribati energy sector, in-depth analyses were performed in the following areas:

- Current **demand** trends, demand breakdown and potential issues that require special attention from Kiribati policy makers.
- The current electricity **supply** system, modelling in detail existing diesel generators and PV systems, and including the additional PV system expected to be commissioned in 2016. The analysis included the **simulation of power system** dispatching, impact of PV deployment on fuel savings, renewable energy share and grid operations.

- The **optimal evolution of the power system** for both South Tarawa and Kiritimati has been modelled, using a least-cost approach. Next steps for further deployment of renewables have been identified in terms of **clear and implementable milestones**, which would allow for an ambitious yet techno-economically sound expansion of renewable energy capacity in Kiribati.
- The potential for **coconut oil as a replacement for diesel** fuel has been assessed and best practices identified from other countries; these can guide the design of a pilot project for the gradual replacement of diesel fuel with coconut oil for power generation.
- **Renewable energy options for transportation** have been considered and a summary of commercial and pre-commercial options have been presented. Quantitative analysis of the possibilities offered by current technology for inter-island transportation using solar PV and electric motors for current catamarans have been conducted, with the aim of assessing the pre-feasibility of such an option.
- In support of the KIER, a full report on **renewable energy options for seawater desalination** in South Tarawa, Kiritimati and Nonouti (with possible replication on other outer islands) was prepared. The key findings of this report are detailed in the KIER document.
- There are numerous **options to** significantly **improve energy efficiency** through specific measures in power generation, buildings, cooking, transport and the entire value chain surrounding fossil fuels. Section 15 of the KIER provides detailed plans with specific implementation strategies, milestones and cost estimates for the proposed energy efficiency measures.
- There is an **urgent need for the Kiribati Oil Company (KOIL) terminal management and staff to be fully and regularly trained in** all aspects of **fuel terminal operations and management**. KOIL storage and distribution facilities comply with international industry standards, including AS 1940-2004, the storage and handling of flammable and combustible liquids, AS/NZ 1596-3014, and the storage and handling of LP Gas and others by 2020.

2 KEY FINDINGS AND RECOMMENDATIONS

2.1 Key findings: Kiribati in-country visit

In support of the KIER, an in-country visit conducted by personnel with expertise in the Kiribati energy sector identified the following key issues that will affect the implementation of the KIER recommendations:

- When energy efficiency schemes are implemented from both supply and demand side, it is expected that electricity demand will drop, further increasing the effective penetration of grid connected PV systems on the South Tarawa grid.
- Scheduled maintenance has not been performed on the Public Utilities Board (PUB) generators. In some cases, needed maintenance has been missing for years due to limited revenue collection. The lack of proper maintenance significantly reduces generator efficiency and reduces its ability to support high shares of PV penetration versus well-maintained generators, which can cope with more demanding operating conditions.
- Unregulated connection of PV systems may further exacerbate PUB's challenges with integrating renewable energy.

2.2 Key findings: Demand analysis

In 2014, Kiribati's electricity peak demand was 4.17 MW with the total generation of 23,774 MWh. However, PUB billed for only 18,587 MWh of generation. The difference in total generation versus billed generation resulted from line losses of 1,484 MWh, station/auxiliaries losses of 1,209 MWh and non-technical losses consisting of 1,179 MWh of unmetered demand and 1,314 MWh of unbilled demand.

The unbilled portion of annual demand (non-technical losses) has increased significantly since 2010. The missing revenues from unbilled and unmetered demand pose a threat to PUB's continued operations. The unmetered demand represents known services provided by PUB free of charge and represent a financial loss. It is understood that the unmetered demand is composed primarily of the water and sewerage pumping, which are deliberately provided for free. The government and PUB should re-examine this strategy as it represents a significant loss of revenue for PUB and because charging these customers would likely provide a strong incentive to operate in a more energy efficient manner.

The current water distribution network, which provides water to individual households from the village reservoirs and the household connections, is in poor condition and is responsible for the bulk of water distribution losses (estimated at 50%). Upgrading to a fully automated and computerised data collection system would help to mitigate issues related to data quality and availability that may result from the currently manual data collection method. Better data would greatly assist with ongoing and future energy planning efforts.

In 2015, diesel fuel for power generation stood at AUD (Australian dollars) 8.011 million, representing consumption of 6.31 million litres of fuel at an estimated average diesel cost of 1.27 AUD/litre. The average electricity generation per litre of diesel is 3.77 kWh/litre, which is quite low and could be increased to international standards, at least above 4.0 kWh/litre. For South Tarawa, there is an official target to reduce diesel fuel use for power generation by 22% by 2025 compared to the BAU through Energy Efficiency – Supply Side Management (EE-SSM) and Energy Efficiency – Demand Side Management (EE-DSM). There are no data available to extrapolate the energy efficiency targets for Kiritimati; therefore, these targets will be set once available data are provided.

Estimated fuel use for land transport in 2014 was 7.16 million litres (4.45 million litres of diesel and 2.71 million litres of petrol). Additional investigation into the substantial fuel use for private, commercial or government should be undertaken and measures to reduce fuel uses identified, especially for government-owned vehicles.

In 2010, 58% of households in urban areas used kerosene for cooking; 49% used bioenergy (wood); 25% used liquefied petroleum gas (LPG) and 1% used copra residue. By 2025 the goal is to reduce the number of households using wood for cooking to 25%, with 100% of these households using improved bioenergy cook stoves.

2.3 Key findings: Current power system

South Tarawa

The current power system relies primarily on diesel generation and is composed of two power stations. The Bikenibeu power station has three diesel generators with a nominal capacity of 1,400 kW each; however, all three have been de-rated to 1,200 kW. The Betio power station has one diesel generator with a nominal capacity of 1,250 kW it has been de-rated to 1,100 kW. As a result, total installed diesel capacity is only 4,700 kW versus a peak demand in 2014 of 4,170 kW. This means that in peak operating hours the system must operate all four generators to meet demand and no spare capacity is available.

Fuel use for power generation for South Tarawa and Betio was 6.29 million litres in 2014 with an estimated total generation cost of AUD 7.5 million. This cost is equivalent to 85% of the total electricity revenue (AUD 8.9 million). Electricity tariffs have been constant since 2010: domestic 0.40 AUD/kWh, government and industry 0.70 AUD/kWh and commercial 0.55 AUD/kWh.

In addition to diesel capacity, there are 920 kWp of grid-connected PV. It is expected that 500 kWp of additional PV capacity will be commissioned in 2016 for a total of 1.42 MWp of PV capacity. The introduction of 1.42 MWp of solar PV into the current electricity system of South Tarawa will require changes in the current operational practices of PUB to efficiently manage the expected power fluctuations. Dedicated reserves to compensate for variations of PV power must be allocated according to real time operational conditions. Similarly, curtailment of part of PV power to guarantee secure system operation may be necessary under certain operational conditions. This will require real time, constant monitoring of system performance.

Some of the installed PV systems have been fitted with controls that allow automatic curtailment to avoid problems with over-frequency in cases of excess of generation. Diesel generators remain responsible for under-frequency control, through spinning reserve. At the current level of renewable energy deployment, it is already advisable to implement a supervisory control system that allows real time monitoring and assessment of the operation and enables automatic control of the generation to regulate the variations in PV power.

It is ***not*** recommended to allow installation of further PV power capacity in the system until sufficient experience with the new operational conditions have been acquired by PUB. Also, additional studies using measured data of system performance should be conducted before installing more capacity. The addition of new renewable energy capacity must be in line with long-term plans, taking into account future battery storage projects.

Further dynamic electrical studies, using acquired system measurements and benefiting from the experience derived from operating the system with solar PV, are strongly recommended. These studies will not only serve the purpose of assessing PV integration but will also define additional expansion measures to increase current reliability levels in the system. These new studies should be in line with current and planned renewable energy generation expansion plans. Aspects to be considered in future studies include protection coordination[2], implementation of an under-frequency load disconnection scheme and development of an N-1 system[3].

Besides power reduction by using an over-frequency function and the capability to receive curtailment signals from generator operators, the PV inverters to be installed in 2016 should provide sufficient frequency

2 The introduction of PV and/or wind generation into the electricity grid can change some of the natural responses of the grid to disturbances and can reduce the effectiveness of current protection devices (*i.e.* devises installed to protect integrity of equipment, persons and the overall system). A protection coordination study is an analytical technical study done with the purpose of determining optimal characteristics and settings of network protection devices and may be required to ensure that the system is properly configured to deal with new PV and/or wind generation.

3 N-1 is a criteria to operate and plan power systems where it is assumed that the system must be able to continue normal operation after losing one element (a line, a transformer or a generator).

and voltage ranges of operation to cope with the power quality conditions in the system of South Tarawa.

Kiritimati Island:

The Kiritimati electricity sector is undergoing a significant transformation with currently isolated load centres being connected to create three separate grids identified as Zones 1, 2 and 3. Data on the configuration and performance of current power system are extremely limited and should be recorded and disseminated to all stakeholders as the planning process for the new grid zone proceeds. These details would help to support additional analysis beyond what the KIER has examined using the limited data available.

Outer Islands:

There are only very limited data on the generation assets installed in the outer islands and even less data available on the performance of these systems. It can be generally stated that Outer Islands with larger populations are served with diesel micro-grids that often incorporate PV generation. Smaller population islands are often dependent upon individual diesel generators with no grid and/or solar house systems that provide minimal services like lighting. Section 5.3 provides the available details on the Outer Island power systems.

2.4 Key findings: Future power system analysis

South Tarawa

The current power system already has enough installed or planned grid connect PV capacity so that battery storage needs to be deployed in the immediate future to ensure system stability. This battery system, sized on expected future load, can allow both to optimise the fuel efficiency of the diesel generators, to deal with under-frequency issues by injecting power and, when load is below the power capacity of the battery system, to turn off diesel generators during the central hours of sunny days.

The deployment of a properly-sized battery system will be a key enabler for further deployment of solar PV in South Tarawa. If an adequate wind resource can be identified, this system would also support the deployment of substantial wind generation capacity. KIER analyses show that the economically optimal power system with a combination of 2.5 MWp of additional PV (for a total of 3.92 MWp) and 2.64MW/5.6MWh of battery storage would exceed the current 23% renewable energy target and allow for a 35% annual renewable energy share. Table 2 details the options for PV and battery deployment investigated in the KIER

Table 2: Impact of PV and battery storage on diesel operations and fuel consumption

	System as in 2016, 2025 load **1.42 MW PV and no storage (as status by 2016)**	***Minimum cost next step system*** **2.92 MW PV and 264 kW/560 kWh storage**	***Minimum recommended next step system*** **2.92 MW PV and 2.64 MW/5.6 MWh storage**	***Optimal system*** **3.92 MW PV and 2.64 MW/5.6 MWh storage – least cost system**
Generator	Total running hours	Total running hours	Total running hours	Total running hours
Bikenibeu #3	7,006	6,299	1,854	1,510
Bikenibeu #4	8,168	6,482	7,772	6,802
Bikenibeu #5	1,120	171	0	0
Betio #1	2,757	4,417	2,785	2,992
Fuel consumption per year	3.60 Million litres	3.25 Million litres	3.03 Million litres	2.77 Million litres
Cost of electricity	0.304 USD/kWh	0.296 USD/kWh	0.288 USD/kWh	0.279 USD/kWh
RE share	12.1%	21.5%	24.6%	35%
Investment for additional PV with storage	0	3.5 Million USD	7.8 Million USD	9.8 Million USD

analysis and clearly shows the benefits of a properly sized battery storage system.

Kiritimati

It is proposed that the current fragmented generation systems on Kiritimati be replaced by three larger grid systems referred to as "zones", operating independently from each other (MISE, 2013). The proposed zones in order of total demand (kWh) are:

- Zone 1: Ronton (London), Tennessee and Tabwakea
- Zone 2: Banana, New Banana and the Kiritimati Island airport
- Zone 3: The village of Poland on the western side of the island

Table 3 and Table 4 provide details on the addition of PV, wind and battery storage to the existing diesel power systems for the proposed Zone 1 and Zone 2. Zone 3 already has a hybrid energy system with 16 kWp of PV. For the case of rapid demand growth in Zone 1, as expected in some scenarios, increased demand can be covered by additional PV, additional storage and finally additional wind added in a modular fashion.

Outer islands

Table 5 provides an overview of the future projects that have been identified to upgrade services on the outer islands. These include renewable energy systems already in the planning process and ice plants for preservation of fish.

2.5 Key findings: Coconut oil power generation

The logistics of collecting, shipping and refining the copra required for coconut oil (CNO) production, along with those needed to produce and distribute a high quality CNO fuel, will likely require a sophisticated and well-run supply chain. Detailed analyses demonstrating the sustainability of CNO production and elaborating how the challenges detailed above can be overcome

Table 3: Kiritimati Zone 1 generation assets

Location Zone 1	Rating kW	Capacity Factor	Annual Energy MWh	RE share %	Cost USD	Status Sep. 2015
Tennessee Diesel 1	400	n/a	n/a	n/a	?	Old unit
Tennessee Diesel 2	100	n/a	n/a	n/a	?	2016
Tennessee Diesel 3	100	n/a	n/a	n/a	?	2016
New PV	200	17%	300	15	400,000	2016
Battery storage	264	n/a	0.56 (capacity)		500,000	future
Wind	275	36%	875	45	800,000	future
TOTAL	1339		875	n/a		

Table 4: Kiritimati Zone 2 generation assets

Location Zone 2	Rating kW	Capacity Factor	Annual Energy MWh	RE share %	Cost USD	Status Sep. 2015
Banana Diesel 1	60	n/a	12.5	n/a	?	2016
Banana Diesel 2	60	n/a	12.5	n/a	?	2016
PV	150	0.17	220	83	300,000	future
Battery storage	165	n/a	0.35 (capacity)	n/a	280,000	future
TOTAL	435		245.35	n/a		

Table 5: Planned Outer Island PV Systems

System type	Number	Capacity (kWp)		Capacity (kWp)	Status (Sep. 2015)
		Per system	Total	Thousand AUD	Comments
Households (solar lighting kits)	6,000	0.035	210	1,500	Cost estimate by end 2015
Police Stations	23	0.12	2.8	60	
Councils	20	5.0	100	710	
Health Clinics	58	1.0	58	230	Size estimated
Junior Sec School	36	0.41	14.8	285	
School Mini-grid – small	3	16.5	49.5	1,000	Size estimated for one
Desalination systems	13	2	26	115	Size estimated
Fish Centres	20	3.75	75	610	
Ice Plants	18	20	360	3,600	Size and estimated cost
Southern Hospital (Tab. N.)	1	265	265	2,400	
TOTAL			1161.1	10,510	

should be completed before any investment in CNO production takes place. In addition, such a study should examine all current uses of copra (e.g. cooking) and determine how these uses would be affected by dedicated CNO production.

Assuming that the challenges detailed above can be overcome, a CNO supply chain for Kiribati could replace large amounts of diesel for power generation. Together with solar PV and possibly wind, CNO could contribute to Kiribati's transition to a 100% renewable power sector. Table 6 shows the results of KIER analysis on potential CNO production.

Table 6 shows that CNO has the potential to offset a significant percentage of diesel consumption in the electricity sectors of both South Tarawa and Kiritimati. It also demonstrates that the variability in copra production would require careful management if CNO is to become a reliable source of fuel for reducing diesel imports. This could require the rehabilitation and attentive tending of existing coconut resources to ensure a reliable and predictable source of copra. It is important to note that the quality of CNO is variable and depends on numerous factors, including: the quality of raw materials, harvesting and transport conditions, and the efficiency of processing, purification and storage.

2.6 Key findings: Renewable energy transportation

Sea transportation

Table 7 gives an overview of the number and type of larger commercial and government marine vessels

Table 6: Estimated CNO production potential and impact on diesel consumption

Island	Historic copra production 2003-2012 (tonnes / year)		CNO potential (litres of diesel equivalent / year)	Reduction of annual diesel usage for electricity generation
South Tarawa	min	5,000	2,500,000	40%
	max	11,500	5,750,000	91%
Kiritimati	min	1,000	500,000	50%
	max	2,500	1,250,000	126%

Source: (KIIREP 2008) and (Zieroth, 2012)

Table 7: Inventory of Kiribati-registered vessels as of July 2014

	Motor Vessels	Outrigger Canoes	Catamarans	Landing Crafts
Registered vessels	10	12	10	4

registered with the government as of July 2014. There are many small private outboard motor boats and canoes with engines that are not registered.

The ten registered catamarans would be perfect candidates for a pilot project to assess the viability of solar powered electric drives for inter-island transportation. Both inboard and outboard solutions could be tested and compared in terms of effectiveness in fuel savings, ease of maintenance and reliability. For instance, outboards use gasoline, while inboards use diesel; therefore, savings are expected to be higher for outboards.

Kiribati has relied on indigenous sailing craft between islands since the island group was settled by Micronesians speaking the same Oceanic language sometime between 3000 BC and AD 1300. Traditional navigation knowledge and skills may have been passed on though oral traditions but most may have been lost when diesel engine-powered boats and ships entered the local market. The values and priorities afforded to traditional sailing systems have eroded alongside the deployment of modern boats and shipping.

The global maritime transportation and shipping market is shifting from a fossil fuel-driven market to a clean energy one in response to the need to mitigate detrimental climate change and the consequent environmental impact on the global economy and human survival. The industry is pursuing a target to reduce greenhouse gas emissions by 20% by 2020 and 50% by 2050.

The global industry has a lot to offer Kiribati although much of the ongoing effort to find commercially viable renewable energy technology shipping options is exploratory with few designs demonstrating adequate commercial viability to capture the market. Global market research and testing of renewable energy technologies are mostly dedicated to wind, solar photovoltaic, biofuel and wave energy.

Kiribati's maritime transportation and shipping sector relies on diesel-powered boats and ships. The small scale (by world and regional standards) of economic activities limits the opportunities available to shift Kiribati's maritime transportation and shipping sector to a cleaner future. However, renewable energy options worth exploring include wind (soft sail), hybrid solar and biofuel (CNO). Deployment of these renewable technologies will require appropriate legal and regulatory frameworks and incentives to encourage public and private investment; ongoing planning and training of local capacity to install, manage and repair new systems; and the availability of financing facilities and relationship-building with development partners.

Electric drives are increasingly becoming commercially available, also for smaller scale vessels as opposed to large ships where electric drives are powered by dedicated on-board diesel generators. Small-scale electric outboards are also increasingly being used to power small craft.

Road transportation (South Tarawa):

The road network in the Kiribati group covers only ca. 40 km from Betio to Buota while the Kiritimati road network covers ca. 100 km with the longest route from Paris to Ronton. Table 8 provides a breakdown of the vehicles imported into South Tarawa between 2004 and 2013; no data are available on the vehicle imports for Kiritimati.

Table 8: Vehicles imported into Tarawa between 2004 and 2013

	Minivans (10-15 seat) and Pickups	Saloon	Trucks and Tractors	Motorcycles
Vehicles imported 2004-2013	544	2,323	1,534	4,774

There is a growing number of electric vehicles (EVs) available as motorcycles, cars, utility vehicles and buses. Not all are suitable for the aggressive marine environment in Kiribati; however, there are examples of motorcycles and utility vehicles known to have been used in an equatorial atoll environment. Once charging points are available at various locations, these vehicles can be charged from the electrical grid, or even from stand-alone PV systems, provided they have sufficient generation capacity. It is recommended to explore the possibility of a pilot project to assess the viability of EVs in Kiribati, starting with public transportation (*e.g.* mini-buses) and private motorcycles in South Tarawa.

2.7 Key findings: Renewable energy desalination

Desalination based on renewable energy is technically feasible and, if properly operated and maintained, could provide a sustainable supply of fresh water for Kiribati's islands. However, it should be noted that desalination is the most technically complex and expensive option available in terms of both initial cost and operation and maintenance. Before any investment in desalination takes place, financial resources should be dedicated to reducing the very high rates of fresh water leakage, as well as addressing other significant issues with the current water delivery system.

Among the combinations of technologies reviewed, reverse osmosis (RO) desalination powered by PV or wind is the most suitable option for use in Kiribati. RO desalination plants previously installed in Kiribati failed due to lack of proper maintenance. Any future use of desalination needs to be accompanied by a comprehensive and well-funded plan that ensures the long-term maintenance and sustainable operation of desalination plants.

South Tarawa's large and growing population results in a water demand exceeding sustainable use of the current water supply. Desalination could help to reduce or eliminate this gap in water supply; however, it is an expensive option for water supply and needs to be considered in combination with the following lower cost options:

» Reducing significant leakage in the water distribution system, currently estimated at over 60%;
» Eliminating contamination of the fresh water supply from sewage and salt water; and
» Boosting safe and sanitary rain water collection and storage.

In Kiritimati, sustainable and efficient use of the current fresh water supplies could support a population increase from 5,500 to 27,500. However, current population growth is concentrated from Tabakea to London, where ground water supplies support only ca. 6,000 people. If population continues to grow in this area, desalination should be investigated.

Limited data on both water usage and resources greatly limited the scope of the desalination study for Nonouti. The government should consider measures to increase data collection on water usage in the outer islands with larger populations so that accurate studies of the possible need for desalination can be conducted.

For South Tarawa, the desalination study recommends using a modular system configuration based on desalination plants with individual capacities of 528,000 litres per day. Assuming that issues with distribution losses have been addressed, analyses indicate that two of these plants would provide the most economical option for meeting 2015 water demand. The number of plants would need to be expanded to a total of six in order to meet the projected water demand in 2025; however, decreasing water distribution losses and increasing rain water collection would allow for a total of only five new plants by 2025.

A modular approach to deploying desalination plants is recommended. This allows for a single plant design, which reduces the cost of construction, operation and maintenance. It also decreases the complexity of planning future capacity expansion to meet growing water demand. However, it is recommended that the plant size indicated in the desalination study be reviewed to ensure that it is cost-optimal and maximises flexibility in planning for future demand.

3 KIRIBATI ENERGY SECTOR STATUS

3.1 Primary energy supply

There are two primary energy sources in Kiribati: imported petroleum products and indigenous energy sources which are mainly bioenergy and solar. The imported petroleum includes automotive distillate oil (ADO), petrol, dual-purpose kerosene (DPK), liquefied petroleum gas (LPG) and aviation gasoline (Avgas), which is used for small turboprop planes. See Appendix 1 for energy balance figures for Kiribati.

Being a remote small island state, Kiribati is highly dependent upon imported primary sources. This dependence on imported energy is clearly demonstrated in Figure 3. In 2014, the reliance on imported petroleum fuel was 63% with renewable energy sources accounting for the remaining 37%. Energy needs for commercial use are virtually all met by imported petroleum products. The renewable energy sources are predominantly comprised of bioenergy used for cooking (485,865 gigajoules) and solar energy (7,756 gigajoules). Bioenergy is predominantly used in open fire cooking which is inefficient with only 20% of the energy content captured. It is expected that, from 2015 onwards, the share of solar energy for electricity generation will increase due to installation of a number of grid connected solar PV systems in South Tarawa.

Figure 4 provides information on energy imports showing an overall increase of 39% between the years 2000 and 2014. From 2000 to 2008, fuel imports grew by 29% but from 2008 to 2014, the percentage growth was reduced to 7.2%. There was a reduction of imports from 2008 to 2010 when the supply of imported fuel was impacted by the 2008 hike in international oil prices.

Figure 3: Trends in primary energy supply 2000–2014

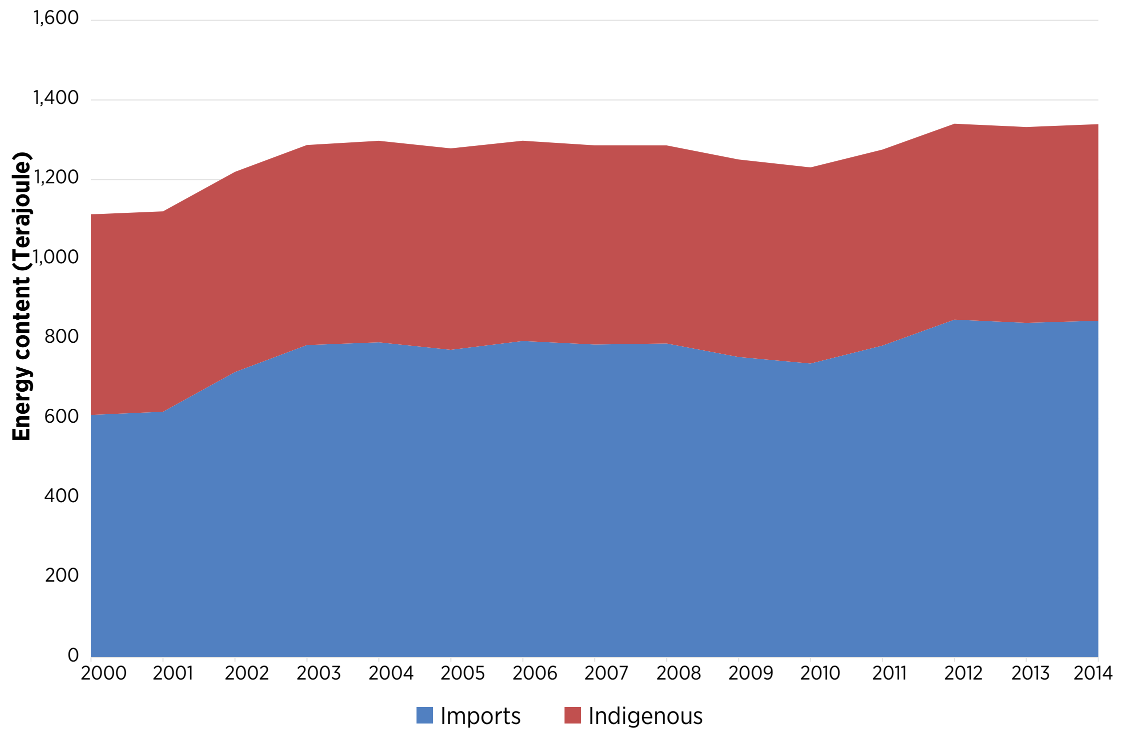
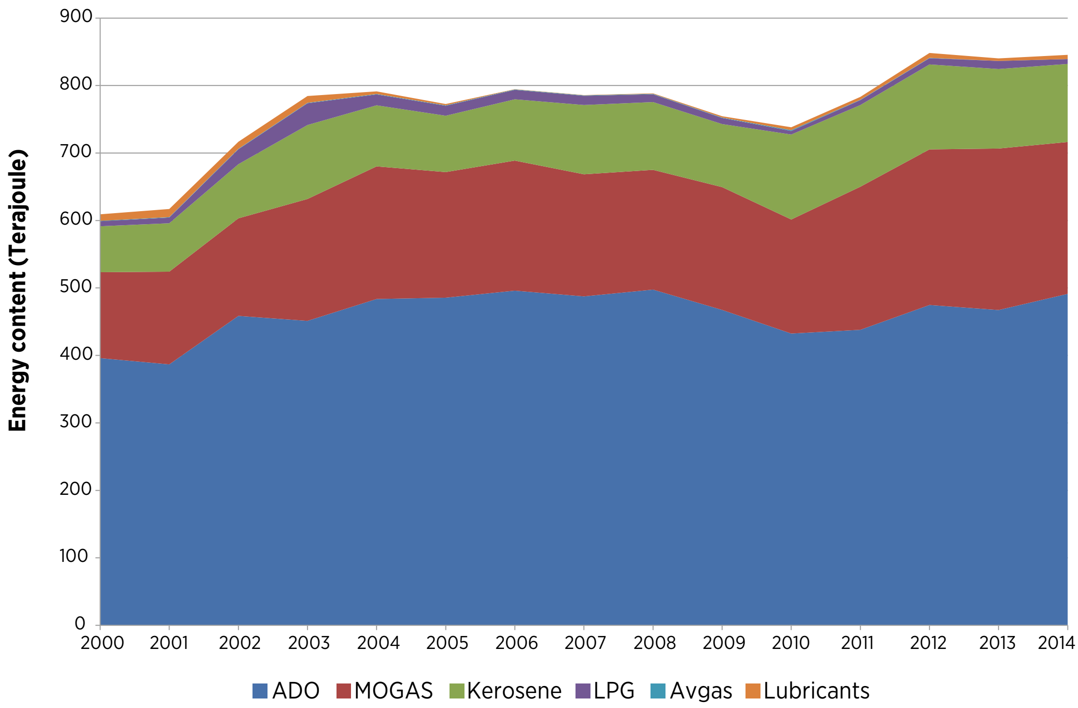


Figure 4: Energy imports 2000–2014



In terms of overall imports, diesel import ranks highest with 58% of the total imports as depicted in Figure 5. In 2013 the total diesel import volume was 12.73 million litres of the total fuel imports of 22.8 million litres. In 2013, total import value recorded was AUD 19.49 million compared to AUD 17.28 million in 2012.

Figure 5: 2014 Fuel imports by type

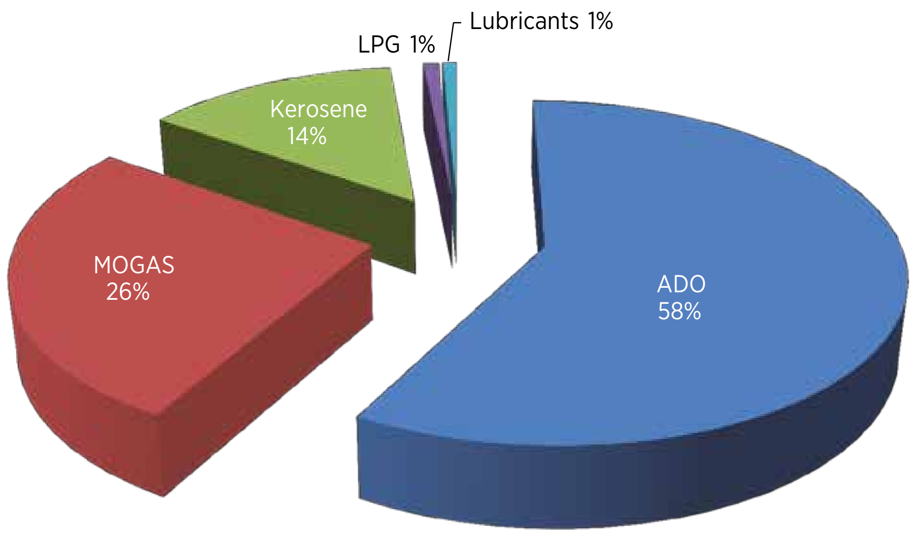
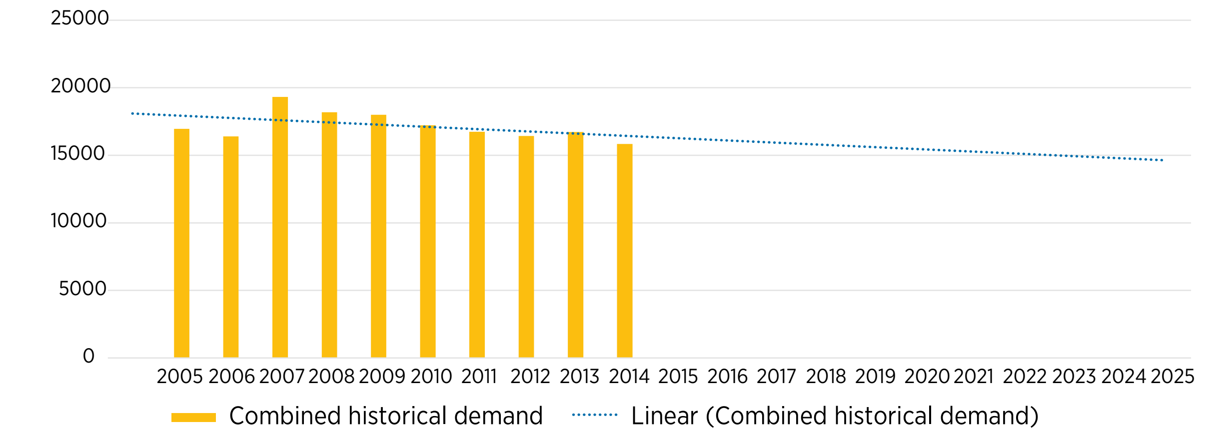


Figure 6: South Tarawa and Betio electricity demand 2005–2014



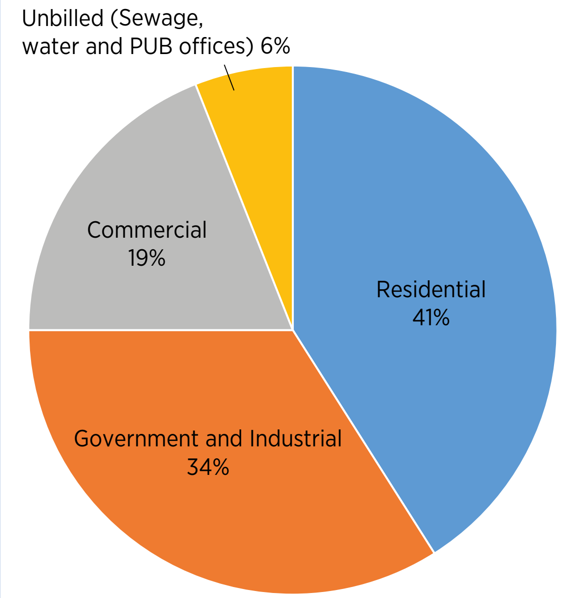
3.2 Secondary energy supply: Conversion

Electricity is generated and transmitted for use in buildings (residential, commercial, government and industries) to provide lighting, heating and cooling and for use in other electrical applications. The Public Utilities Board (PUB) is the main service provider for grid-connected electricity for South Tarawa, Betio and Kiritimati, while the Kiritimati's electricity services are managed by the Ministry of Line and Phoenix. In 2014, diesel use for electricity generation was 6.29 million litres, equivalent to 48% of total diesel imports. The total electricity production from 2000 to 2014 for South Tarawa and Betio is provided in Figure 6 (IRENA, 2012).

On the recommendation of the Government of Kiribati, the criteria in the definition of the GHG "business as usual" (BAU) in the Kiribati Indicative Nationally-Determined Contributions (INDCs) were adopted. According to this methodology, the annual average growth rate for electricity demand from 2005–2014 was extrapolated all the way to 2025. This results in a reduction of demand of ca. 11% between 2014 and 2025. Applying this reduction to the 2014 generation for South Tarawa (23.774 GWh) results in a BAU 2025 generation of ca. 21 GWh. Note that this is in absence of additional energy efficiency measures.

Figure 7 gives the percentage breakdown of electricity demand between key sectors of residential buildings, government and industrial buildings, commercial buildings, water and sewage, and PUB offices.

Figure 7: Breakdown of 2014 electricity demand



4 RENEWABLE ENERGY RESOURCES

Being equatorial atolls, Kiribati's major renewable energy resource is solar, with some wind (winds are generally stronger away from the equator) and bioenergy (the sandy soil of the atolls and unreliable rainfall make it difficult to rely on bioenergy outputs). Other technologies may in future allow extraction of energy from the ocean (OTEC, wave and ocean currents), but at this stage are not considered commercially proven. Tidal range is not great so tidal energy is not considered here. Concentrating Solar Thermal Electric requires high percentages of direct radiation usually found in hot dry climates, such as deserts, and also complex mechanical tracking mechanisms, difficult to maintain in a marine environment, such as found on the atolls. No geothermal resource is known to exist close to the surface on any of the atolls.

4.1 Solar energy

Solar radiation data from the Betio Meteorological Station were not available due to a defunct solar recorder, which appears to have been non-operational for quite some time. However, solar radiation data for South Tarawa are available from NASA 2011 satellite records, with some cross-correlation with ground station data (when operational). The solar radiation data given in Table 9 were collected from sensors located at Latitude 1.332N, Longitude 172E and were used for the design some of the larger grid-connected PV systems on South Tarawa (World Bank, 2014).

Table 10 gives 2013 monthly solar radiation data for Kiritimati from the NASA Atmospheric Science Data Centre.

Outer Island data may exist, but at the time of report, no write-up was available. The collected solar radiation data are consistent over the months of the year for both sites, with highest insolation in the December Solstice and lowest in the September Equinox. Variability from worst to best month is less than 20% for South Tarawa and 15% for Kiritimati, not surprising for equatorial sites.

Fixed photovoltaic flat panel technology is ideally suited to the atolls, where both direct and diffuse radiation can be captured without no moving parts, and with a proven track record over many decades in a salty, humid, maritime environment.

4.2 Wind energy

Two wind monitoring studies at 34m height were carried out in 2009-2011 on Kiritimati Island by the wind power development firm Garrad Hassan, one in London (Ronton) and the other in Banana (Garrad, 2012). The prevailing wind direction was from the northeast, and

Table 9: Average daily horizontal radiation (kWh/m²/day) in South Tarawa.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
5.60	6.00	6.11	5.97	5.88	5.76	5.97	6.17	6.55	6.47	6.16	5.53	6.01

Source: (World Bank, 2014)

Table 10: Average daily horizontal radiation (kWh/m²/day) in Kiritimati.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
6.06	6.35	6.37	6.13	6.08	5.98	6.17	6.61	6.80	6.69	6.42	5.99	6.30

Source: NASA Atmospheric Science Data Centre average annual wind speeds were 6.7m/s and 6.6m/s, respectively. These wind speeds are considered a good, but not excellent, wind resource. A wind turbine of 200–300kW was proposed for Ronton in Garrad Hassan's 2012 report, but this would require an upgrading of the Kiritimati Island distribution system.

Subsequently, wind monitoring was carried out on South Tarawa with a tower of similar height (34m), and wind speeds of 5.7m/s reported by word of mouth (Tiaon Aukitino). This is corroborated by data from the tide gauge anemometer, which reported 4.55m/s at a height of around 5m, which, if extrapolated to 34m using the $1/7^{th}$ power law $V_2 = V_1*(h_2/h_1)^{1/7}$, gives an estimated wind speed of 6.0m/s. This wind regime is not ideal for power generation but can support the deployment of a wind turbine designed for low wind speeds.

While there *are* wind turbines produced for these wind speeds, the number of turbines designed to survive in a tropical marine environment and available in the small sizes required for the atolls are very limited. In addition, the installation, operation and maintenance of wind turbines are significantly more complex versus PV systems, as they have moving parts and require cranes to install and maintain the nacelle and machinery at the top of the tower, or turbines that can be raised and lowered. These issues are not insurmountable but must be taken into consideration.

4.3 Bioenergy

While bioenergy is used extensively for cooking on the Outer Islands, atoll vegetation is highly prized as a source of food and building materials. This leaves little opportunity for energy crops, with the exception of copra produced from the coconut tree. There has been a tradition of copra production for export from Kiribati for over a century, and it has been one of the few sources of income for people living on the Outer Islands. Copra production is, however, highly dependent on rainfall, which is quite variable and is expected to become even more so as a result of climate change.

Copra production occurs in both the Kiribati island group where Tarawa is the main island and the Line island group where Kiritimati is the main island. As noted, copra production is highly variable with the total national production fluctuating from 6,000 to 14,000 metric tonnes per annum over the period from 2003 to 2012. The proportion from the Line island group varied between 10% and 30% of the total production during this period (1,000 to 2,500 metric tonnes per year).

Table 11 presents the estimated CNO production potential along with the approximate percentage of offset diesel consumption on the two main islands. These estimates assume that all harvested copra in the two island groups could be directed to the production of CNO for use in electricity generation in respective main islands. The reduction of diesel usage is based on the reported 2014 diesel consumption for South Tarawa of 6,294,450 litres and an estimated annual diesel consumption of 995,010 litres for Kiritimati. Before any CNO investments for electricity generation are made, a much more detailed analysis is required to ensure that these copra yields are achievable and that directing all copra production to CNO will not adversely affect other activities (*e.g.* cooking) that currently depend on copra production.

Table 11 shows that coconut oil (CNO) has the potential to offset a significant percentage of diesel consumption in the electricity sectors of both South Tarawa and Kiritimati. Table 11 also demonstrates that the variability

Table 11: Estimated CNO production potential and impact on diesel consumption

Island	Historic copra production 2003-2012 (tonnes / year)		CNO potential (litres of diesel equivalent / year)	Reduction of annual diesel usage for electricity generation
South Tarawa	min	5,000	2,500,000	40%
	max	11,500	5,750,000	91%
Kiritimati	min	1,000	500,000	50%
	max	2,500	1,250,000	126%

in copra production would require careful management if CNO is to become a reliable source of fuel for reducing diesel imports. This could require the rehabilitation and attentive tending of existing coconut resources to ensure a reliable and predictable source of copra. An increase in copra and CNO production could then be considered to ensure an adequate fuel supply.

It is important to note that the quality of CNO is variable and depends on numerous factors, including the quality of raw materials, the harvesting and transport conditions, and the efficiency of processing, purification and storage. In addition, use of CNO for electricity generation requires further refining to de-gum and remove minute contaminants (washing with water), to lower the Free Fatty Acid (using caustic soda), to remove moisture (heating under vacuum), and to further filter the final product. These processes reduce the maintenance requirements for the diesel engines and increase their longevity.

The logistics of collecting, shipping and refining the copra required for CNO production, along with those needed to produce and distribute a high quality CNO fuel, will likely require a sophisticated and well-run supply chain. In addition, it may be necessary to blend the CNO with diesel or kerosene, and to start and stop the engine using only diesel fuel to avoid additional servicing of the engines. Despite these challenges, significant CNO use to offset diesel consumption has been demonstrated on Pacific islands, most notably in Vanuatu. Before committing to a major programme, Kiribati should undertake limited trials to investigate the practicality and confirm the potential of CNO as a diesel substitute.

5 PRESENT ELECTRICITY SUPPLY SYSTEM

Kiribati's electricity generation system is composed of numerous isolated island grids that can be divided into three categories based on generation capacity; 1) South Tarawa, 2) Kiritimati and 3) Outer Islands.

South Tarawa accounts for the vast majority of electricity demand in Kiribati (23.7 GWh of generation in 2014). As a result, South Tarawa has the largest and most complex electricity generation system in Kiribati with an installed capacity of 4.7 MW of diesel generation and 0.92 MWp of PV. An additional 0.5 MWp of PV is due to be commissioned in 2016.

Kiritimati Island has the second largest electricity demand in Kiribati with 2014 total generation estimated at 1.65 GWh. The electricity generation system in Kiritimati Island is currently undergoing a major refurbishment that will likely result in the creation of three separate electricity grids. The details of these proposed systems are provided in this section 5.2.

The remainder of Kiribati's power generation systems are composed of small diesel generators, PV-diesel micro grids and solar home systems distributed across the outer islands. Data on these systems are lacking but the available information is presented in section 5.3.

5.1 South Tarawa

The Tarawa atoll, shown in Figure 8, can be divided into two distinct regions, which have different types of electricity generation systems. North Tarawa is composed of the islands running north from Buota to Naa. These islands are lightly populated and rely on small PV or diesel-based systems similar to those used in the outer islands.

South Tarawa is the capital of Kiribati and home to approximately 50% of the country's population. South Tarawa also has the country's highest electricity demand, the largest generation capacity and the most extensive distribution grid. All generation assets and distribution infrastructure are owned and operated by the state owned utility, the Public Utilities Board (PUB).

Under the 1977 Public Utilities Ordinance (Kiribati House of Assembly, 1977), PUB had a monopoly on the generation and supply of electricity. However, 24-hour electricity is not consistently available in South Tarawa and there are some independent generators, including a fish processing and freezing facility, and other businesses that maintain private diesel generators to ensure a continuous electricity supply. Private PV generation is also now allowed to connect to the grid, if given permission by PUB.

Table 12 details the PUB electricity generation system in South Tarawa, which has a total capacity of 4.7 MW. The main power house is situated at Bikenibeu and comprises three Daihatsu generators. The more heavily loaded West Feeder is extended towards Betio and the lightly loaded East Feeder towards Nabeina (via Bonriki). There is a second power station located on the island of Betio with one diesel generator. The distribution grid consists of 11 kV lines running from Betio to Nabeina, a distance of around 50 km.

Figure 8: Map of Tarawa Atoll

Source: Google Maps

Table 12: PUB Generators South Tarawa

Location	Generator Number	Make	Model	Manufacturer's rated capacity (kW)	De-rated capacity (kW)	Total running Hours 30/06/2014	Year Commissioned
Bikenibeu	#3	Daihatsu	6DK28	1,400	1,200	87,574	2002
Bikenibeu	#4	Daihatsu	6DK28	1,400	1,200	82,931	2002
Bikenibeu	#5	Daihatsu	6DK28	1,400	1,200	45,893	2005
Betio	#1	Daihatsu	6DK26	1,250	1,100	62,862	2003

Due to a lack of proper maintenance, all of the generators in South Tarawa have had their generation capacity significantly de-rated. Some generators are up to three years overdue for a 25,000-hour service. In addition, it should be noted that, starting in October 2014, the generator at the Betio powerhouse became non-operational and was out of service for a significant part of the year. As a result, during periods of peak demand, there was no reserve generator.

The lack of maintenance significantly reduces generator efficiency and compromises the ability of the electricity system to integrate variable renewable energy, such as PV and wind. Proper maintenance of the generators should be a high priority for PUB. It has been indicated that the upcoming PUB infrastructure investment plan aims to establish a fund that will ensure proper long-term maintenance of the generation assets.

It should also be noted that, with the upgrade of South Tarawa's main road, many of the low voltage distribution cables have been shifted to clear the new roadworks and lie exposed at the roadside. Many of the distribution boxes are also in a state of disrepair, either broken and/or with doors missing. All high voltage and low voltage wiring is underground. However, house wiring has been buried as well to connect many consumers, a dangerous practice as this wiring is not designed for underground use. The PUB should seek to remedy these issues to ensure that they can safely and efficiently deliver electricity to customers in South Tarawa.

Table 13: PUB grid-connected PV systems.

<table>
<tr><th rowspan="2">Location</th><th rowspan="2">System</th><th colspan="3">PV Modules</th><th colspan="3">Inverter</th><th rowspan="2">Date Commissioned</th></tr>
<tr><th>Make</th><th>Model</th><th>Rating (kWp)</th><th>Make</th><th>Model</th><th>Rating (kW)</th></tr>
<tr><td>Bikenibeu</td><td>#1 PEC</td><td>Sharp</td><td>ND-R245A5</td><td>400</td><td>Fuji</td><td>NA</td><td>100</td><td>28 February 2015</td></tr>
<tr><td>Bonriki</td><td>#2 UAE</td><td>Yingli</td><td>YL250P-29b</td><td>500</td><td>SMA</td><td>25000TL</td><td>25</td><td>September, 2015</td></tr>
<tr><td>Betio Sports</td><td>#3a WB</td><td>NA</td><td>NA</td><td rowspan="4">500</td><td>NA</td><td>NA</td><td>NA</td><td>2016</td></tr>
<tr><td>Betio KIT</td><td>#3b WB</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>2016</td></tr>
<tr><td>Bikenibeu Hospital</td><td>#3c WB</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>2016</td></tr>
<tr><td>Bikenibeu King George V high school</td><td>#3d WB</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>2016</td></tr>
<tr><td>Betio KSEC</td><td>#4</td><td>Centrosolar</td><td>S240P60</td><td>10</td><td>SMA</td><td>12000TL</td><td>12</td><td>February, 2014</td></tr>
<tr><td>Taeoraereke USP</td><td>#5</td><td>Sanyo</td><td>HITN235SE10</td><td>9.6</td><td>SMA</td><td>SB4000TL</td><td>12</td><td>2015</td></tr>
</table>

South Tarawa renewable energy deployment

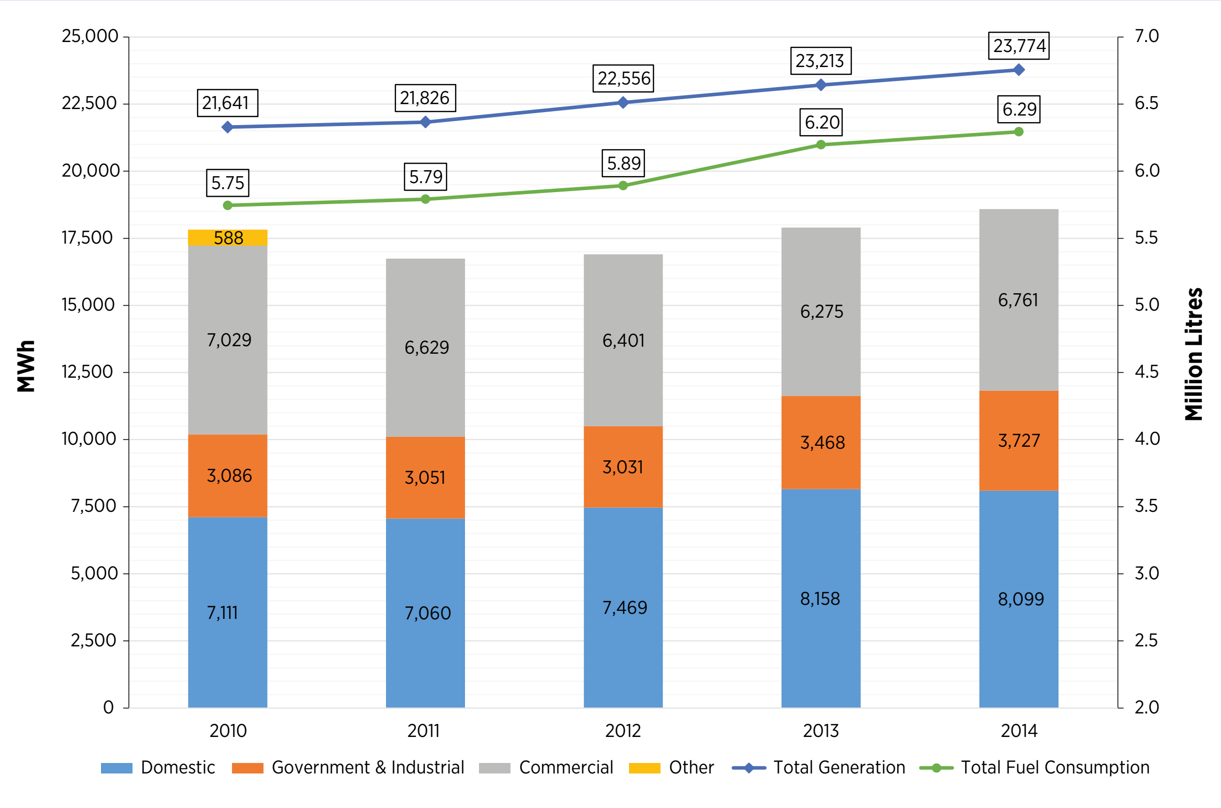
A number of large grid-connected PV systems have been installed or will soon be operational in South Tarawa. In total these systems will have a generation capacity of ca. 1.42 MWp. Table 13 gives details on the current and planned PV systems. The 400kWp PEC system has been operational at Bikenibeu Power Station since March 2015. The 500kWp system at Bonriki fund by The United Arab Emirates (UAE) and Masdar was commissioned in September 2015. The World Bank funded systems, with 500kWp generation capacity spread over four sites, is expected to be commissioned in 2016 (TTA, 2012 and World Bank, 2014)

There are at least two small grid-connected PV systems installed or being installed on the PUB grid. The 10 kWp system installed at the KSEC offices on Betio has been operational since February 2014. Verbal reports indicated that at times it produced more power than used within KSEC, leading to the energy meter running backwards (power injection into the grid). Installation of a 9.6 kWp system at USP in Teaoraereke was begun early July 2015, but it has not been confirmed if this system has been commissioned. Available information indicated that no application had been made to PUB for connection of the USP system. As this is a legal requirement under current legislation, the KSECs system may be operating without a completed and approved PUB application.

The Ministry of Infrastructure and Sustainable Energy (MISE) had also indicated that other hotel and business owners were interested in installing grid-connected PV systems as well. If an uncontrolled development of these systems continues to occur, it is possible that up to another 200–500 kWp of PV might be installed.

According to the analyses performed to date, it is not recommended to have instantaneous penetration levels above 50%. Beyond this value, curtailment would be required to maintain system stability. If the amount of installed PV capacity increases and, at the same time, the demand profile decreases, then the

Figure 9: Annual breakdown of electricity sales versus total generation



situations when curtailment actions would be necessary (penetration level above 50%) will increase significantly. The re-calculation of the required spinning reserves to compensate the new expected variations, their allocation during operation and the increased amount of required curtailment actions would make PUB's work even more challenging than expected with current projects. Without experience in operating the system with high shares of variable renewables and, even worse, without appropriate control and monitoring tools, it is recommended to avoid installing PV capacity above 50% without the appropriate mitigation measures (*e.g.* modern control systems, low-load/high-ramp rate diesel generators and/or battery storage).

Table 14: PUB annual sales versus generation 2010-2014

Year	Total Generation (MWh)	Total Sales (MWh)	Sales versus Generation
2010	21,641	17,814	82.3%
2011	21,826	16,740	76.7%
2012	22,556	16,901	74.9%
2013	23,213	17,901	77.1%
2014	23,774	18,587	78.2%

Analysis of the present South Tarawa electricity system (2014)

To support the modelling of options for renewable energy deployment in South Tarawa, an analysis was undertaken to determine the performance of the present electricity system. This analysis indicates that there is room for improvement. Figure 9 compares PUB total generation and fuel consumption to annual electricity sales to provide an overview of recent system performance.

Overall, between 2010 and 2014, PUB's total generation increased by 2,133 MWh; however, during this same period, sales increased by only 773 MWh. This discrepancy is mostly the result of a drop of 1,074 MWh in billing between 2010 and 2011. Since 2011, PUB has been able to increase its MWh sales but, as can be seen in Table 14, the percentage of sales versus total generation has still not recovered to the level achieved in 2010.

For the period prior to 2010, data on total generation were not available; however, PUB was able to provide a detailed breakdown of electricity sales and fuel consumption from 2005 to 2014, which is shown in Table 15.

Table 15: PUB electricity sales and fuel consumption 2005–2014

Year	Domestic (MWh)	Commercial (MWh)	Government (MWh)	Other (MWh)	Total (MWh)	Fuel (kl)	Electricity Sales versus Fuel Consumption (kWh/l)
2005	7,893	5,093	3,376	591	16,953	5,914	2.87
2006	6,864	4,500	4,458	571	16,393	6,236	2.63
2007	7,562	2,854	8,331	579	19,326	6,293	3.07
2008	7,197	3,073	7,335	577	18,182	5,882	3.09
2009	7,396	2,827	7,170	612	18,005	5,813	3.10
2010	7,111	3,086	7,029	588	17,814	5,745	3.10
2011	7,060	3,051	6,629	0	16,740	5,791	2.89
2012	7,469	3,031	6,401	0	16,901	5,921	2.85
2013	8,158	3,468	6,275	0	17,901	6,197	2.89
2014	8,099	3,727	6,761	0	18,587	6,294	2.95

It should be noted that, between 2010 and 2014, the overall generation efficiency in South Tarawa (kWh of total generation per litre of fuel consumed) was relatively constant, ranging from 3.75–3.81 kWh/litre. Discussions with PUB indicated that this level of efficiency was likely achieved or even exceed from the period between 2005 and 2009. As such, electricity sales versus fuel consumption can be used a metric of the overall cost recovery of the electricity system.

Figure 10 examines electricity sales versus fuel consumption from 2005 to 2014 and provides further evidence that overall performance can be improved. Over the period from 2007 to 2010, the ratio of sales to consumed fuel was increasing/stable around 3.1 KWh/litre. **From 2010 to 2012,** sales declined significantly while fuel consumption remained flat or increased. Given the stable generation efficiency during this period, this offers evidence of **a fall in recovered costs**. Since 2012 the situation has been improving but has still not returned to the levels achieved from 2007 to 2009.

As additional evidence, Figure 11 shows the total number of operational electricity meters in each year from 2010 to 2014. As can be seen, 2,681 additional electricity meters were installed in South Tarawa between 2010 and 2014. The significant increase in the number of meters from 2012 to 2013 correlates with the improved overall performance in sales versus generation from Figure 9 and sales versus fuel consumption in Figure 10. This suggests that the additional meters may be helping to capture lost revenue.

Analyses were undertaken to determine how PUB revenues have been impacted by the trends in sales versus generation from Figure 9. PUB data indicate that, from 2010 to 2014, diesel fuel prices have been constant in South Tarawa (1.20 AUD/litre) and that, over the same period, electricity tariffs were constant for all customer classes. The outputs of this analysis are shown in Table 16, which compares electricity sales and diesel fuel costs in 2014 versus 2010.

Table 16 shows that the margin between annual electricity sales and diesel fuel costs has decreased by almost 1.6 Million AUD from 2010 to 2014. **The significant loss in revenue between 2010 and 2014 confirms that there is room for improvement in the performance of the electricity system in terms of cost recovery.**

In order to investigate this issue further, detailed analyses were performed on the 2014 PUB data for hourly load (kW) and total monthly generation (kWh).

Figure 10: Electricity sales versus fuel consumption

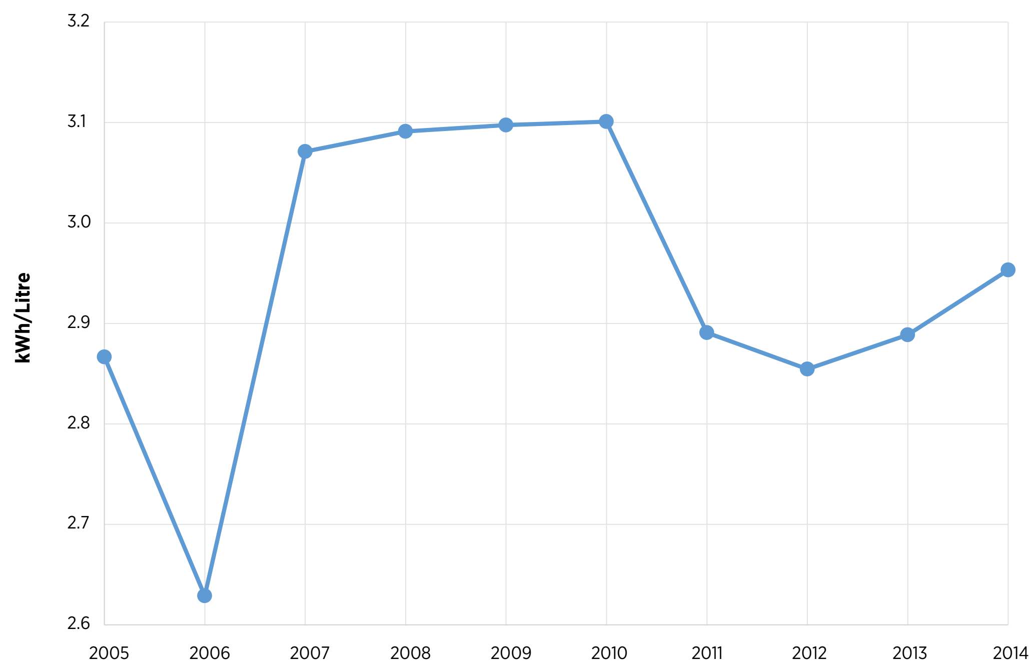
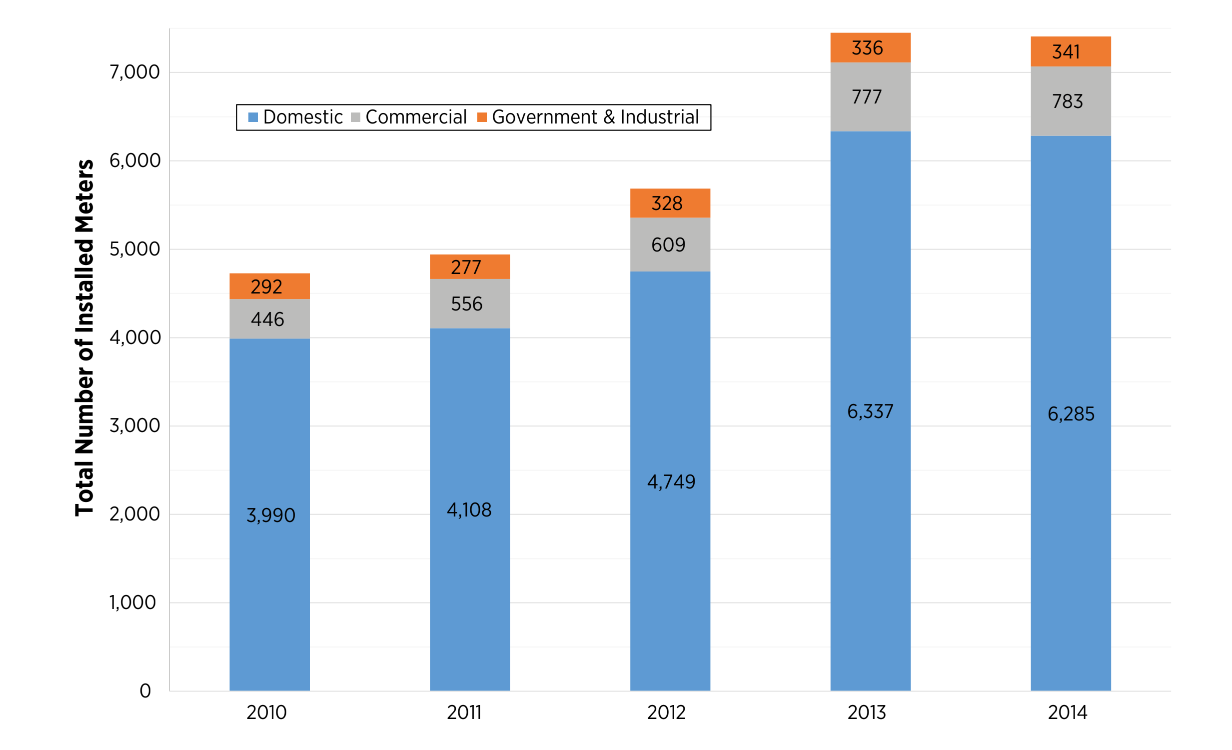


Figure 11: Recent deployment of electricity meters in South Tarawa



The goal of this analysis was to estimate the total hourly electricity demand in South Tarawa (to support the models examining renewable energy deployment) and to break down the demand for the entire year into categories supporting analysis of possible underlying causes for the lost revenue. This analysis is detailed in the following section.

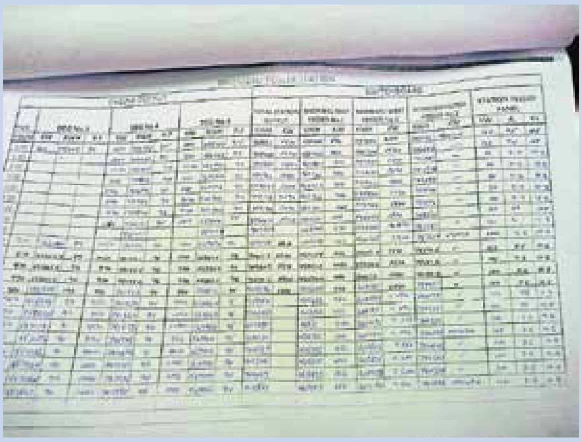
Estimation of South Tarawa annual electricity demand

In support of the KIER analysis, PUB provided hourly data covering the power (kW) output of all four generators in South Tarawa for 2014. These data were based on the manually recorded kW output of each generator, which

Table 16: Comparison of 2010 and 2014 electricity sales and total diesel fuel costs

Sector	Tariff by Sector 2010-2014 (AUD/kWh)	2010 Sales by Sector (AUD)	2014 Sales by Sector (AUD)
Domestic	0.40	2,844,400	2,722,400
Government and Industry	0.70	4,920,300	3,837,400
Commercial	0.55	1,697,300	1,956,350
Other	0.70	411,600	420,000
Annual Totals		2010	2014
Electricity Sales (AUD)		9,873,600	8,936,150
Diesel Cost (AUD)		6,893,964	7,553,340
Sales – Fuel Cost (AUD)		**2,979,636**	**1,382,810**

Figure 12: Bikenibeu Power Station log book showing hourly kW and kWh records



Source: PUB

Figure 13: South Tarawa Bikenibeu power station control panel

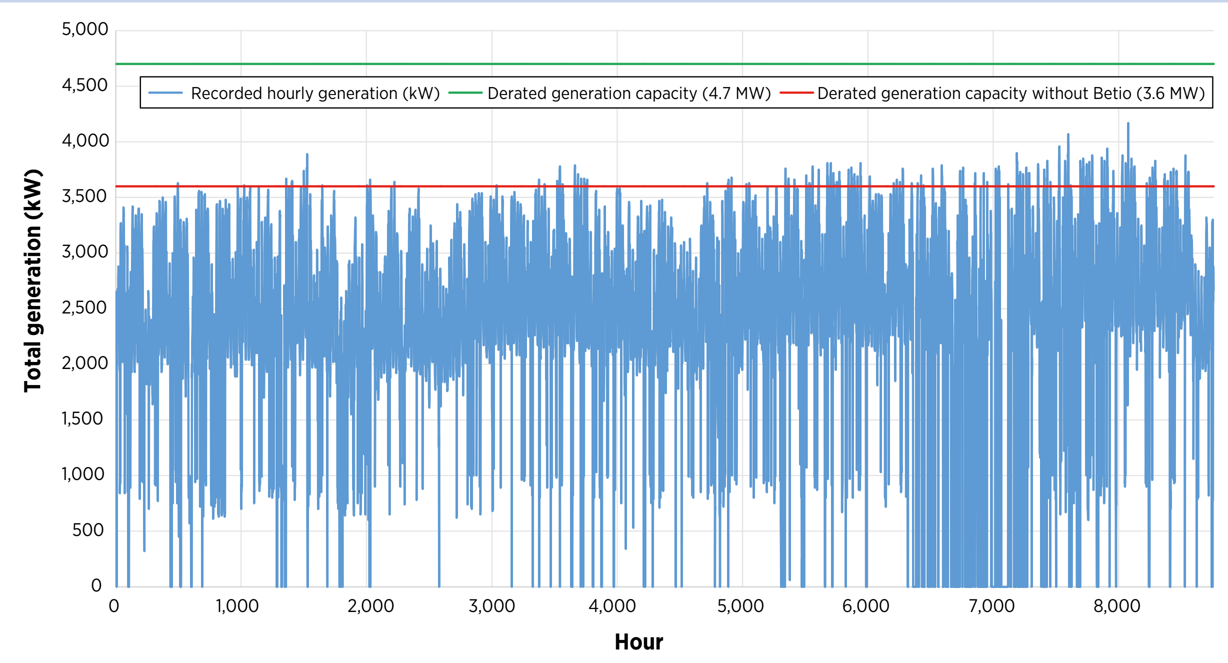
Source: PUB

are observed hourly by an operator at the power house, along with a monthly record of the total accumulated generation energy (kWh) recorded by a separate meter on each generator. Figure 12 shows the log book used to record data while Figure 13 provides an image of part of the control panel where some of the data were observed.

Using the data provided by PUB, Figure 14 shows the 2014 hourly combined power (kW) output of all diesel generators in South Tarawa. These include three 1,400 kW generators at the Bikenibeu power station, which have been de-rated to 1,200 kW, plus the single 1,250 kW generators at the Betio power station, which has been de-rated to 1,100 kW. Also shown are the total de-rated capacity for all four generators and the total de-rated capacity minus the generator at Betio.

Figure 14 shows a large number of hourly readings with a zero power (kW) output, especially beginning in

Figure 14: South Tarawa total hourly generator output in 2014



October of 2014, when the Betio power station became inoperable and was taken offline for repairs. Despite the loss of this station, it is believed that blackouts were minimised by running the remaining generators above their de-rated capacity to meet peak demand. It is likely that, due to the increased work load resulting from repairs being made to the Betio power station, PUB staff may not have had sufficient time to record the hourly data. Given the fact that a significant percentage of hourly data values were not recorded, it is recommended that the government and PUB investigate the cost and benefits of upgrading to a fully automated and computerised data collection system.

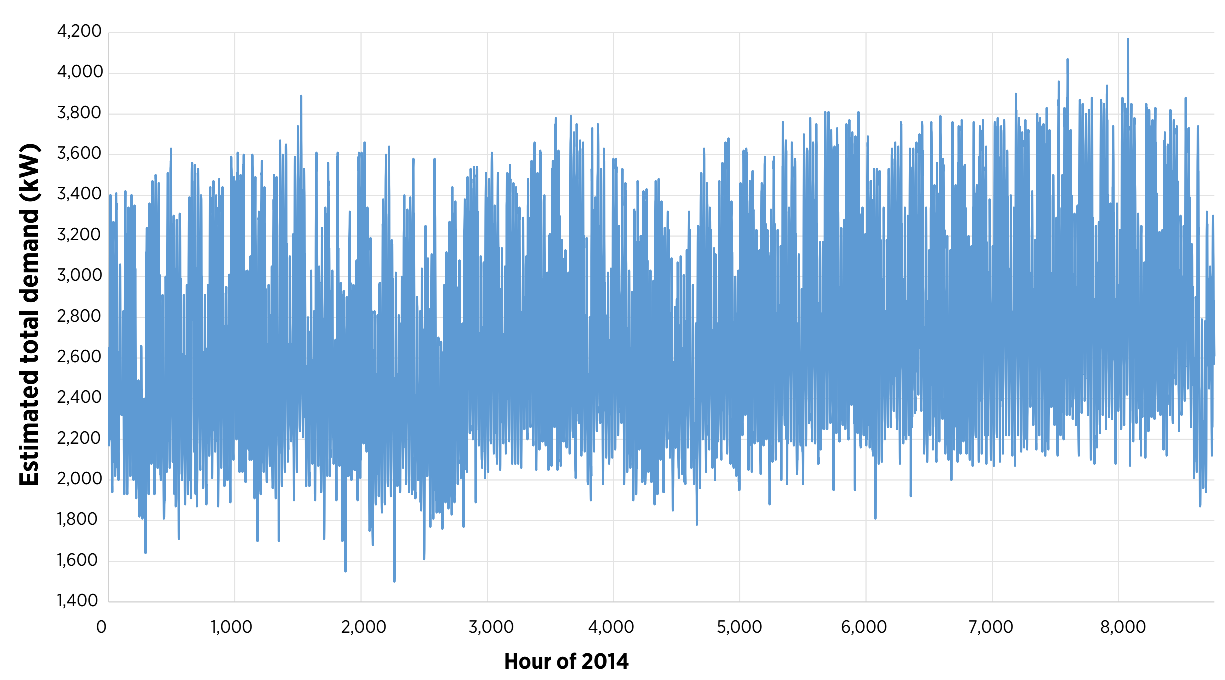
However, analysis indicates that while some of the zero values actually represent periods when no electricity was available, the majority of the zero values likely result from a failure to record the power (kW) reading in the official data log. This assertion is supported by a comparison of the cumulative energy (kWh) generation for each generator, which is recorded on a cumulative basis and therefore, unlike the instantaneous power (kW) output, these data do not need to be recorded on an hourly basis to be accurately captured. PUB data for 2014 shows a total annual energy generation of 23,774,381 kWh. This can be compared to the data in Figure 14 by integrating across the hourly power (kW) reading, which yields a total energy generation of only 20,766,524 kWh.

In order to estimate the actual hourly demand in South Tarawa and compensate for the missing power (kW) readings in Figure 14, all zero values were filled in using the power (kW) reading from the same hour of the same day of the previous week. This method should account for both daily variation and seasonal variation in demand. The results of this "data smoothing" produced an estimated annual hourly demand curve shown in Figure 15.

Integrating across the hourly power (kW) values in Figure 14 gives a total energy demand of 24,051,779 kWh, which is 277,398 kWh above the total recorded generation of 23,774,381 kWh. The 277,398 kWh represents demand *requested*—but not *provided*—from the system.

This unmet demand represents only 1.15% of total demand (assuming 100% power delivery of 24,051,779 kWh), which confirms that the majority of the zero values observed in recorded generation shown in Figure 14 resulted from failures to record the hourly kW output (*i.e.* human error) and not from an actual loss of electricity. This confirms that the hourly electricity demand estimate shown in Figure 15 is a valid

Figure 15: Estimated 2014 hourly energy demand for South Tarawa



approximation of demand. As such, this demand curve was used to support the HOMER model that examined possible renewable energy deployment options for South Tarawa, which are detailed in Section 6.

The unmet demand represents only a small percentage of the total annual generation; however, it should be noted that this unmet demand resulted in a notable loss of revenue for PUB. For 2014, the weighted average tariff was 0.57 AUD/kWh, diesel fuel cost was 1.20 AUD/litre and generation efficiency was 0.265 litre/kWh. If PUB had been able to supply the unmet demand of 277,398 kWh, it would have resulted in AUD 158,017 of generation sales at a fuel cost of AUD 88,213. As a result, the failure to supply this unmet demand equates to a revenue loss of AUD 69,804 for PUB.

Breakdown of South Tarawa electricity demand

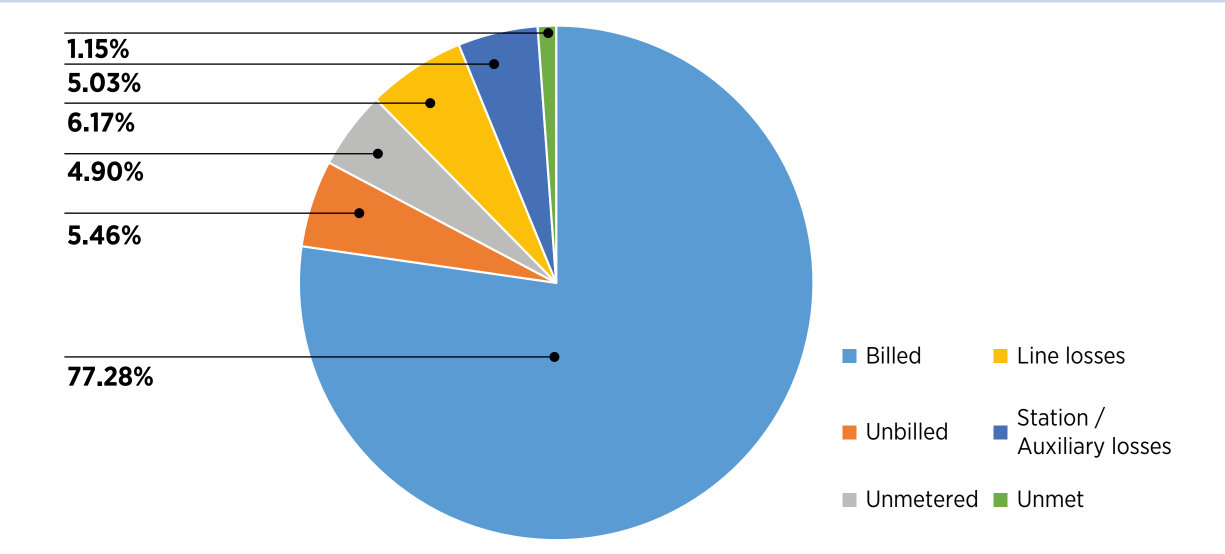
A breakdown of the 2014 total electricity demand into several key categories was estimated using statistical data from PUB, the 2012 PPA Utility Benchmarking Report (PPA, 2015), the Quantification of the Power System Energy Losses in Southern Pacific Utilities Consolidated Report (PPA. 2012) and the analysis detailed in the previous section. The results of this analysis are shown in Figure 16 and detailed in Table 17.

Figure 16 and Table 17 show that, in terms of MWh, **PUB is recovering 77.28% of the total generation for 2014.** As noted in Table 16, this figure has improved in recent years but still does not match the 2010 performance of

Table 17: Estimated breakdown of South Tarawa 2014 total annual energy generation

Generation Category	2014 Total Generation		Source
	kWh	percent	
Billed	18,587,000	77.28%	PUB Statistics
Unbilled	1,314,236	5.46%	KIER Analysis
Unmetered: water, sewage and PUB building usage	1,179,293	4.90%	(PPA, 2012)
Line Losses	1,484,385	6.17%	(PPA, 2012)
Station losses	1,209,467	5.03%	(PPA, 2012)
Unmet demand	277,398	1.15%	KIER Analysis
Total Recorded Generation	23,774,381	NA	PUB Statistics (Figure 14)
Total Generation assuming no blackouts	24,051,779		KIER Analysis (Figure 15)
Unmet Demand	277,398		Difference

Figure 16: Estimated breakdown of South Tarawa 2014 total annual energy generation



82.3%. The analysis does not identify a clear single cause for the gap between generation and billed sales; rather, several underlying factors contribute.

Technical losses at the South Tarawa power stations and across the lines of the distribution network total 11.2% of total generation; however, these represent costs inherent to operating power systems. While supply side energy efficiency measures may be able to reduce these losses, the current levels are close to what is technically achievable so significant reductions are not anticipated. Detailed analysis on options for dealing with these losses are provided in section 7.

Analysis shows that **non-technical losses amount to 10.36% of total energy generation.** 1,179,293 kWh or 4.90% of this loss results from PUB policies and/or requirements to supply no cost electricity for water and sewage pumping, street lighting and other public services. The government and PUB should re-examine this strategy as it represents a significant loss of revenue for PUB and because charging these customers would likely provide a strong incentive for them to operate in a more energy efficient manner.

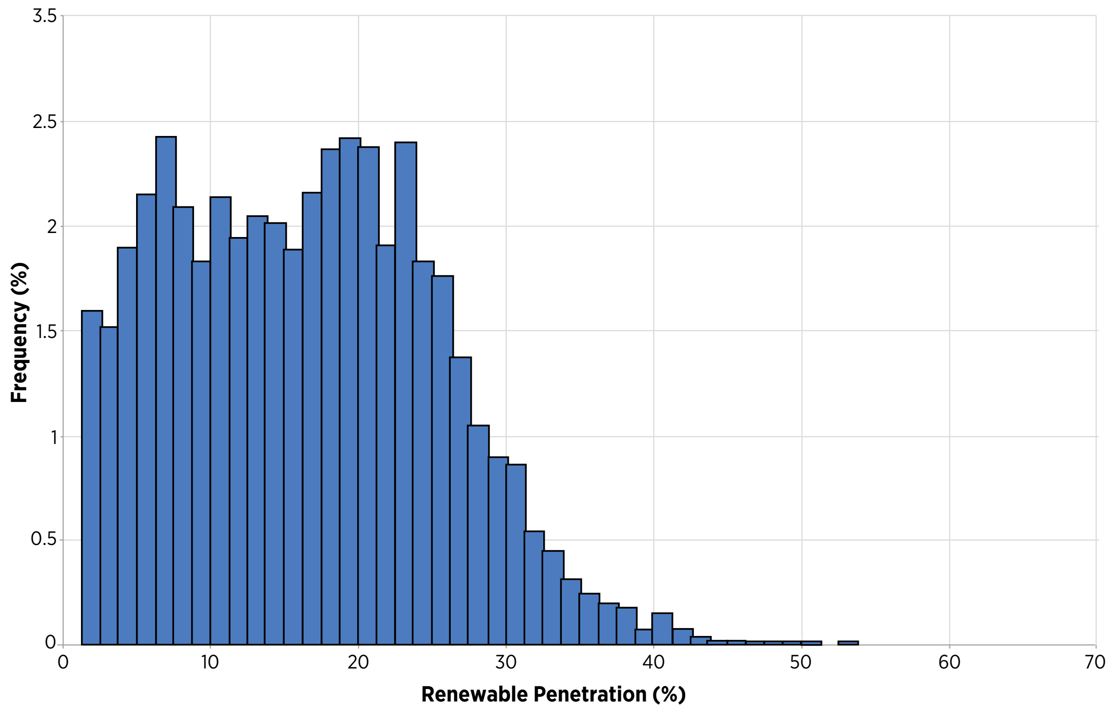
The 1,314,236 kWh of total annual energy generation that is currently unbilled represents another significant revenue loss for PUB. Measures should be taken to eliminate these non-technical energy generation losses as this would increase revenues and could also result in an overall reduction in demand.

Present electricity generation in South Tarawa

Once the World Bank-funded system is commissioned in 2016, assuming electricity demand will remain as in 2014, renewable energy contribution to the total will stand at ca. 8.4%. While the maximum hourly power penetration is estimated to reach 53.5%, instantaneous penetration might reach higher levels. However, due to the automatic curtailment system in place with the UAE-funded PV system, this will be automatically managed. Based on the simulation, the amount of curtailed electrical energy in 2016, once all PV systems are in place, will be negligible (less than 1 kWh/year). Reduction in electricity demand, as expected once billing is restored for all customers and energy efficiency measures are implemented, will lead to increasing curtailment; however, never to a level constituting an economic concern, or enough to justify energy storage to avoid curtailment.

As Figure 17 illustrates, most of the time PV penetration is below 30%, with rare occurrences beyond that. The

Figure 17: 2016 Tarawa hourly PV penetration probability: 1.4 MWp PV and 23 GWh/year of demand



0.5 MWp solar PV system funded by the UAE is able to reduce its output automatically to maintain the frequency within an acceptable range.

As far as the day with maximum PV penetration (the day with the lowest load and good solar radiation), Figure 18 illustrates the situation quite clearly. Solar power output will slightly exceed 1 MW in the middle of the day, while demand will drop during the same hours to less than 2 MW, translating into an hourly penetration just above 50% for the 13:00-14:00 interval.

In the case of the day with the *highest* load, the situation looks quite different, with PV penetration not exceeding 20% and providing only a limited contribution to fuel reduction during that day (See Figure 19). On average, the contribution over one year to electricity generation from the 1.42 MWp of solar PV, based on 2014 generation figures, amounts to 8.4%. This is due to increased penetration if demand drops as assumed in this study, due to reduction of technical and non-technical losses, and implementation of energy efficiency measures by ca. 30% in 2025.

Figure 18: Impact of existing and committed solar PV on lowest load day in 2014

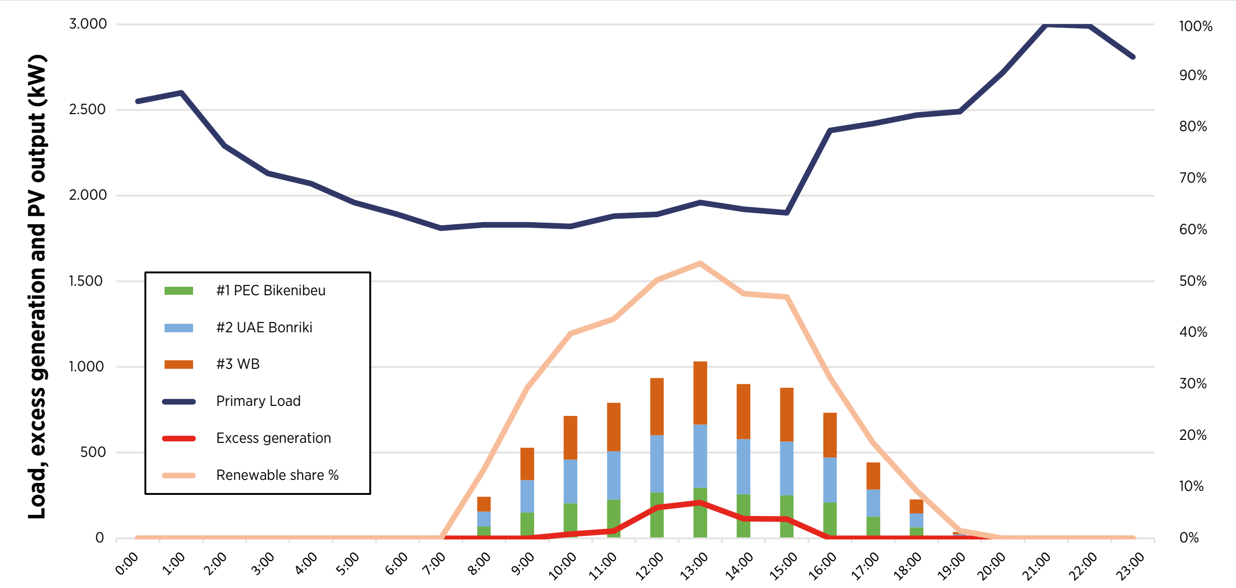


Figure 19: Impact of existing and committed solar PV on highest load day in 2014

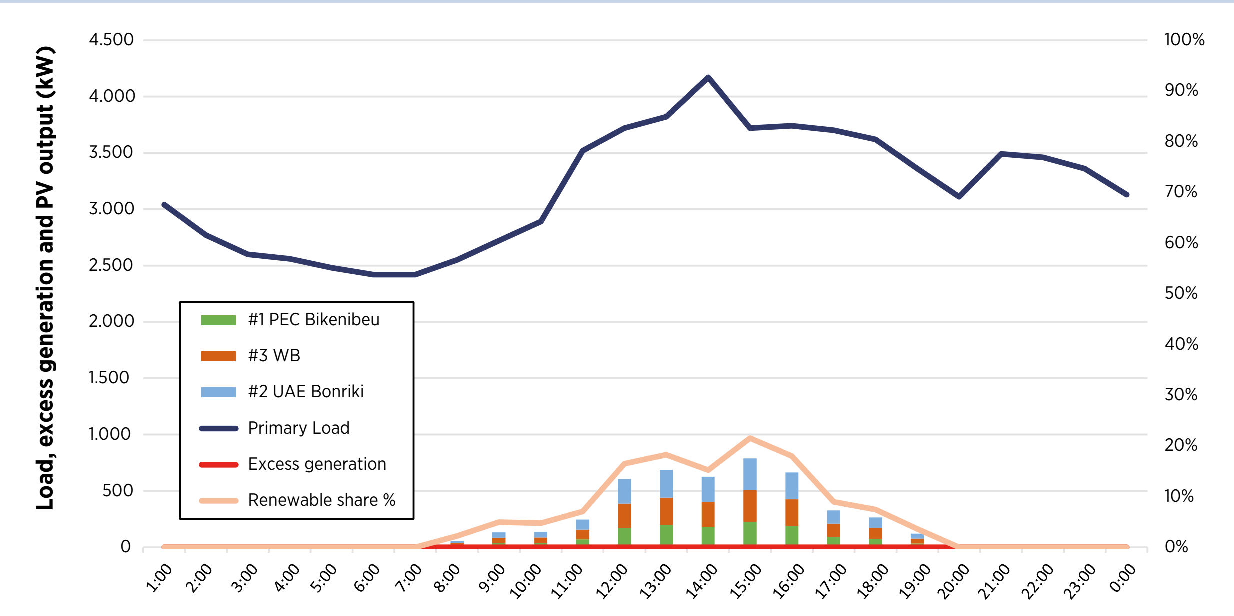


Table 18: Impact on diesel operations and fuel consumption of PV

Generator	*System in 2014* No PV Total running hours	*System in 2016* 1.42 MW PV and no storage Total running hours	% variations due to PV
Bikenibeu #3	6,671	5,896	-11.6%
Bikenibeu #4	8,760	8,760	0%
Bikenibeu #5	811	44	-95%
Betio #1	8,141	7,851	-3.6
Fuel consumption per year	6.16 Million litres	5.59 Million litres	-9.2%
Cost of electricity	0.328 USD/kWh	0.301 USD/kWh	-8.2%
RE share	0%	8.4%	+8.4%

Impact of variable renewables on grid operations

Analysis Integration of 1.4 MW of Solar PV in South Tarawa: The introduction of 1.4 MWp of solar PV power into the current electricity system of South Tarawa will demand changes in the current operational practices from PUB. An assessment of the impact of the new PV systems in the operation of the electricity network was conducted based on the available information. It should be noted that the analyses presented in this section are based on assumptions and very limited available data. Therefore, they have only an indicative character and do not replace a proper grid integration study, based on long-term measurements and validated simulation models. The implementation of measurement campaigns and validations of simulation models, together with the experience acquired through operation of the first installed PV systems, should be used to conduct further detailed studies to identify and fine-tune operational measurements to facilitate the secure and economic operation of the grid in South Tarawa. A full report with the details of the conducted analysis will be prepared in collaboration with the PPA and delivered separately from the KIER.

The expected production of the PV systems to be installed and their variability was assessed using three sets of data described in Table 19.

The histogram in Figure 20 shows the variability of the expected solar PV power output according to the originally available sets of data (Set 1 and Set 2). The variability is calculated as the ramping (*i.e.* increase or reduction) of the expected PV power output between two consecutive radiation measurements. The frequency of occurrence in the histogram is presented as percentage of the total available number

Table 19: Available data sets to assess variability of solar resources

Set	Source	Time interval measurements	Available measurements
Set 1	Hourly radiation data synthetically generated in software HOMER based on NASA Surface meteorology and solar energy database[3]	60 minutes	1 year
Set 2	Measurements in a single point in 400 kWp system installed in Bikenibeu (JICA system)	10 min[4]	1 month
Set 3	Smoothed data from Set 2, according to size and geographical dispersion[5]	10 min[6]	1 month

3 Monthly averages of GHI between July 1983 and June 2005. Resolution 1x1 degree.

4 Exact time intervals differ for each measurement, ten minutes is an assumed time for purposes of the assessment

5 “Smoothing effect” estimation based on empirical equation (Marcos et al, 2011) assuming areas of 500 kWp (instead of 710 kWp) for two PV systems (Betio and Bikenibeu).

6 Exact time intervals differ for each measurement, ten minutes is an assumed time for purposes of the assessment.

of measurements. Given the different data sources and the differing time measurement intervals (Set 2) and the estimations (Set 1), the variance of power ramps in the two data sets differs significantly. **Data Set 2**, based on ten-minute measurements of the solar radiation in a single point of the currently installed 400 kWp systems, presents the larger variance and therefore represents *a* **worst case scenario** in terms of power ramps, which will need to be compensated to control the system frequency.

Operational reserves are required to compensate for reductions of solar PV power output (*i.e.* negative power ramps in the histogram from Figure 20) in order to maintain the frequency of the power system within acceptable levels. These reserves must be enough to cover a significant amount of ramping events.

Figure 21 below shows the values of the negative ramps under which 99% of the analysed measurements fall (99 percentile or P99). In other words, only one percent of the time will the expected reduction in the output power of the PV be higher than in Figure 21. The values are presented according to the available PV power at the moment of the ramp. Figure 22 shows the same results but in percentages of the available power.

Besides compensating for reduction in the actual PV power production, the system must be able to compensate for increases (positive ramps, right side of Figure 22) in the PV power to maintain the frequency within acceptable ranges. Figure 23 shows the P99 of the estimated positive ramp events according to the PV power output. It is expected that the positive ramp events (increases in the PV output power) are going to be larger than in Figure 23 only 1% of the time.

Generally speaking, the total amount of spinning reserves in a system results from the addition of contingency reserves allocated to cover loss of the largest online generator in the system, and the regulating reserves allocated to compensate variations in load and generation. The current operational practice in South Tarawa does not contemplate contingency reserves. At the same time, the regulating reserves are the result of the dispatch of generators at certain loading level to achieve higher efficiencies in fuel consumption. For this reason, events like the trip of a generator lead, in most cases, to a system black-out. In the case of a simple system, such as in South Tarawa, it is convenient if the operational reserves are synchronised (*i.e.* online) to immediately respond to changes in power balance. Synchronised reserves are often called "spinning reserves". Spinning reserves must be allocated for at least the interval of time required to start and load a new generator. In the case of South Tarawa, this interval is, according to collected information, ten minutes.

The introduction of high shares of solar PV power requires that enough regulating (spinning) reserves

Figure 20: Histogram of power ramps for the available sets of solar radiation data

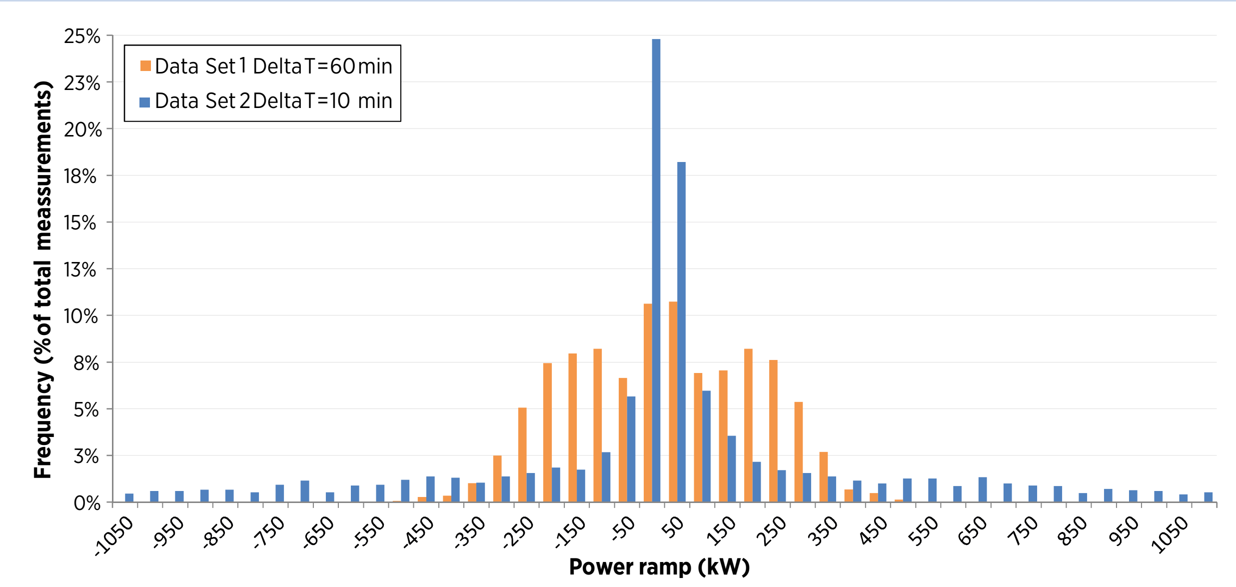


Figure 21: P99 of negative power output ramps for installed PV in kW

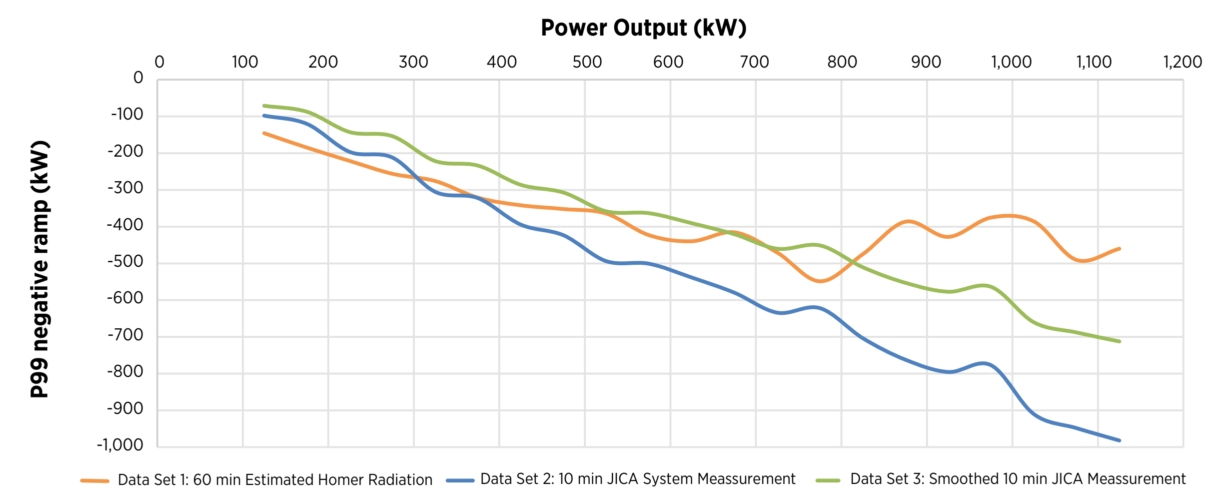


Figure 22: P99 of negative power output ramps for installed PV as a percentage of the available PV output

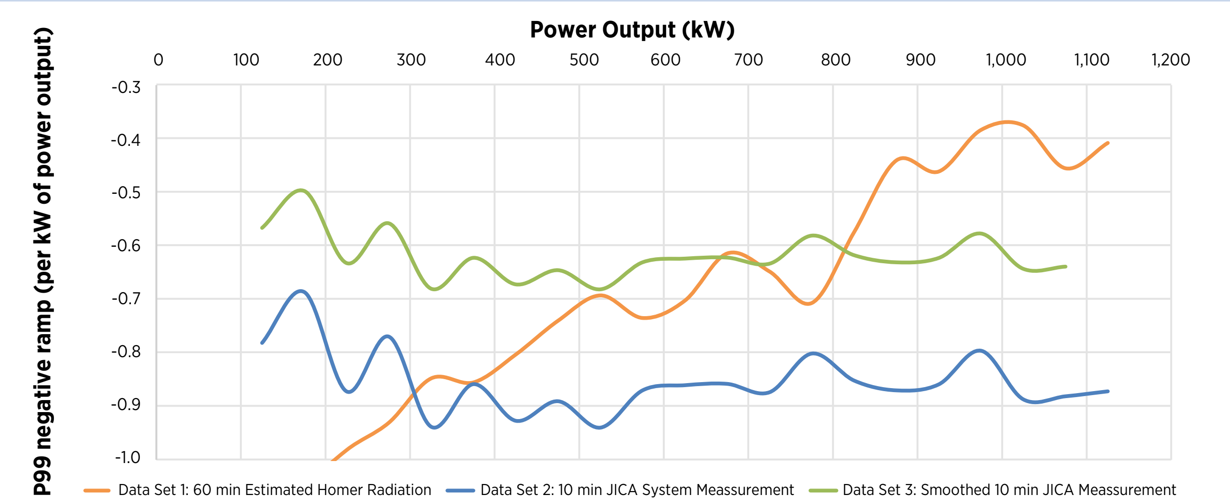
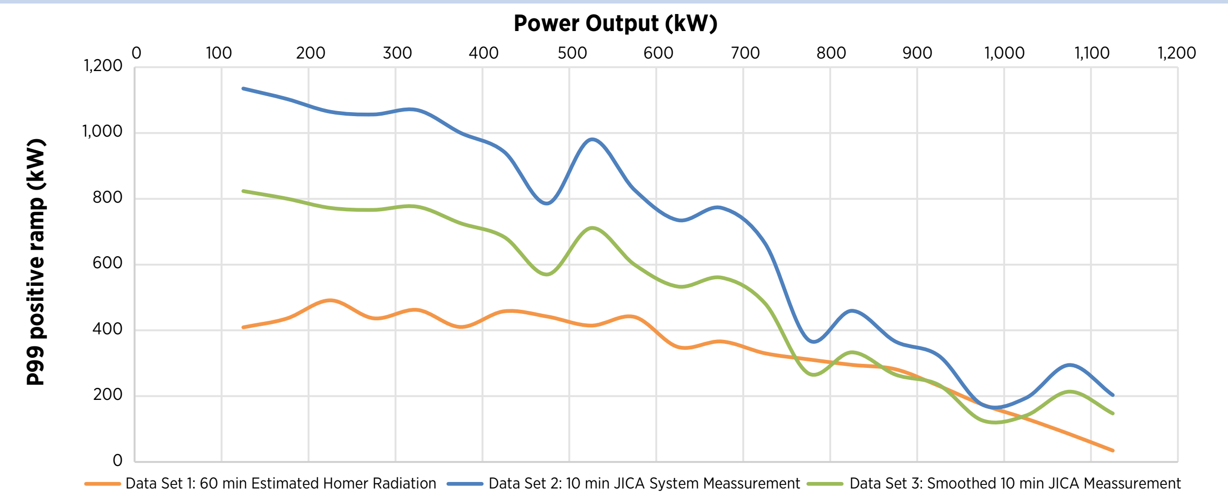


Figure 23: P99 of positive power output ramps for installed PV as a percentage of the available PV output



are allocated to guarantee reliable system operation. This means that the current operational practice of having regulating reserves resulting from an economical dispatch should be changed. Taking into account the fact that allocating contingency and regulating reserves in a simple system like in south Tarawa may result in extra costs to cover the simultaneous occurrence of two non-frequent events (*i.e.* trip of a generator and large negative ramp of PV power), only the allocation of regulating reserves to cover PV ramps was explored in this assessment.

Three alternatives are proposed to allocate enough regulating reserves for the expected PV variations. These alternatives are dimensioned to cover 99% of the expected negative ramps according to the analysed data (Figure 21 to Figure 23)

Alternative 1: Allocation of reserves to cover 80% of the available PV power. In this case, the reserve allocation will change every dispatch period (*i.e.* every ten minutes), depending on current and expected PV power output. Constant monitoring of diesel generator loading and PV power output, as well as PV forecasting, would be required.

Alternative 2: Allocation of reserves to cover the loss of one generator. In this case, according to the loading of the generators, the system operator must make sure that at least 1.2 MW of reserves are available, at least during the sunshine hours.

Alternative 3: Allocation of a fixed amount of reserves for each hour, corresponding to 80% of the maximum possible PV power output (see Table 20). In this case, the system operator must make sure that at least the amount of reserves shown in Table 20 are available during the corresponding hour, unless it leads to unnecessary commitment of generators as in Figure 26

From the three alternatives, Alternative 1 permits the most efficient operation of the diesel generators due to reduced spinning reserve requirements. However, it is the most challenging one in terms of system operation procedures. Alternative 2 is the simplest from the operational point of view but leads to less efficient use of the generators and, according to calculations done with HOMER software, the cost of energy may be increased by 8.5 %.

Alternative 3 offers a compromise between Alternatives 1 and 2. With this method, fixed values of the regulating reserve to cover PV negative ramps are set for each hour between 6:00 and 19:00. The required reserve values, calculated from the available radiation data, are summarised in Table 20. The network operator must aim to guarantee the required level of reserves at every moment, based on the loading of the online diesel generators (*i.e.* the net load). The available online power production capacity should be equal to, or greater than, the total power output plus the reserves corresponding to the operational hour.

Figure 24 and Figure 25 below show a dispatch of the generation for different levels of demand (P95 to P10) on sunny days. Even for low expected demand levels (*e.g.* P10[8]), dispatch with enough reserves, according to alternative 3, and without PV curtailment is feasible. Notice that in the plots "Min_Generation" corresponds to 50% on current generator capacity, while "Min_Gen 'Short time'" corresponds to 40%.

8 P10 means that the demand value for a certain hour will be larger than 10% of the cases or, in other words, that in a year the demand will be larger at that hour 90% of the time.

Table 20: Hourly reserve requirements to compensate for negative ramps

Hour	Required Reserves to compensate PV negative ramps (kW)
6:00 to 7:00	145
7:00 to 8:00	360
8:00 to 9:00	580
9:00 to 10:00	730
10:00 to 11:00	850
11:00 to 12:00	915
12:00 to 13:00	930
13:00 to 14:00	900
14:00 to 15:00	835
15:00 to 16:00	680
16:00 to 17:00	510
17:00 to1 8:00	280
18:00 to 19:00	130

Figure 24: Example of a dispatch for a sunny day with high demand

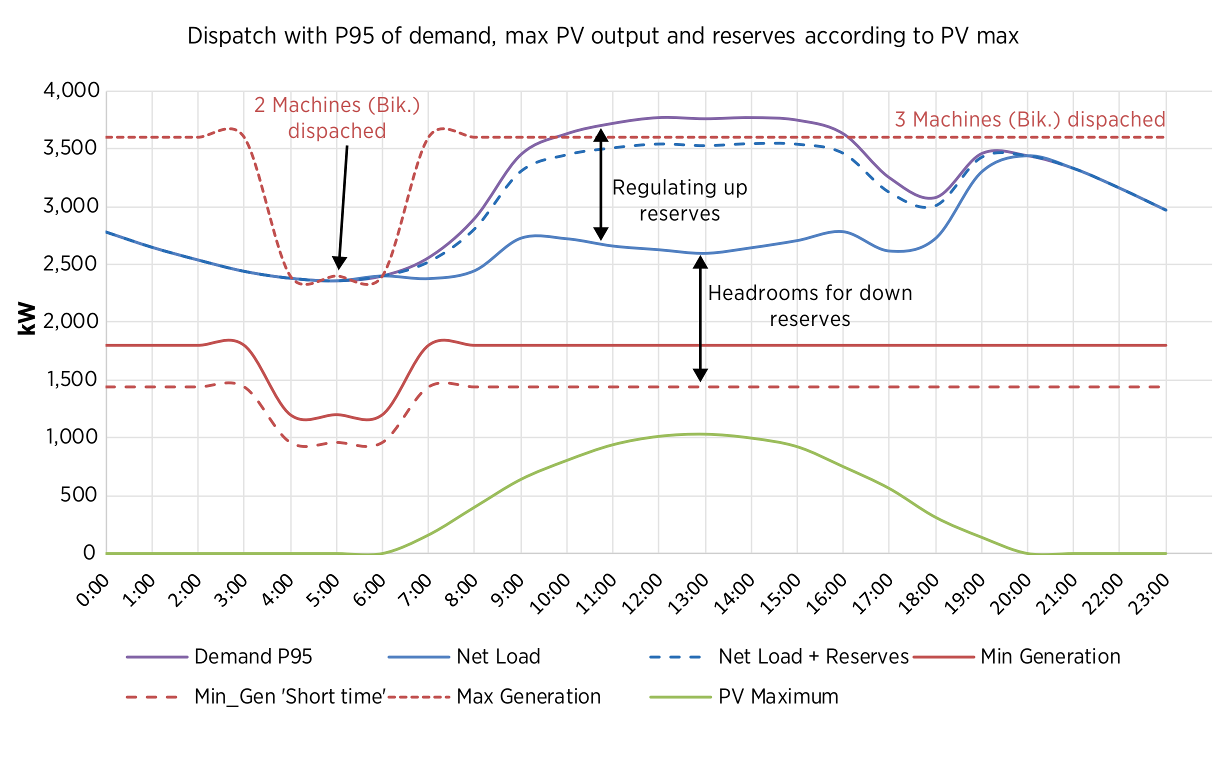


Figure 25: Example of a dispatch for a sunny day with low demand

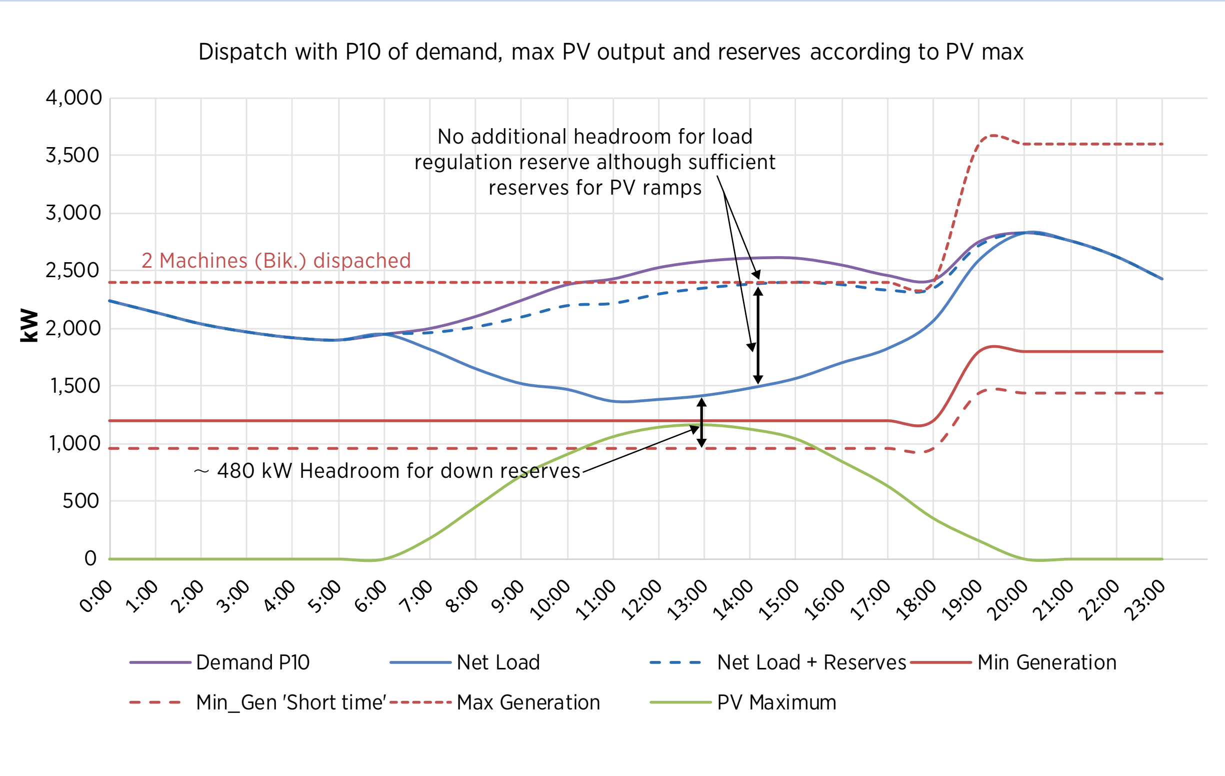
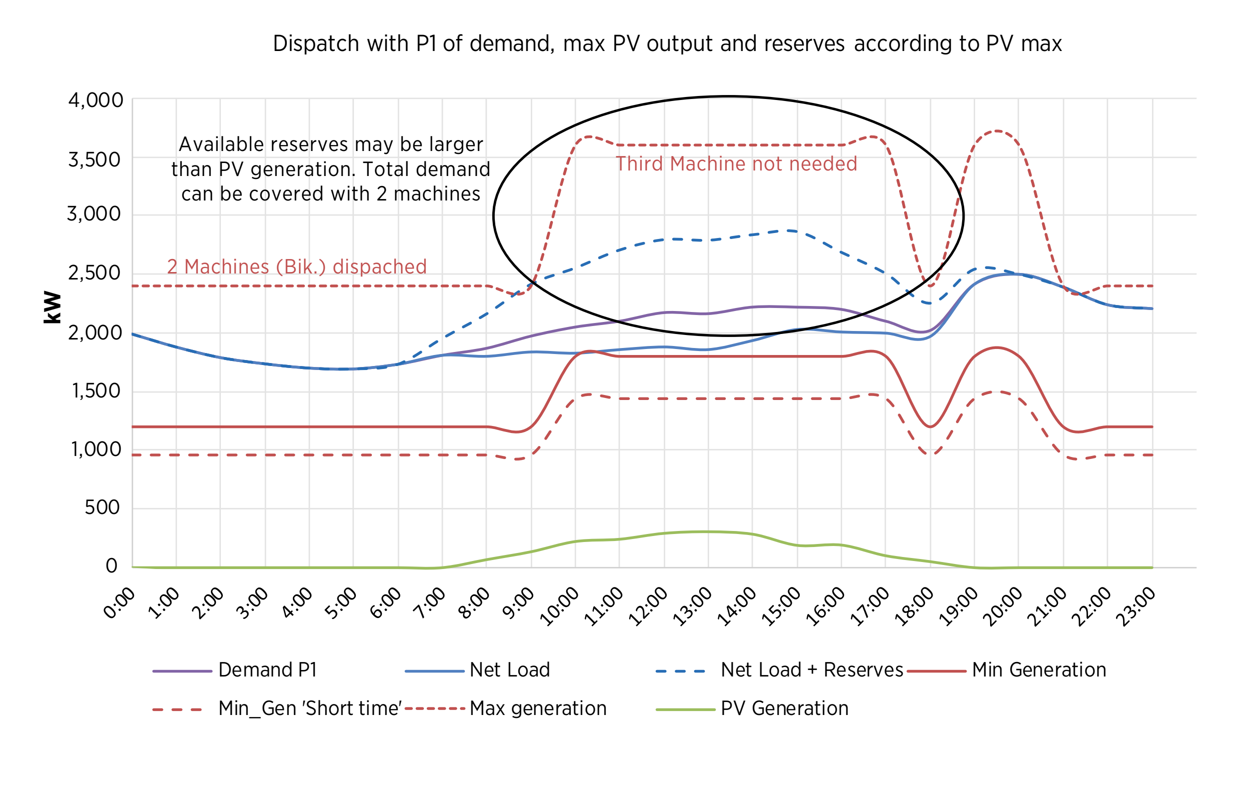


Figure 26: Example of a dispatch for an overcast day with low demand



The drawback of Alternative 3 is that, on days with low PV power availability (overcast days) and when the net load plus the reserves from Table 20 are getting close to the maximum available generation, unnecessary additional generators would be kept on line (see Figure 26). This situation can be avoided if, on top of the rule from Table 20, an additional condition is set to start new generation only when the amount of reserves is not enough: that means that additional generators can be committed only if the required amount of power (MW) online (net load plus reserves) is greater than 110% of the current available online power (MW).

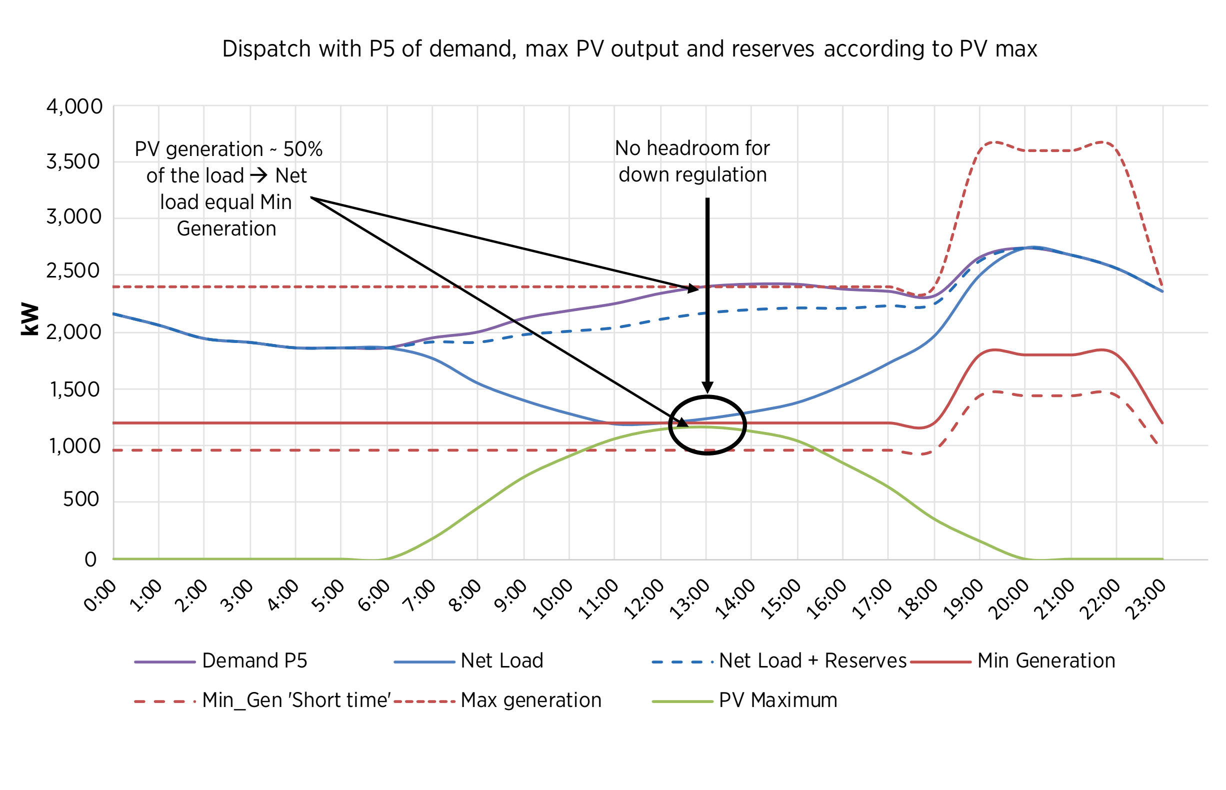
At very low levels of demand, curtailment of PV power output may be required if it leads to operation of the diesel generators below their technical minimum. These situations, whose probably of occurrence is very low, may happen in South Tarawa on holydays or weekends if the demand at maximum PV power output hours is well below its normal levels, as illustrated in Figure 27.

Besides providing spinning reserves to compensate for reduction of the actual PV power output, the system must be able to compensate for positive ramps without causing generators to operate below technical minimum values. According to Figure 23, positive power ramps of around 800 kW can be expected at least 1% of the time in a year. This situation can happen at noon on cloudy days. To be able to compensate for these situations without operating generators at very low loading levels (as, for example, shown in Figure 25 for a sunny day with low demand), two complementary actions are recommended which should be implement together:

- Curtailment of PV generation as soon as it leads to loading of the generators (net load) at below 50% of their nominal power; and
- Installation of PV inverters in 2016 with over-frequency power reduction function (according to received information regarding appropriately equipped UAE-funded inverters) to avoid further curtailment. Over-frequency power reduction is a commonly available grid function on *state of the art* PV inverters.

The allocation of enough spinning reserves to compensate for negative ramps, as well as having enough headroom to manage positive ramps, is

Figure 27: Dispatch situation that leads to curtailment of PV power



necessary to guarantee the operation of the system. However, it does not guarantee stability as it is not granted that the resources will be fast enough to deploy in a timely fashion.

Dynamic simulation studies using validated, real system measurements with models of the generators can be used to assess these situations. The analyses conducted in this work include certain dynamic simulations, which will be delivered in the separate detailed report. However, these assessments have an indicative/ informative character as no measures were available to do model validations.

Given the current operational practices and levels of reliability in the system of South Tarawa, the most critical dynamic aspect to consider is the capacity of the system operation to regulate the variations of solar PV power, as this may have a negative impact on reliability levels. At the current stage of renewable energy deployment, it already advisable to implement a supervisory and control system that allows real-time monitoring and assessment of the operation and enables automatic generation control of the diesel generators to regulate the variations in PV power.

Further dynamic electrical studies, using acquired system measurements and benefiting from the experience of operating the system with solar PV, are also strongly recommended. These studies will not only serve the purpose of assessing PV integration but will also define additional expansion measures to increase current reliability levels in the system. These new studies should be in line with current and planned renewable energy generation expansion plans. Aspects to be considered in future studies include:

» Protection coordination;
» Implementation of an under-frequency load disconnection scheme; and
» Development of an N-1 system, coordinating with future renewable energy development plans.

Finally, one aspect which should be considered for the PV inverters to be installed in 2016 is the provision of sufficient frequency and voltage ranges of operation to cope with the power quality.

5.2 Kiritimati Island

Figure 28 shows how the various small settlements on Kiritimati Island are separated by both lagoons and distances that make electric interconnection difficult and costly. At present Kiritimati Island has six public centres or villages with their own generation. In addition, the Captain Cook Hotel has its own generation. **It is proposed that the current fragmented generation systems on Kiritimati be replaced by three larger grid systems referred to as "zones", operating independently from each other (MISE, 2013).** The proposed zones in order of total demand (kWh) are:

- Zone 1: Ronton (London), Tennessee and Tabwakea
- Zone 2: Banana, New Banana and the Kiritimati Island airport
- Zone 3: The village of Poland on the western side of the island

The plans for the Kiritimati Power System upgrade for Zones 1 and 2 have not been officially released, and forecast loads for these zones are rough estimates at this stage. Zone 3 already has a hybrid energy system with 16 kWp of PV.

The generation assets for the proposed Zone 1 are given in Table 21. This distribution area comprises an HV overhead line of about eight km linking the mini-grids of Ronton (London), Tennessee and Tabwakea, with a new power station recommended to be built at Tennessee near the current wharf and fuel farm. There is residential expansion of up to 300 lots being planned for Tabwakea. One of the older (2012) Cummins engines is to be relocated to this new power station. A back-up for this 400 kW engine is proposed, and two smaller engines to carry the off-peak (night) load. At this stage, only estimates of combined centre loads are known and these are around 2,000 MWh per annum.

It should also be taken into account that a new fish processing plant may be built at Ronton. There are a number of schools and a small motel within Zone 1 that may want to connect to a new grid, especially if it is cheaper and more reliable than their own power. Total loads here are estimated to be 400 kW maximum demand, tripling in value if the 300-household sub-division goes ahead along with a new fisheries centre.

Figure 28: Map of Kiritimati Island

Source: Google Maps

Table 21: Generators proposed for Kiritimati Zone 1 power station

Location	Generator number	Make	Rating (kW)	Year commissioned
Tennessee	#1	Cummins	400	2013
Tennessee	#2	?	250	new
Tennessee	#3	?	250	new

The generation assets for the proposed Zone 2 are given in Table 22. Zone 2 combines Banana, new Banana and the Airport and includes around 4.5 km of HV grid, possibly some MV to link the Captain Cook Hotel and a new power station mooted for New Banana, away from the fresh water lens. Estimates of the Banana load foresees a peak of 80 kW with energy use 200 MWh/annum, or 10% of the amalgamated Zone 1 load. Zone 2 may also take in the Captain Cook Hotel. However, the hotel is understood to use United States standard power (120V at 50Hz) and so may not wish to convert to Kiribati standard power (240V and 50Hz). It is estimated that energy use here is similar to Banana at 200 MWh/annum, so total load for Zone 2 could constitute up to around 400 MWh/annum (including the upgraded airport).

Table 22: Generators proposed for Kiritimati Zone 2 power station

Location	Generator number	Rating (kW)	Year commissioned
Banana	#1	60	new
Banana	#2	60	new

There are a number of PV systems on Kiritimati. The first three of these are at Ronton while the fourth is at Tabwakea. The TSKL system is not grid-connected. Details on these systems are given in Table 23.

5.3 Outer Islands

Most of the outer islands have limited alternating current power, restricted to small generators for part-time use. This is why the use of PV has flourished there. **Kiribati has three main demographic groups: 1) the heavily populated Gilbert group in the east, of which Tarawa is national capital and main economic centre; 2) the sparsely populated central Phoenix group (Kanton has only a few families); and 3) the western Line group, of which Kiritimati is the most populated island. There are only two populated outer islands, Tabueran or Fanning Island and Teraina.**

There are many small power systems on the Outer Islands, mainly PV-powered. These range from solar household systems (SHS), solar maneaba (community meeting halls) systems, and those operated by the government and other institutions. It is planned for the Outer Island diesel or gasoline generators to be replaced by small to medium PV systems; however no data are currently available on the status of this project.

The 2010 census stated that there were 8,011 Outer island households (the 2015 census was just being organised as this report went to press). With 2,923 households having SHS at this time, and a further 2,000 or so being installed under the 10th European Development Fund (EDF10) of the European Union, over 5,000 Outer Island households had an SHS designed to run lighting and a small entertainment device (radio/music player).

Table 23: Kiritimati grid-connected PV systems

Location	Module make	Module model	Rating (kWp)	Year commissioned
ANZ	?	?	18	2008
TSKL	Photowatt	BPX47500	8	1980/90s?
Internet	?	?	?	?
Mormon Church	?	?	4?	?

Further projects implemented under EDF10 included Small Business and Teacher systems (2x100 Wp modules) of which 240 were provided, 30 maneaba systems (similar size, included in the description below) and eight large school mini-grids (4x16, 2x25, 29 and 42 kWp) located on seven different islands (*i.e.* two on Abaiang, North Tarawa, Abemama, Nonouti, Tabiteuea North, Beru and Poland on Kiritimati Island).

There are also eight solar pumping systems funded by the Italian Government for Outer Island schools, which were commissioned from late 2009 up until late 2013. They are powered by a 0.3 kWp PV array and pump water from a shallow well into a 5,000 litre poly-header tank, the base of which is three meters above ground level. From here, the water is gravity-fed into a reticulation system to the schools. There are three systems on Abemama, two on Abaiang, and one each on Tabiteuea North, Nonouti and Beru.

Small home lighting systems comprising a 35 Wp PV module powering three LED lights (5W plus 2 x 3W) with lithium batteries (7.4V 5.2Ah for 5W and 7.4V 2.6Ah for 3W) and a USB port on each for mobile phone charging have been deployed across the Outer Islands. As of September 2015, approximately 9,200 systems had been supplied, with 8,850 delivered to the Outer Islands and North Tarawa by Kiribati Solar Energy Company (KSEC). A further 6,000 systems have been deployed in the west of the Gilbert group, in the east of the Line Islands and the central area of the Phoenix group. Some concerns with these "free" systems are that people will stop paying rental on their current KSEC systems, and that they are too small to power radio/entertainment systems.

Solar Maneaba Systems. There were 52 such systems in the Gilbert group as of 2014 and these are assumed to be installed in village maneabas (community meeting halls). It is expected there would be many more systems installed in church maneabas. The systems all use 100 Wp modules and come in three different system sizes. There were seven systems with six modules, 36 systems with four modules and nine systems with two modules. No systems were recorded as having existed in the Line and Phoenix groups.

Table 24 lists the currently known installed Outer Island systems but does not purport to be complete as some systems are privately owned and installed (*e.g.* church groups). A more in-depth survey of existing systems, including their operational status (*i.e.* working, defunct or awaiting repair), should be undertaken.

Table 24: Current Outer Island PV systems 2015

System type	Number	Capacity (kWp)		Status as of September 2015
		Per system	total	
Households (EDF10. etc.)	5,000	0.12-0.16	700	Many systems up to ten years old
Households (solar lighting kits)	9,200	0.035	322	Most systems distributed since 2014
Solar Pumping	8	0.3	2.4	Only a few years old
Maneabas – small	9	0.2	1.8	
Maneabas – medium	36	0.4	14.4	
Maneabas – large	7	0.6	4.2	
School Mini-grid – small	4	16	64	Only a few years old
School Mini-grid – medium	2	25	50	Only a few years old
School Mini-grid – large	1	29	29	Only a few years old
School Mini-grid – largest	1	42	42	Only a few years old
TOTAL			1229.8	

6 RENEWABLE ENERGY EXPANSION IN POWER GENERATION

There are a number of ways to increase the proportion of renewable energy in Kiribati's energy mix, with wind for marine vessels being the most traditional and solar PV being the most recently proven and reliable of the newer technologies. Coconut oil (CNO) has been trialled but not used in any quantity to date. The renewable resource mix available is largely solar, with some wind (Kiritimati) and CNO, although the latter requires many steps to achieve sustainable production, thus making it a less reliable solution.

It is often argued that PV and wind technologies, being variable rather than constant energy sources, are difficult to integrate into an electricity grid. Many people are only aware of electricity storage as a solution; however, this is often the most expensive course of action. There are, however, a number of ways to improve or increase penetration limits from variable renewable energy systems.

Paramount among them is reducing the electrical demand while retaining the same level of service through energy efficiency measures. This reduces the need for renewable energy generation, storage and other measures, along with the requisite transmission and distribution infrastructure. It can be achieved by better building design and energy efficient appliances although both require ongoing maintenance to remain effective. Below are ten options.

1. Controllable and deferrable loads (Demand Response)

There are some services that can be switched off for short periods without noticeable loss of service, such as air conditioning, compressors, food dryers, ice machines, desalination plants and electric vehicle battery chargers.

Demand Response is defined as "*a set of activities usually carried out in commercial, industrial and sometimes residential buildings that change, shed or shift electricity use with the goal of improving electric grid reliability and managing costs*". When the demand for (and cost of) electricity is high (*e.g.* when a PV plant is clouded over), managers in large commercial and/or industrial facilities can, for example, dim lights or turn them off in unused areas; temporarily raise a building's temperature set point by a degree or two to reduce air conditioning use without impacting the building's occupants; or defer the use of certain industrial equipment until later when PV power is restored or an additional Genset is put online. Such measures reduce electric demand or "load" and the possibility of grid failure.

Californian studies suggest that fast-acting, automated-demand response in the commercial and industrial sectors is more cost-effective than grid-scale battery storage. It offers grid operators a less expensive tool for managing the grid than battery storage. The infrastructure for demand response does, however, need to be implemented (*i.e.* through "smart grids").

2. Storage of "service" (*e.g.* ice, chilled water, desalinated water)

In most cases, it is cheaper to store the ultimate service than it is to store electricity. For example, it may be possible to "super chill" a fridge or freezer, freeze-dry food, make ice or pump and purify water in times of excess variable renewable energy. The length of time that a service can do without power will depend on the type of service and the inherent storage capacity within that service. This is especially the case when one considers lifecycle costs. For example, the cost of providing water storage per unit of water stored is both cheaper in capital cost terms than storing the equivalent amount of electricity in batteries, and is usually longer lived, thus further reducing lifecycle costs.

3. Load shifting (*e.g.* streetlights to PV, off-grid households)

Many loads can be taken off-grid and supplied individually by PV (*e.g.* self-contained streetlights that are already in use in Kiribati). These have the advantage of improving service diversity since light is provided even when the grid is down. In some cases, the cost of having to install and maintain underground wiring for conventional grid-connected lights makes the capital cost of stand-alone PV streetlights competitive. Another good example is the use of PV-powered uninterruptable power supply for computer systems or critical health services that can also have mains back-up.

4. Electric vehicles (*i.e.* workplace and home-charging)

Many vehicles used for commuting spend most of the day parked. If commuter vehicles can be parked at a charging station at work (*e.g.* weekdays) and at home (*e.g.* nights and weekends), and there are many on such a "smart network", then they can absorb excess variable renewable energy power on sunny and/or windy days.

"Smart" vehicle chargers could determine how much capacity is made available to the utility to allow enough range to fulfil the rest of the journey, and what consumer/prosumer charges/benefits could be generated. They could also be used for "peak lopping" in the early evening, and then topped up in off-peak times ready for the morning's run. However, this "two-way" technology is still being developed and may be a decade away.

There are also some vehicles (*e.g.* small motorcycles, utility vehicles) with "swappable" batteries so that one could be left on charge while the other is being used in the vehicle. These are then rotated. As this technology is advancing rapidly, a "watching brief" should be kept and a few sample vehicles trialled to determine their suitability for Kiribati (*e.g.* price/performance ratios).

5. Specialised diesel generators (*e.g.* fast-acting, CNO-capable)

Any new generators that are planned should be selected based on their ability to support the integration of variable renewables (*e.g.* fast response to correcting voltage and frequency transients, good low-load performance). It would be an advantage if they were CNO-capable as well, especially in Kiritimati where CNO use is feasible, and could provide a good "pilot" as Kiritimati is smaller than South Tarawa.

6. Biofuels (*e.g.* stored for use when PV is insufficient)

It appears that there may be sufficient copra production in Kiritimati to fuel an energy efficient back-up diesel for a PV/wind/battery hybrid (Zieroth, 2012). However, much processing is required before a suitable CNO fuel is produced. It also should be noted that if all the previous strategies are implemented, the required level of diesel back-up energy may not be as high as initially estimated and, as a result, the required amount of CNO would also be lower. However, CNO substitution for diesel in road vehicles and sea transport is another outlet for the product, provided the engines in these vehicles are suited to the fuel.

7. Battery storage (*e.g.* Utility PV and diesel PS, sub-stations, households and institutions)

Battery storage could be placed in various locations on the network: for example, at the PV power station with a choice of direct current or alternating current buses; at the diesel power station, at sub-stations and at the customer level (*e.g.* residential, commercial and government).

Major utilities in Australia and around the world are trialling different technologies, many of them using li-ion batteries. However, it has been found that control systems vary significantly with little consistency on how they operate. There are limited standards in the area and system qualities have been found to be very variable. Many suppliers do not have a good understanding of the integration of these battery energy storage systems with renewables energy to maximise PV penetration (they are more familiar with systems being used for peak-load lopping). Companies that offer a complete system with both diesel and renewable generation, as well as storage, tend to have these storage and control problems sorted out and could thus be used as industrial "role models".

Another possible "role model" or reference point might be the Energy Networks Association of Australia's Case Study Report on Energy Storage released in September 2015 (ENA, 2015). However, at about AUD 1,000 per kWh of storage for good quality systems, this is a relatively expensive solution since previous solutions most often had lower lifecycle costs. The advantage of the lithium technologies is that they can be cycled deeply and for many cycles, whereas the traditional lead acid technologies (wet or sealed) have only limited depth of discharge if high cycle life is to be achieved. There is ongoing work in the lead acid field to improve lifecycles while allowing deeper levels of discharge (*e.g.* carbon nano fibres inserted into the plates to prevent sulphation).

One advantage of the older lead acid technology is that the lead recycling process is well understood and large amounts of lead *are* recycled, whereas the recycling of lithium is in its infancy and is less well understood. If large amounts of battery storage are to be used, this is an issue that must be addressed.

8. Shut-off or absorption of excess PV (e.g. Curtailment in times of high insolation)

There will be times when PV penetration is high and diesels are under-loaded to the point where either system stability is threatened or diesel maintenance costs increase. In these (most likely brief) situations, it is best to either reduce some PV inputs or add fast-acting, resistive loads to restore stability and reduce stresses on the diesels. Commercially marketed products exist that can curtail PV output automatically to maintain reliability of the grid operations and ensure that diesel generators are not pushed beyond their operational boundaries. For example, the UAE-funded system employs these technologies and it is recommended that all future systems would also do so. However, this is "wasted" energy. Diversion of this energy to useful loads is also a possibility if that load can accept variable energy inputs (*e.g.* copra drying, charging of changeover electric vehicle batteries).

9. Variable renewable energy forecasting

Macro-forecasting (*e.g.* satellite, long-term meteorological projections) and also some micro-forecasting (*e.g.* rain radar, sky cameras on island sensors) can be beneficial in giving advance knowledge as to what variable renewable energy inputs will occur, allowing for the planning of battery storage state of charge, the amount of spinning reserve to carry, warning of load cuts to non-critical areas and so on.

10. Geographical distribution

Having smaller variable renewable energy units spread over as wide an area as possible will give some diversity to inputs. Given that grid sizes are small (*e.g.* Tarawa: 30km; Kiritimati Zone 1: 10km), the opportunities remain modest, however concentrating PV generation assets in only one area should be avoided as much as possible.

6.1 South Tarawa

There are three major grid-connected PV systems either already installed, being installed or planned for South Tarawa, expected to total 1.42 MWp by the end of 2016. There are also smaller systems, which may total 100s of kWp if no regulations are put in place.

There may also be a case for adding wind turbines if systems are put in place to allow greater renewable energy penetration. It has been shown that wind can often replace diesel as so-called "base load" as power is often available at night-time as well as daytime; however, this option is often reserved for larger wind farms. The choice of wind turbines with AC-DC converters can also add inertia/spinning reserve. Studies have also found that storage at a strategic point in a feeder can greatly support voltage stability, obviating the need for Automatic Voltage Regulators (as on the Betio Feeder mid-point), as well as assisting with PV penetration issues.

As an example, Hydro Tasmania operates an isolated diesel-powered grid at King Island in the Bass Strait between Victoria and Tasmania (Gamble, 2015); its maximum demand is about the same as the PUB South Tarawa system. Tasmania has an excellent *wind* regime—unlike South Tarawa, which has a better *solar* regime—and has been able to achieve 100% renewable energy penetration at times through judicious design and the addition of various components. This has included the initial addition of large, fast-acting, resistive loads to absorb renewable energy "spikes". Later a flywheel synchronous condenser/generator, separated by a clutch system from its diesel engine, was added to increase system inertia. Lastly, a large battery inverter system was added that has further increased inertia and enabled operation at 100% renewable energy for much of the day – thus, a diesel "off" situation.

There are also companies that either supply diesel systems or inverters or that offer "complete system solutions". However, as system control is critical when using large amounts of variable renewable energy, a totally integrated solution – ideally one that has been tried and positively tested elsewhere – has a greater chance of successful long-term operation in remote island countries, such as Kiribati.

Another example is Ergon Energy of Queensland (Australia) that has a lot of experience with adding battery inverter storage at strategic points on their network to both reduce feeder overloading and improve power quality (*i.e.* voltage drops on long feeders).

Overall, the issues are *complex* and beyond the scope of this report. They require specialist electrical engineering studies of the *complete* system to come up with an integrated solution covering policy, planning, design, control and operation. As well as a steady-state stability analysis, a *step-wise* stability change is also required. This is difficult with a system that is comprised of many components from different manufacturers and that was not *designed* as a "whole", especially with the high penetration ratios planned. The following remarks thus necessarily provide at best a "broad brush" approach.

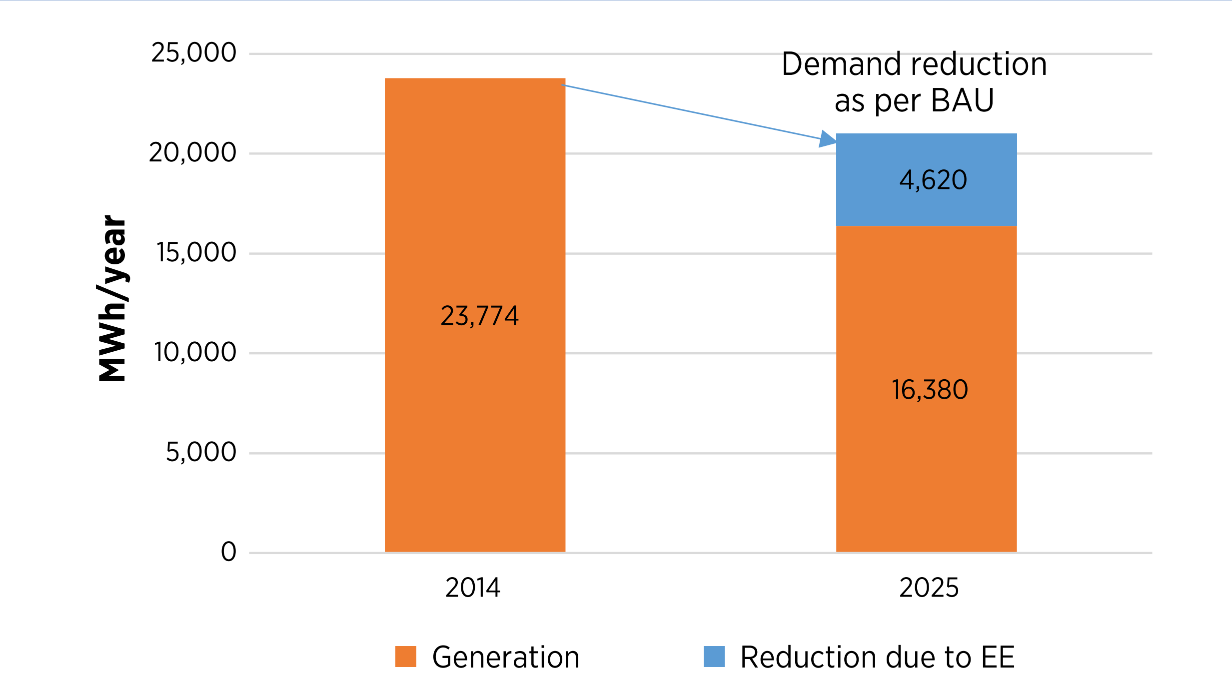
The steps required to increase the variable renewable energy to meet the goal of 23% of all energy from renewable energy follow. This is assumed to be 23% of energy *generation* – *i.e.* 23,700 MWh per year in 2014. According to the business-as-usual calculation based on the demand trend over the last ten years (2005-2014), expected generation may *fall* to 21,000 MWh per year by 2025.

Without considering drops which may occur due to pre-payment meters, 22% energy efficiency (EE) translates to 4,620 MWh savings while renewable energy at 23% translates to 4,830 MWh required. Note that with the EE savings, the total to be generated falls to 16,380 MWh per year, so the 4,830 MWh of renewable energy means the contribution from renewables would reach 29.5%.

For the purposes of this study, the 21,000 MWh generated as the "Business as Usual" figure for electricity demand in 2025 will be used. If energy efficiency measures are implemented by 2025, as per target, the residual electricity demand for South Tarawa will be 16,380 MWh in 2025, as illustrated in Figure 29.

From estimates based on detailed modelling of South Tarawa's power system, the combination of the existing and planned PV systems for a total of ca. 1.4 MW, ca. 2,000 MWh will be generated from solar PV, or around half the renewable energy target (ca. 17% capacity factor). If maximum loads are taken to have fallen to 3.5 MW at midday, this would result in a 40% renewable energy penetration. While the UAE 0.5 MW PV system is "controlled", the remaining 0.9 MW of PV still equates

Figure 29: Impact of reduction in non-technical losses and achievement of EE targets for electricity demand



to around 26% of non-controllable PV penetration. If loads fall further (*e.g.* weekends, EE), this uncontrolled penetration will increase.

The load duration curve of the South Tarawa system, based on the assumptions above, will simply shift down proportionally, as shown in Figure 30 and Figure 31.

Figure 30: South Tarawa 2014 load duration curve: EE targets achieved and reduction of non-technical losses

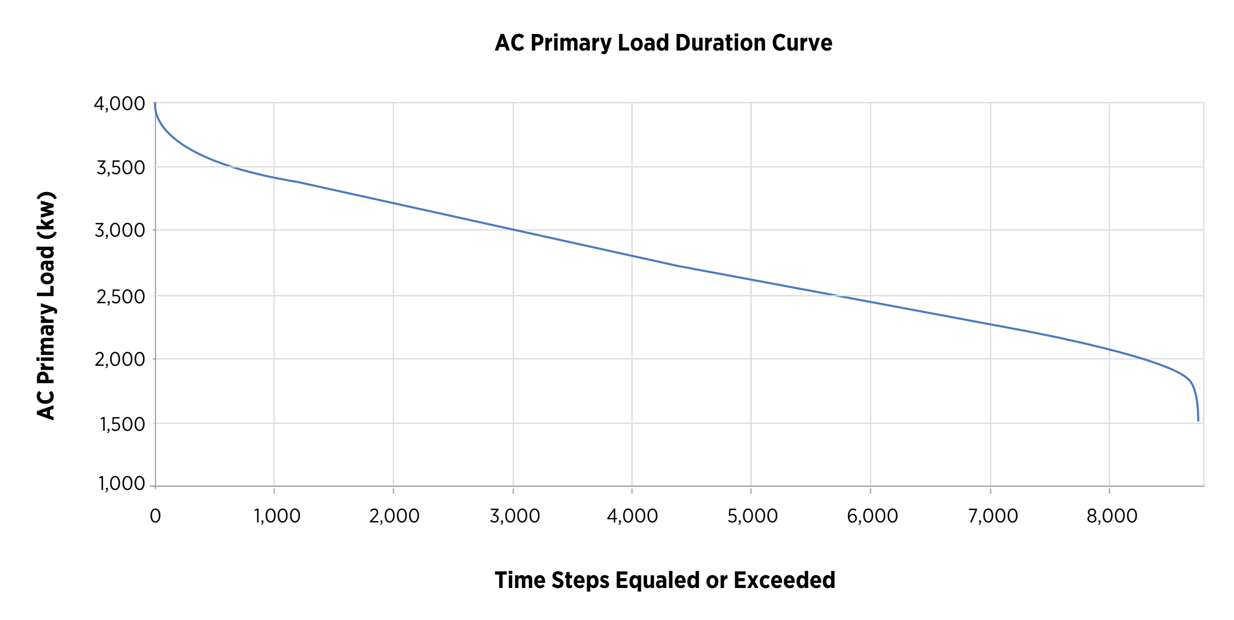
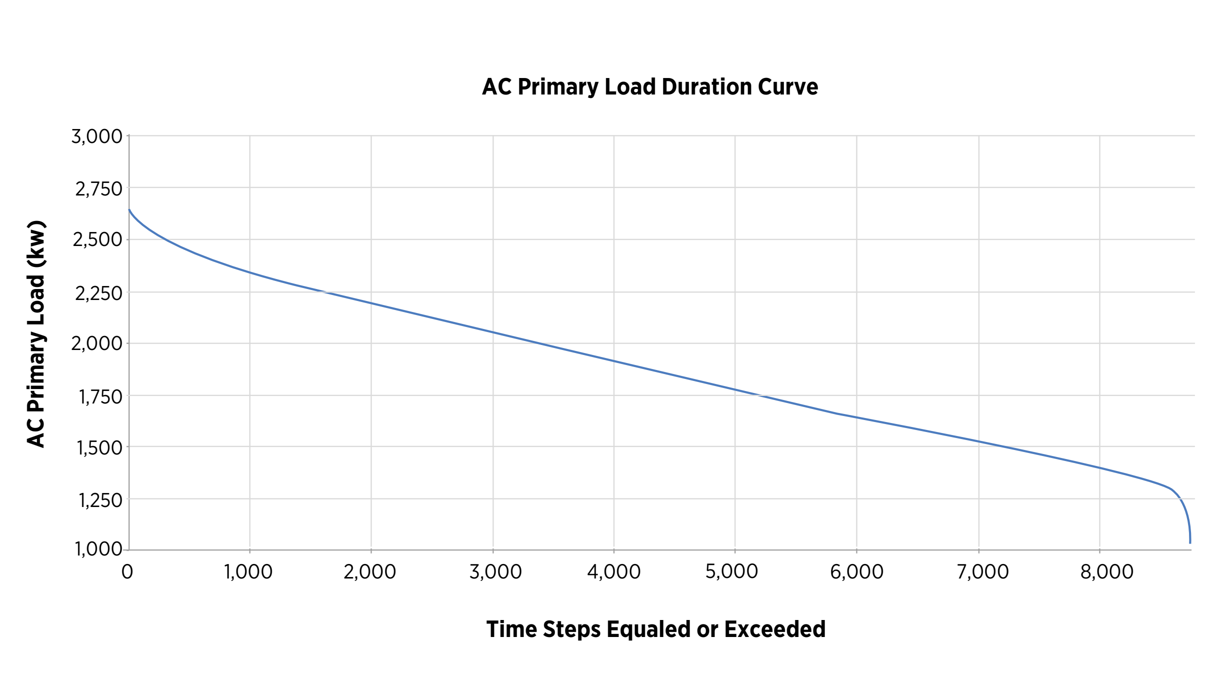


Figure 31: South Tarawa 2025 load duration curve: EE targets achieved and reduction of non-technical losses



The reduction in electricity demand between 2014 and 2025 – even *without* any additional solar PV installations – will translate into a maximum hourly penetration of solar PV in the lowest load day of over 75%, thus increasing the renewable energy share from 8.4% to 11.6%.

However, as Figure 32 illustrates, maximum penetration of PV would rarely exceed levels that cannot be safely managed with advanced inverters

With an aim of maintaining 80% of the solar output as operational reserve, the curtailment on lowest-load days

Figure 32: 2025 Tarawa hourly PV penetration probability: 1.4 MWp PV and 16.4 GWh/year of demand

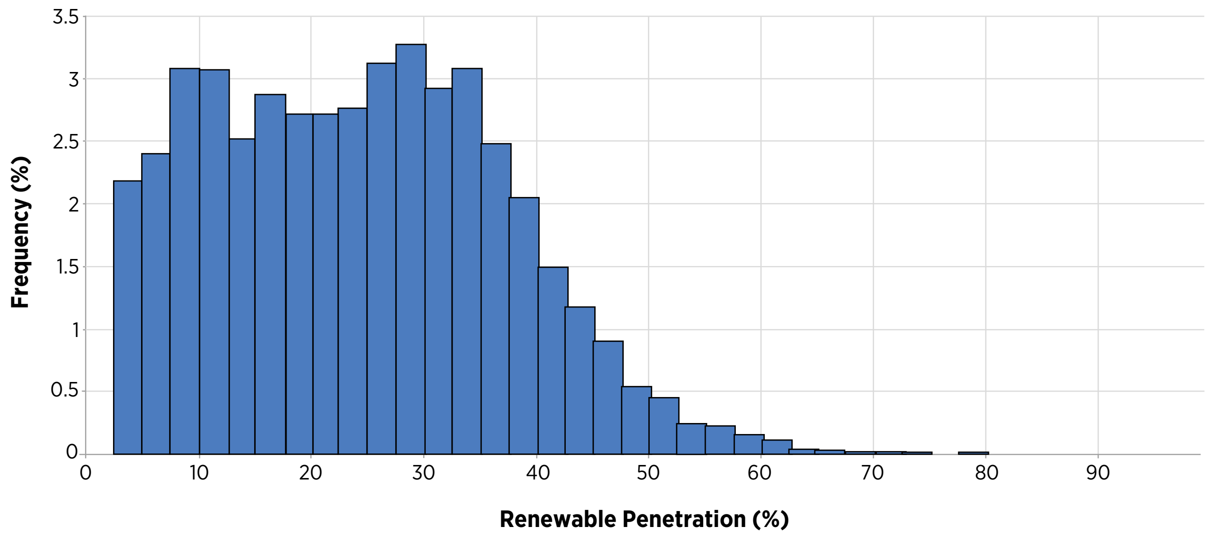
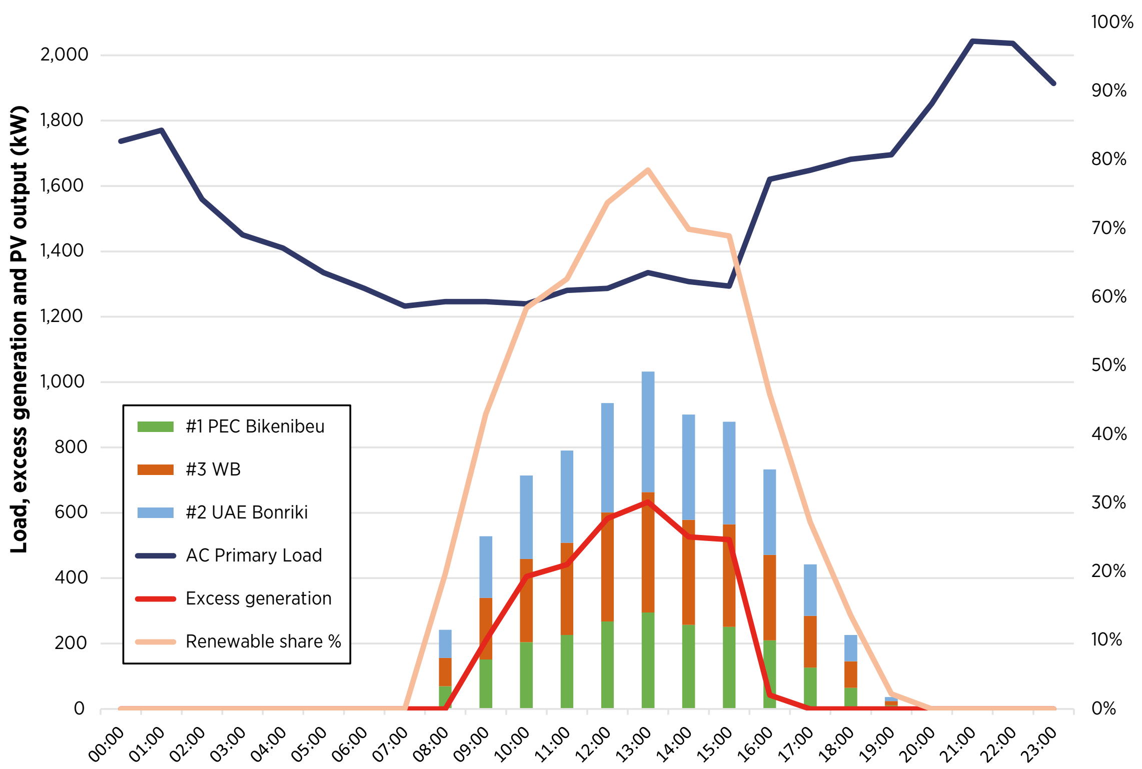


Figure 33: Estimated impact of existing and committed solar PV on lowest load day in 2025



could become substantial (see Figure 33). However, over one year's curtailment amounts to only a negligible 0.2 % of the generation from solar PV. As solar PV penetration reaches 80%, concerns about the operational reliability in the absence of storage will arise. A more detailed grid study has already been undertaken to assess the impact on grid operations, as well as the need for integration measures.

Based on the 1.4 MWp of solar PV installations expected to be in place in 2016, and assuming 80% of PV production to be available as spinning reserve from diesel (see Figure 34 for an illustration of PV output, load and operational reserves required on a typical day), there would be only a limited impact on diesel operations. This means that diesel will still play an important role. In particular, the third unit at Bikenibeu (#5) will be operational most of the time to provide additional spinning reserve during the central hours of the day. Its impact on system reliability will be limited.

To reach the 23% target without introducing storage, an additional 2.5 MWp of solar PV would be required. Such an increase in variable renewable energy penetration would lead to an estimated 10% of the total electricity production (1.8 GWh/year) being curtailed from PV production. However, reliability of operations would likely be affected, and substantial spinning reserve would be required (see Figure 35). Thus, this configuration *cannot* be recommended.

The addition of even modest quantities of battery storage (ca. 0.5 MWh) could eliminate the need to operate the #5 diesel generator (less than 50 h/year or ca 0.5% load factor) that could then just be kept as back-up). An increasing amount of battery storage would have a positive impact on both the economic and technical performance of the system. For example, reducing PV curtailment would reduce the levelised cost of electricity for the South Tarawa grid, while at the same time reducing the need for diesel capacity in stand-by to provide spinning reserve.

A simple 1 MW and 2.2 MWh Li-Ion battery storage system would enable the targeted achievement of the 23% renewable energy target, with only 1.5 MWp of additional solar PV (see Figure 36 and Table 25), as opposed to 23% reached with 2.5 MWp of additional

Figure 34: Impact of PV on operational reserves.

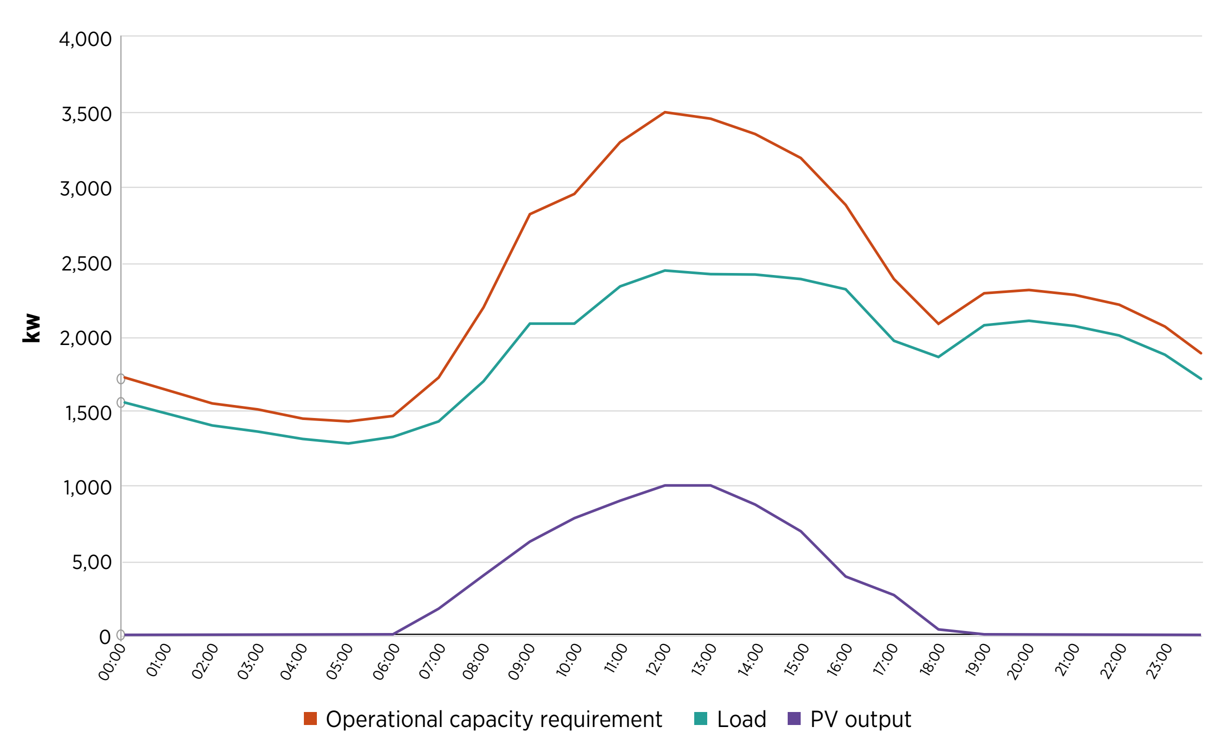


Figure 35: Impact on PV curtailment of additional 2.5 MWp of controllable PV (total PV 3.9 MW) without storage

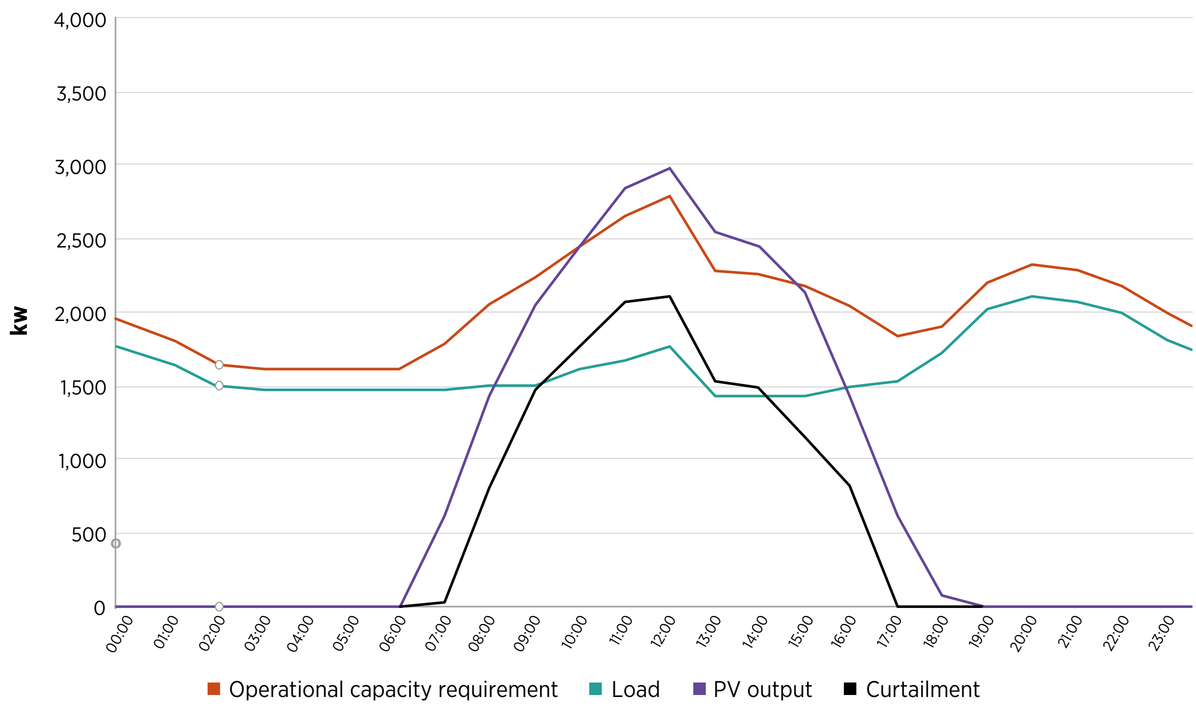
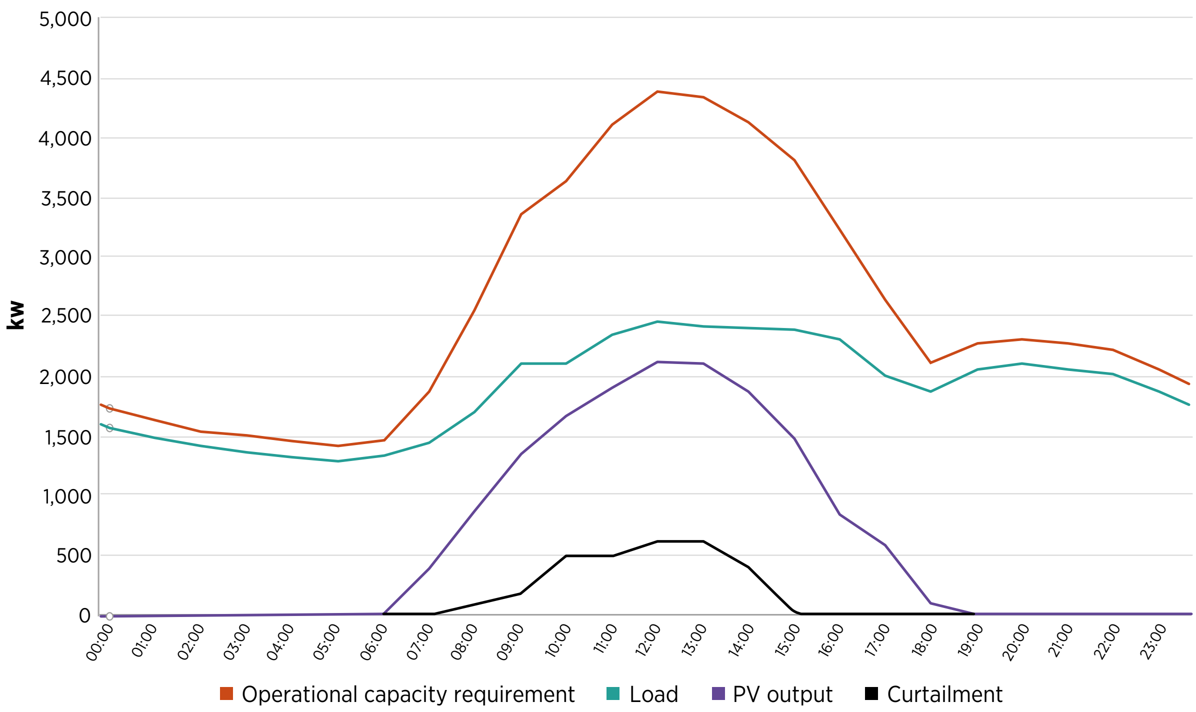


Figure 36: Impact on PV curtailment of additional 1.5 MWp of controllable PV (total PV 2.9 MW) with storage



PV without storage, due to reduction in curtailment, now down from 1.8 GWh/year to ca. 0.7 GWh/year. A further increase in battery storage capacity could almost eliminate the need for curtailment.

To suggest a simplified approach to a system transition, **it is recommended to install a battery bank that would be able to carry the load of South Tarawa – *without* the need for diesel generation – to be operational during the central hours of sunny days.** In simulations, this would be equivalent to a minimum of 2.64 MW and 5.6 MWh of storage capacity. However, it would be necessary to carry out a detailed engineering design to determine the technical details for the implementation of this solution.

As illustrated in Figure 30, demand in 2014 is estimated to have exceeded 2.64 MW for roughly half of the time. With the expected demand reduction, the 2025 load curve (Figure 31) shows that demand will remain below 2.64 MW the whole year, allowing for the battery storage system to take over the role of grid master, as all load can be carried at all times for two or more hours. This translates into **drastic reductions in running hours for diesel generators and substantial fuel savings.** Once deployed, the 1.5 MWp solar PV system, together with the battery storage system, additional PV will be available at a later stage to allow for further reductions in electricity generation cost. 1 MWp is the recommended further system size, to approach a total of 4 MWp, inclusive on systems installed in 2015 and 2016 (1.42 MWp), an additional 1.5 MWp system with battery storage and finally 1 MWp of controllable solar PV.

As the recommended system would be able to take over the role of "grid master" from diesel and have the battery inverters setting the grid parameters (*e.g.* frequency and voltage), while controlling the output from PV when necessary, **a more reliable system can be put in place, where the reduced inertia in the system becomes a virtue rather than a challenge**. In order for this to be achieved smoothly, the transition should be designed as a single system design, to minimise complexity and operational challenges due to the complex interaction among different power electronics from several manufacturers. Since a single standard for grid control from power electronics has yet to be identified, the reliable operation of high renewable energy share systems cannot be ensured using a mix of different technologies.

Table 25: Impact on diesel operations and fuel consumption of increasing of battery storage and solar PV

	System as in 2016, 2025 load	***Minimum cost next step system***	***Minimum recommend next step system***	***Optimal system***
	1.42 MW PV and no storage (as status by 2016)	**2.92 MW PV and 264 kW/560 kWh storage**	**2.92 MW PV and 2.64 MW/5.6 MWh storage**	**3.92 MW PV and 2.64 MW/5.6 MWh storage – least cost system**
Generator	**Total running hours**	**Total running hours**	**Total running hours**	**Total running hours**
Bikenibeu #3	7,006	6,299	1,854	1,510
Bikenibeu #4	8,168	6,482	7,772	6,802
Bikenibeu #5	1,120	171	0	0
Betio #1	2,757	4,417	2,785	2,992
Fuel consumption per year	3.60 Million litres	3.25 Million litres	3.03 Million litres	2.77 Million litres
Cost of electricity	0.304 USD/kWh	0.296 USD/kWh	0.288 USD/kWh	0.279 USD/kWh
RE share	12.1%	21.5%	24.6%	35%
Investment for additional PV with storage	0	3.5 Million USD	7.8 Million USD	9.8 Million USD

At this stage, the following phased-in approach is suggested:

» **Phase 1:** Maximise the performance of existing generators by ensuring they are well-maintained, including possible improvements to diesel governors and automatic voltage regulators.
» **Phase 2:** Improve billing so that all electricity used is actually paid for. This may include the use of pre-payment meters to assist with debt recovery, as has been successfully introduced in the neighbouring Marshall Islands and Federated States of Micronesia (FSM) over the past half since 2005.
» **Phase 3:** Implement an assertive EE campaign to assist with service provision using less energy (*e.g.* more efficient air conditioners and building upgrades to reduce infiltration losses).
» **Phase 4:** With the expected drop in peak load (estimated up to 1 MW), a number of detailed studies would be required to determine how to improve penetration of the existing 1.4 MW of PV, and how to add more renewable energy (*e.g.* synchronous condenser/flywheel, battery inverter systems, resistive load dumps, smart grid and discretionary loads). These include dynamic studies to ensure that there are no stability issues as a result of intermittency.

The studies for Phase 4 should include (but not be restricted to);

» Load flow modelling for baseline, future, seasonal (if there is any significant seasonality) and contingency cases;
» Genset low-loading problems;
» Network flicker and power quality impacts from PV/wind intermittency;
» Step loading problems on the generators/ stability analysis;
» Contingency analysis; and
» Protection study and fault level impacts.

The next step, if sufficient funding is available, would be to install a 2.5 MWp solar PV system with 2.64 MW/5.6 MWh Lithium-ion battery storage. In case of insufficient funding, a phased-in approach might be to have 1.5 MWp of solar PV instead of 2.5 MWp, with the same battery storage system.

6.2 Kiritimati

With the upgrade of the Kiritimati Island grid systems into Zones 1 and 2, there are opportunities for integrating grid-connected PV, and perhaps wind, into these zones. Further data will be needed on the aggregated loads at these sites since, with more reliable power and load growth in the years to come, it is expected that loads could grow, even with energy efficiency measures.

Zone 1: This larger system is nevertheless smaller than the PUB South Tarawa system and may prove the best site to trial some of the PUB concepts, as it has yet to be constructed and so could be designed from the ground up, or even supplied as an integrated system from one supplier where many of the control- and component-matching issues have already been solved.

Zone 2: Being a smaller system, this could possibly be operated as a hybrid system, like Poland. However, an engaged EE program should be carried out so that energy and peak power requirements are reduced, allowing a smaller system to be designed to satisfy the loads.

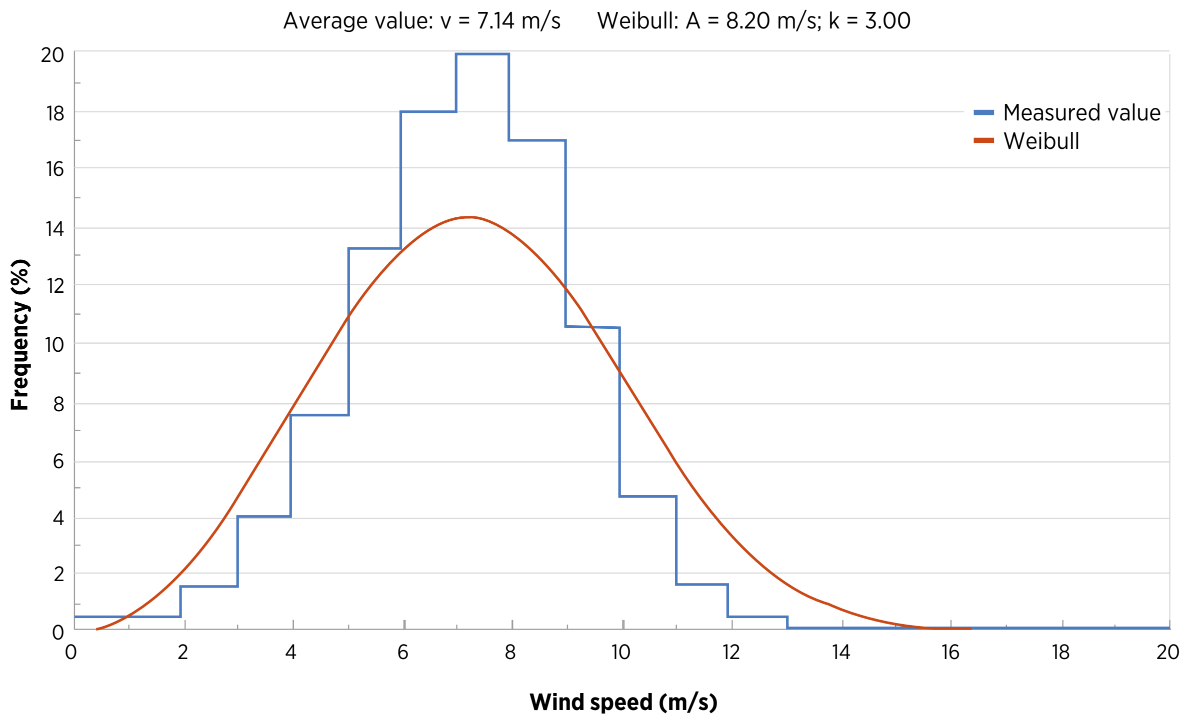
Zone 3: Will be the smallest of the three systems. Poland already has a hybrid energy system installed with 16 kWp of PV.

Unlike South Tarawa, Kiritimati has already developed a detailed wind study. Its results suggest that serious consideration should be given to the option of "small wind power" with some specific recommendations on suitable technologies. The study does not provide statistical distribution parameters for wind speed; however, it estimates long-term averages for wind speed at 34m for London (Garrad, 2012). Using an online tool available at: *http://wind-data.ch/tools/weibull.php*, data from this study for a 34m mast in London was used to reproduce the Weibull distribution shown in Figure 37.

The wind speed and its Weibull parameters are promising and used to estimate the productivity of one of the turbines recommended in the report. Conclusion: Wind power is a feasible option to consider for Kiritimati and could form part of a least-cost system for the island.

Analysing the larger Zone 1 system, load is expected to be 400 kW peak (initial) and 1.65 GWh per year. With EE

Figure 37: Estimated Weibull distribution for long-term wind speed in London, Kiritimati



assumed to be 20%, this translates to 330 MWh and a renewable energy target of 40% translates to 660 MWh.

The possible combinations of solar, wind and battery storage are detailed in Table 26.

The least-cost system, shown in green in Table 26, includes the envisioned 200 kWp solar PV system, with the addition of one unit of 275 kWp of wind and some battery storage.

Table 26: Possible combinations of solar PV, wind and battery storage on Kiritimati (Zone 1)

PV capacity (kW)	# of 275 kWwind units	diesel #1 (kW)	diesel #2 (kW)	diesel #3 (kW)	Battery storage 264kW/560kWh (Y/N)	Cost/COE (USD)	Cost/NPC (Million USD)	Cost/Operating cost (Million USD)	Cost/Initial capital (Million USD)	Annual renewable energy share (%)	diesel consumption (litres/year)
200	1	400	100	100	Y	0.267	5.07	0.28	1.79	55	206,685
0	2	400	100	100	Y	0.271	5.14	0.25	2.19	65	161,347
400	0	400	100	100	Y	0.323	6.12	0.41	1.39	29	327,653
0	0	400	100	100	Y	0.387	7.33	0.58	0.59	0	471,031
0	0	400	100	100	N	0.423	8.02	0.68	0.10	0	463,489

Table 27: Existing, planned and recommended generation and storage on Kiritimati (Zone 1)

Location Zone 1	System	Rating kW	Capacity Factor	Annual Energy MWh	Renewable energy share %	Cost USD	Status Sep. 2015
Tennessee Diesel	#1	400	n/a	n/a	n/a	?	Old unit
Tennessee Diesel	#2	100	n/a	n/a	n/a	?	2016
Tennessee Diesel	#3	100	n/a	n/a	n/a	?	2016
New PV	#4	200	17%	300	15	400,000	2016
Battery storage	#5	264	n/a	0.56 (capacity)		500,000	future
Wind	#6	275	36%	875	45	800,000	future
TOTAL		1339		875	n/a		

Some sources (Garrad, 2012) estimate a doubling of demand by 2025. Others estimate no load growth. For the purpose of this analysis, the above system is considered as modular. In case of rapid demand growth, the recommendation is to double the PV size first, then double the size of the battery storage once peak demand exceeds peak power output from the storage system, and finally to add a second wind turbine. Figure 38 show a visual representation of this modular deployment approach.

The Zone 2 system was initially expected to have a 40 kW peak load with 150 MWh annual energy use. In this case, a large energy system design comprising a PV/diesel/battery hybrid would be possible. Tokelau has similar but larger systems that have been operational since late 2012 (MFAT, 2013). Wind was not considered given the small size of the Zone 2 system.

Having two diesels generators could provide some redundancy and back-up to accommodate moderate future demand growth. Therefore, two 60 kW diesel generators have been recommended (ITP, 2014)

As Table 28 highlights, the least-cost solution for Kiritimati, shown in green, presents the highest share of RE, exceeding 80% thanks to the combination of a comparatively large (over three times the peak demand) PV systems and an efficient battery storage system with the ability to absorb all excess PV output during daytime to serve the load during night time. Diesel would be employed only to recharge the batteries once depleted (*i.e.* only ca. 5% of the time in a year). This would lead to an 88% reduction in fuel consumption. The PV system is able to produce 220 MWh/year; however, 60 MWh would be curtailed, and 25 MWh would be still produced by diesel.

Figure 38: Modular approach to a hybrids system deployment on Kiritimati.

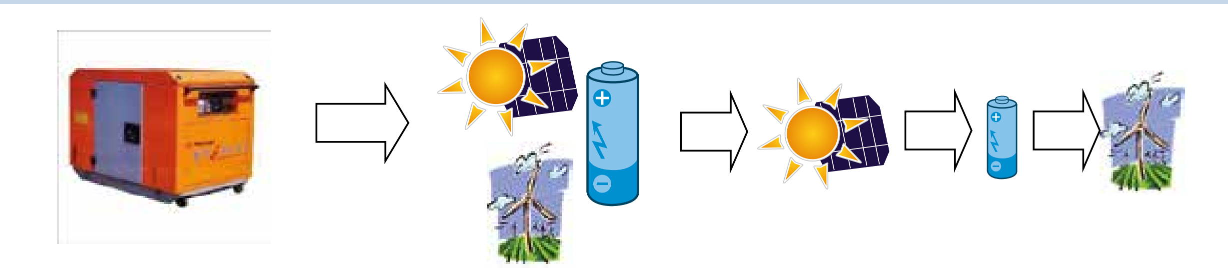


Table 28: Possible combinations of solar PV, wind and battery storage on Kiritimati (Zone 2)

PV capacity (kW)	Diesel #1 (kW)	Diesel #2 (kW)	Battery storage power (kW)	Battery storage capacity (kWh)	Cost/COE (USD)	Cost/NPC (USD)	Cost/Operating cost (USD)	Cost/Initial capital (USD)	Renewable energy share (%)	Diesel running hours	Diesel production (kWh/year)	Diesel consumption (l/year)
150	60	60	165	350	0.45	800,362	13,934	639,000	83	505	25,469	7,292
	60	60	33	70	0.58	1,034,740	78,926	120,750	0	5,227	175,659	53,223
	60	60			0.60	1,060,840	86,426	60,000	0	8,760	159,701	55,122
50	60	60			0.64	1,140,300	84,652	160,000	2	8,759	150,732	52,852

Table 29: Existing, planned and recommended generation and storage on Kiritimati (Zone 2)

Location Zone 2	System	Rating kW	Capacity Factor	Annual Energy MWh	RE share %	Cost USD	Status Sep. 2015
Banana Diesel	#1	60	n/a	12.5	n/a	?	2016
Banana Diesel	#2	60	n/a	12.5	n/a	?	2016
PV	#3	150	0.17	220	83	300,000	future
Battery storage	#4	165	n/a	0.35 (capacity)	n/a	280,000	future
TOTAL		435		245.35	n/a		

Note that for these systems which include a battery/inverter, depending on the degree of cycling, a loss factor should be added to take account of the inefficiencies of such systems (efficiencies of 80% are possible when batteries are new, falling to perhaps 70% at the end of their lifecycles).

6.3 Outer Islands

Future projects have been identified to upgrade services on the Outer Islands. These include those already flagged, as well as ice plants for the preservation of fish. These projects are outlined below:

» **Households:** It was planned to deploy an additional 6,000 of the small home lighting systems by the end of 2015. Each system is composed of a 35 Wp PV module powering three LED lights with lithium batteries and a USB port on each for mobile phone. As of the publication of this report, no data were available on the status of this project.

» **School mini-grids**: Two additional "large systems" are planned for 2016: the 16.5 kWp mini-grid PV systems at the Meleangi Tabwai Secondary School in Tabuaeran (Line Islands) and the Alfred Sadd Memorial College on Abemama. The systems will cater for computer laboratories, dormitory lighting, and refrigerators/freezers in the kitchens, office and audio-visual equipment, as well as teachers' residences. In addition, there are 36 Outer Island Junior Secondary Schools which have 0.41 kWp PV systems planned for lighting and laptop charging in two classrooms and the staff room. The Christian Community Leaders (CCL at Manoku – IUCN-funded) is another school on Abemama that has a mini-grid

PV system (size unknown at the time of this writing).

- **Hospitals and clinics:** The Southern Kiribati Hospital on Tabiteuea North has a 265 kWp system planned for a fully equipped outer island hospital, including staff residences. Presently, the hospital relies on diesel power generation, which is costly and also unreliable when fuel supplies are disrupted or there are major breakdowns. There are 58 Outer Island Clinics, which have PV systems planned to provide back-up lighting and HF radio communication in case the main power systems fail.
- **Administrative centres:** There are around 20 Outer Island Council administrative centres in the Kiribati and Line Groups which have 5 kWp PV systems planned to provide power for office equipment, phone and internet telecommunications.
- **Fisheries:** There are around 20 Outer Island Fish centres in the Kiribati and Line Groups, which have 3.75 kWp PV systems planned to provide power for lighting, refrigeration and other equipment. As with all Outer Islands, this will improve power reliability and hence fish supply, due to fewer breakdowns and fuel supply issues.
- **Vulnerable communities:** There are around nine selected islands with 13 identified vulnerable communities that have had PV-powered desalination systems planned to address potable water shortages. The status of these projects could not be determined at the time of publishing this report.
- **Police stations:** There are around 23 Outer Island Police Stations in the Kiribati and Line Groups, which have 0.12 kWp PV systems planned to provide power for communication and lighting. Existing systems are old and require replacement.
- **Ice plants:** There are 18 ice plants on the Outer Islands in the Kiribati Group (including Banaba), which are presently diesel-powered. These are said to be 3-4 kW Ice Plants, but are being presently run from 18 – 26 kW diesel generators, which appear to be under-loaded. There may be other equipment at each site, but these data were unavailable. With careful design, and possible upgrading of the ice plants, a much smaller PV-powered system should be able to service these loads. Assuming a total load of 5 kW for the facilities with a 0.5 cycling factor, a system capable of supplying 60 kWh per day would be required at each site. This is a fairly substantial system and might require up to 20 kWp of PV. Installed cost for a quality system is likely to be in the range of AUD 200,000 to AUD 300,000.

Table 30: Planned Outer Island PV systems

System type	Number	Capacity (kWp)		Cost	Status (Sep. 2015)
		Per system	Total	Thousand AUD	Comments
Households (solar lighting kits)	6,000	0.035	210	1,500	Cost estimate. By end 2015
Police Stations	23	0.12	2.8	60	
Councils	20	5.0	100	710	
Health Clinics	58	1.0	58	230	Size estimated
Junior Secondary School	36	0.41	14.8	285	
School Mini-grid – small	3	16.5	49.5	1,000	Size estimated for one
Desalination systems	13	2	26	115	Size estimated
Fish Centres	20	3.75	75	610	
Ice Plants	18	20	360	3,600	Size & cost estimated
Southern Hospital (Tab. N.)	1	265	265	2,400	
TOTAL			1161.1	10,510	

7 ENERGY EFFICIENCY IN POWER GENERATION: SUPPLY SIDE

This section outlines significant opportunities available to increase the energy efficiency of the current electricity generation system in Kiribati.

7.1 Electricity generation efficiency overview

Electricity is supplied by two power stations located at Betio and Bikenibeu, which are owned and operated by the Public Utilities Boards (PUB). Three medium-speed Daihatsu generators at Bikenibeu currently supply the base load with additional generation from another Daihatsu at Betio Power station, supplementing the generation. Table 31 below provides information on the generators.

2014 peak electricity demand was 4.17 MW, while installed diesel capacity is now only 4.7 MW due to the de-rating of all four operational generators. Additional to the diesel capacity, grid-connected 400 kWp and 500 kWp PV installations were commissioned in 2015.

It is important to note that **all serviceable generators have been de-rated due to delayed overhauls.** The delayed overhauls give rise to **increased fuel consumption and hence decrease fuel efficiency.** The measure of fuel efficiency in diesel generators is the Specific Fuel Consumption (SFC) in kilowatt-hours per litre of fuel. Table 32 illustrates the SFC variation.

Table 31: Installed diesel capacity

Bus No.	Generator Name	Rating (kW)	Speed (RPM)	Running Hours as at 30/06/14	De-rated Capacity (kW)	Year Installed
1	Bikenibeu – No.3 Daihatsu	1,400	750	87,574	1,200	2002
1	Bikenibeu – No.4 Daihatsu	1,400	750	82,931	1,200	2002
1	Bikenibeu – No.5 Daihatsu	1,400	750	45,893	1,200	2005
2	Betio – No.1daihatsu	1,250	750	62,862	1,100	2003
3	Bikenibeu Station Solar Grid Connect – PEC	400	Commissioned 28 February 2015			
	Bikenibeu Station Solar Grid Connect – UAE	500	Commissioned September 2015			

Table 32: Kiribati's total generation and fuel use 2010–2014

Year	Generation / MWh	Fuel used / litres	kWh / litre
2010	21,641	5,665,000	3.82
2011	21,826	5,791,000	3.77
2012	22,556	5,921,000	3.81
2013	23,212	6,196,000	3.75
2014	23,774	6,294,450	3.78

Source: PPA Benchmarking Data 2010 – 2013 (PPA, 2015)

Table 33 shows the results of detailed analysis of generation output and fuel consumption for the month of December 2010 with SFC ranging from 3.49 to 3.80 kWh/litre.

Timely maintenance of the plant can improve its SFC to an average of 4 kWh/ litre. This translates into possible savings of 350,200 litres of fuel per annum based on the 2014 fuel consumption or 5.6% annual fuel savings.

It should be noted that PUB's current generation availability does not meet N-1 criteria for firm capacity. This means that if, for any reason (*e.g.* fault or required maintenance) one of the generators goes offline, the rest of the operational generators will not have sufficient capacity to meet demand and this will result in load shedding.

It would, therefore, be expedient that PUB consider additional diesel generation capacity to address the shortfall, but in doing so to also consider sizing the new generators such that they give PUB operational flexibility to meet variable daily load demand.

PUB's renewable energy generation assets are limited to solar at present, with the possibility of wind and wave/ tidal systems in future. A number of grid-connected solar PV systems were installed on the PUB systems in 2015 with more planned in coming years. **As the level of renewable energy generation increases, PUB must ensure that impacts of high renewable energy penetration are properly addressed through either storage or modern control systems.** Part of the solution could be the utilisation of high-speed/ low-load generators that could address the capacity issue, as well as the high renewable energy penetration. Analysis of the PUB power system performed by KEMA 2010 determined that the total system loss was 20.63% of annual generation, which, for such a small power system, is relatively high. This loss consisted of:

- 4.81% in power station auxiliaries (station losses);
- 5.90% in technical losses;
- 5.23% in non-technical losses;
- 1.93% in PUB own building usages; and
- 2.76% in unbilled water and sewer pump usage.

Section 5 provides a detailed analysis of 2014 electricity generation and shows that total system losses still represent a significant concern in South Tarawa.

The technical losses are a summation of transformer core losses, transformer copper losses, distribution feeder losses, secondary wire losses and losses of any other equipment in the system (*e.g.* reactors and capacity banks). Electricity supply standards require that a power factor of 0.8 lagging be maintained to ensure that the machinery functions efficiently. However, the power system losses will increase where the power factor lags significantly below 0.8.

Non-technical losses are the result of inaccurate meters, meter tampering or by-passing, theft, meter-reading errors, irregularities with prepaid meters, administrative failures, wrong multiplying factors, etc. Unbilled usage is energy consumption that is metered but not paid for, especially those incurred by other functions of the utility, such as water and sewage; this is considered a financial loss for PUB. A re-assessment of the PUB power system losses in 2014 showed that these losses were still unacceptably high and work needed to be done to reduce total losses to less than 5%.

7.2 PUB operations

The Public Utilities Board (PUB) faces a number of challenges; in particular, limited financial resources that has directly led to deferred or non-existent maintenance of its diesel generator sets in the

Table 33: Average fuel efficiency of individual units in December 2010

Diesel Engine Generator	Diesel Fuel (Litres)	kwh	kWh/litre
Unit 3 – Bikenibeu Power Station	90,800	319,470	3.52
Unit 4 – Bikenibeu Power Station	139,120	528,939	3.80
Unit 5 – Bikenibeu Power Station	110,560	385,700	3.49
Unit 8 – Betio Power Station	135,110	505,090	3.74
Total average	475,590	1,739,190	3.65

past years. The 2015 report, entitled *Performance Improvement Plan and Preliminary Reform Options,* developed under the Kiribati Utilities Services Reform Programme (KUSRP), highlighted the ongoing challenges to the electricity sector's operational performance;

- Neglected maintenance over the years, resulting in reduced fuel efficiency and increased incidence of service interruptions when generators fail. The original equipment manufacturers (OEM) recommended scheduled maintenance was not carried out in 2009 to 2011 or in 2013 to 2014.
- The number of power outages has increased. There were six total or major power outages in 2013 and 26 in 2014, caused by generation faults, fuel shortages and faults on the 11kV distribution network.
- Fuel for power generation accounts for 75% of the total operating costs, followed by staff costs, which accounted for 16%, indicating PUB's limited ability to make significant cost savings in other areas. The diesel fuel cost has remained at AUD 1.27/ litre since 2009, although PUB is VAT-exempted and, with the recent drop in world oil prices, one would expect some savings of AUD 0.11/litre on diesel fuel.
- PUB supports solar PV projects with both Japanese and UAE solar PV systems installed in February and August 2015, respectively. The World Bank solar PV grid-connected project is expected to be installed in 2016 (World Bank, 2014).
- In June 2015, AUD 8 million was recorded as Accounts Receivables and, of this AUD 8 million, electricity debtors comprised the bulk of debtors (AUD 7.524 million or 94%) while water debtors comprised only AUD 468,000 or 6%). Pre-payment metering is an option which would improve PUB's collection rates and eliminate the high level of debtors.

To improve electricity performance, the 2015 KUSRP report proposed the following measures:

- Introduce long term maintenance contracts for generators and auxiliaries;
- Remedy the HV distribution system to address losses;
- Introduce pre-payment meters for improved revenue collection; and
- Improve the billing system and IT applications.

The KUSRP-proposed changes needed to reform PUB are substantial and challenging in terms of change and project management. The KUSRP proposes structural reforms of PUB, as well as support of the management team through short-term consultancies to implement the proposed major investment programme and lead the reforms. One of the major reforms would be the separation of PUB into two new state-owned enterprises (SOEs): 1) electricity generation and transmission managed by the proposed "Kiribati Power" and 2) "Kiribati Water and Sewerage" to manage the water and sewerage services. The proposal is expected to go into effect by 1 January 2017.

7.3 Energy efficiency: Supply side strategic direction

Energy efficiency supply side management is an important day-to-day activity of any utility since its purpose is to reduce fuel consumption for power generation and electricity losses. KIER notes and fully concurs with KUSRP's recommendations and is providing the following energy efficiency supply side management (EE–SSM) activities, anticipating a **reduction on total losses (*i.e.* auxiliaries, technical and non-technical) of 9.74% by 2025.**

Overhaul and replacement of diesel engines

As noted in Table 31, the current fleet of diesel generators is way past due for critical maintenance and, as a result, has to be operated at a de-rated capacity. Efficiently operating diesel engines are critical to the optimisation of the system. The KIER recommends that PUB implement regular maintenance for all generators and determine which units are in need of replacement. This effort should focus on transitioning the existing diesel fleet to one that is properly sized in terms of total capacity and the size of individual generators, which would enable more efficient operation of the system. Emphasis should also be placed on transitioning to generators with high ramp rates and that also support low loading since these characteristics allow efficient operation when high shares of variable renewable energy are integrated into the electricity system.

Rehabilitation of transmission and distribution lines

Technical losses arise as a result of electric current passing through the power system network. The network comprises distribution cables and conductors, transformers and customer service drops. The system technical loss for PUB was 5.9% in 2012.

The 2012 KEMA report noted that the recent upgrades to the 11 kV distribution system, which is entirely underground, is adequately sized for load-serving purposes and does not require replacement to serve the existing load.

The low voltage distribution system, however, does requires substantial upgrade as it is evident that little or no maintenance has been carried out for some time. The state of the low voltage network poses a danger to PUB staff and the public with pillar boxes in dilapidated conditions and cable terminations exposed as seen in Figure 39.

It is recommended that PUB carry out thermal imaging of the 11 kV and low voltage network to identify "hotspots" in the network. These "hotspots"—high-resistance joints and connections that can result in faults and that give rise to energy losses—need to be eliminated.

Figure 39: Pillar boxes and exposed cable terminations

The KEMA study also highlighted the low utilisation factor on the distribution transformers, which significantly contributes to technical losses. It is, therefore, strongly recommended that **transformers be correctly sized to accommodate new distribution loads.** Furthermore, a programme of swapping transformers should be undertaken on an *ad hoc* basis to match the transformer size to the existing load.

These initiatives would reduce technical losses from 6% to 3%. The cost for this activity provided in section 15.1 would also cover tools and equipment and repair of the Betio electrical workshop. The proposed rehabilitation of the distribution network is anticipated to be implemented in between mid-2016 and 2018.

Meter audits and pre-paid meters

KIER concurs with the findings of the KUSRP study that PUB's collection rate (85 – 90%) is **too low** while level of arrears (*i.e.* AUD 6.4 million for electricity debtors at the end of the 2014 financial year) is **too high**. PUB needs to **install a pre-payment billing system**, which would then address the low collection rate and payment of customers in arrears.

PUB meter data collected for the PPA Regional Benchmarking for the 2014 Fiscal year indicated a total of 7,765 connections, of which 6,401 were residential (PPA, 2015). The pre-payment programme could immediately address discrepancies in the residential customer category, as well as delinquent small business accounts.

In line with the pre-payment metering programme, a physical meter audit would need to be carried out to ensure that PUB has a full list of all existing meters in its management information system (MIS) and that all customers do, in fact, *receive* a bill. Such an exercise would also serve to identify any theft, meter tampering and other causes of non-technical losses and thus should be coupled with appropriate legal actions.

The introduction of pre-payment metering systems would also do away with having to undertake meter testing on the current batch of meters. The pre-payment system, however, would increase the need for monitoring of customer consumption patterns. There is technical expertise available within the PPA member utilities to prove the benefits of pre-payment metering. PUB's non-technical losses in 2012 amounted to 5.23%, which is considered too high and should be reduced to 4.23% (*i.e.* savings of at least 1%) by 2025.

7.4 EE-SSM targets

The Energy Efficiency-Supply Side Management (EE-SSM) initiatives proposed are projected to reduce the station auxiliaries, technical and non-technical overall losses by 1.81%, 3.12% and 4.75%, respectively, by 2025. The electricity saved is projected to be 2,033 MWh in 2025.

The total savings through EE-SSM for electricity generation is estimated at 802,794 litres of diesel; thus, a savings on generation costs of around AUD 1.017 million by 2025.

Table 34, Table 35 and Table 36 provide projected savings against the BAU as percentages of overall savings when the fuel generation saved is achieved through the proposed EE-SSM activities. Note that the reduction in non-technical losses will come from meter auditing and installation of pre-paid meters

The energy efficiency targets proposed by the Government of Kiribati in its INDC aim at a 22% reduction fossil fuel use for power generation from improvements in energy efficiency on both the supply and demand side by 2025. In the analysis for this Roadmap, it is anticipated that 9.68% savings can be achieved by 2025 through the supply side energy management efficiency, while the rest through demand side energy efficiency.

Table 34: BAU generation baseline and SSM targets

	2015	2020	2025	2030
BAU total generation (MWh)	23,508	22,218	21,000	19,848
Station auxiliaries target (MWh)	0	284	380	429
Technical losses target (MWh)	0	355	655	685
Non-technical losses target (MWh)	0	571	998	960
Total SSM target (MWh)	**0**	**1,210**	**2,033**	**2,074**

Table 35: SSM targets

SSM targets in percentage (%) against BAU	2020	2025	2030
Station Auxiliaries	1.28%	1.81%	2.16%
Technical losses	1.60%	3.12%	3.45%
Non- technical losses – Meter Audit and Installation of Prepaid Meters	2.57%	4.75%	4.83%
Total Target Saved in percentage	**5.45%**	**9.68%**	**10.45%**

Table 36: SSM fuel generation cost reductions 2020–2030

SSM fuel generation cost reductions (AUD)	2020	2025	2030
Station Auxiliaries	3,378	3,192	3,017
Technical losses	5,230	9,884	9,342
Non- technical losses – Meter Audit and Installation of Prepaid Meters	9,379	17,724	16,752
Total	**17,987**	**30,799**	**29,110**

It is also anticipated that by 2025, most of the EE-SSM activities (*e.g.* maintenance and installation of new generators, pre-payment meters and rehabilitation of transmission and distribution lines) would be completed with a fuel savings cost of around AUD 30,799. The upfront investment required to complete these activities is around AUD 17,695 million[9] as shown in Table 37. However, this investment is high as PUB needs to invest in two diesel generators, in addition to investment in the annual maintenance cost over the life span of these diesel generators.

7.5 EE-SSM financing plan

Most of the investments aim at improved efficiency considered in terms of reducing losses in diesel use for power generation, as well as reducing losses on electricity distributed and transmitted to end users. The costs extracted from the KUSRP report include investments related to the strategic directions discussed in sections 7.2 and 7.3.

Table 37: Financing plan

Description of investment	Est. Cost (AUD)	Secured (Identified under existing programmes)	Unsecured	Possible Donors
1. Generator maintenance contract AUD 1 million per gen set for engine overhaul, 4 engines 4 million over the ten-year period	4,000,000	0	4,000,000	ADB Loan, EU, NZAid, Private Investors
2. Procurement of two diesel generators New high speed, low load generator; 1MW New high speed, low load generators; 500kW	6,700,000	0	6,700,000	NZAID, JAPAN[9], EU, GIZ, etc
3. Rehabilitation of low voltage mains and service connections to households including work on thermal imaging of the 11 kv to identify "hotspots" in the network and transformers resizing to suit existing loads and new distribution loads and repair to the electrical workshop in Betio	6,290,000	0	6,290,000	EU[10], NZAid ADB loan
4. Meter audits to identify meter faults and eliminate illegal power connections	5,000	0	5,000	Green Climate Fund, (Energy efficiency)
5. Pre-payment meters for 6,401 residential customers at a cost of USD 100 per meter, supporting software, TA and labour costs	700,000	0	700,000	
Total Investment	17,695,000	0	17,695,000	

Source: KIER analysis based on KUSRP report, 2015

9 The budget identified by the Kiribati PUB Reform Analysis to improve PUB overall capacity to meet the demand – for electricity, water and sewerage

10 Procurement and maintenance of diesel gen-set from reputable suppliers that can provide continuous long-term maintenance through contracts. New Zealand and Japanese companies involved in power utility projects are listed in the KUSRP report.

11 The EU has financially supported rehabilitation of grid extension in Niue; NZAID has supported PICs expansion of grid network including Kiritimati, so this activity needs to become Government of Kiribati priority in order to get funding from the country's development partners.

8 ELECTRICITY REGULATIONS AND STANDARDS

Without enforceable regulations and standards, the quality, longevity and safety of services provided by energy systems are likely to be diminished. There are numerous standards for both on-grid (also known as grid- connected) and off-grid (also known as stand-alone) electricity. At the 2014 Pacific Energy Ministers Meeting, Kiribati, along with other Pacific Island Countries and Territories, endorsed the following SEIAPI Guidelines and recommended that they be formally adopted (SPC, 2014a).

- Grid-connected PV Systems – System Design Guidelines; (PPA and SEIAPI, 2012a)
- Grid-connected PV Systems – System Installation Guidelines; (PPA and SEIAPI, 2012b)
- Off-grid PV Power Systems – System Design Guidelines; (PPA and SEIAPI, 2012c) and
- Off-grid PV Power Systems – System Installation Guidelines. (PPA and SEIAPI, 2012d)

8.1 Grid-connected PV systems

The supply of electricity on South Tarawa is covered by the Public Utilities Ordinance of 1977 (Kiribati House of Assembly, 1977) and is exclusively that of PUB, with a subsequent amendment to Section 6 (1) in May 2010 to allow the use of solar power by others (Kiribati House of Assembly, 2010). However, Section 6 (2) states that it is still necessary for any third party to have written permission from PUB to connect generation equipment to the grid, with Section 6 (3) defining penalties for not obtaining permission. Now a system of application and approval would need to be set up for PV systems **not** owned and operated by PUB. Given that there may be grid-stability issues, even if approved for connection, third-party PV systems should not be encouraged to inject energy into the grid (reverse power protection). Inverters are available that would stop reverse power flow.

In general, Kiribati has adopted the Australian/New Zealand standards. For grid electricity, these include (but are not limited to):

- AS/NZ 3000 – electrical wiring rules;
- AS5033 – solar arrays;
- AS4777 (2015) – grid-connected inverters;
- AS/NZ5139 – battery standard (new); and
- IEC62109 – Electrical Safety (Parts 1 and 2).

8.2 Stand-alone PV systems

There are an increasing number of stand-alone systems in Kiribati. The standards in use for off-grid electricity, include the relevant grid-connected systems standards listed in section 8.1 plus;

- AS4509 – stand-alone systems

9 ENERGY EFFICIENCY IN BUILDINGS: DEMAND SIDE

9.1 Residential buildings

The total number of residential buildings, comprising private and Kiribati Housing Corporation residential houses connected to the PUB electricity grid, was 6,995 as of October 2015.

The 2011–2030 Tarawa Water and Sanitation Roadmap Report (Fraser Thomas Partners, 2012) projected two scenarios: a high-growth population forecast and a low-growth population forecast.

The high growth scenario assuming that there is very limited intervention on reducing in-migration from the Outer Islands and no major growth management initiatives are introduced, a maximum population of about 107,700 is anticipated in South Tarawa in 2030, with an average annual growth rate of 3.87% from 2010 to 2030. Using the number of persons per household size of seven[12], the total number of residential buildings in 2030 is projected to increase to 15,400, an increase of 99.8 % from 2010, inferring a doubling of the total household numbers in Tarawa. Table 38 provides the number of residential houses in the urban areas of Kiribati, Betio, South Tarawa and Kiritimati. Availability of space for residential buildings is a challenge with this projected increased number of households. Some potential areas have been identified that could be utilised but they are limited and need to be refilled prior to use. The North Tarawa area has greater potential land area available to cater for an increasing population and residential areas on South Tarawa and Betio. However, access to appropriate infrastructure (*e.g.* roads, water, sanitation and electricity) would encourage people to move to North Tarawa, thus reducing the pressure on South Tarawa resources.

9.2 Government and industrial buildings

The Joinery and Construction Division of the Ministry of Infrastructure and Sustainable Energy (MISE) keeps a record of government buildings through its maintenance schedule. The PUB records a total of 392 electrical meters for government-owned buildings. In 2015, there were 15 government ministries located in four different villages along South Tarawa; Bairiki, Betio, Bikenibeu and Tanaea. The Government of Kiribati provides an allocation of AUD 500,000 annually for

Table 38: Kiribati residential household statistics 2016

	Population	Households	Person/ Household	Land Area	Density (Pop/ km²)	Household /km²
Kiribati Total	**103,058**	**16,043**	**6.42**	**726**	**142**	**22**
Tarawa	56,284	7,707	7.30	31.1	1,810	248
South Tarawa	34,427	4,728	7.28	14.1	2,442	335
Betio	15,755	1,977	7.97	1.7	9,268	1,163
Kiritimati	5,586	857	6.52	388.4	14	2
North Tarawa	6,102	1,002	6.09	15.3	399	65

Source: SPC data, 2016

12 Kiribati's national average of persons per household is 6.4. For Tarawa, the number of persons per household is 7.3.

maintenance work on government buildings. The Ministry of Commerce, Industries and Cooperatives (MCIC) keeps a record of government industries. The government industries in 2015 were the Kiribati Copra Mill Company, the Central Pacific Producers Ltd. and Kiri Trading Limited. In 2015 PUB recorded 392 meters for government and industrial customers

9.3 Commercial buildings

Commercial buildings on South Tarawa include hotels, mini-supermarkets, printer, professional consultants, restaurants, a second-hand clothing shop, a tire shop, etc. There is no proper enforcement on the zoning of these buildings and, in some instances, commercial buildings (*e.g.* kava bars, tire shops, restaurants) are housed within residential zones as extensions to existing residential buildings. This is a problem that PUB encountered over the past years, as the electricity bills are undercharged for these buildings. A proper metering assessment and audit would provide PUB with evidence to reduce electricity theft through unreported commercial activities.

The number of commercial meters recorded by PUB in October 2015 was 877. In 2015 the Kiribati Housing Corporation (KHC) also conducted an assessment of commercial activities connected to its housing fleets in Betio, Bairiki, Nanikaai and Bikenibeu. The assessment led KHC to implement a policy to remove all commercial activities connected to its housing fleet. This move not only reduced the risk of high usage of electricity in homes, electrical safety and fire prevention, but also reduced undercharged uses of electricity.

9.4 Unbilled uses

Unbilled electricity users are considered "non-technical losses" by PUB. However, these unbilled uses are actually for PUB electricity use in utilities, offices and buildings and electricity usages for water and sewerage activities. These uses are considered in this analysis as electricity demand for the main users: PUB offices and buildings and Water and Sewerage.

As of 2016 there were a total of 4,237 water connections recorded by PUB, of which 1,139 were government and SOE employees in Kiribati Housing Corporation (KHC) quarters while 3,098 were private customers. In addition, there were 55 commercial and 23 industrial customers. In the PUB 2015 budget, electricity cost for water pumping was AUD 480,652 based on the industrial tariff of 0.70/kWh. The proposed target for electricity use for water pumping would provide a 30% savings by 2020, based on 2016 usage.

The sewerage system, which serve three areas in South Tarawa-Betio, Bairiki and Bikenibeu, is currently being rehabilitated by the South Tarawa Sanitation Improvement Sector Project (STSISP) and is scheduled for completion by the end of 2017. It will feature a fully restored system utilising salt water flushing and the disposal of sewerage through outfalls to the open ocean. PUB estimates that, as of 2015, there were 2,302 connections to the sewerage systems with 1,094 connections to KHC houses rented to government employees, 957 private residential homes, 118 commercial premises and 133 industrial/institutional connections.

The water and sewer pump usages are considered in KIER as financial losses incurred by PUB's water and sewerage operations and not as non-technical losses. In addition, a South Tarawa Water and Sanitation Roadmap 2011–2030 (Fraser Thomas Partners, 2012), highlighted stringent measures to be adopted to improve the water and sanitation deliveries and accessibility by South Tarawa residents and, at the same time, improved electricity usages in these sectors.

9.5 Total electricity demand: "BAU" scenario

Using the "Business As Usual" (BAU) scenario, the four categories of electricity customers listed in the PUB billing system are provided in Table 39. This table shows a total electricity consumption of 19,766 MWh **in 2014** and notes that **residential buildings consumed the highest amount of electricity (41%), followed by government and industrial buildings (34%), commercial users (19%) and unbilled customers (6%).** The unbilled customers, as mentioned in section 7, included electricity use for PUB's own buildings, and electricity for water and sewerage pumps.

Total electricity demand for buildings (*i.e.* residential, commercial and government and industries) is expected

Table 39: Total electricity consumption (MWh) per customers

Energy Users	Number (2015)	2014 Electricity Consumption (MWh)	Percentage of total energy use
1. Residential / Domestic	6,995	8,099	41%
2. Government and Industrial	392	6,761	34%
3. Commercial	877	3,727	19%
4. Unbilled Customers (Water and Sewerage and PUB buildings)		1,179	6%
Total		**19,766**	**100%**

Source: PUB revised data, November 2015

to drop by 11.7% by 2025, according to BAU developed using INDCs methodology (linear interpolation of the last ten years).

Due to Kiribati's climatic environment (*e.g.* constant temperatures all year round), electricity demand generally remains stable. However, a combination of factors, including rising population and increasing economic activities, will lead to a growing number of residential, government and commercial buildings on South Tarawa and Betio. In addition, while electricity demand for buildings is increasing, electricity uses for other services (*e.g.* water and sewerage) will also show similar trends.

9.6 Total electricity demand with EE-DSM

Energy Efficiency Demand Side Management (EE-DSM) is one of the priority activities that Government of Kiribati will implement through its Ministry of Infrastructure and Sustainable Energy (MISE) to meet its energy efficiency target. This will, in turn, reduce Kiribati's dependence on imported primary energy sources for power generation. The EE-DSM activities, when fully implemented, project a total reduction in electricity demand for buildings and water and sewerage water pump uses of 4.05% by 2020, 12.84% by 2025 and 16.40% by 2030.

Table 40 and Figure 40 provide a summary of projected electricity savings. Further details on these EE- DSM activities, including investment costs, are provided in Sections 9.1 through 9.5.

The EE-DSM activities and targets were developed for South Tarawa during the consolidation of this report. There are still only limited data available for Kiritimati Island so a compilation cannot yet be completed. The targeted reduction in electricity demand was tabulated based on an SPC excel spreadsheet model analysis that will be made available online through the Pacific Regional Data Repository (PRDR) Portal.

Table 41 provides a summary of savings targeted for the four customer classes—residential, commercial, government and industrial and unbilled—by the years 2020, 2025 and 2030, respectively.

Table 40: Electricity demand projections in MWh with EE-DSM activities

	2020	2025	2030
Total Savings (MWh) from EE-DSM	**863**	**2,587**	**3,945**
Total Savings Residential	162	579	1,318
Total Savings Commercial	263	897	1,536
Total Savings Government/Industrial	63	756	756
Total Savings Unbilled, Water, Sewerage	376	355	336

Figure 40: Total electricity demand projections with EE-DSM, 2014–2030

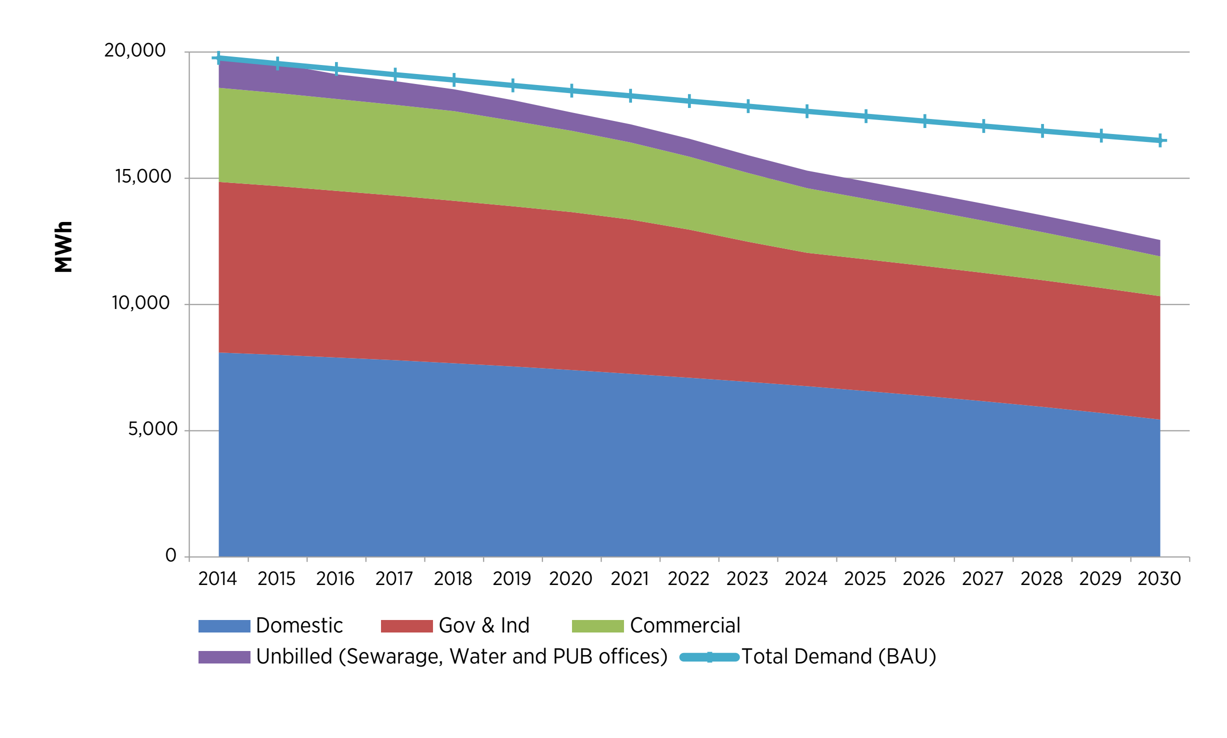


Table 41: Overall energy efficiency (EE) DSM target savings

Target Savings (%)	2020	2025	2030
DSM Total Savings	**3.89%**	**12.32%**	**19.88%**
1. Residential	**0.73%**	**2.76%**	**6.64%**
PALS (refrigerators)	0.15%	0.86%	2.50%
PALS (freezers)	0.16%	0.93%	2.71%
Lighting	0.42%	0.96%	1.43%
2. Commercial	**1.18%**	**4.27%**	**7.74%**
PALS (refrigeration)	0.62%	2.29%	4.16%
PALS (AC)	0.48%	1.78%	3.24%
Lighting	0.08%	0.19%	0.34%
3. Government & Industrial	**0.28%**	**3.60%**	**3.81%**
Cooling load improvements	0.25%	3.12%	3.30%
Lighting Improvements	0.01%	0.11%	0.12%
Office Equipment	0.03%	0.36%	0.38%
4. Unbilled	**1.69%**	**1.69%**	**1.69%**
Water and Sewerage	0.75%	0.75%	0.75%
PUB-owned building usage	0.94%	0.94%	0.94%

Figure 41 shows a reduction in electricity demand when implementing the EE-DSM activities expected to be delivered between 2014 and 2030. The overall savings of 12.32% by 2025 on electricity demand equate to a reduction on imported diesel by 0.78 million litres and an estimated AUD 0.99 million in savings in avoided generation costs.

Figure 42 provides a projection of total savings to be achieved for both the EE-SSM and EE-DSM by 2025. The savings on electricity demand to be achieved from EE-SSM is 9.68%, equivalent to 2,033 MWh while savings from EE-DSM would be 12.32%, equivalent to 2,587 MWh, representing a total reduction of 4,620 MWh (22%) to the 2025 "business as usual" demand.

Figure 41: BAU projections with EE-DSM and EE-SSM

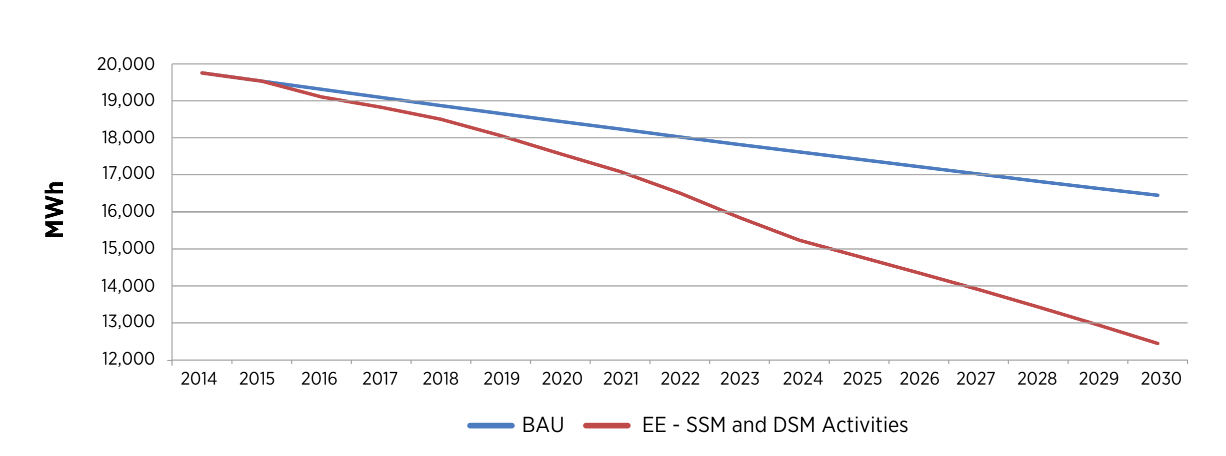


Figure 42: Electricity demand reduction, 2014 – 2025

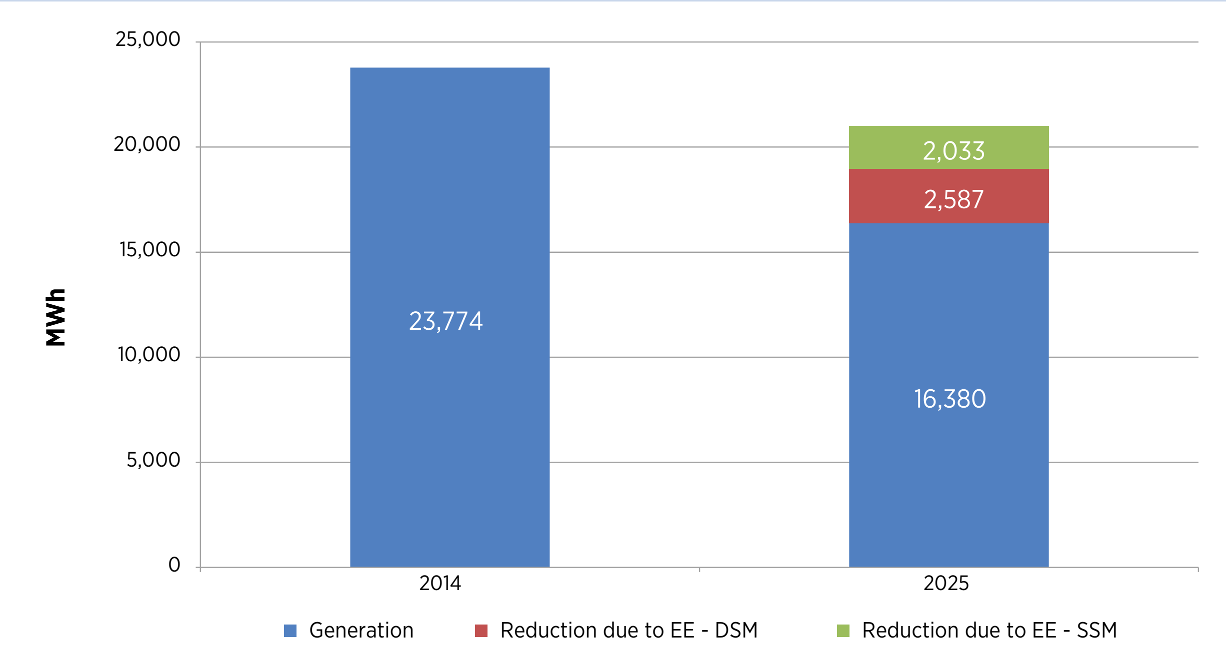
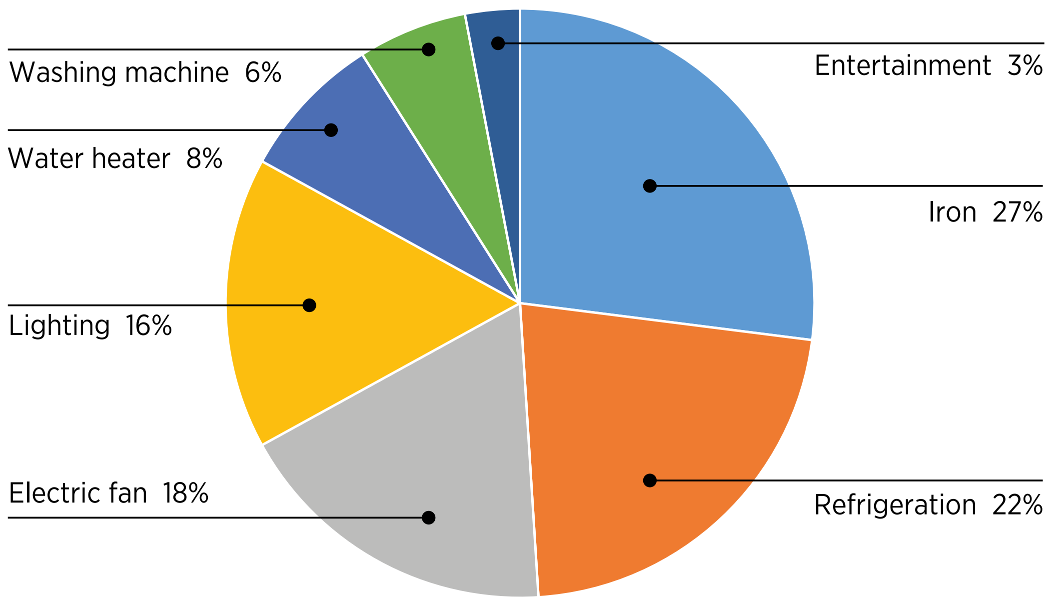


Figure 43: Electricity consumption by appliance type for households in South Tarawa



Source: (EPU, 2012a)

Electricity uses in residential buildings

Electricity consumption in typical residential buildings could be categorised into heating, cooking, lighting and other uses, as shown in

Figure 43. The electricity consumption analysis below was tabulated using household survey data and conducted by the Energy Planning Unit (EPU) in 2012. The use of cooling electric appliances, such as fridge and fans, consumes the highest amount of electricity (40%); second is heating (35%) that includes the use for iron and electric water kettles; then lighting use (16%); followed by other electricity uses (*e.g.* washing machines, entertainment, such as TV and laptops and mobile phone charging) that are widespread but account for only 9% of total electricity consumption (EPU, 2012a).

The electricity demand for residential buildings is projected to drop from 2014 demand by 11.7% in 2025 on a "business as usual" scenario. However, if EE-DSM activities are implemented from the year 2016 to 2030, the electricity consumption for residential buildings could be reduced by 0.73% in 2020, 2.76% in 2025 and 6.64% by 2030, with a total electricity savings of, respectively, 190 MWh by 2020, 641 MWh by 2025, and 1330 MWh in 2030. A summary of these projected savings is provided in Table 42.

Table 42: Projected electricity consumption and DSM targets in residential buildings

	2020	2025	2030
Residential Electricity Demand BAU (MWh)	7,569	7,154	6,762
Residential Demand with DSM (MWh)	7,407	6,575	5,444
Expected DSM Savings (MWh)	162	579	1,318
% savings towards overall EE target	0.73%	2.76%	6.64%

Strategic Direction

The activities to be implemented in residential buildings to meet the EE-DSM targets include:

- Lighting Improvement Programmes covering replacement of inefficient lights with efficient light bulbs such as compact fluorescent lamps (CFLs) and LEDS, awareness-raising for the general populace; and
- Electric Appliance Labelling and Standards Programme (PALS) covering awareness-raising, policy and adoption of a legislative framework to mandate the use of more efficient electric appliances (*e.g.* freezers and refrigerators) through minimum energy performance standards and energy rating labels.

The following section provides a detailed plan of the activities for the two programmes listed above, including projected financial savings and upfront capital investment required.

Lighting improvement programme in residential buildings

Activity 1. Replacement of 60 watt incandescent lights with an 11 watt CFLs in 1,408 (40%) residential buildings in South Tarawa and Betio by 2025. The 40% number of buildings targeted is considered low as the incandescent bulbs are rare due to changes in the lighting market as it is expected that there has been an increased uptake of CFLs. However, this activity will save an estimated 99.3 MWh on electricity demand by 2025. This activity will be accompanied by a vigorous awareness campaign on energy conservation in the residential sector.

Activity 2. Replacement of four foot linear fluorescent lights (LFLs) with LED lights in 2,815 (40%) residential buildings. There is no report on the exact number of lights in residential buildings for South Tarawa and Betio; however, it is assumed that each residential building has at least two of the four foot LFLs. This activity will save 64.2 MWh on electricity demand by 2025.

Activity 3. Replacement of one two foot LFL with LED lights in 2,815 (40%) residential building by 2025. This activity will save an estimated 38.6 MWh if all 2,815 LFLs are switched to LED lights.

These LED lights are not readily available on the local market and, therefore, the government should consider policy, legislative and fiscal frameworks that would encourage private sectors participation supporting importation and use of LED lights. The affordability and the capital costs required to purchase LED fluorescent lights will be a barrier; therefore, fiscal incentives (*e.g.* subsidies, such as reduced import duties or VAT on these items) should be recommended to policy makers based on the benefits that Kiribati will achieve when implementing these lighting improvement programmes in residential buildings.

A summary on the financial savings, including investments required to implement the lighting improvement programme in residential buildings, is provided in Table 43. A total investment of AUD 126,693 is needed with a financial savings on the avoided generation costs[13] and the savings on electricity bills[14] of AUD 80,864 and AUD 77,151 respectively.

Electric appliance labelling and standards programme

Kiribati participates in the Pacific Appliance Labelling and Standards (PALS) project implemented regionally by the Pacific Community (SPC, formerly called the "*South* Pacific Community"). The project aims to introduce a relevant law or regulation on the mandatory adoption and use of both an energy labels system that allows buyers to compare the energy efficiency products and minimum energy performance standards on selected electric appliances (*e.g.* freezers, refrigerators, lights and air conditioners). It is anticipated that the impact of the PALS programme will be realised after the legislation is comprehensively enforced (Lomaloma, 2014). The PALS programme collaborates with the Energy Planning Unit, the Ministry of Commerce, Industries and Cooperatives and other stakeholders on the review of the Consumer Act and development of regulations that would mandate compliance with the Australian / New Zealand appliance performance standards and energy labelling requirements.

The PALS programme's estimated savings on the use of efficient refrigerators and freezers is 376.7 MWh by 2025. Table 44 presents the projected savings on electricity, the estimated investment required to implement the PALS programme in Kiribati and the

13 The cost of diesel for power generation of 79,395 litres at a cost of AUD 1.27.

14 Estimates are based on the electricity savings of 263,860 kWh with a residential tariff rate of 0.40 cents per unit (kWh).

Table 43: Lighting improvements programme savings

Activity	Typical ratings (watt)	EE improved ratings (watt)	No. of appliance replaced by 2025	Electricity savings achieved by 2025 (MWh)	Electricity Bill saved by 2025 (AUD)	Savings on generation cost in 2025 (AUD)	Estimate. Invest-ment[14] (AUD)
1. CFL promotion	60	11	1,408	99	39,731	37,906.85	21,116
2. Replacement of 4 ft Linear fluorescent lights (LFL) with LED	45	20	2,815	64	25,708	24,527.84	70,385
3. Replacement of a 2 ft LFL to LED	25	10	2,815	39	15,425	14,716.71	35,193
TOTAL (AUD)					80,864	77,151	126,693

Table 44: Electricity savings on replacing inefficient refrigerators and freezers by 2025

Activity	Savings achieved from Standards and Labelling programme (MWh)	Savings on electricity bill costs (AUD)	Savings on generation costs (AUD)	Investment cost (AUD)
1. Repalcement of inefficient refrigerators	181	72,398	69,074	929,863[15]
2. Replacement of inefficient freezers	195.7	78,265	74,671	
Total	**376.7**	**150,664**	**143,746**	**929,863**

Source: SPC, 2011

total financial savings on avoided generation cost and electricity bill savings.

Energy end use: Government and industrial buildings

The phrase "government and industrial buildings" includes government departments and offices, including the two main hospitals on South Tarawa and Betio, health centres, as well as government boarding school buildings (*i.e.* dormitories and classrooms) that are connected to the electricity grid.

A typical consumption pattern for government buildings is depicted in Figure 44. The highest use of electricity in government offices is for air conditioning units, (46%), followed by computers (18%), water dispensers (8%), lighting (8%), followed by fans (6%) and other small appliances.

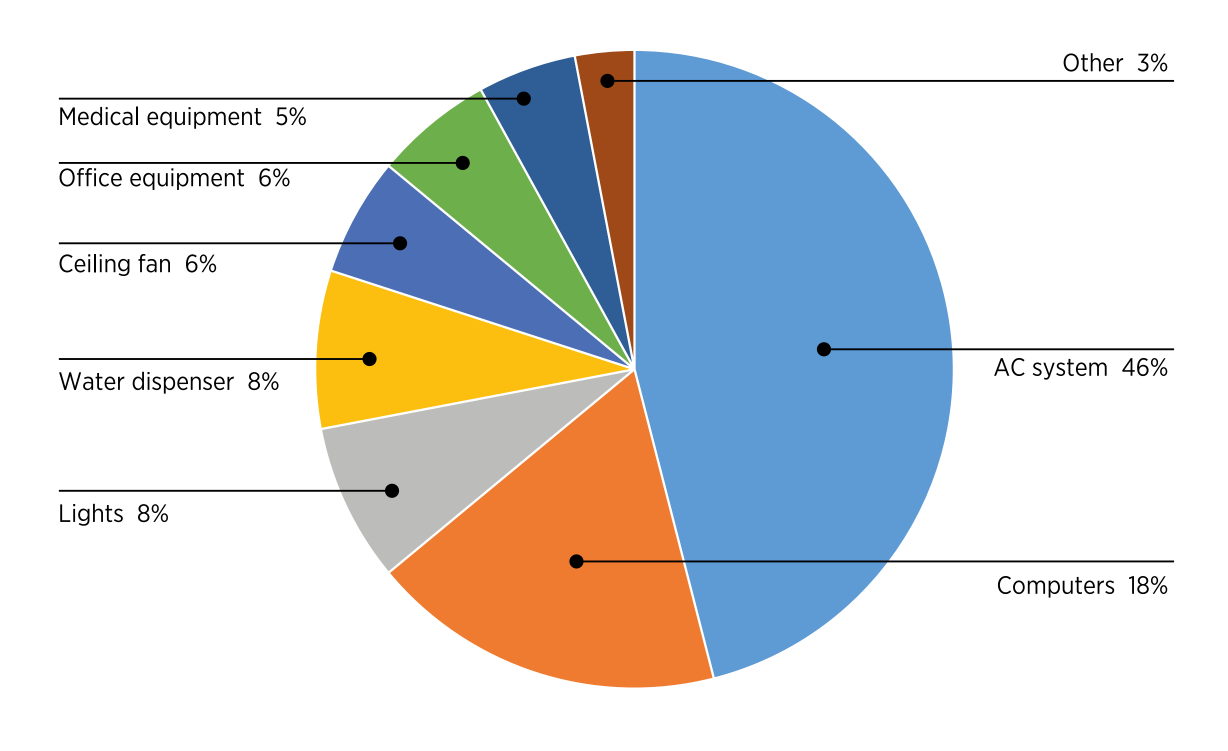
In 2014 electricity consumption for government and industrial buildings was 6,761 MWh, but a 3.6% drop to 5,972 is projected by 2025 when EE-DSM activities are implemented.

Table 45 also provides estimated percentage savings in 2020, 2025 and 2030 through implementation of EE-DSM activities. These savings are to be achieved by implementing the recommendations of the Energy Audit Report conducted in 2012 for eight government ministries (EPU, 2012b). EE-DSM activities will be implemented in the remaining thirteen ministries starting in 2016-2017 and completed by 2028.

15 Based on Fiji costs including 20% mark-up and taxed.

16 For Kiribati's PALS project, the total cost is AUD 929,863 for both commercial and residential PALS activities, including management, policy and coordination, certification and registration, training and promotion, compliance and check testing.

Figure 44: Government buildings energy use consumption, 2012



Source: (EPU, 2012b)

Strategic directions and investments

Implementing EE-DSM programmes in government and industrial buildings is mainly being undertaken for economic reasons. The Government of Kiribati's budget for the year 2015 allocated AUD 2,509 million for electricity and fuel costs for vehicles, a 17% increase over 2014 allocations. Thus, electricity and gas comprise one of the highest expenditures. Therefore, it is considered urgent to reduce this amount in the future since savings on electricity can be used for other useful, more productive sectors. In addition, one of the reasons that electricity allocation is so high in annual budget is that government ministries and industrial buildings are charged the industrial rate of 0.70 cents per unit, the highest tariff. It might be preferable to charge these government institutions and state owned enterprises a *reduced* tariff as some of these consumers are the largest PUB debtors for outstanding electricity bills.

However, the EE-DSM recommended implementation of activities that would contribute to meeting its target

Table 45: Projected government and industrial electricity consumption and EE-DSM savings

Government and Industrial	Base year 2014 (MWh)	2020 (MWh)	2025 (MWh)	2030 MWh)
Government and Industrial Electricity Demand (BAU)	6,761	6,319	5,972	5,645
Electricity Demand including EE DSM savings (MWh)		6,255	5,216	4,889
EE DSM Savings (MWh)		63	756	756
% savings towards overall EE target		0.28%	3.60%	3.81%

and realise tangible improvements in the following areas:

Activity 1. Cooling Load: Alternating current Systems Monitoring and Retrofit, replacement of selected alternating current units with electric fans and renovation of buildings to accommodate more natural ventilation and lighting.

Activity 2. Lighting in government office rooms and industries/state-owned companies and industries.

Activity 3. Office equipment (*e.g.* computers, photocopiers) electricity uses and energy conservation.

There are 21 ministries in the current government portfolio, of which eight have been audited with respect to their overall electricity consumption. The remaining 13 ministries will undergo energy audits as part the EE-DSM activities for Government Ministries. Table 46 provides recommendations on EE-DSM measures, showing that alternating current replacement will contribute more to the potential percentage savings; however, investment costs are higher compared to other activities.

The Government of Kiribati's 2016 budget allocation for maintenance work on government buildings amounts to AUD 500,000. It is recommended that each ministry allocation provide initial funding required to implement

Table 46: EE-DSM activities with estimated investment in government and industrial buildings

Activities	Key elements	Estimate Investment (AUD)	Potential percentage of savings
Activity 1: Cooling Loads Improvements – Air conditioner replacement	» Replacement of ten old air conditioning units with the more energy efficient types available on the market for offices and conference rooms	225,000	20%
	» Installation of timer switches for new AC units already installed in buildings.		
	» Retrofitting cost to improve insulation in air conditioned rooms (reflectors, door springs, double walls, fixing doors and windows) as well as improving ventilation in Open rooms with fans Fixing doors and windows, Installing mosquito netting.	472,500	
	» Replacement of air conditioning units with industrial type fans in open rooms.	90,000	
	» Target of 20 electrical fans per ministry		
Activity 2: Lighting improvements in government offices	» Replacement of at least 2,250 tube lights to more efficient LED type lights.	112,500	4%
	» Target of 150 tube light per ministry		
Activity 3: Improvements in office equipment electricity use	» Targeting Staff behaviour patterns through conservation activities – Setting of office equipment on sleep mode or switched off when not in use.	Free	5%
	» Establishing an energy efficient vetting team to advise the procurement office from government on the selection of energy efficient appliances.		
	Total Investment	**900,000**	

Source: (EPU, 2012b)

Table 47: Costs and benefits savings on proposed EE-DSM by 2025

Activities	Electricity saved (MWh) by 2025	Savings on Electricity Bills (AUD)	Savings on generation costs (AUD)
1. Air conditioner replacement	656	459,036	250,263
2. Lighting improvement	23	16,444	8,966
3. Improvements in office equipment electricity uses	76	53,432	29,131
Total	**679**	**475,482**	**259,229**

the recommended activities. The Government's savings on electricity, given full implementation of all recommended EE-DSM measures, is estimated at AUD 475,482 by 2025 (see Table 47).

Electricity use in commercial buildings

Commercial buildings in South Tarawa include the banks (*i.e.* ANZ Bank, Development Bank and Provident Fund Building), hotels, Super Mall (newly built mall), supermarkets, shops and small canteens connected to the PUB electricity grid and located within the commercial zones.

There are no data available on electricity consumption in commercial buildings. Therefore, **one of the recommendations of this report is to conduct an energy audit for all commercial buildings in Kiribati.**

The total electricity consumption growth rate for the commercial buildings based on 2009 to 2014 historical data showed a 10% increase; thus, an average annual growth rate of 2%. However, proper analysis of this trend can be correctly done only if other information is made available, such as the number of commercial set-ups and registered business, as well as the number of electrical appliances imported and used in this sector. However, similar to residential electricity demand, an **11.7% drop in electricity demand is projected for commercial buildings from 2014 to 2025.**

For the commercial sector, a reduction in projected energy demand can be achieved through EE–DSM activities with a percentage saving of 1.12% by 2020, 4.04% by 2025 and 7.32% by 2030. The reduced demand would be equivalent to 263 MWh by 2020, 897 MWh by 2025 and 1,536 MWh by 2030 as shown in Table 48.

Strategic direction and investments

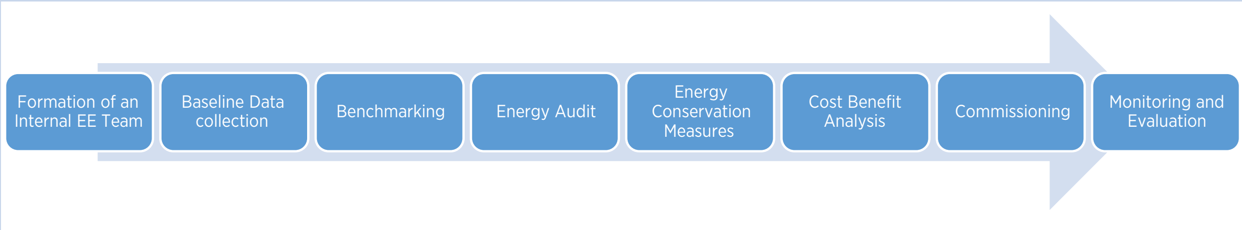
A proper walk-through energy audit is required to collect baseline information on energy consumption in commercial buildings. Putting in place energy efficiency measures in commercial buildings should be included in the building permits approval process currently sighted by the Joinery and Construction Division of the MISE, the PUB and other stakeholders. The need to establish mandates and compliance with building codes and standards (*i.e.* including energy efficiency compliance in commercial buildings) should be a priority, along with capacity building in energy auditing.

Owners of commercial buildings should also take the initiative to monitor the energy consumption and invest in measurement devices, such as strip charts and data loggers on major loads (in particular ACs)

Table 48: Commercial buildings' electricity demand with EE-DSM savings in 2020, 2025 and 2030

Sector	2020	2025	2030
Commercial Electricity Demand Projection (BAU) (MWh)	3,483	3,292	3,112
Electricity Demand Projection with EE-DSM (MWh)	3,220	2,395	1,575
EE-DSM projected reduction (MWh)	263	897	1,536
Projected % savings towards overall EE target	1.12%	4.04%	7.32%

Figure 45: Energy management and improvement process



Source: (IIEC, 2015)

Table 49: Lighting improvement activities and savings in the commercial sector

Activity	Typical ratings (in watts)	EE improved ratings	Number of appliances to be replaced	Savings to be achieved by 2025 (MWh)	Savings on electricity bills (AUD) to be achieved by 2025	Savings on generation costs (AUD)	Estimated Investment[16]
Replacement of 3 x 4 ft LFLs with LED lights	45	20	695	25	13,961	9,687	50,037
Replacemen of 3 x 2 LFLs with LED lights	25	10	782	15	8,377	5,812	22,239
Total (AUD)					**22,338**	**15,500**	**72,276**

to obtain the data over a period of time required for an energy assessment. Before committing to building improvements, it is important to determine if the process/efforts will result in measurable benefits for the organisation or company. The energy management and improvements to existing commercial and public buildings will require executing the steps shown in Figure 45.

KIER recommends that the following activities be implemented for commercial buildings in order to assist in meeting EE-DSM targets and obtaining the investment required:

A. Lighting improvement programme

The market for LED lights is not saturated as yet and there may be some reservations for commercial customers to change from conventional lights to LED lights all at one time. Therefore, awareness raising on the benefits, both financial and environmental, is required prior to implementing these changes. Table 49 provides a summary of savings through the lighting improvement programme for commercial buildings, as well as financial benefits: cumulative savings of AUD 23,338 from electricity bills as compared to BAU the total investment amount of AUD 72,276.[17]

B. Pacific Appliance Labelling Standards (PALS)

The PALS project will also reduce the energy demand for commercial buildings since alternating current units and refrigerators are commonly used in hotels and commercial buildings. It is anticipated that a proper building assessments will be carried out to determine energy wastages from improper sealing of windows and doors. Evenso, the following estimated savings given in Table 50 when replacing inefficient ACs and refrigerators/freezers with more efficient appliances.

17 Based on Fiji costs including 20% mark-up and applicable taxes.

Table 50: Electricity savings projections through replacement of inefficient ACs and refrigerators

Activity	Savings on electricity by 2025 (MWh)	Savings on electricity bill costs (AUD)	Savings on generation costs (AUD)	Investment costs (AUD)
Replacement of inefficient ACs	375	206,103	143,010	929,863
Replacement of inefficient refrigerators	482	264,989	183,871	
Total savings	**857**	**471,092**	**326,881**	**929,863**

Electricity used in PUB offices and buildings

Due to the unavailability of data during the consultation, the share of unbilled uses for the base year 2014 has been extrapolated from the 2012 PPA report *"Quantification of the Power System Energy Losses in South Pacific Utilities*". An increase in demand for PUB's own uses is projected in the KURSP report and is also used in this report.

Strategic direction and investments

Activity 1. Energy audit of PUB offices and adjacent buildings

Electricity uses in water and sewerage uses

The electricity uses for water and sewerage pumps is projected to drop between 2014, the baseline year for this sector, and 2025 and 2030. It is assumed that ongoing projects in this sector are to be implemented from 2017 to 2018; therefore, measurable impacts (*e.g.* improvements in performance of pumps) will be realised by 2020. Although the overall percentage of savings towards the EE targets is less than 1%, this will nevertheless contribute to the overall projected increase in the electricity consumption for this sector. The KRUSP report, providing recommendations on the rehabilitation of water and sewerage services and investments required, is included as part of this Roadmap.

Table 52 and Figure 46 illustrate the impact of EE DSM versus the BAU water and sewerage demand.

Strategic direction and investments

The strategic direction recommended to meet the EE target for this sector includes the following activities:

Activity 1. Assess water pump performance, as well as the servicing and maintenance of water pumps and capacity factor corrections in motors, including replacement of inefficient motors and oversized pumps due to leakages to pump sewerage and losses.

Activity 2. Reduce water distribution losses by repairing water pipe leakages and installation of pre-payment meters and tariff rates; and

Table 51: PUB electricity demand projection (BAU and EE-DSM) from 2014 to 2030

PUB Use	2014 (MWh)	2020 (MWh)	2025 (MWh)	2030 (MWh)
PUB use demand (BAU)	485	454	429	405
Electricity demand, including EE-DSM savings (MWh)		244	231	218
EE-DSM savings (MWh)		209	198	187
% savings towards overall EE target	0.00%	0.94%	0.94%	0.94%

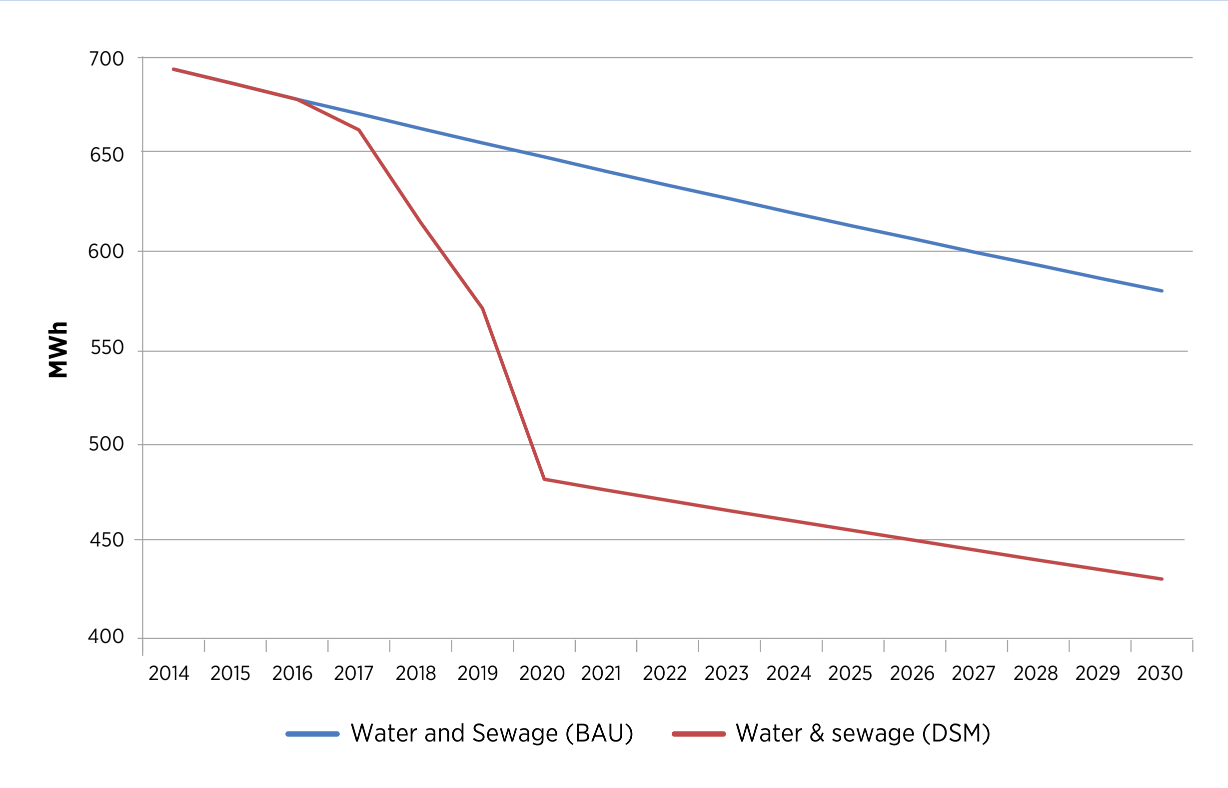
Source: SPC data, 2016

Table 52: Electricity projected demand for water and sewerage on EE-DSM

Water and Sewerage	2020 (MWh)	2025 (MWh)	2030 (MWh)
Water and sewerage demand (BAU)	649	613	579
Electricity demand, including EE DSM savings (MWh)	482	456	431
EE DSM savings (MWh)	167	157	149
% savings towards overall EE targets	0.75%	0.75%	0.75%

Source: SPC data, 2016

Figure 46: Projection electricity consumption for unbilled customers



Activity 3. Introduce a sanitation project to repair leakages and improve sewerage infrastructure, including metering and tariff rates.

The investments required to improve the distribution network and ongoing rehabilitation on the sewerage system are provided in Table 53.

Table 53: Investments in energy efficient for unbilled uses

Activities	Estimate Investment (AUD)	Benefits
1. Energy audit of PUB-owned buildings - Energy audit, meters of all buildings and street lights that may be covered under "unbilled"	5,000	Revenue received for unbilled usages
2. Servicing and maintenance of water pumps and capacity factor corrections in the motors	216,000	Reduce losses by at least half (50% by 25%)
3. Reducing water distribution losses through repair of water pipe leakages and installation of pre-payment meters and tariff rates	5,500,000	Doubling of volume delivered; an improving benefit of increased supply from other investments
4. Current sanitation project to repair the leakages and improve sewerage infrastructure, including metering and tariff rates – Betio network rehabilitation	2,500,000	Reduce sewerage pump uses
Total	7,921,000	

Source: KUSRP Summary Presentation, October 2015

9.7 EE-DSM financing plan

Description of investment	Estimated cost (AUD)	Secured funding: identified under existing programmes (AUD)	Unsecured funding (AUD)	Possible donors for unsecured funds
Strategy 1: Electricity savings in residential buildings (lighting improvement and PALS)	591,625	23,628[17] (SPC-PALS)	567,997	Financing institutions, private sector
Strategy 2: Electricity savings in government and industrial buildings	900,000	500,000[18] (GoK)	400,000	NZMFAT, ROC
Strategy 3: Electricity savings in commercial buildings (lighting and PALS)	537,208	23,628 (SPC-PALS)	513,580	NZMFAT, ROC, Private sector
Strategy 4: Electricity Savings in PUB buildings (water and sewerage pump uses)[19]	7,921,000	2,500,000 (STSISP)	5,422,000	Government of Kiribati (loans to SOE), private investors PUB
Total Investment	**9,949,833**	**3,045,256**	**6,902,577**	

18 AUD 47,256: SPC contribution to PALS in Kiribati for the review and adoption of legislation on energy-rated labels for AC, freezers and refrigerators. 50% of the cost will contribute to the use of efficient appliances in the residential buildings and 50% in the commercial buildings

19 Government Of Kiribati's annual budget for maintenance work is AUD 500,000 per annum; KIER estimates that 10% of this amount over the ten coming years could be set aside to support DSM activities in the governmental sector.

20 Electricity use for PUB-owned buildings is very small (0.94% share of PUB buildings) and therefore no capital investment would be required.

10 ENERGY EFFICIENCY AND SUSTAINABLE COOKING

A "Kiribati Cooking for Life" (KCFL) Strategy developed by SPC in collaboration with the EPU has been revised and updated in this Roadmap. Figure 47 provides information on South Tarawa's energy used for cooking.

The KCFL strategy promotes the use of liquefied petroleum gas (LPG), which is considered an efficient and modern form of cooking fuel compared to kerosene and bioenergy. It also identifies targets to promote the use of improved cooking-stoves to reduce energy wastage in open-fire cooking. This will help reduce the amount of firewood/bioenergy use that could also contribute to reducing greenhouse gas emissions.

The targets to improve the uses of LPG and improved cooking-stoves respectively;

- 75% of households in urban centres have access to modern sources of energy for cooking by 2025; and
- 100% of households use improved cooking-stoves for cooking by 2025.

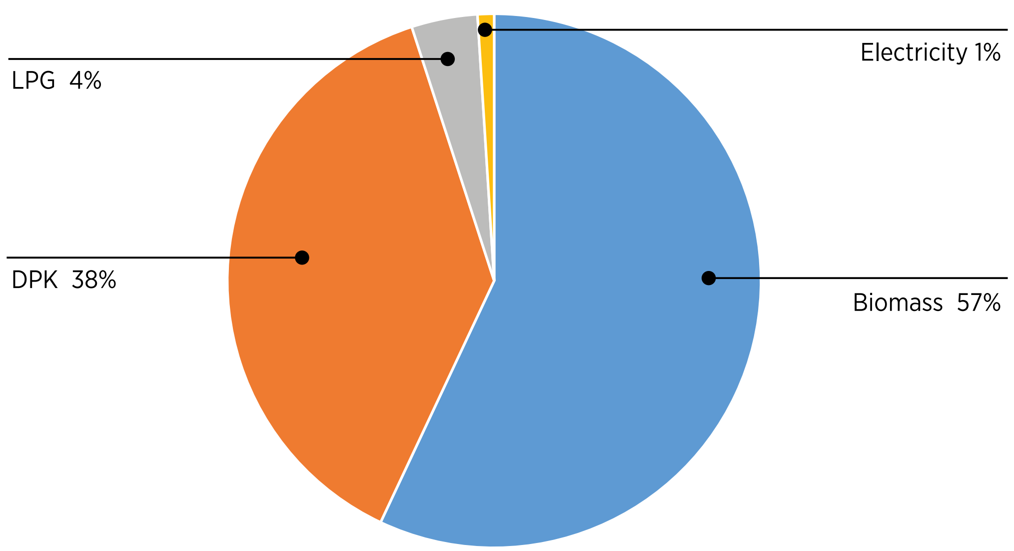
Strategic direction and investments

Provides and supports LPG affordability

One of the barriers to LPG uptake in Kiribati is its high cost, which is perceived to be more expensive compared to kerosene. Kerosene prices have been subsidised for a long time while LPG were not. The conversion programme (*i.e.* from kerosene use to LPG) will yield immense savings at all levels (SPC, 2014c).

- **At the household level,** as a result of the cheaper and cleaner LPG cooking fuel, households will benefit from energy cost savings. Based on the cooking fuel daily and monthly consumption levels, an estimated monthly energy savings of AUD 18.00 will result from the switch from kerosene to LPG. These have been calculated and documented in the report entitled "An economic analysis of kerosene subsidy policy reform". Based on this report, households should save almost AUD 219/year in running costs, which is

Figure 47: Estimated breakdown of energy use for cooking Kiribati 2012



Source: (EPU, 2014)

about 22% of their current cost of using kerosene (or running a kerosene stove).

- **Within the business environment** the switch to LPG, due to the effective implementation of the subsidy programme, will generate higher demand for LPG stoves, cylinders and other LPG accessories. All of these will encourage the entry of new investors and, thus, the creation of new jobs. **The conversion programme will also lead to the use of a cleaner, cheaper, more efficient and more environmentally-friendly fuel. This is in addition to the health benefits that will result from the use of LPG instead of kerosene.**
- **The Kiribati Government will accrue the largest benefits from the subsidy programme.** These benefits would primarily come from subsidy savings as a result of the elimination of price controls and the implicit subsidy (which includes the various duty/levy exemptions). The government stands to gain gross subsidy savings of close to AUD 1 million (SPC, 2014c).

Provides and supports LPG availability

Availability of liquefied petroleum gas (LPG) has been one of the main challenges to increasing its usage in past years. This is due to the limited number of retailers selling LPG. However, a gas cylinder smaller than the normal 13 kg vessel is preferable as it is more portable and affordable. A nine kg cylinder is now widely available on South Tarawa from the Kiribati Oil Company (KOIL). However, bringing in more of the smaller cylinders (*e.g.* the four kg version that is available in other countries) will support the accessibility of LPG for most households.

Increased access to improved bioenergy cooking stoves

Bioenergy fuel use through open-fire cooking is still very common in many households in South Tarawa, mainly among low income earners, and commonly used for prolonged cooking such as boiling water and pigs' food. As part of the KCFL strategy, use of an improved cook-stove stove has been promoted in South Tarawa. The first demonstration was for the "Ezy Stove", which was considered too small and firewood chamber too small for long cooking. A second demonstration was on the "Silver Fire Rocket Stove", which proved more appropriate considering its efficiency and size compared to the "EZY stove". This "rocket stove" is currently in use in the Federated States of Micronesia and considered more efficient than the EZY stove. SPC is providing assistance to Kiribati through partnerships with NGOs in the procurement of these stoves, including LPG stoves to increase access to modern forms of cooking.

10.1 Efficient cooking financing plan

Table 54 defines the costs associated with implementation of the identified goals for efficiency in the cooking sector.

Table 54: Financial plan for energy efficiency in Kiribati's cooking sector

Description of investment	Estimated Cost (AUD)	Secured: identified under existing programmes (AUD)	Unsecured (AUD)	Possible Donors for unsecured funds
Strategy 1: Provides and supports the affordability of LPG	13,000	2,500 (NGO)	10,500	Government of Kiribati, KOIL, private sector, donors
Strategy 2: Provides and supports LPG (stove and fuel) availability	316,165	5,230 (SPC-SEPP)	310,935	KOIL, private sector
Strategy 3: Develops capacities related to LPG use, safety and health	7,500	2,000 (KOIL)	7,500	Private sector, Government of Kiribati
Strategy 4: Increases access to improved bioenergy cooking stoves	23,675	8,266 (SPC-SEPP)	15,409	NGO, private sector, donors
Total Investment	**360,340**	**17,996**	**344,344**	

11 DESALINATION IN KIRIBATI

In support of KIER, the Fraunhofer Institute for Solar Energy Systems conducted an analysis of desalination options for Kiribati (Koschikowski, J. et al. 2015). A specific focus was placed on determining the viability of renewable energy to power the desalination process. The study examined deployment of a variety of desalination technologies in the main population centres of South Tarawa and Kiritimati Island. The island of Nonouti was also included in the analysis to examine the replicability of desalination on outer islands with higher populations. The results of this study have been used to develop recommendations for desalination options in Kiribati, which are summarised in Section 2.7 and detailed here in Section 11.

11.1 Renewable desalination options for Kiribati

Based on the island characteristics in the outline in Table 55, the following two desalination technologies were analysed to determine their suitability for use on South Tarawa, Kiritimati and Nonouti.

- Multi-Effect Distillation (MED) in combination with Concentrating Solar Power (CSP), flat plate collectors (FPC) or evacuated tube collectors (ETC);
- Reverse Osmosis (RO) in combination with either Photovoltaics (PV) or wind energy.

Table 55: Key island characteristics for analysis of desalination technology suitability

Location	Population	Freshwater demand (m^3/d)	Solar irradiation (kWh/m^2/day)	Wind speed (m/s)	Availability of		
					Land	Operation and maintenance capacity	Grid back-up
South Tarawa	50,000	2,112	6.01	4.5	Scarce	Yes	Yes
Kiritimati	5,500	280–310	6.63	7.1	Good	Training needed	Mini-grids (50–400 kW)
Nonouti	2,500	110–140	6.18	4.4	Good	Training needed	No

The results of an assessment of each desalination technology's capabilities, levelised cost of water (LCOW) and suitability for each island's characteristics are given in Table 56. The technologies with the best suitability are shown in green, the least suitable in red and those in between in yellow.

Table 56: Assessment of renewable desalination technologies for Kiribati

	PV-RO	Wind-RO	MED-FPC/ETC	MED-CSP
South Tarawa: Pros	» Scale fits demand » Low LCOW » Components available in the Australasian region » Mature technology » RO and PV are locally known technologies	» Scale fits water demand » Low LCOW » Components available in the Australasian region » Mature technology » RO is a locally known technology	» Scale fits water demand » 24 hour operation possible with heat storage for reasonable costs	» 24 hour operation possible with heat storage for reasonable costs » providing water and electricity
South Tarawa: Cons	» Poor performance of previously installed RO plants » Requirement of skilled workers for O&M	» Low wind speeds » Poor performance of previously installed RO plants » Requirement of skilled workers for O&M	» Higher investment costs than PV-RO » Energetically not able to compete with PV-RO » Technology has only been deployed at pilot scale	» Scarcity of land: Potential land use conflicts » Insufficient capacity of the grid to absorb further solar energy input » Economical limitations for downscaling » Technology has only been deployed at pilot scale
Kiritimati: Pros	» Scale fits demand » Low LCOW » Components available in the Australasian region » Mature technology » PV is a locally known technology	» Scale fits demand » Low LCOW » Components available in the Australasian region » Mature technology » High wind speeds	» 24 hour operation possible with heat storage for reasonable costs	» 24 hour operation possible with heat storage for reasonable costs » providing water and electricity
Kiritimati: Cons	» Lack of skilled workers for O&M	» Lack of skilled workers for O&M	» Scale does not fit water demand » More expensive than PV-RO » Energetically not able to compete with PV-RO » Technology has only been deployed at pilot scale	» Scale does not fit water demand » Insufficient capacity of the grid to absorb further solar energy input » Economical limitations for downscaling » Technology has only been deployed at pilot scale

	PV-RO	Wind-RO	MED-FPC/ETC	MED-CSP
Nonouti: Pros	» Scale fits demand » Low LCOW » Components available in the Australasian region » Mature technology » PV is a locally known technology	» Scale fits demand » low LCOW » Components available in the Australasian region » Mature technology	» 24 hour operation possible with heat storage for reasonable costs	» 24 hour operation possible with heat storage for reasonable costs » providing water and electricity
Nonouti: Cons	» Lack of skilled workers for O&M	» Potential land use conflicts » Low wind speeds » Lack of skilled workers for O&M	» Scale does not fit water demand » More expensive than PV-RO » Energetically not able to compete with PV-RO » Technology has only been deployed at pilot scale	» Scale does not fit water demand » Scarcity of land: Potential land use conflicts » Economical limitations for downscaling » Technology has only been deployed at pilot scale

11.2 Desalination in South Tarawa

Based on the above analysis, it was determined that **PV-powered RO desalination is the best technology combination for South Tarawa.** In order to estimate the demand for desalination, an analysis was conducted to determine the gap between water demand and supply for 2015 and 2025. The results are shown in Table 57 for 2015 and Table 58 for 2025.

Key assumptions for this analysis include an estimate of 50 litres per day per capita of water demand and a sustainable water extraction rate for 2015 of 2,160,000 litres per day from the Bonriki freshwater lens and 350,000 litres per day from the Buota water reserve.

For 2025, total sustainable water extraction rates are estimated to be reduced by 13% as a result of climate change. The water distribution losses of 25 %for 2015 and 20 % for 2020 are taken from the *South Tarawa Water and Sanitation Roadmap 2011 – 2030* and reflect future goals for reducing water losses, not the current status.

It is important to note that consultations with PUB indicate that current distribution losses are still above 60%, as per 2011 data, from the water Roadmap report. It is essential that these water losses be reduced to acceptable industry standards prior to deployment of any desalinations systems. Based on a detailed 2012 desalination feasibility study by Fraser Thomas Partners, a per-plant desalination capacity of 528,000 litres per day was assumed.

Table 57 clearly shows the impact of current water distribution losses, with the total estimated to be 1.8 million litres per day. Investing in desalination before addressing these water loss issues does not make financial sense as it would require a larger number of plants whose water output would mostly be wasted. If the *South Tarawa Water and Sanitation Roadmap* goal of reducing losses to 25% is achieved, it would mean that the same reduction in the gap between demand and supply could be achieved with only two desalination plants versus four plants if no steps were taken to limit losses. Table 57 also shows that if larger water distribution losses were combined with increased rain water harvesting, **just *two* desalination plants would be sufficient to cover the entire gap between fresh water supply and total water demand.**

Table 58 shows the analysis for 2025 and indicates that a total of **six systems would be needed to meet demand in 2025.**

Table 57: Analysis of 2015 water demand and supply with desalination options

		2015: current losses	2015: water roadmap	2015: improved distribution and rain collection
water demand	Population	60,936		
	Estimated water demand per capita (litres/day)	50		
	Total net water demand (litres/day)	3,046,800		
	Water distribution losses (%)	60%	**25%**	**20%**
	Water distribution losses (litres/day)	1,828,080	761,700	609,360
	Total gross water demand (litres/day)	4,874,880	3,808,500	3,656,160
fresh water supply	Sustainable yield from ground water (litres/day)	2,510,000		
	Households with rain water tanks (%)	10%	10%	**25%**
	Rain water supply per household (litres/day)	5		
	Total rain water supply (litres/day)	30,468	30,468	76,170
	Gross fresh water supply gap (litres/day)	2,316,131	1,260,415	1,054,756
Desalination supply	Gross RO system production (litres/day/system)	528,000		
	Number of systems to fully cover supply gap	4.39	2.39	2.00
	Number of systems recommended	**4**	**2**	**2**
Total gross water supply **gap** or *surplus* (litres/day)		**-204,131**	**-204,415**	*+1,244*
Total net water supply **gap** or *surplus* (litres/day)		**-81,652**	**-153,311**	*+995*

However, Table 58 also makes clear that the investment in desalination can be significantly reduced through the lower cost options of reducing water distribution losses and increasing rain water collection. For example, **decreasing water distribution losses to 15% while increasing rain water collection to include 65% of households by 2025 would eliminate the need for an entire desalination plant while still leaving surplus water supply.**

Finally, it should be noted that the desalination plant capacity of 528,000 litres/day needs to be further analysed. For example, although a smaller capacity for each plant might increase the per plant cost, it could reduce overall system costs by allowing the total desalination capacity to be more accurately matched to the gap in fresh water supply. A more in-depth analysis of the interaction between PV systems and desalination plants is also warranted to ensure a system that meets the water demands of South Tarawa in the most cost-effective manner.

Analysis of South Tarawa desalination options

Due to the low wind energy potential on South Tarawa, only photovoltaic-reverse osmosis (PV-RO) systems were economically analysed in the desalination study. This analysis examined several options for PV-RO operations, including a grid-connected system and off-grid systems with back-up from batteries or diesel. The analysis also compares PV-RO systems to diesel-powered, grid-connected and off-grid systems to determine the cost competitiveness of renewable energy-based desalination. This analysis is based on the assumed desalination plant fresh water production capacity of 528 m^3/day as defined the previous section of this report.

The desalination study first determined the required capacity of each system component necessary to support the fresh water production capacity of 528 m^3/day. Based on these capacities, the individual and total capital costs for each of the desalination configurations

Table 58: Analysis of 2025 water demand and supply with desalination options

		2025: water roadmap	2025: improved distribution and rain collection
water demand	Population	89,131	
	Estimated water demand per capita (litres/day)	50	
	Total net water demand (litres/day)	4,456,550	
	Water distribution losses (%)	20%	15%
	Water distribution losses (litres/day)	891,310	668,483
	Total gross water demand (litres/day)	5,347,860	5,125,033
fresh water supply	Sustainable yield from ground water (litres/day)	2,177,000	
	Households with rain water tanks (%)	10%	65%
	Rain water supply per household (litres/day)	5	
	Total rain water supply (litres/day)	44,566	289,676
	Gross fresh water supply gap (litres/day)	3,117,381	2,614,905
Desalination supply	Gross RO system production (litres/day/system)	528,000	
	Number of systems to fully cover supply gap	5.90	4.95
	Number of systems recommended	**6**	**5**
Total gross water supply **gap** or *surplus* (litres/day)		*+50,619*	*+25,095*
Total net water supply **gap** or *surplus*(litres/day)		*+40,495*	*+21,330*

were estimated. The results of this analysis are given in Table 59.

The analysis next considered the operational strategies required for each configuration and determined the associated electricity demand. Table 60 details the operational strategy and associated electricity demand for each of the desalination configurations analysed.

Based on the capital cost and electricity demands detailed above, the LCOW was determined for each operational configuration. Where appropriate, the

Table 59: System capacities and associated capital costs of desalination plant configurations

Configuration		System capacity					Capital cost (USD)				
Energy supply	Backup	PV (kWp)	Diesel (kW)	Battery (kWh)	RO (m^3/d)	Tank (m^3)	PV	Diesel	Battery	RO	Total
PV		1,759	-	-	1,324	1,800	5,899,686	0	0	2,659,012	**8,558,698**
	Battery	1,281	-	1,786	687	2,500	4,296,474	2,965,882	0	1,463,848	**8,726,203**
	Diesel	493	83	-	758	2,000	1,653,522	0	80,676	1,601,654	**3,335,852**
	Grid	493	-	-	758	2,000	1,653,522	0	0	1,601,654	**3,255,176**
Diesel		-	118	14	563	1,200	0	23,918	114,696	1,221,451	**1,360,066**
Grid		-	-	-	563	1,200	0	0	0	1,221,451	**1,221,451**

Table 60: Operational and electricity demand of desalination plant configurations

Configuration		Operation strategy	RO water production (h/d)	RO electricity demand (kWh/y)	Operating hours per year		RO electricity supply (kWh/y)		Average specific energy consumption (kWh/m³)
Energy supply	Backup				PV	Battery or diesel	PV	Battery or diesel	
PV	-	dynamic	11.2	788,064	4,103	-	788,064	-	4.1
PV	Battery	continuous	19.5	702,496	3,079	4,619	364,566	337,930	3.6
PV	Diesel	continuous	23.9	659,944	3,420	5,315	378,338	281,606	3.4
PV	Grid	continuous	23.9	659,944	3,420	5,315	378,338	281,606	3.4
Diesel		continuous	23.8	619,319	-	8,701	-	619,319	3.2
Grid		continuous	23.8	619,319	-	8,701	-	619,319	3.2

impact of varying the cost of electricity from the grid was included in this analysis. The resulting LCOW values are given in Table 61.

Table 61 shows that grid-connected PV-RO systems are the most economic options with LCOWs ranging between 2.4 and 2.8 USD/m³. However, electricity prices in South Tarawa are heavily subsidised and the real cost of electricity might be even higher than the 0.76 USD/kWh assumed. In this case, both off-grid options (with and without battery storage) could be cost competitive with grid-connected systems. In order to compare the water production costs of renewable with conventional desalination, the LCOW for RO-systems powered solely by diesel generators or electricity from the grid are shown in Table 62. Figure 48 presents a comparison of the estimated LCOW values for all of the desalination configurations analysed.

Table 61: LCOW for PV-RO desalination plant in South Tarawa with capacity of 528 m³/day

Renewable desalination options			Off-grid (dynamic)	Off-grid + battery	Off-grid + diesel generator	Grid-connected		
PV	PV capacity	(kW_p)	1,759	1,281	493	493		
PV	LCOE (PV)	(USD/kWh)	0.24					
PV	Battery capacity	(kWh)	---	1,786	---	---		
PV	LCOS	(USD/kWh)	---	0.67	---	---		
PV	Diesel generator	(kW)	---	---	83	---		
PV	LCOE (Diesel generator)	(USD/kWh)	---	---	0.67	---		
PV	Specific CAPEX RO	(USD/m³/d)	2,009	2,131	2,113	2,113		
PV	Electricity price (commercial)	(USD/kWh)	---	---	---	0.49		
PV	Electricity price (industrial)	(USD/kWh)	---	---	---		0.62	
PV	Electricity cost (PRIF, 2009, p. 20)	(USD/kWh)	---	---	---			0.76
PV	**LCOW**	**(USD/m³)**	**2.8**	**3.1**	**2.7**	**2.4**	**2.6**	**2.8**

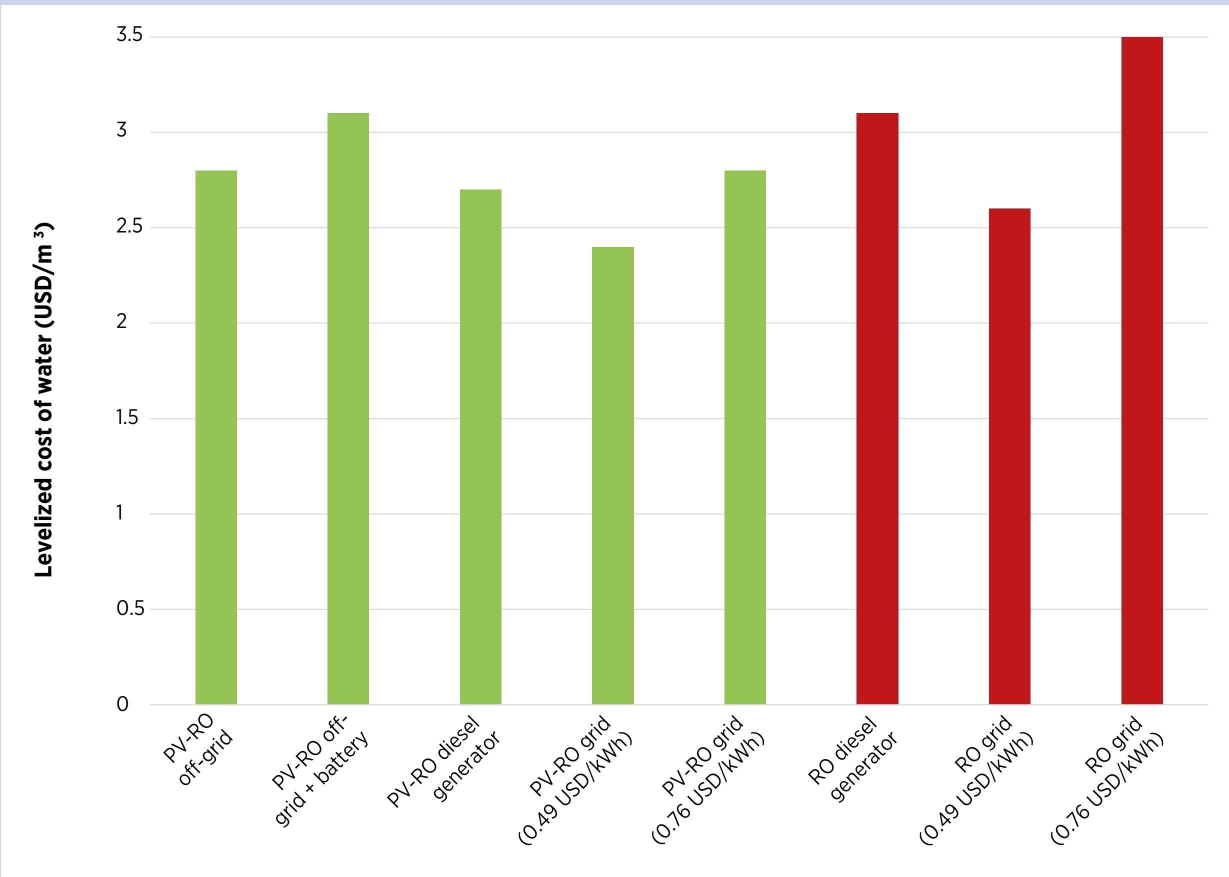
Table 62: LCOW for diesel-powered desalination options on South Tarawa

Conventional desalination options		Diesel generator	Grid		
Diesel generator	(kW)	118	---		
LCOE (Diesel generator)	(USD/kWh)	0.65	---		
Specific CAPEX RO	(USD/m³/d)	2,168	2,168		
Electricity price (commercial)	(USD/kWh)		0.49		
Electricity price (industrial)	(USD/kWh)			0.62	
Electricity cost (PRIF, 2009, p. 20)	(USD/kWh)				0.76
LCOW	**(USD/m³)**	**3.1**	**2.6**	**3.0**	**3.5**

In summary, **renewable desalination is already cost-competitive with fossil-driven desalination on South Tarawa and might become even more economically preferable if diesel prices, and with them electricity prices, rise in future,** The same applies to the fully renewable energy-driven desalination options, whose LCOW is currently still slightly higher than the LCOW of options with fossil back-up energy supply.

From an operational perspective, it should also be noted that reversible osmosis (RO) system configurations considered in the analysis are based individual RO lines/units that can be operated in a modular fashion. The number of units varies from 22 to 34 based on the RO capacities given in Table 59. This option should allow both fresh water production capacity and associated electricity demand to be stepped up and

Figure 48: LCOW for renewable and conventional desalination options on South Tarawa



down incrementally, which could allow RO to act as a deferrable load that would help with the integration of grid-connected variable renewable energy, such as PV and wind.

11.3 Desalination in Kiritimati

Table 63 shows the analysis of the water supply in Kiritimati. The per capita water demand and reduction in fresh water supply due to climate change were assumed to be the same as South Tarawa.

Table 63 indicates that the sustainable use of current fresh water supplies, in combination with a reduction in water distribution losses and an increase in rain water collection, would meet the total water demand even with a fivefold increase in Kiritimati's population by 2025. Data from an Asian Development Bank (ADB) study considering only ground water concluded that sustainable use could support a population of ca. 22,000. However, the ADB study showed that current population growth is concentrated from Tabakea to London, where ground water supplies support only ca. 6,000 people. If population continues to grow in this area, desalination should be investigated.

The proposed fish-processing plant might also create a substantial demand for fresh water and its water supply should be carefully assessed in the design phase of the plant.

11.4 Desalination in Nonouti

Unfortunately, no data on water supplies or demand were available for Nonouti. As such, water demand was estimated assuming a population of 2,500 and a water demand equal to that used for South Tarawa and Kiritimati (50 litres per day per person), which yields an annual fresh water demand of 125,000 litres per year. This demand figure was used as the basis for analysis of a desalination plant capable of covering all the fresh water needs of Nonouti. It is recommended that the government collect data on water demand and supply for all of the Outer Islands with larger populations to determine if gaps in fresh water supply exist.

Table 63: Analysis of 2025 water demand and supply for Kiritimati

		2015	2025
water demand	Population	5,500	27,500
	Estimated water demand per capita (litres/day)	50	
	Total net water demand (litres/day)	275,000	1,375,000
	Water distribution losses (%)	30%	15%
	Total gross water demand (litres/day)	357,500	1,581,250
fresh water supply	Sustainable yield from ground water (litres/day)	1,810,000	1,569,869
	Households with rain water tanks (%)	1.3%	10%
	Rain water supply per household (litres/day)	5	
	Total rain water supply (litres/day)	358	13,750
	Gross fresh water supply **gap** or *surplus* (litres/day)	*+1,452,947*	*+5,806*

12 TRANSPORT

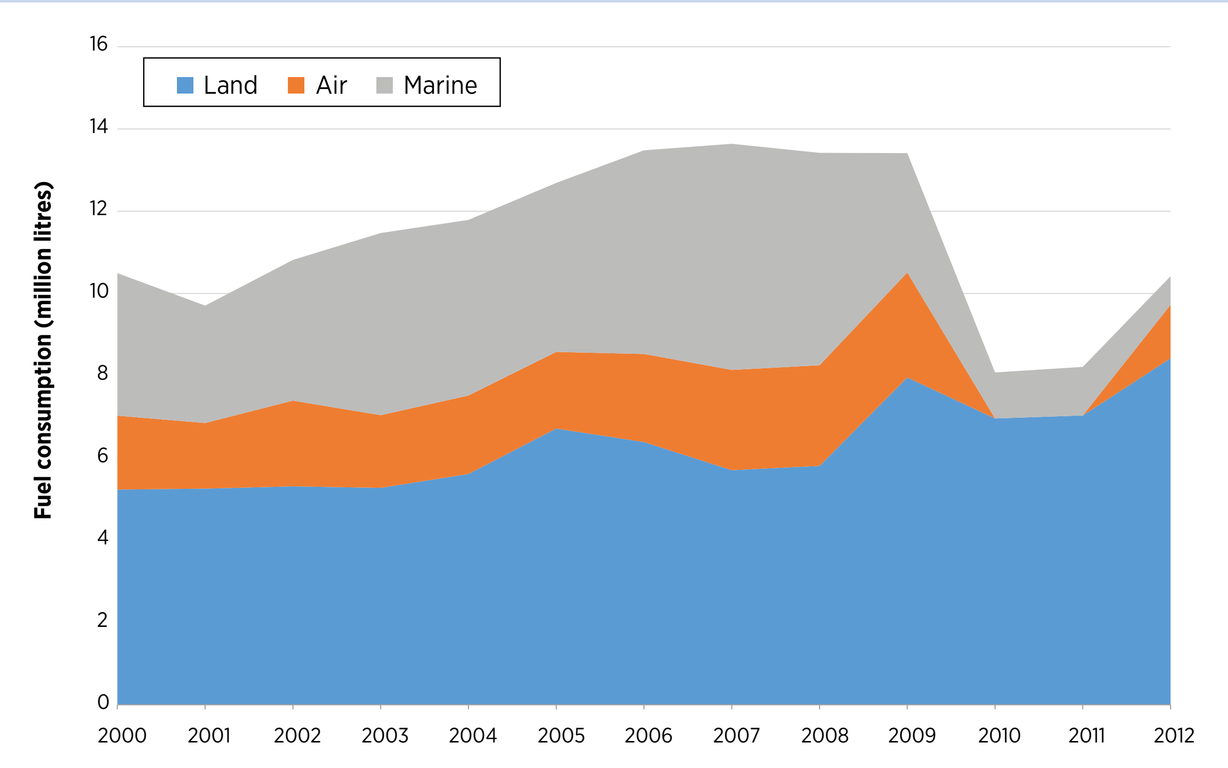
Kiribati's transport sector includes land, marine and air transport and refers to the movement of people, goods and services, largely using motorised vehicles and local shipping, together with their fuels such as petrol, diesel and lubricant oils. International shipping and aviation are *excluded* as operations do not lie within Kiribati's domestic jurisdiction. Domestic aviation, however, is *included* as its fuel is imported and used locally. Figure 49 shows the trend of fuel consumption for the transport sector from 2000 to 2012.

In 2014, 51% of total petroleum imports was for transport alone. Of this total, approximately 45% was for diesel, 46% for petrol and 9% was Dual Petroleum Kerosene (DPK) for aviation fuel. It was reported that diesel was used mainly for heavy machinery vehicles, as well as inter-island ships and large shipping vessels, while petrol was used for land transport, primarily for cars, motorbikes and outboard motors mainly for offshore fishing.

The growing number of imported cars accounted for most of the increasing reliance and dependence on fossil fuels, mainly for South Tarawa and Betio. Between 2003 and 2013, the number of vehicles imported to Kiribati has more than doubled for all types of vehicles, including buses, cars, trucks and motorcycles (*i.e.* from 606 in 2003 to 1,370 in 2013). Similarly, the number of registered vessels for sea transport has also increased from 22 in 2003 to 36 in July 2014. The increased number of different modes of transportation for land and sea has consequently increased the demand for petroleum products, mainly automotive diesel oil and petrol.

Kiribati is opting for the use of renewable energy sources for transportation; in particular, for the use of biofuel for land and marine transport. Policy measures that could assist in easing the pressure of growing fossil fuel demand could include imposing restrictions on energy-inefficient vehicle based on their engine

Figure 49: Fuel consumption for the transport sector, 2000–2012



sizes and model year. Other policy measures include introducing incentives for vehicles with greater fuel efficiency and lower cylinder capacity. Since 2014, there has been a growing trend towards hybrid vehicles being imported into Pacific island countries and territories with more of these types of vehicles expected to become available in the Kiribati market in the coming five years (*i.e.* 2020).

12.1 Transport sector overview

Most of the fuel consumed for land-based transport occurs on South Tarawa, which is home to ca. 50% of Kiribati's overall population. Also, most of the sea transport refuelling activities are undertaken on South Tarawa. For the purposes of this study, air transport was not considered, as there are no immediate options for fuel substitution for aircraft.

Land-based transport

The data available for land transport covered the period 2002-2013 and showed the number of vehicles of various classes imported. As it is unlikely that vehicles imported over the ten previous years (*i.e.* 1992 – 2002) are still operational, and many only last for five years due to the aggressive marine environment and the extremely rough roads, it is suggested that only half of the ten years' imports would still be operational. To obtain a better idea of the numbers of vehicles in operation, registration numbers would be a better indicator.

A total of over 9,000 vehicles were imported in the period 2004–2013, and these were split into the categories shown in the table below. There was no split between private, commercial or government vehicles, but this would hopefully come from registration records, once they are made available.

Buses and pick-ups are most likely in the same category since they are large "people movers", the back of a pick-up (or utility vehicle) being able to carry many people. Almost all buses and many pick-ups would use diesel (ADO) while the rest would use gasoline (ULP).

Saloon cars are unable to carry more than five or six people ordinarily and so are less popular than pick-ups in Kiribati, where the extended family is an important social unit. 2,323 of these were imported in this ten-year period. Most are second-hand imports and it is assumed that most would use gasoline (ULP).

Trucks and tractors are mainly commercial and government vehicles. 1,534 were imported in this period. Most would use diesel (ADO) as a fuel.

Motorcycles are the most affordable transport and so, unsurprisingly, are the most prevalent in number. There were a large number of Chinese brands being imported. 4,774 were imported in this period, accounting for over half of all imports. It is assumed that all would use gasoline (ULP).

Marine-based transport

The figures below are based on craft registrations, the latest figures being for July 2014. There are probably many small, private outboard motor boats and canoes with engines that are not registered. The figures in Table 65, however, apply to larger commercial and government vessels.

There are a number of possibilities for the replacement of petroleum fuels in land and sea transport, the most promising of which are electric vehicles (EVs – land and sea) powered from renewable energy (grid or off-grid) and the replacement of petroleum with CNO. Specialist companies that manufacture complete "systems" (*i.e.*, *not* retrofitted current vehicles, but land and sea craft designed from the ground up) have flourished in recent years. This approach may require higher upfront investment but greatly improves performance, range and longevity, and ultimately lowers lifecycle costs.

Table 64: Vehicles imported to Kiribati, 2004–2013

	Buses and Pick-ups	Saloon	Trucks and Tractors	Motorcycles
Vehicles imported 2004–2013	544	2,323	1,534	4,774

Table 65: Registered vessels as of July 2014

	Motor Vessels	Outrigger Canoes	Catamarans	Landing Crafts
Registered vessels as of July 2014	10	12	10	4

- *Of the ten motor vessels registered, all had diesel (ADO) engines.*
- *Of the 12 outrigger canoes registered, all had gasoline (ULP) engines.*
- *Of the ten catamarans registered, four had inboard diesel engines and six outboard gasoline engines.*
- *Of the four landing crafts registered, all had diesel engines.*

12.2 Transport sector renewable energy potential

Land

The road network in the Kiribati group is not large—only about 40 km from Betio to Buota and is only slightly larger on Kiritimati for the longest route from Paris to Ronton being around 100 km.

There are a growing number of electric vehicles available as motorcycles, cars, utility vehicles and buses. Not all are suitable for the corrosion-aggressive marine environment in Kiribati; however, there are examples of motorcycles and utility vehicles that have been trialled in equatorial atoll environments. Once charging points are available at various locations, these vehicles could be charged from the electrical grid, or even stand-alone PV systems, provided they had sufficient capacity. Some vehicles can even use a standard 240V 10A power point, although charging times would be extended due to the limited charging power. Faster charging could be achieved if 15A power points or specialised charging stations were provided.

One advantage of EVs is their ability to absorb excess renewable energy. With specialised networks and large numbers of EVs plugged into the grid at any one time, there is the possibility to use the combined stationary battery capacity as an element of load levelling. Owners could opt to allow the utility to use the top 20% or so of battery capacity for this purpose, perhaps in exchange for "free" energy for charging purposes. A well-designed electric vehicle is *mechanically* very simple but *electronically* more complex than a modern car, which often has a computer-controlled internal combustion engine. Servicing is usually less expensive and time consuming while battery lifetimes are gradually increasing.

In keeping with the "economies of scale" principle, as the volume of EV production increases, its price will decrease accordingly. This has been the case in the past for everything from colour TVs to mobile phones to PV modules so, predictably, it will not be long before affordable EVs are widely available. Examples of well-proven EVs suitable for the tropics are:

- *e-Ride Industries*' single and dual-cab utility vehicles, as used successfully on Kwajalein Island since 2010; boasts a fibreglass body, aluminium chassis, 45 km per hour top speed and a 60 km range (with extended range options available).
- *Zero Motorcycles* sell on- and off-road versions and even produce these for police and security services. Ranges of over 200 km at 60 km per hour are possible with some models.
- Numerous types EVs from major car manufactures have been successfully operating on islands in the Caribbean and Pacific.

Marine

Kiribati being an island nation—its 33 atolls, reef islands and one raised coral island dispersed over 3.5 million square kilometres (1,351,000 square miles) of open ocean—connection by means of air and sea transport is essential. Travelling and transporting goods and services from the main island to the Outer Islands relies significantly on limited air service and shipping.

IRENA, in collaboration with the University of the South Pacific, developed a technology brief on renewable energy options for shipping, which is available on IRENA's website here:

http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=517

This report outlines a number of renewable energy technology options for maritime transport covering the shipping of passengers and goods. The options explored in this report are discussed broadly below to provide an overview of how developments in the global shipping industry may impact maritime transportation and shipping in Kiribati.

Shipping industry overview

According to open source documents, the earliest seaworthy boats may have been developed as early as 45,000 years ago while evidence of maritime trade between civilizations dates back at least two millennia. Island countries and communities have long relied on shipping as a trade lifeline and, increasingly, as an integral part of the local, regional and international economy that promotes and enables the trading of goods and services.

Of course, the shipping industry has changed dramatically from past centuries when, for example, small outrigger canoes and sailing boats were the main means of transportation between islands.

Today, enormous cargo ships running on heavy fuel oil and marine diesel oil dominate the industry. The United Nations Conference on Trade and Development estimated that the global shipping tonnage loaded annually increased from 2.6 billion tonnes to 9.5 billion tonnes just in ca. four decades between 1970 and 2013 (IRENA, 2015a). This rising demand impacts fuel consumption. The International Maritime Organisation estimated that, between 2007 and 2012, on average, the world's marine fleet consumed between 250 million tonnes and 325 million tonnes of fuel *annually*, accounting for approximately 2.8% of annual global greenhouse gas emissions (IRENA, 2015a).

GHG emissions are expected to rise further, in tandem with the growth in shipping and could triple by 2050. The International Convention for the Prevention of Pollution from Ships has stipulated mandatory technical and operational measures, requiring more efficient use of maritime energy and, simultaneously, less emissions. These regulations came into force in 2013. The industry itself has set targets to reduce carbon dioxide emissions by 20% by 2020 and 50% by 2050 (IRENA, 2015a).

To meet these targets, container shipping giants need to consider cleaner fuel and power options, including the use of renewables. Rising bunker fuel prices, amid a globally volatile market, provide another compelling reason to scale up modern shipping solutions based on renewable technologies.

Transition to a clean energy sector will require a shift from fossil fuel-powered transport to efficiently designed renewable energy technologies even though efforts today are hampered by the oversupply of fossil fuel-powered shipping. Current barriers to development include: the lack of commercial viability of such systems; and split incentives between ship owners and operators, resulting in limited motivation for deployment of clean energy solutions in this sector (IRENA, 2015a).

In order to ensure that shifting to a cleaner energy shipping industry is successful, a number of actions must be taken, including instituting a regulatory framework that governs the acceleration of renewable energy deployment; putting in place policies and incentives to support research and innovation; developing and building appropriate infrastructure; and improving organisational set up.

Renewable energy technology options

The potential of renewables for marine transport and the shipping industry is very high and could transform the global shipping fleet at all levels. It could also impact the international and domestic transport of goods, people and services; fishing; tourism and other maritime pursuits.

Renewable power applications in ships of all sizes include options for primary, hybrid or auxiliary propulsion, as well as on-board and shore-side energy uses. Potential renewable energy sources for shipping applications include wind (*e.g.* soft sails, fixed wings, rotors, kites and conventional wind turbines), solar photovoltaics, biofuels, wave energy and the use of energy storage charged from renewables. (IRENA, 2015a) These clean energy solutions can be integrated through retrofits to the existing fleet or incorporated into new shipbuilding and design, with a small number of new ships striving for 100% renewable energy or zero emissions technology for primary propulsion (IRENA, 2015a).

Table 66 below provides an overview of renewable energy technologies that has been the focus of efforts for the shipping industry. A summary on each technology application is also provided below:

Table 66: Summary of renewable energy technology applications for the global shipping industry

Renewable energy type		Retrofit (RF)/ New Build (NB)	Vessel category, application and potential			
			< 400 tonnes e.g., recreation, artisanal/small fishery, tourism, passenger, break, landing craft, barges, research, coastal patrol and security	**400 – <10 000 tonnes** e.g., large landing craft, small-medium fishery, domestic Ro-Ro, break bulk, bulk, container, tanker, tramp	**10 000 – <50 000 tonnes** e.g., Ro-Ro, deep sea fishery, bulk, container, tanker, car carrier, cruise liner	**>50 000 tonnes** e.g., Very Large Crude Carrier (VLCC), Panamax, Aframax, large container ships
Wind	Soft sails	RF	●●● (In commercial use)	●●● (Design)	●●● (Design)	●● (Design)
Wind	Soft sails	NB	●●● (In commercial use)	●●● (In commercial use)	●●● (Design)	●● (Concept)
Wind	Fixed wings	RF	●● (Concept)	●● (Proven)	●● (Design)	● (Design)
Wind	Fixed wings	NB	●● (In commercial use)	●●● (Design)	●●● (Design)	●● (Design)
Wind	Rotors	RF	●● (Proof-of-concept)	●● (Proven)	●● (Concept)	●● (Uncertain)
Wind	Rotors	NB	●●● (Proof-of-concept)	●●● (Proven)	●●● (In commercial use)	●● (Design)
Wind	Kites	RF/ NB	●● (Design)	●● (In commercial use)	●● (Design)	● (Concept)
Wind	Turbines	RF/ NB	● (Concept)	● (Concept)	● (Uncertain)	● (Uncertain)
Solar photovoltaics	Main propulsion	RF	N/A (Design)	N/A (Uncertain)	N/A (Uncertain)	N/A (Uncertain)
Solar photovoltaics	Main propulsion	NB	● (In commercial use)	N/A (Concept)	N/A (Uncertain)	N/A (Uncertain)
Solar photovoltaics	Auxiliary propulsion	RF	●● (Proven)	N/A (Concept)	● (Proof-of-concept)	N/A (Uncertain)
Solar photovoltaics	Auxiliary propulsion	NB	●● (In commercial use)	N/A (Concept)	● (Proof-of-concept)	N/A (Uncertain)
Solar photovoltaics	Ancillary power	RF/ NB	●● (Design)	N/A (Concept)	● (Proof-of-concept)	N/A (Uncertain)
Biofuels	1st Generation	RF	●● (Proof-of-concept)	●● (Proof-of-concept)	●● (Proof-of-concept)	● (Concept)
Biofuels	1st Generation	NB	●● (Proof-of-concept)	●● (In commercial use)	●● (Proof-of-concept)	● (Concept)
Biofuels	2nd Generation	RF	N/A (Uncertain)	N/A (Uncertain)	N/A (Uncertain)	N/A (Uncertain)
Biofuels	2nd Generation	NB	●●● (Concept)	●●● (Design)	●●● (Design)	●● (Concept)
Biofuels	3rd Generation	RF	N/A (Uncertain)	N/A (Uncertain)	N/A (Uncertain)	N/A (Uncertain)
Biofuels	3rd Generation	NB	●●● (Concept)	●●● (Concept)	●●● (Concept)	●● (Concept)
Wave	Main propulsion	NB	● (Proven)	N/A (Uncertain)	● (Concept)	N/A (Uncertain)
Wave	Auxiliary propulsion	NB	● (Concept)	N/A (Uncertain)	● (Concept)	N/A (Uncertain)

Keys:

Current Application

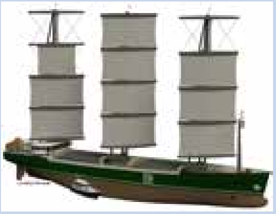
- In commercial use
- Proven
- Proof-of-concept
- Design
- Concept
- Uncertain

Potential Application

●●●	High potential (Scores well on all three metrics: economic, environmental and social)
●●	Medium potential (Scores on two of the three metrics)
●	Limited l (Scores on only one of the three metrics)
N/A	Not available

Figure 50: Examples of ship designs deploying soft-sails

(a) Greenheart



(b) B9

(c) Ecoliner

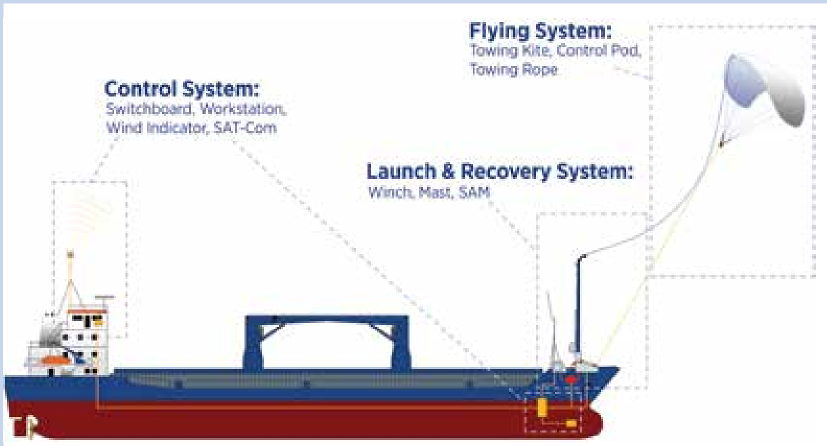
(d) Seagate delta wing sail

Source: (IRENA, 2015a)

Wind is readily available and shipping was sails-dominated before the arrival of steam engines. However, the main disadvantages are wind force variation and difficulty in harnessing the full propulsion when sailing into or close to the wind. Categories of wind propulsion as follows (IRENA, 2015a):

- **Soft-sail** is conventional and has proven itself to be a "mature technology". Advances in the yacht racing industry can be incorporated. Examples of designs are shown in Figure 50.
- **Kite sails** attached to the bow of a vessel operate at altitude to maximise wind speeds. In 2008 *MS Beluga Skysails* was the world's first commercial container cargo ship partially powered by a 160-square-metre kite. (IRENA, 2015a) This technology shown in Figure 51 has been advocated for over a decade.
- **Fixed-sail** are rigid wings on rotating masts. Various forms of fixed wings have been proposed since the Japanese experiment in the 1980s, although these have failed to demonstrate savings (IRENA, 2015a). New designs are being developed, but it may take some years for a design that is commercially viable.
- **Flettner Rotors** harness the Magnus Effect, created when wind passes over an already revolving cylinder, for propulsion. First proven in the 1920s, it was forgotten until 1980s. Since then, there have been various new designs developed and adapting the Flettner rotor style. Retro-fitting of rotors is being considered but deck space must be taken into account.
- **Wind turbines:** Small wind turbines can be deployed on ships to power secondary systems and charge batteries.

Figure 51: Kite-assisted vessels



(a)

(b)

Source: (IRENA, 2015a)

Figure 52: Fixed wing and solar hybrid

(a) Eco Marine Power's Aquarius MRE system

(b) OCIUS Technology's SolarSailor

(c) NYK's Auriga Leader

Source: (IRENA, 2015a)

Biofuels blended with fossil fuel in the transportation sector are a viable solution today, but their deployment in the shipping sector remains minimal. However, in the Marshall Islands, biofuel is being blended with fossil fuel for inter-island ferries. Biofuel can be used in many forms such as biodiesel, bioethanol, straight vegetable oil (SVO), etc. and can be used as a direct substitute in diesel- and fuel oil-powered engines.

- **Liquid biofuels** are potentially applicable to all vessel types. In 2006, trials demonstrated the viability and feasibility of biofuels for the marine sector. In 2012, the first commercial shipment using 100% biodiesel was delivered by Meriaura Ltd, Finland (IRENA, 2015a). Trials of various types of biofuel are ongoing.
- **Biogas:** Biomethane can be liquefied (like natural gas) and used as a fuel for transportation. Liquid biomethane (LBM) can be combined with other proven renewable energy technologies such as wind. The industry favours liquefied natural gas (LNG) as a transitional fuel while increasing development of storage infrastructures at ports will facilitate the use of this technology, along with biomethane.

Solar photovoltaic and hybrid systems: All solar PV applications and advanced designs are available for maritime transport although the lack of space and storage present challenges. Battery storage enables hybrid solutions for ships in the short term. Hybrid fixed sails in tandem with solar PV arrays, both sail- and deck-mounted, have been commercially applied in Australia and China An illustration of this hybrid system is shown in Figure 52.

Battery electric propulsion is currently being used to power large commercial ferries and is available on numerous types of smaller water craft. Batteries are charged using renewable energy when the vessel is docked. In addition solar panels can be installed on board the vessel to meet some of the electricity demand.

Hydrogen fuel cells: Potential for hydrogen as a fuel for shipping is directed to its use in fuel cells for electricity generation, to drive electric motors. The developments in fuel cell technology are attractive to off-shore supply vessels, passenger and cruise ship markets. Despite various testing, the sustainability of hydrogen production has been a critical issue, with current production coming from natural gas.

Renewable energy options for shipping applicable in Kiribati

Development of renewable energy technologies for maritime transportation appears to be moving forward rather slowly and there has not been sufficient demonstration of commercially viable solutions. Kiribati is dependent on the international market to develop viable solutions that could be locally incorporated. Table 67 provides commentary on technology options for Kiribati within the context of deployments presented in the previous section.

Solar-powered electric drives for inter-island sea transport: A preliminary quantitative assessment

There are a number of developments in the marine area for electric drives. These range from inboard electric

Table 67: Renewable energy options for shipping applicable to Kiribati

Technology		Commentary
Wind	Soft sails	Conventional sails are currently used in Kiribati on small canoes for lagoon sailing and short inter-island voyages. They will continue to be an integral part of local maritime transportation. Soft sails have not yet been used at a commercial level but this option may be worth exploring as it could be suitable for small- to medium-sized boats carrying cargo and passengers between islands.
	Fixed sails Rotors Kites Wind turbines	These technologies are still in their initial exploratory phases and therefore not yet applicable to Kiribati. However, some of these technologies might develop within the time horizon of this roadmap, so it would be important to stay abreast of developments in this sector.
Solar	Solar PV Battery	Solar PV applications for maritime use are deployed in the market, mostly for small boats. The hybrid solution with storage may present opportunities for small- to medium-sized ships and is worth exploring.
Biofuels	Liquid biofuel	Blending CNO and fossil fuels for inter-island ferries is currently being trialled in the region (*e.g.* Marshall Islands). Kiribati produces copra but the sustainability of copra supply may need to be assessed to ensure long-term supply and quality. The possibility of ships running entirely (*i.e.* 100%) on coconut oil (CNO) as fuel is also worth exploring. Other sources of biofuel from vegetables and marine algae are likely not viable options for deployment in Kiribati.
	Biogas	Biogas production will be challenged by the sustainability of stock for biogas production. Therefore, this option is not practical for Kiribati.
Wave		Not yet applicable as the technology is still being explored.
Hydrogen fuel cells		This technology is still in its infancy and therefore not yet feasible for Kiribati.
Battery electric		Due to the rapid decrease in storage costs, this option might be practical for the short term and best deployed in combination with wind (*e.g.* soft sails, or small wind turbines to recharge the batteries) or solar PV.

drives for larger marine crafts to small outboard electric drives for smaller crafts. There are also advances in hull design. As with land-based vehicles, a well-designed hull requires less energy to propel it, increasing the craft's performance, range and lifetime.

Considering the rapid evolution of commercially available, battery-powered, electric marine drive systems, the feasibility of PV-charged, battery-powered, marine electric drives would appear deserving of comprehensive pilot testing.

Based on the catamarans currently used for inter-island travel from Tarawa, there is a case for the potential application of these technologies to replace diesel engines for displacing hulls, or wave-piercing catamarans, like those currently in use. ***Advantages*** of multi-hulls include higher speeds for a given hull length and power, shallow draft (important where there are shallow reefs as in Kiribati), and large areas to accommodate solar arrays. ***Disadvantages*** include low load capacity for a given length, and greater complexity and materials (and hence costs) used for a given length.

Calculations have been made for an efficient catamaran design 18 m length x 10 m beam, with a 20 tonne cargo capacity, cruising at five knots. This is common for slower displacement hulls and easily achievable by the better performing multi-hull configuration. It is estimated that this option, based on such a boat design, could sustain 12 knot sailing speeds, although greatly reducing its range. However, the efficiency of marine propulsion depends substantially on marine conditions (*e.g.* waves, winds, currents), on hull shape and on speed, and thus has to be assessed through testing under real-world conditions.

It is proposed that funding be identified to **pilot these technologies and assess their viability as a replacement for current inter-island transportation.** As reference points, there are designs that have been in operation for almost two decades already, such as the "solar sailor" in Australia, which might provide insights on how to design a pilot project for Kiribati.

Their ideal application would be in combination with sailing, to maximise safety and range and minimise cost.

For vessels that have sails, redundancy for the motor drive is of less concern. For those that rely solely on the motor, a dual motor drive configuration with a back-up generator should be considered for safety reasons. This is also more suitable for catamarans, due to their hull design (*i.e.* one drive per hull).

A solar and battery configuration for retrofitting of existing catamarans in Tarawa is detailed in Table 68. This option based on currently available products including inboard and outboard electric motors and would be worth considering for real-life testing. Note this options is redundant (if one motor fails there is a second back-up motor for safety) and is designed for trips of up 40 nautical miles (nm) without solar, 25 nm per day from solar, 40 nm at 2.5 knots when solar radiation is low.

Next steps to support renewable marine transportation and shipping

The shipping industry is pursuing a number of initiatives to find commercially viable opportunities. Kiribati should thoroughly investigate these use of these technologies as they represent a major opportunity to reduce the fossil fuel dependence of the shipping sector.

In deciding to pursue conventional wind, solar hybrid or biofuel solutions, a number of components need to be put in place at the outset, including (but not necessarily limited to):

1) Instituting an appropriate policy framework and providing incentives to encourage private sector participation and pilot testing;
2) Strengthening the regulatory framework to ensure that entry and exit from the industry is effectively coordinated;
3) Reviewing and drafting new legislation where needed to ensure that the roles and responsibilities of stakeholders, regarding coordination and implementation, are clearly defined;
4) Planning for, and developing local skills, knowledge and capacity to sustain the installation, maintenance and repair of systems; and

Table 68: Pilot testing options: Inter-island catamaran solar and battery powered electric drives

Motor options	Dual, Industrial-grade
Max power input (kW)	2 x 25
Equivalent gasoline outboard propulsion power (HP)	2 x 40
Battery options	2 x 345 V 12.8 kWh (long life Li-Ion)
Usable battery capacity (kWh)	25.6
Range (nm) @ 5 knots	40
Range (nm) @ 20 knots	18
Ideal PV size for 5h/day daytime cruising at 5 knots (kWp)	6
Motor price (AUD)	60,000
Battery price (AUD)	50,000
PV price (AUD)	6,000
Total price (AUD)	116,000

5) Building ongoing relationships and entering into new partnerships wherever possible to ensure that financial assistance for new demonstration projects is available.

A global shift to cleaner transportation and shipping based on renewable energy will take time but will impact positively on Kiribati's efforts to replace fossil fuels with renewables in the shipping sector.

12.3 Energy efficiency in transport

Government-led initiatives

Kiribati's Government should take the lead, acting via its Plant Vehicles Unit, in evaluating the use of more efficient vehicles, such as hybrid cars and electric vehicles that use solar PV for charging. The use of hybrid cars is emerging in other Pacific Island countries, such as in Fiji, and has demonstrated the ability to consume less energy than conventional diesel fuel. The use of LPG cars is also increasing. However, Kiribati needs to establish its LPG infrastructure to maintain a proper standard. Fiscal incentives should be considered in this area so that people are encouraged to import more efficient vehicles and thus reduce the increasing pressure on fuel dependency for land transport.

Table 69 details some of the current government-led initiatives.

Improved transport data collection

As part of the data collection activity for the Pacific Regional Data Repository (PRDR), the land vehicle data were collected from the two island councils in South Tarawa and Betio; however, there are still some important elements relating to energy efficiency that were not captured. The inspection of vehicles prior to registration and licensing of drivers is carried out by the police department under the provisions of the Traffic Act 2002 (Kiribati House of Assembly, 2002). The inspection of vehicle registration forms provided under the Traffic Act requires an amendment that would show the vehicle's engine sizes and the type of fuel it uses. This would allow policy makers to make more accurate estimates of fuel consumption based on the number of registered vehicles and also project future trends. Therefore, due to limited data, no target could be set for this sector.

Kiribati's Energy Planning Unit (EPU) has also started collating fuel consumption used from retailers as part of the petroleum licensing process, but this sector needs to be strengthened by improving data access, entry and analysis. SPC can provide funding support for an energy database officer with one of the responsibilities being to monitor fuel consumption for transport uses so that better analysis could be obtained to make more informed decisions. These activities will be relevant as well for the monitoring of fuel use for government and SOE vehicles. In terms of maritime registration, the Marine Department under the Ministry of Information, Communication, Transport and Tourism Development is responsible for the collation of data. However, there is a need to work with KOIL and retailers to accurately assess fuel consumption shares for these two users—land and sea transport.

Table 69: Efficiency in transport financing plan

Description of investment	Estimated Cost	Secured (under existing programme)	Unsecured	Possible donors for unsecured funds
Strategy 1: Efficient lagoon and sea public transportation developed for nearby islands to South Tarawa (North Tarawa, Abaiang and Maiana)	10,000	0	10,000	Private sector, Government of Kiribati
Strategy 2: Efficient use of fuel for transport for government sector	**10,000**	0	10,000	Government of Kiribati, Donors
Total Investment	**20,000**	**0**	**20,000**	

13 PETROLEUM

The Government-owned Kiribati Oil Company (KOIL) is the main fuel importer and distributor in Kiribati. KOIL operates the main fuel terminal on Tarawa, which was purchased from Mobil Oil in 2007, as well as a smaller bulk fuel terminal on Kiritimati. Mobil Oil continued to exclusively supply KOIL from 2007-2012 as part of the terminal sale agreement. In 2012, national fuel supply was tendered out and Mobil Oil was chosen once again as the preferred supplier until mid-2014. This arrangement was renewed in August 2014 for up to two years, but with the provision that KOIL could exit the arrangement with appropriate notice to the supplier.

In practical terms then, Kiribati's fuel *supplier* has not changed. However, the nature of the *relationship* has. There is evidence that Mobil Oil's support for KOIL management and operations has changed dramatically, with a significant downgrading of training and technical support since 2007. This situation brings with it a significant increase in national risk that will require professional management.

13.1 Terminal operations and training

Bulk fuel terminal operation is a specialised business requiring qualified and properly trained staff operating under very stringent industry guidelines to maintain product quality, safe and efficient handling and storage of fuel and compliance with all relevant Environment, Health and Safety requirements.

A 2014 review of the Kiribati petroleum sector carried out by the SPC Petroleum Advisory Service's Economic Development Division identified a number of issues covering four broad areas including: 1) fuel pricing, 2) the retail fuel industry; 3) KOIL fuel terminal and management of bulk fuel storage; and 4) the wharf area and import fuel pipeline. A number of issues were identified that required urgent attention, some of which involved serious and potentially catastrophic risks to ongoing fuel supply, environment, and health and community safety.

In order to assist KOIL to address these issues, the SPC formally offered to organise a no-obligation professional review of operations and management, to identify KOIL management, operational, training and professional development needs and to find effective ways to address those needs. The review would also assist KOIL in preparing a fuel tender to obtain ongoing fuel supply at favourable price levels.

13.2 Fuel pricing

Kiribati has been reporting retail fuel prices among the lowest in the Pacific Region in recent times, comparing very favourably with much larger markets, such as American Samoa, Hawaii and Sydney, Australia as shown in Figure 53 (SPC, 2014b), which gives the average petrol price for the period of October to December 2014. This can be explained by the Government of Kiribati's intervention in subsidising the price of fuel for some time.

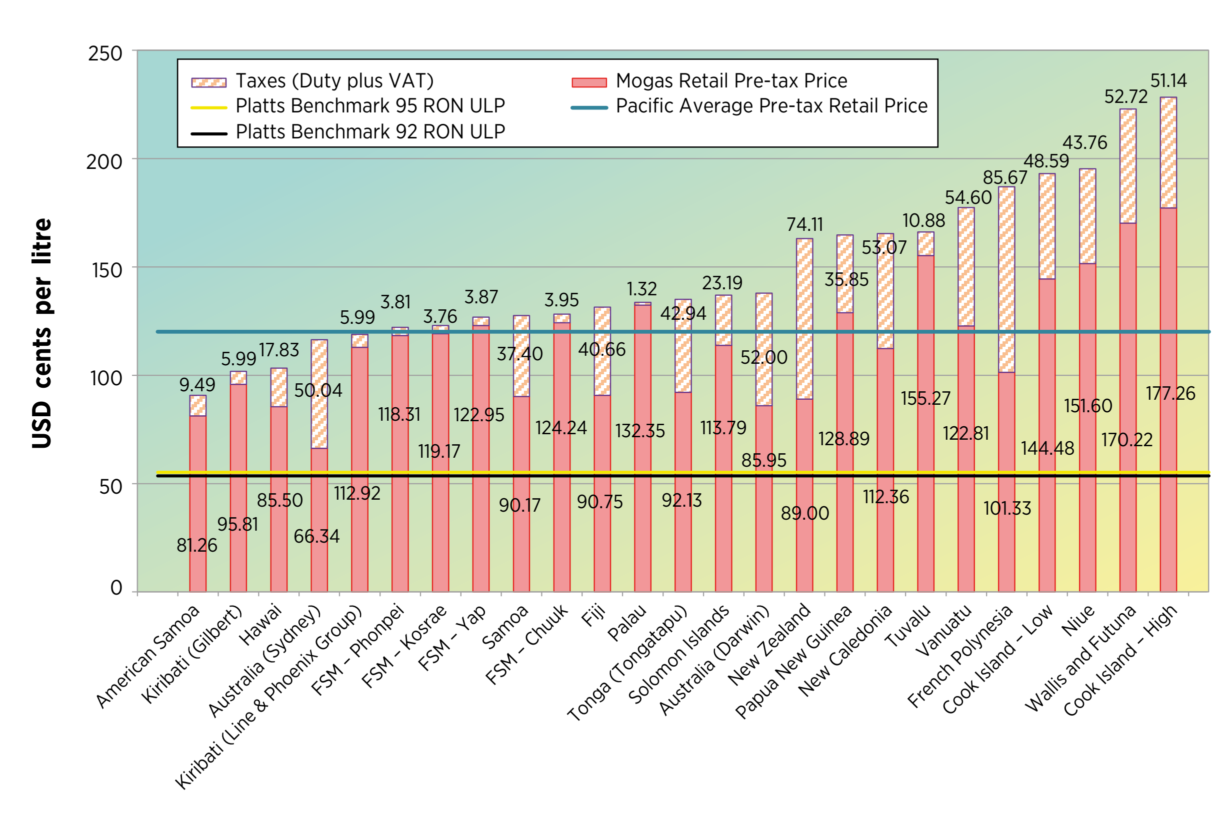
13.3 Quality, testing and certification issues

It is essential that the fuel supplied to Kiribati be of acceptable quality since the country is relatively remotely located and highly reliant on fuel to support its communities, livelihoods, education, power generation, transportation and quality of life. For this reason, it is strongly recommended that any future supplier is properly accredited, experienced and has the organisational strength to stand behind its products. Product quality must be guaranteed by suppliers along with adequate testing and certification for critical products such as jet fuel.

13.4 Future fuel demand

Current fuel demand is ca. 22 million litres per year and has not increased since 2012. It is expected that total

Figure 53: Tax inclusive raetail petrol price



Source: (SPC, 2014b)

fuel demand will remain flat in the foreseeable future with various factors influencing the different fuels, as follows;

Motor gasoline: The increasing number of vehicles in Kiribati will be offset by the importation of increasingly fuel-efficient cars and eventually hybrid cars, a process that has already started in other Pacific island countries and territories including Fiji.

Diesel fuel: Diesel fuel demand growth will come primarily from the electricity sector as more widespread electrification of households and businesses takes place. This will be partially or fully offset by the introduction of new sources of renewable, such as solar energy, as well as efforts to improve energy efficiency initiatives.

Kerosene: The bulk of the demand for kerosene is for aviation fuel, which is relatively constant in Kiribati. It can be expected that LPG will gradually replace household kerosene use as its clean and efficient burning qualities are recognised and appreciated.

LPG: LPG volume should gradually increase as the replacement of household kerosene takes place over time. This should be given an added impetus once the significantly lower costs of bulk LPG are achieved.

13.5 Fuel procurement financing plan

Table 70 gives a detailed breakdown of the three strategies recommended for improving fuel procurement.

Table 70: Fuel procurement financing plan

Description of investment	Estimated Cost (AUD)	Secured: identified under existing programmes (AUD)	Unsecured (AUD)	Possible Donors for unsecured funds
Strategy 1: KOIL management supported, supply secured and staff regularly trained	92,000	0	92,000	Private Sector, KOIL
Strategy 2: Efficient fuel price management	315,000	10,000	305,000	SPC, KOIL, MCIC, Government of Kiribati
Strategy 3: Development of alternative fuels	5,000	0	5,000	Donors
Total Investment	**412,000**	**10,000**	**402,000**	

14 CROSS-CUTTING ISSUES

14.1 Alternatives to liquefied petroleum gas

Opportunities exist for the development and deployment of alternatives to liquid petroleum gas (LPG) in Kiribati. Currently, LPG is imported into Kiribati but only in relatively high-cost ISO containers. LPG is known around the region as one of the cleanest burning fuels and is especially suited for household use, demonstrating significant benefits when compared to cooking with either bioenergy or kerosene.

Unfortunately, in Kiribati, the cost of LPG does not compare favourably since kerosene is subsidised by the government while LPG is taxed. There is scope for the government to correct this by either removing the tax on LPG, removing the subsidy on kerosene cooking, or both. A project promoting the use of LPG as cooking fuel as an alternative to kerosene was discussed in Section 10.

There is some interest in developing alternative fuels from indigenous raw materials, with at least one project exploring the potential for biofuel from coconuts. To the degree that this does not adversely impact the supply or price of coconut for traditional uses or food, this project should be encouraged, especially as a fuel supply for remote islands.

Another option is the development of biogas through bio-digesters, using garden and animal waste as raw materials. This biogas could be captured and used to generate electricity, thus reducing the volume of imported petrol fuels.

14.2 Capacity needs assessment

The institutional and legislative framework of Kiribati energy sector in is not yet well enough established to provide effective management. The Energy Planning Unit (EPU) would benefit from having energy/electricity legislation that both establishes EPU's legal roles and functions and defines a complete regulatory framework to better manage the energy sector. The EPU currently administers only the Petroleum Act; however, other sectors (*e.g.* renewable energy, energy efficiency and energy data) would also benefit from regulatory frameworks. For example, a legislative framework would provide a mandate for the EPU to legally integrate energy efficiency measures into building plans for residential, government and, in particular, commercial buildings. An Electricity Act to this effect has been drafted; however, it would need high-level support and commitment to ensure that it is enacted.

In addition to a legal framework, other capacity challenges have been identified through the Intended Nationally Determined Contribution (INDC), the Pacific Lighthouses report (IRENA, 2013), SIDS Lighthouses Quickscan (IRENA, 2015b) and from PUB field visits. They recommend:

- Support and assistance for energy planning, project development and donor coordination;
- Capacity need for financial planning and analysis;
- Improvement in energy data management and record-keeping; and
- Capacity development using Microsoft programmes, especially Excel in all energy sector departments such as PUB, KOIL, KSEC and Energy Planning Units.

14.3 Energy data and information

KIER's formulation depended solely on the availability and reliability of energy data. There were challenges concerning the reliability of data collated from different stakeholders during the development of this report, in particular on electricity consumption as the data collated were different.

The coordination of data and information collation should be strengthened by the Energy Planning Unit through support from the SPC Pacific Regional Data

Figure 54: Options for improved data collection

Repository. The SPC will provide support to the EPU in terms of data collection and back-up. Figure 54 shows a possible option for the improved flow of data.

14.4 Climate change and environment

Climate change is a serious issue, especially for the low-lying islands that comprise Kiribati. The 2014 Kiribati Joint Implementation Plan on Climate Change and Disaster Risk Management 2014-2023 defined priority adaptation measures to address current and ongoing risks from climate change. The 2014 energy sector contribution to greenhouse gas emissions was approximately 63,000 tons per carbon dioxide equivalent per capita, which is extremely small, representing approximately just 0.0002% of global emissions (INDC, 2015).

Still, energy generation is the largest source of human-induced greenhouse gas emissions and has contributed to the cause of adverse global climate change, which has, in turn, negatively impacted human habitats and livelihoods that continually affect Kiribati.

KIER provides a policy and legal framework guide, as well as proposed activities with investments required for implementation to support the reduced use of fossil fuels in power generation and transport, thus reducing greenhouse gas emissions. It is imperative to note the importance of each country's legislative framework on its own domestic environmental degradation; in particular, the effect on land and water resources from the use of other renewable energy technologies' wastes. Kiribati is a small country with limited land area; therefore, the use of land and existing resources to set up renewable energy technologies, such as solar and wind, should be minimized.

14.5 CO_2 emission reductions

In support of the government's climate change goals, the reductions in CO_2 emissions compared to the Business-as-Usual electricity generation have been estimated for South Tarawa. Emission reductions from energy efficiency measures and renewable energy deployment options for South Tarawa, as presented in the KIER, have been estimated and presented in Table 71 and Table 72. CO_2 emission reductions have been calculated versus the 2025 BAU scenario using emissions factors from the Intergovernmental Panel on Climate Change (IPCC). The following assumptions have been used for the estimation:

- 2025 BAU electricity generation comes only from diesel generators
- 2025 BAU has no energy efficiency measures implemented
- 2025 BAU annual electricity generation of 21,000,000 kWh for South Tarawa
- IPCC diesel emission factor of 74.07 tonnes CO2 per terajoule (TJ) of diesel
- Diesel energy content of 0.04338 TJ per tonne
- Specific fuel usage of 0.265 litre/kWh (or 3.77 kWh/litre)
- Diesel density of 0.834 kg per litre
- Diesel calorific value of 0.855 kg of oil equivalent (koe) per litre

Based on these assumptions and considering the least cost renewable energy deployment option in combination with all demand and supply side energy efficiency measures results in a significant reduction in CO_2 emissions, which would fall from the 15,104 tonnes per year in the 2025 BAU to 7,934 tonnes per year, a savings of ca. 47%

Table 71 gives the estimated reduction in CO_2 emissions in 2025 that would result from the deployment of renewable energy systems to meet the KIER's 23% fuel reduction goal and from the deployment of the least cost renewable energy system (recommended system that exceeds the target and further reduces electricity generation cost). See section 6.1 for additional details on renewable energy deployment options. Note that the least cost renewable energy deployment option represents 24.57% reduction in generation from diesel versus BAU or a 35% RE share once the energy efficiency measures have been implemented.

Table 72 details the reduction in CO_2 emissions in 2025 versus BAU that would result from the implementation of demand side and supply side energy efficiency measures detailed in the KIER. The difference between demand savings and generation savings is represented by the technical and non-technical losses in generation and distribution. The corrected CO_2 savings reflects an assumed one percent unoxidized carbon factor.

Table 71: 2025 CO_2 emission reductions: Renewable energy

Scenario	Annual generation	Diesel consumption			CO_2 emissions
	kWh	litres	tonnes	TJ	tonnes
2025 BAU	21,000,000	5,570,292	4,701	204	15,103
Electricity generation from renewables instead of diesel		**Diesel consumption reduction**			**CO_2 emission reductions**
2025 RE reduction: 23% of BAU	4,830,000	1,281,167	1,081	47	3,474
2025 RE reduction: Least cost system	5,733,000	1,520,690	1,283	56	4,123

Table 72: 2025 CO_2 emission reductions: Energy efficiency measures

Demand-side energy efficiency: Proposed activities/projects	Demand savings (kWh)	Generation savings (kWh)	Avoided diesel consumption			CO_2 savings (tonnes)	Corrected CO_2 savings (tonnes)
			litres	TOE	TJ		
Energy efficiency in residential buildings							
Replacement of incandescent bulbs to CFL	99,328	112,580	29,888	26	1.1	79	78
Replacement of 4 feet LTL tubes with LEDS lights	64,271	72,846	19,339	17	0.7	51	51
Replacement of 2 feet LTL tubes with LEDS lights	38,562	43,707	11,603	10	0.4	31	30
EE labels for refrigerators	180,997	205,146	54,462	47	1.9	144	143
EE labels for freezers	195,662	221,767	58,875	50	2.1	156	154
Energy efficiency in commercial buildings							
Replacing 4 ft. LTL tubes with LEDs	25,384	28,770	7,638	7	0.3	20	20
Replacing 2 ft. LTL tubes with LEDs	15,230	17,262	4,583	4	0.2	12	12
Replacing inefficient refrigerators: 40% of commercial buildings	374,732	424,730	112,757	96	4.0	299	296
Replacing inefficient air conditioners: 40% of commercial buildings	481,799	546,081	144,974	124	5.2	384	380
Energy efficiency in government buildings							
Energy efficient lighting	655,767	743,260	197,321	169	7.1	523	518
Fans replacing inefficient air conditioners	23,493	26,627	7,069	6	0.3	19	19
Retrofits: proper insulation, fixing doors...	76,332	86,517	22,968	20	0.8	61	60
Energy efficiency in PUB building and water and sewage pumps							
Energy audit and implementation	157,381	178,379	47,356	40	1.7	126	124
Improve water pump performance, servicing and maintenance	197,663	224,036	59,477	51	2.1	158	156
Total: Demand side energy efficiency	**2,586,601**	**2,931,710**	**778,311**	**665**	**27.9**	**2,063**	**2,042**
Supply side energy efficiency: Proposed activities/projects							
Improving energy supply and mitigating station auxiliary losses	380,367	380,367	100,980	86	3.6	268	265
Mitigating technical losses	655,221	655,221	173,948	149	6.2	461	456
Reducing non-technical losses	997,811	997,811	264,899	226	9.5	702	695
Total: Supply side EE	**2,033,399**	**2,033,399**	**539,827**	**461**	**19.3**	**1,431**	**1,416**
Total: All energy efficiency measures	**4,620,000**	**4,965,109**	**1,318,138**	**1,127**	**47.2**	**3,494**	**3,459**

15 ENERGY EFFICIENCY IMPLEMENTATION PLAN

This section provides a detailed plan, including costs breakdowns and specific milestones, for the implementation of KIER's energy efficiency and safety measures.

15.1 Energy efficiency in power generation

Goals	Indicators	Relevant Targets	Means of Verification	Risks and Assumptions
Goal 1: Increase access to sus-tainable, reliable and affordable energy services for all	**Indicator 1**: Total power system losses (technical and non-technical) improved	Reduction on total losses (technical and non-technical) of 9.68% equivalent to 2,033 MWh energy saved by 2025	PUB data report	Financial support Availability Political support Technical support
	Indicator 2: Number of diesel generators replaced by 2025	2 new diesel generator procured and replaced	Asset management plan	Financial support Availability Political support
	Indicator 3: Total generation costs reduced through EE SSM by 2025	Around AUD1.0 million saved on diesel fuel	PUB data reports	Financial support availability Technical support

Strategy 1: Improving energy supply and mitigating station auxiliaries and technical losses

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 1.1 Contract for annual maintenance for 3 – 5 years, competitively bid. Estimated annual cost AUD 350,000. For ten years, estimated costs AUD 3,500,000	PUB, contracting engineers	Very High	2017-2025	Fuel saving AUD 0.27 million per annum, Maximum output of generations improved Life expectancy of generators increased to 59 years compared to 25 years without proper and adequate maintenance	4,000,000
Activity 1.2 Procurement of two new high speed, low load generators to enable efficiency aligning to solar PV generation. Additional costs required to rebuild the Betio Power station to house the two new gen sets. The current gen-sets have a life expectancy of at least ten years	Contracting/ consultant	Very High	2017-2020	Fuel saving Meet peak demand – fewer outages	6,700,000
SUB TOTAL					**10,700,000**

Strategy 2: Mitigating technical losses

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 2.1 Carry out thermal imaging of the 11 kV and low voltage network to identify hotspots in the network and develop an action plan to eliminate these from the network	PUB, contractor, donor	Very High	2017-2018	Reduce technical losses from 6.0 % to 3.0 % over the three year period, Saving of 0.2 million pa Fewer outages Safety Meet peak demand – fewer outages	6,290,000
Activity 2.2 From the study above, develop a programme to match the transformer size to existing load and ensure that transformers be correctly sized for new distribution loads					
Activity 2.3 Rehabilitate distribution and transmission lines, including equipment and tools and repair of the electrical workshop at Betio					
SUB TOTAL					**6,290,000**

Strategy 3: Reducing non-technical losses

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 3.1: Meter audits to identify meter faults and preclude illegal power connections	PUB, contractor/ consultant	Very High	2017 –2020	Meter Audits report available Improves revenue collection Reduce non- technical losses from by-passed meters or damaged meters. A 5% reduction in non-technical loses over a 4-year period will reduce generation and save on fuel costs progressively up to AUD 156,250 pa. 700,000	5,000
Activity 3.2: Procurement of pre-payment meters and installation in all residential buildings and government offices	MISE, PUB, Board	Very High	2017 –2020		
SUB TOTAL					**705,000**

15.2 Energy efficiency in buildings

Goals	Indicators	Relevant Targets	Means of Verification	Risks and Assumptions
Goal 2: Improve energy efficiency in the electricity generation, buildings, water and sewerage and transport and cooking	**Indicator 1**: Total electricity demand for residential, government and commercial buildings reduced	12.32% reduction on electricity demand equivalent to 2,586MWh avoided from generation by 2025	PUB statistics Energy Balance Energy security Indicator	Funding opportunities Technical capacity Political support

Strategy 1: Energy savings in residential buildings

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 1.1. CFL promotion – to replace incandescent lights with CFL a cost of AUD 15.00 per light. Target: 1,408 light bulbs to be replaced by 2025	EPU – MISE PUB, private sector and communities (NGOs)	Very High	2017–2025	Reduced use of fossil fuel, savings on electricity costs	21,116
Activity 1.2 Replacement of 4 feet LTL tube lights with LEDs. Targeted number of LTLs:5 2,815 (40%) of total households by 2025 at a cost of AUD 40.00 per light	EPU – MISE, PUB, private sector and communities (NGOs)	Very High	2017–2026	Reduced use of fossil fuel, savings on electricity costs	70,385
Activity 1.3 Replacement of 2 feet LTL tube lights with LEDs Targeted number of 2 ft. LTLs: 2,815 (40% of total households) by 2025 at a cost of AUD20.00 per light	EPU – MISE, PUB, private sector and communities (NGOs)	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	35,193
Activity 1.4 Adopt and implement the use of energy efficient labels and standards for freezers, refrigerators through an amendment to the Consumer Act- Kiribati Cash Advance from PALS is FJD 80,000 equivalent to AUD 51,000.00. This activity includes awareness programmes targeted at communities	EPU – MISE, MCIC	Very High	2017–2020	Reduce use of fossil fuel, savings on electricity costs	929,863
SUB TOTAL					**1,056,556**

Strategy 2: Energy savings in commercial buildings

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 2.1 Replacing 4 ft. LTLs with LEDs lights in 40% of commercial buildings by 2025. This is equivalent to 371 commercial buildings or 1,112 lights replacement	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	9,266
Activity 2.2 Replacing 1112 x 2 ft. LTLs with 2 ft. LED lights	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	4,633
Activity 2.3 Replacing inefficient air conditioners in 40% of commercial buildings (Kiribati PALS)	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	882,607[20]
Activity 2.4 Replacing inefficient refrigerators (Kiribati PALS)	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	
SUB TOTAL					**896,506**

Strategy 3: Energy savings in government offices and industrial buildings

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 3.1 Replace 40 tube lights in 15 government ministry buildings. One ministry to change 100 tube lights to LEDs at a cost of AUD 40.00 per tube light	MISE, EPU, Architectural Division	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	112,500
Activity 3.2 Replace an average of 10 inverter type alternating current units per ministry at a cost of AUD 1,250 per AC	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	187,500
Activity 3.3 Ceiling Fans Regulations Switch and replacement of inefficient ACs to Fans	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2025	Reduce use of fossil fuel, savings on electricity costs	60,000
Activity 3.4 Building renovations and retrofits including fixing of door springs and proper insulation to keep cool air, etc. in all government buildings, including energy auditing activities	EPU – MISE, Building and Furnishing Division – MISE, private sector	Very High	2017–2020	Reduce use of fossil fuel, savings on electricity costs	390,000
SUB TOTAL					**750,000**

20 Additional investment already committed for legislation formulation for the PALS is AUD 47,256 (FJD 80,000)

Strategy 4: Energy efficiency in PUB buildings, water and sewerage pumps

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 4.1 Energy audits at PUB-owned buildings and implementation of recommendations	PUB, EPU	Very High	2017–2020	Increased revenue received for unbilled usages	5,000
Activity 4.2 Assessments of water pump performance, servicing and maintenance of water pumps	PUB	Very High	2017–2020	Reduce losses by at least half (50% by 25%), doubling of volume delivered and improved benefit of increased supply from other investments	216,000
Activity 4.3 Repairing water pipe leakages and installation of pre-payment meters and tariff rates	MISE	Very High	2017–2020		5,500,000
Activity 4.4 Current sanitation project to repair leakages and improve sewerage infrastructure including metering and tariff rates	STSISP, PUB, MISE	Very High	2017–2020	Reduce sewerage pump uses	2,500,000
SUB TOTAL					**8,221,000**

15.3 Energy efficiency in the transport sector

Goals	Indicators	Relevant Targets	Means of Verification	Risks and Assumptions
Goal 2: Improve energy efficiency in electricity generation, buildings, water and sewerage and transport and cooking	**Indicator 3**: Efficient sea ferry system developed for nearby outer islands	An efficient alternative transport option	Sea ferry/boat system available	Financial and Technical capacity Political Support
	Indicator 4: Reduction on fuel use for land transport for Ministries	A reduction on fuel use for transport sector for Ministries	Operation cost (fuel use for land transport)	Financial and Technical capacity Political Support

Strategy 5: More efficient sea transportation

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 5.1 Develop a cost-benefit analysis, including social impacts of the existing sea transportation to nearby outer islands (North Tarawa, Abaiang and Maiana) to provide recommendations for a more fuel efficient and safe uses	Civil Engineering Unit[21] EPU, MISE	Medium	2017–2018	A number of new multi-use wharves with priority for outer island ferry service	10,000
SUB TOTAL					**10,000**

21 Responsible for the design, construction and maintenance of basic national infrastructure, including transport, coastal and protection structures

Strategy 6: Efficiency in fuel use for government ministries

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 6.1: Conduct a cost-benefit analysis of centralizing all government buildings / departments in one location – preferably Bairiki— to reduce use of fuel for transport required for financial errands and attending meetings, etc.	Civil Engineering Unit EPU, MISE, Office of Te Beretitenti Building and Furnishing Division, MISE[22]	High	2017–2020	A cost-benefit analysis on fuel savings on transportation (land) for government ministries	3,000
Activity 6.2: Conduct wide consultation on the establishment of a centralised government building including ministers/cabinet, land department and land owners, urban planning, ministries, etc and presenting the findings of the cost benefit analysis report	EPU, MISE, Office of Te Beretitenti, Building and Furnishing Division, MISE	High	2018–2025	Wide consultations conducted at various sectoral levels	3,000
Activity 6.3: Develop a proposal on the investment required to centralise government departments in one location (Betio and Bikenibeu ministries move to Bairiki, if feasible and practical)	Ministry of Information, Communication, Transport and Tourism Development (MICTTD), EPU, MISE Building and Furnishing Division, MISE	High	2017–2020	A proposal and concept developed including investment required	2,000
Activity 6.4: Establish targets to reduce fossil fuel use for transport in all government ministries using the case study of MISE monitoring of transport fuel use	MICTTD, EPU, MISE Building and Furnishing Division, MISE	High	2017–2020	A target on land use transportation for government ministries established and adopted	2,000
SUB TOTAL					**10,000**

22 Responsible for the construction and maintenance of all government buildings and public premises, including ministry-related houses.

15.4 Energy efficiency and sustainable cooking

Goals	Indicators	Relevant Targets	Means of Verification	Risks and Assumptions
Goal 2: Improve energy efficiency in the electricity generation, buildings, water and sewerage and transport and cooking	**Indicator 5**: Number of households with access to modern forms of cooking fuel (LPG) in urban areas	75% of households in urban areas access to modern forms of cooking fuel (LPG) by 2025	Energy security indicators Project reports	Funding opportunities Household support and interest
	Indicator 6: Volume of kerosene imports for household use reduced	Kerosene imports reduced by 50% by 2025 (base-year 2014)	Energy security indicators Energy statistics	Funding opportunities Household support and interest to change ways of cooking
	Indicator 7: Number of households using improved cook-stove	100% households by 2025	Energy security indicators Energy Statistics	Funding opportunities Household support and interest ICS suppliers support

Strategy 7: Provides and supports the affordability of LPG

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 7.1 Government to consider the transfer of subsidies on kerosene to LPG and regulates the price of LPG gas and stoves; requires Cabinet submission	EPU – MISE, NGO[23], MCIC	Very High	2017–2018	Promotes the affordability of LPG compared to kerosene Improves saving on cooking fuels to households	0
Activity 7.2 Develop and deliver promotional materials, activities and training on LPG use. Carry out survey prior to monitoring the use of LPG	EPU – MISE, NGO	High	2017–2018	Public awareness is improved on benefits, advantages of using LPG over kerosene, Triggers the increase in demand.	13,000
Activity 7.3 Integrate and promote the use of alternative cooking fuels into other stakeholders' activities including Ministry of Women's Environmental Health (SODIS[24]) Foundation of the South Pacific Kiribati (FSPK) and other NGOs	EPU – MISE, NGO	High	2017–2025	Partnerships developed between organisations and increased awareness on issues such as SODIS, gardening (FSPK)	0

23 A registered NGO – KI-Gender CC signed an Memorandum of Agreement with SPC to implement the project "Cooking for Life Initiative", a partnership between SPC and NGOs/Private Sector to promote cleaner cooking fuels and technologies in the Pacific Region.

24 SODIS stands for Solar Water disinfection – a project initiated in South Tarawa, Kiribati by SPC Public Health Division to combat the water infection issues, thus offers a solution for preventing diarrhoea.

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 7.4 Establish and promote existing loan schemes offered at KHC and DBK	KHC, EPU-MISE, NGOs	Very High	2017–2020	Assess fund for initial capital costs for clean cooking fuels and technologies	0
SUB TOTAL					**13,000**

Strategy 8: Provides and supports LPG accessibility

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 8.1 KOIL investment to procure smaller cylinders (4.5 kg) to improve accessibility and portability (similar to kerosene)	KOIL	High	2017	Improves accessibility to LPG Improves portability, thus easier to carry/purchase LPG by younger children and women or those without transport who could walk to nearby LPG retailers	171,015
Activity 8.2 Review LPG retailing commission	KOIL	High	2017	Number of LPG retailers increased per village Easy access by potential users	0
Activity 8.3 Expand Gas Storage at KOIL to cater for increased demand or purchase of more isotainers, whichever cost is more economical	KOIL, gas retailers	Very High	2017–2020	Infrastructure for future demand available Increase number of households using LPG for cooking Increase number of isotainers per year from 16-17 per year to 42 isotainers per year	140,000
Activity 8.4 Pilot study of 100 starter kits to implement in South Tarawa through SPC financial support	SPC – EDD, NGOs, EPU-MISE	Very High	2017–2018	Improves accessibility of LPG Baseline information collected	5,150
SUB TOTAL					**316,165**

Strategy 9: Develop capacities related to LPG use, safety and health

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 9.1 Licensing of LPG storage is regulated OR amendment/review of the Petroleum Act to include LPG as one of the petroleum products (currently *not* included)	EPU – MISE	High	2018 –2020	LPG agents are licensed Increased understanding of safety and health measures	1,500
Activity 9.2 Increase promotional activities on LPG in all media, particularly radio programmes (as these are more accessible to most households)	NGOs, EPU – MISE	High	2017 – 2018	LPG demand increases and safety issues related to LPG used are evident	5,000
Activity 9.3 Conduct awareness raising on harmful effects of cooking fuels (kerosene and bioenergy smoke); but also awareness of the time and money savings that arise from alternative cooking fuel sources. To be conducted back-to-back with energy efficiency demand-side management and awareness programmes	KOIL, NGOs, EPU – MISE	High	2017	School children, women and men are aware of adverse health impacts of smoke from kerosene stoves and open fires	1,000
SUB TOTAL					**7,500**

Strategy 10: Increase access to improved bioenergy cook stoves

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 10.1 Government support of Cooking for Life – Project Steering Committee (PSC), its roles and functions	NGO, KOIL, EPU-MISE, and KHC	High	2017	Supports future projects on improving clean cooking fuels and efficient technologies Well-coordinated project and committee, actively reporting on project progress	500
Activity 10.2 Energy Programme – SPC financial support to NGO imports of ICS and implementation of project. Implement the 100 pilot starter kit	NGO, private sector, SPC-EDD – energy programme	Very High	2017	Funding support to import ICS Saving on firewood as fuel for cooking Initial capital evolves and more ICS purchased to meet target	8,175

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 10.3 Develop capacity for using ICS proposed under the South-South Collaboration (NZMFAT support)	SPC, NGO, EPU-MISE, private sector, donors	High	2017	Improves capacity on use of ICS	15,000
SUB TOTAL					**23,675**

15.5 Efficiency and safety in fuel procurement, handling and distribution

Goals	Indicators	Relevant Targets	Means of Verification	Risks and Assumptions
Goal 3: Sustainable, cost effective and incident free supply and distribution of petroleum fuels	**Indicator 1**: Incident-free, safe, management and operation of KOIL	No adverse incidents at KOIL-operated facilities	KOIL Annual Report	Financial and Technical Support Political Support
	Indicator 2: KOIL terminal management and staff fully and regularly trained in all aspects of fuel terminals and operations	All KOIL staff trained to an appropriately high level to deal with any reasonably foreseeable situation	Training reports	Training institutions identified Staff interest and trainers interest
	Indicator 3: Fuel pipeline from wharf to KOIL terminal properly segregated and secured	Pipeline secured to an appropriate standard	Inspection report Project report	Funding opportunities Technical capacity
	Indicator 4: Government inspectors are properly trained and qualified to administer fuel industry regulations	Appropriate regulations in place and enforced by qualified government officials	Training report EIA reports Regulations	Political support KOIL Interest and support Technical capacity
	Indicator 5: Provision of adequate and regular training on the safe and secure operation of commercial fuel supply sites	Commercial fuel operators trained to an appropriately high standard	Fuel operators training reports	Fuel industry operators interest KOIL interest and support
	Indicator 6: Emergency plans in place to cope with significant oil spills, terminal fires or supply disruption incidents	Formal plans in place and their operation periodically tested	Emergency Oil Spill Plan	Technical capacity availability KOIL interest and support

Strategy 1: KOIL management supported, supply secured and staff regularly trained

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 1.1: Undertake formal needs assessment of KOIL in terms of management, operations, environment, health and safety	SPC with intra-regional consulting group	Very High	2 months	KOIL management supported	20,000
Activity 1.2: Develop and implement a priority action plan to address a number of immediate and critically important KOIL operating issues, including terminal operations and maintenance and immediate staff training needs	KOIL with SPC support	Very High	3 months	Potential disasters averted	5,000
Activity 1.3: Physically segregate the fuel pipeline running from the wharf area and put in place measures to minimise the risk of damage to the pipeline, including proper signage	KOIL	Very High	1 year	Potential disaster averted	5,000
Activity 1.4: Develop and launch an international supply tender to establish reliable ongoing supply, favourable cost of acceptable quality fuels into Kiribati, supported by regular and adequate operator training and relevant technical support	KOIL with SPC support	High	6 months	Efficient, cost effective supply secured	10,000
Activity 1.5: KOIL to work with Ports Authority and Fire Authority to develop and implement emergency procedures with respect to oil spill management and fire incidents	KOIL, Ports Authority, Fire Authority. Ministry of Environment, Lands and Agriculture Development	High	6 months	Emergency plans developed and put into place	50,000
Activity 1.6: Develop an emergency fuel supply back-up plan that could be put into operation in the event of catastrophic failure of one or both of the KOIL bulk fuel terminals	KOIL	Medium	Within one year and trials annually	Emergency plan put into place, necessary logistics identified	2,000
SUB TOTAL					**92,000**

Strategy 2: Efficient fuel price management

Activities	Organisation Responsible, Supporting Organisations	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 2.1: Remove import duties on LPG in recognition of its clean burning characteristics and contribution to women and family health when used in preference to kerosene for cooking	KI government	Very High	3 months	Improved women and family health through better air quality in residences	0
Activity 2.2: Construct new LPG bulk import and filling facility	KOIL and/ or private operator	High	1 year	LPG bulk facility, significantly lower LPG prices	300,000
Activity 2.3: Develop and apply an effective liquid fuel and LPG pricing templates for all island groups	MCIC – Price Control Unit with SPC support	Medium	6 months	Equitable fuel pricing applied	2,000
Activity 2.4: Establish a formal 'industry issues' complaints process to promptly deal with all complaints, including weights and measures and fuel quality issues	Ministry of Commerce, Industry & Cooperatives	Medium	3 months	Consumer issues relating to fuels are heard and dealt with	3,000
Activity 2.5: Introduce regular inspection, cleaning, reconditioning and appropriate industry acceptable labelling of fuel drums and LPG cylinders.	KOIL – training	Medium	1 year	Appropriate information available to the public	10,000
SUB TOTAL					**315,000**

Strategy.3: Development of alternative fuels

Activities	Organisation Responsible	Activity/ Importance	Time Frame	Expected Outputs/Results	Estimated Cost (AUD)
Activity 3.1: Explore the feasibility of the development of alternative liquid fuels based on indigenous raw materials, such as coconut	Energy Planning Unit	Medium	1 year	Commercially viable alternative fuels	5,000
SUB TOTAL					**5,000**

16 RENEWABLE ENERGY IMPLEMENTATION PLAN

	Results chain	Indicators	Current value (2016)	Target (2025)	Sources and means of verification
Overall objective: Impact	Impact: Increased renewable energy in the national energy system				
Specific objectives: Outcomes	Oc 1: Increase renewable energy share in power generation	No national target. Targets defined by Island. See Op 1.1, 1.2 and 1.3			
	Oc 2: Introduce renewable energy in transport	Renewable energy options available for all forms of Island transport			
	Oc 3: Use renewable energy to support reliable and affordable water supply	RE-power water desalination systems with efficient water supply systems in operation			
	Oc 4: Establish sustainable local biofuel production based on coconut oil (CNO)	Sustainable CNO supply chain established			
Outputs	Op 1.1: Renewable energy deployment in the power system of South Tarawa	Percent reduction in fossil fuel use from renewable energy	12.1% (annual RE share)	23% *IRENA analysis shows a least cost RE share of 35%*	PUB generation data
	Op 1.2: Renewable energy deployment in the power system of Kiritimati	Percent reduction in fossil fuel use from renewable energy	ca. 50 kWp PV	40% *IRENA analysis shows a least cost RE share of 60% in Zone 1 and 83% in Zone 2*	PUB and Ministry of Line and Phoenix generation data
	Op 1.3: Renewable energy deployment for electricity supply in the Outer Islands	Percent reduction in fossil fuel use from renewable energy	1,229.8 kWp PV	1) 40% rural public infrastructure 2) 100% rural public and private institutions	Government statistical data
	Op 2.1: Renewable energy pilot deployment in marine transport	Successful pilot test of inter-island renewable energy catamaran	Possible catamaran configuration defined	Pilot test completed(2017)	Government statistical data
	Op 2.2: Renewable energy deployment in land transport	Reduction in fuel imports from renewable energy land transport	0	Study required to develop target	Government statistical data
	Op 3.1: Renewable desalination deployment in South Tarawa	Number of systems (single system capacity: 528,000 litres/day)	0	5	Government statistical data
	Op 3.2: Renewable desalination deployment in outer islands	Data on water usage for all outer islands	0	All outer islands	Government statistical data
	Op 4.1: Establish local, CNO-based biofuel production chain	Litres/year of biofuel available in local market	0	Study required to develop target	Government statistical data

Activities	A 1.1.1: Deployment of additional 1500 kWp PV and 264 kW / 560 kWh Li-ion battery storage	Percent of annual generation (kWh) from renewable energy	12.1%	21.5% (2017)	PUB generation data
	A 1.1.2: Deployment of an additional 1000 kWp PV and additional 2376 kW / 5040 kWh Li-ion battery storage	Percent of annual generation (kWh) from renewable energy	12.1%	35%	PUB generation data
	A 1.2.1: Deployment of 200 kWp PV, 275 kW wind and 264 kW / 560 kWh battery storage in Zone 1	Successful deployment of PV, wind and battery systems	ca. 30 kWp PV	60%	PUB and Ministry of Line and Phoenix data
	A 1.2.2: Deployment of 150 kWp PV, and 165 kW / 350 kWh battery storage in Zone 2	Successful deployment of PV and battery systems	ca. 20 kWp PV	83%	PUB and Ministry of Line and Phoenix data
	A 1.3.1: Deployment of PV in rural public infrastructure	kWp of PV deployed	2.4 kWp	627.4 kWp	Government statistical data
	A 1.3.2: Deployment of PV in rural public and private institutions	kWp of PV deployed	1227.4 kWp	1763.5 kWp	Government statistical data
	A 2.1.1: Pilot testing of RE powered inter island catamaran	Successful test of RE powered catamaran	Possible catamaran configuration defined	Pilot test completed (2017)	Pilot test final report
	A 2.2.1: Deploy sufficient renewable energy generation to support EV charging	Dedicated study on RE requirements for EV charging in Kiribati	0	Completed study (2017)	Completed study final report
	A 2.2.2: Deploy EV charging infrastructure	Number of EV charging stations	0	Study required to develop target	Government statistical data
	A 2.2.3: EVs available in local market	EVs as percent of new car sales	0	Study required to develop target	Government statistical data
	A 3.1.1: Short term reduction of losses in water distribution system	Percent of water lost in distribution system	60% (2015)	20% (2017)	Government statistical data
	A 3.1.2: Short term increased rain water collection	Percent of households with rain water collection tanks	10% (2015)	25% (2017)	Government statistical data
	A 3.1.3: Short term deployment of PV RO desalination systems	Number of systems (single system capacity: 528,000 litres/day)	0	2 (2017)	Government statistical data
	A 3.1.4: Long term reduction of losses in water distribution system	Percent of water lost in distribution system	60% (2015)	15%	Government statistical data
	A 3.1.5: Long tem increased rain water collection	Percent of households with rain water collection tanks	10% (2015)	65%	Government statistical data
	A 3.1.6: Long term deployment of PV RO desalination systems	Number of additional RO PV systems (single system capacity: 528,000 litres/ day)	0	3 (5 total)	Government statistical data
	A 3.2.1: Document water usage in outer islands to assess losses and potential for desalination	Percent of outer islands with detailed water usage studies	0%	100%	Government statistical data
	A 3.2.2: Deployment of desalination systems	Number of planned systems (Table 30)	0	13	Government statistical data
	A 4.1.1: CNO for diesel power generation	Percent of annual diesel generation powered using CNO	0%	100%	PUB generation data
	A 4.1.2: CNO for diesel land transportation	Percent of diesel vehicles using CNO	0%	100%	Government statistical data
	A 4.1.3: CNO for diesel marine transportation	Percent of diesel marine vessels using CNO	0%	100%	Government statistical data

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APPENDIX: NATIONAL ENERGY BALANCE 2000–2014

Energy Balance GJ

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Production	**503,522**	**503,073**	**502,684**	**502,289**	**503,320**	**503,137**	**510,687**	**518,366**	**526,100**	**533,925**	**540,933**	**547,985**	**554,789**	**560,904**	**567,467**
Solar PV	468	468	468	468	1,763	1,859	1,843	1,840	1,772	1,673	1,127	965	868	370	583
Biomass	503,055	502,605	502,216	501,822	501,557	501,278	508,843	516,526	524,328	532,252	539,806	547,020	553,921	560,535	566,884
Imports	**607,450**	**615,402**	**715,150**	**782,777**	**789,106**	**770,462**	**792,326**	**783,769**	**786,394**	**752,210**	**736,283**	**780,852**	**845,764**	**837,641**	**842,998**
ADO	395,874	386,881	458,693	451,348	483,727	485,582	496,090	487,359	497,589	467,443	432,458	437,994	474,758	467,230	491,251
MOGAS	125,752	135,807	142,819	178,580	194,234	184,020	190,510	178,883	175,531	179,853	167,057	209,593	227,941	236,560	222,459
Avgas	530	530	530	530	530	530	530	530	530	530	1,192	530	530	0	0
Kerosene	68,086	71,786	80,123	109,492	90,636	83,560	90,698	102,802	100,359	93,418	125,942	121,067	125,916	117,852	115,717
LPG	7,583	8,525	22,354	32,583	16,215	14,957	13,990	13,774	11,687	9,142	5,366	7,419	9,365	12,166	7,300
Lubricants	9,625	11,873	10,631	10,243	3,764	1,813	509	422	698	1,824	4,268	4,249	7,254	3,762	6,271
Exports	**46,581**	**35,878**	**52,496**	**46,526**	**44,153**	**47,611**	**47,086**	**44,666**	**42,070**	**50,342**	**46,511**	**22,582**	**23,568**	**25,687**	**19,755**
Kerosene - International Aviation	46,581	35,878	52,496	46,526	44,153	47,611	47,086	44,666	42,070	50,342	46,511	22,582	23,568	25,687	19,755
Stock changes & statistical differences (GJ)	**1,258**	**57,072**	**68,629**	**127,930**	**88,547**	**20,329**	**-8,788**	**-29,952**	**3,332**	**-13,070**	**-24,576**	**43,831**	**94,888**	**-37,873**	**53,048**
ADO	30,624	46,549	76,723	84,474	55,670	10,625	-12,363	-29,217	444	-6,239	-6,311	6,283	45,019	-32,788	37,485
MOGAS	-14,572	10,717	9,078	17,888	29,843	9,631	10,406	1,832	4,404	6,107	-8,940	28,609	35,547	-3,679	15,593
Kerosene	-14,794	-194	-17,172	25,568	3,034	73	-6,830	-2,567	-1,515	-12,937	-9,324	8,940	14,323	-1,406	-30
LPG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Avgas – Air	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lubricants	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Primary Energy Supply (TPES)	**1,063,133**	**1,025,525**	**1,096,708**	**1,110,610**	**1,159,727**	**1,205,659**	**1,264,715**	**1,287,422**	**1,248,862**	**1,255,280**	**1,262,423**	**1,282,096**	**1,282,096**	**1,410,731**	**1,337,662**

ANNEX: SOUTH TARAWA OTEC PROJECT

Kiribati is poised to become a global leader in the deployment of ocean thermal energy conversion (OTEC). In cooperation with the Korea Research Institute of Ships and Ocean Engineering (KRISO), Kiribati plans to deploy a 1 MW OTEC plant off the coast of South Tarawa. The plant, made possible by funding from the Ministry of Oceans and Fisheries of the Republic of Korea, will be one of the first grid connected OTEC systems in the world. This annex provides an overview of the planned OTEC project and its potential impact on the power system of South Tarawa.

OTEC function

OTEC is a renewable energy technology that uses the temperature difference between warm surface water and cold deep ocean water to drive a cycle in which a working fluid is repeatedly vaporized and condensed to power an electric generator. OTEC is most effective in coastal areas where the water surface temperature is consistently warm year round and deep waters are accessible a short distance from the coast, this makes South Tarawa an ideal location for OTEC. OTEC plants are designed to provide 24-hour power generation with minimal downtime required for maintenance. However, it should be noted that OTEC is an emerging technology and data on performance, cost and reliable operation at scale are still being established.

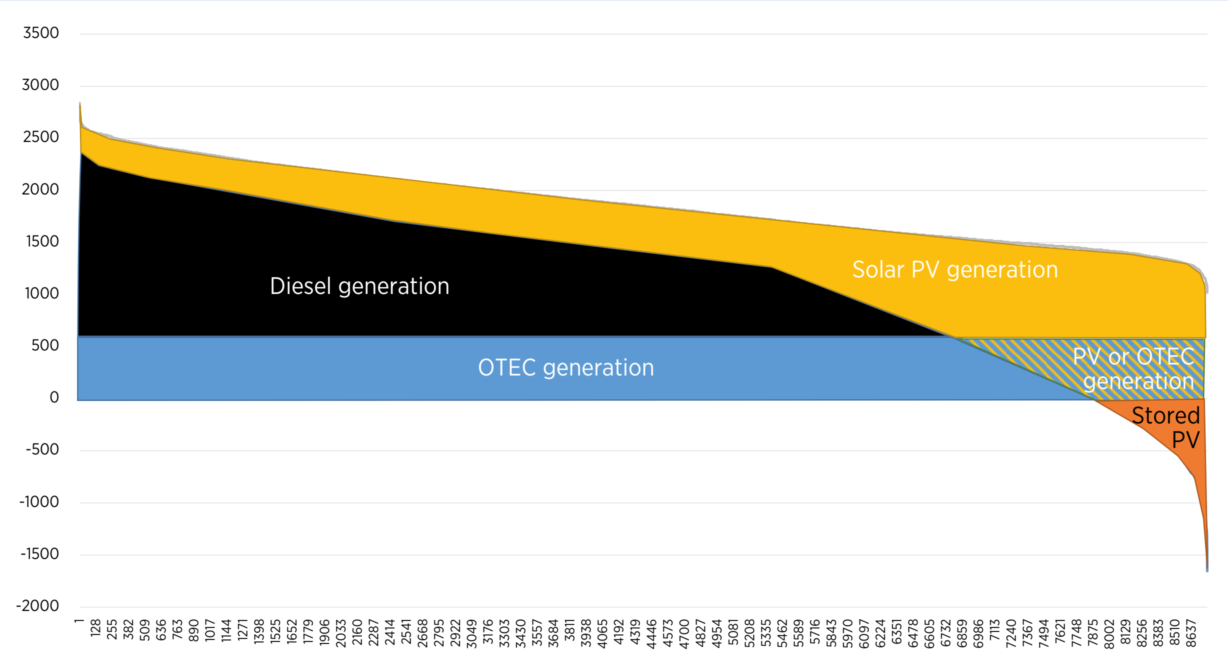
South Tarawa OTEC project details

The planned OTEC plant in South Tarawa has a gross capacity of 1 MW and a net generation capacity of 600 kW (400 kW of power are required to operate the

Conceptual drawing of the South Tarawa OTEC plant

Source: Tidalenergytoday.com

Figure 2: South Tarawa 2025 residual load duration curve



plant, primarily for pumping of sea water). The plant, shown in Figure 1, consists of an octagonal floating platform with four decks measuring 35 meters across and weighing 6,700 tonnes.

It is currently planned to locate the plant six kilometres off the coastline of South Tarawa were the water depth is 1,300 meters. Cold seawater will be brought to the surface from a depth of 1,000 meters through a 1.2-meter diameter pipe and used for power generation, which will be supplied to the island via an undersea cable. The current project schedule aims for deployment of the OTEC plant in 2019, with full time operation slated to commence in 2020. It should be noted that the South Tarawa OTEC plant is a grant funded research project and that one of the primary aims is preforming technology demonstration based on a certified design.[21]

OTEC plant potential impacts

Based on the available data IRENA has conducted a simplified analysis of the impacts of the planned OTEC plant on 2025 the South Tarawa power system, assuming an electricity demand of 16 GWh/year and the deployment of a total solar PV capacity of 3.92 MW. Figure 2 gives the 2025 load duration curve for south Tarawa with specific areas indicating the estimated generation from different technologies and the possible need for storage or curtailment of PV.

Figure 2 indicates that OTEC can make a strong contribution towards increasing the share of renewable energy generation, the entire blue "OTEC generation" section of the chart shows diesel generation that would be displaced by OTEC. However, Figure 2 also indicates that OTEC would also have a significant impact on the overall operation of the power system in South Tarawa. A dedicated study based on detailed performance characteristics of the OTEC system is warranted to determine how the planned OTEC plant would affect the optimal generation mix and operational strategy for maximizing generation from renewable sources.

The right-hand side of the chart illustrates the potential excess generation from solar PV. Part of this can be stored in the battery system for use later in the day, part will be curtailed. With the introduction of OTEC, excess generation from PV is expected to increase, which might suggest a reduction in PV capacity in the optimal

21 *http://www.bureauveritas.com/home/news/business-news/ocean-thermal-energy-converter-approved-290116?presentationtemplate=bv_master_v2/news_full_story_presentation_news_v2*

Table 1: OTEC performance potential

Gross capacity (MW)	Generation capacity (MW)	Capacity factor	Annual operation (hours)	Annual generation (MWh)	Share of 2025 demand
1	0.6	80%	7,008	4,205	26%

energy mix. Assuming the system would be operable with only OTEC, PV and battery storage, the amount of excess energy from PV that will have to be partly stored and partly curtailed could reach 1,171 MWh/year. Based on simulations without the OTEC plant, it is likely that the part in orange will be stored in the battery, while the part overlapping with OTEC generation will be curtailed. If this is the case, the additional curtailment would be 330 MWh/year, in addition to what was already curtailed without the OTEC plant (ca. 700 MWh/year), increasing curtailment from 4.3% to 6.3% of potential PV output.

If this is confirmed once data become available to simulate the dispatch and develop an updated grid study of the system with the OTEC plant in operation, this remains a completely acceptable level of curtailment, which does not significantly affect the economic performance of the system and does not call for a reduction in PV capacity.

Assuming that a clear strategy can be found to allow for 100% utilization of the OTEC plant, IRENA performed a simple analysis to determine the plant's impact on the annual renewable share in 2025. This analysis assumed that the contribution from PV would remain the same as in the roadmaps least-cost generation systems, with the additional curtailment of 330 MWh/year as discussed. The results of this analysis are given in Table 1 and Table 2.

The analysis presented in Table 1 and Table 2 indicates that the planned OTEC plant has the potential to increase the annual renewable energy share in 2025 by 26% which in combination with PV would cover over 60% of total electricity demand. However, as noted a complete understanding of the impacts of the planned OTEC plant and how it can best support an optimal generation mix requires a dedicated study based on a detailed understanding of the performance, cost and operational characteristics of the OTEC plant.

Table 2: OTEC impact on 2025 RE share

2025 demand (MWh)	Optimal PV and battery system		Optimal PV and battery system combined with OTEC plant	
	RE generation (MWh)	RE share	RE generation (MWh)	RE share
16,380	5,733	35%	9,938	61%

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