Report

IRENA
International Renewable Energy Agency

Pacific Lighthouses

Renewable energy opportunities and challenges in the Pacific Islands region

Tokelau

August 2013

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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Preface

In the Abu Dhabi Communiqué on accelerating renewable energy uptake for the Pacific Islands (of 13 January 2012), leaders from the Pacific Island Countries and Territories (PICTs) called on the International Renewable Energy Agency (IRENA) to "...map the Renewable Energy Readiness of the Pacific Islands Countries and Territories to ascertain the status of renewable energy opportunities and identify pathways to close gaps" and to integrate all IRENA activities in the region "...into a coherent roadmap for the Pacific Islands". In response, IRENA has carried out a wide range of activities of specific relevance and application to the PICTs as well as other Small Island Developing States (SIDS). This work has now been integrated into the IRENA report: ***Pacific Lighthouses: Renewable Energy Roadmapping for Islands***.

The report consists of an overview roadmap framework and 15 island-specific studies on the respective energy situations, and the challenges and opportunities for renewable energy deployment, around the region. These studies are available for the Cook Islands, the Federated States of Micronesia, the Republic of Fiji, Kiribati, the Republic of the Marshall Islands, the Republic of Nauru, Niue, the Republic of Palau, Papua New Guinea, Samoa, the Solomon Islands, the Kingdom of Tonga, Tokelau, Tuvalu and the Republic of Vanuatu. The IRENA Pacific Lighthouses report draws on those studies, as well as an additional study on a diesel-renewable energy hybrid power system, intended as a transition measure to a renewables-based energy future for the PICTs, which is also part of the series.

IRENA, in collaboration with its members and other key development partners, will continue to support the development national roadmaps and strategies aimed at enhanced deployment of renewables in the Pacific and other island states and territories.

Acronyms

AC	Alternating current
Ah	Ampere-hour (battery capacity)
C_{20}	Capacity in amount of hours in which a battery will discharge
CIA	Central Intelligence Agency
DC	Direct Current
DoE	Department of Energy
EOI	Expression of Interest
GDP	Gross domestic product
kWh/year	Kilowatts–hour per year (thousands of watt-hours per year)
kWh/m²/day	Kilowatts per square metre per day (measure of solar energy)
kWp	Kilowatts peak of solar panel capacity (at standard conditions)
LPG	Liquefied Petroleum Gas
NZD	New Zealand dollars (currency)
OTEC	Ocean Thermal Energy Conversion
PV	Photovoltaics
TPS	Tokelau Public Service
UNDP	United Nations Development Programme
USD	United States dollars (currency)
USP	University of the South Pacific
V	Volts

1. Country context

Figure 1. Maps of Tokelau and its location in the Pacific

Source (upper map): Adapted from the Perry-Castañeda Library Map Collection, University of Texas.
Source (lower map): Adapted from the CIA World Fact Book.

The boundaries and names shown on this map do not imply official acceptance or endorsement by the International Renewable Energy Agency.

Physical Description. Atafu, Fakaofo and Nukunonu – the three atolls that make up Tokelau – are located about 500 km north of Samoa and have a total of 12 km^2 of land area. Each atoll consists of a lagoon enclosed by a curving reef on which there is a series of coral islets (*motus*), typically less than 200 metres wide, separated by stretches of reef. The highest land point is less than five meters above sea level.

Each of the three atolls has a single population centre, with those of Atafu and Nukunonu on the same islet, while Fakaofo's population is split across two adjacent islets.

Population: The most recent census (2011) recorded 1411 persons usually resident in Tokelau. The census found that 35% of the population lived on Atafu, 36% on Fakaofo and 29% on Nukunonu. The Tokelauan population in New Zealand is around 6800 according to the New Zealand Census of 2006. The median age in Tokelau is around 20 and there are approximately six persons per household.

Environment. Tokelau's environment is tropical marine. The atolls are especially vulnerable to environmental damage and the water supply is easily affected by pollutants. Land biodiversity is low. The primary dangers to the environment are tropical storms and waste from the settlements. Direct impacts from cyclones are not common, although the high waves and storm surges caused by near passages of cyclones can cause serious damage.

There are over 1000 private outboard-powered boats, but only a small number of private automobiles in Tokelau. Each atoll has a government truck and/or tractor and various heavy machinery, mostly used to transfer goods from landing sites to a warehouse, or to undertake work on the reef channels and other village projects. None of the atolls has a wharf, although all have a landing dock. All ships must anchor in the open ocean and use small craft to land goods which are transferred by hand, forklift or mobile crane onto the island's flatbed trucks.

Economic overview. Most of the employment in Tokelau is provided either by the TPS or the Taupulega (Council of Elders, of which there are three in Tokelau). There is a low level of unemployment and anyone over 15 (if they are no longer in school) can join the workforce. In 2011, around 55% of the working age population was employed by the local or national TPS with the rest of those wishing to be employed working for the Taupulega. The primary source of funds is New Zealand. The sale of licences for foreign fisheries to operate in the Tokelau Exclusive Economic Zone (EEZ) is a distant second source of income, although in recent years revenue from this licensing has grown significantly, earning approximately NZD 3.8 million (USD 3.2 million) a year. Attempts to develop a local fishing industry have been unsuccessful, and Tokelau has no real export income. Remittances from family members in New Zealand provide a significant source of cash income for residents. Imports consist mainly of foodstuffs, clothing and fuel. There are no airports on Tokelau and all transport is by sea. The *PB Matua* is chartered by the New Zealand government and, except when unavailable such as when undergoing repairs, provides the bulk of shipping and passenger service to and from Samoa and Tokelau, with voyages are typically separated by a fortnight. Private enterprise is mainly limited to trading, although a few individuals provide services business services.

The Tokelau International Trust Fund was formed in 2004 by the Governments of Tokelau and New Zealand with the aim to support the long-term financial sustainability of Tokelau; today the fund has a value of approximately NZD 70 million (USD 58 million)[2.1]. Tokelauan handicrafts are highly detailed and provide some income, as do commemorative stamps and coins. Copra, once a significant export, is no longer an income source and has not been so for many years.

According to the CIA World Factbook, Tokelau has a very small economy with a gross domestic product (GDP) of approximately USD 1.5 million (NZD 1.83 million) in 2010.

1 See, for example, http://www.ausaid.gov.au/countries/pacific/tokelau/Pages/initiative-tokelau-international-trust-fund.aspx

2. Energy landscape

Institutional and regulatory arrangements for energy

Department of Energy and Taupulegas. The electricity supply is managed by individual Taupulega, with standards and technical support provided by the Department of Energy (DoE). Petroleum imports are also managed by the Taupulega through the stores on each island.

National Energy Policy and Strategic Action Planning (NEPSAP) 2004. The National Energy Policy and an associated strategy documents include strong energy efficiency measures and set a goal of a 100% renewable energy supply, leading to the development and implementation of the Tokelau Renewable Energy Project (TREP) that was completed in 2012. The DoE will coordinates future renewable energy development and is expected to concentrate on coconut oil as a diesel fuel replacement with the goal of 100% renewable electricity generation.

Energy supply and demand.

Petroleum. Until 2012, all power generation was by diesel engines which consumed around 160 000 litres of the 162 000 litres of imported diesel, with the remainder used for transport (Figure 2). Currently, with nearly all electricity generation coming from solar, most of the remaining petroleum imports, predominately petrol and diesel fuel, are for transport. Kerosene is mostly used for cooking. Each atoll has all of its households connected to the electricity grid and power is provided 24 hours a day. Petrol and kerosene are shipped from Samoa in drums while diesel is either shipped in drums or transferred from tanks on cargo vessels into drums on arrival at each atoll.

Tokelau's fuel consumption is quite low, mostly going to inter-island transport and cooking. Tokelauans use mostly kerosene, liquefied petroleum gas (LPG) or electricity for cooking, along with some traditional biomass. The per capita import of LPG is approximately 5 tonnes of LPG per year. Currently, most of the imported diesel

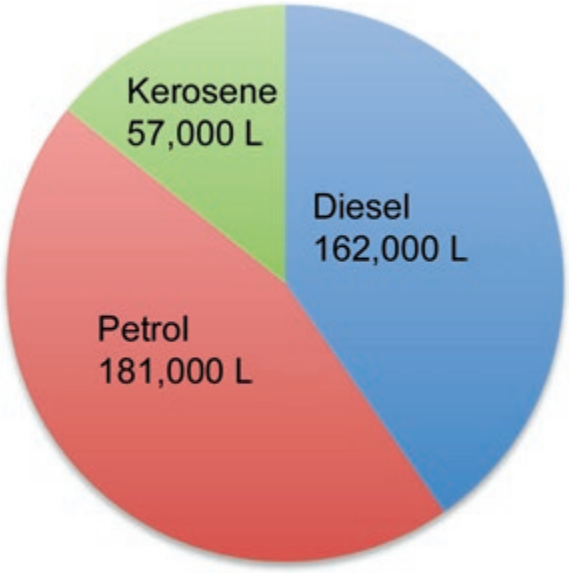

Figure 2. Imported fuel 2011

Source: Provided through communication by the Tokelau Energy Office (2012).

is used for backing up the solar electricity generation system, while petrol is used for outboard motorboats and kerosene for cooking. The PB Matua ship is by far the largest user of diesel fuel but its consumption is not included in fuel imports figures of Tokelau as the ship normally refuels in Samoa.

Electricity generation and demand. Upgrading and reconditioning of the electric power system on each atoll was completed in 2005. New diesel generators and powerhouses, as well as refurbished distribution facilities have improved the efficiency and reliability of services. After the installation of solar photovoltaics (PV) power systems, diesel engines have remained in service as a back-up power source. Solar generation can be mixed with diesel power and the diesel engines can be used to charge batteries if necessary.

The domestic sector is the largest user of electrical energy. According to the 2011 census, over 95% of households own a refrigerator or freezer, 67% own a video system and 63% a shared washing machine. Total electricity use in 2008 was about 677 MWh (Table 1) with strong load peaks in the evening (Figure 3).

Commercial energy use is small. TeleTok is the largest single electricity user although commercial-scale freezers for fish were installed on each atoll as part of an earlier unsuccessful attempt to start a local fishery. Although not currently in use, the freezers would be the largest user by a large margin if put back into service. A ban on government use of air-conditioners has allowed the government sector to remain a modest user of energy.

Assuming business continues as usual, nominal energy demand growth is expected, with little growth in fuel consumption except with LPG for cooking. Kerosene use is expected to fall in step with the rise in LPG use. If the strong measures for energy efficiency and renewable energy measures embodied in the draft National Energy Plan and Strategy document are carried out, energy usage figures for 2013 may be slightly lower than those for 2012, with reductions continuing in subsequent years due to planned investments in energy efficiency.

Electricity tariffs. The tariff paid for electricity varies by island but the base rate is NZD 0.50.

Table 1. Power system statistics (2008)

Island	Peak load kW	kWh/year	Annual Fuel Usage in litres
Fakaofo	51.2	255 100	94 540
Atafu	38.0	201 800	100 470
Nukunnu	36.7	219 400	76 650

Source: Provided through communication by Tokelau Energy Office (2012).
Where kW is kilowatts; kWh/year is kilowatt-hour/year.

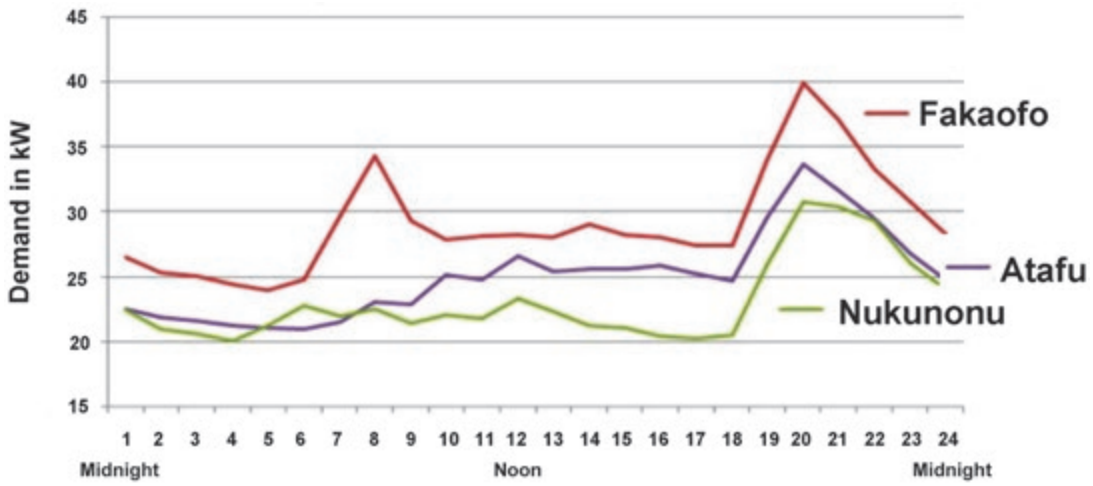

Figure 3. Load curves

Source: Provided through communication by Tokelau Energy Office (2012).

3. Renewable energy opportunities

Biomass. There has been no biomass resource survey in Tokelau to date. The majority of land is unpopulated and densely covered with coconut trees and other woody plants. The biomass resource potential, on a per-capita basis, is therefore substantial. However, developing biomass for energy would not be feasible since transporting low-density biomass fuels between distant islets by small boats would be expensive as well as environmentally costly.

Biofuel. The large number of coconut trees in Tokelau makes coconut oil a logical replacement for fossil fuels. While solar PV has proven economical to meet 90% of electricity demand, diesel engines operating on coconut oil could supply the remaining 10% of electrical energy cost-effectively, given sufficient planning and attention to the logistics of coconut supply.

Biogas. Biogas could replace at least part of the LPG used for cooking if Tokelau's approximately 2000 pigs and 3000 chickens were concentrated in larger groups. Making biogas production viable would require changing the way pigs and chickens are kept, and developing the infrastructure to make, collect and distribute the gas.

Solar energy. The Tokelau solar resource, typical of Pacific island countries, provides around 5.5 kWh/m^2/day with some seasonal variations. The strength of the resource is sufficient to make large-scale implementation of solar PV use technically feasible. At least 90% of electricity demand is presently being met by solar PV with battery storage.

Solar thermal energy for water heating is also economically viable but there is currently little demand for piped hot water.

Wind power. No wind data are available for most of Tokelau. Given the limited land area and the fact that the land is covered by coconut trees that are of economic value, wind installations are only likely to be viable on the reef or in the lagoon.

Hydropower. There is no hydro resource.

Wave energy. Wave energy conversion systems have not been well-tested under Pacific island conditions though there appears to be a moderate resource of the order of 20 kilowatt/metre (kW/m) of wave front in Tokelau.

Ocean Thermal Energy Conversion (OTEC). There is likely to be a large OTEC resource but the current power demand is too small to warrant deployment of this technology in Tokelau.

Geothermal energy. There is no known geothermal resource.

4. Experiences with renewable energy technologies

Up until 2012, when the conversion to solar power began, the only renewable energy installations were those of TeleTok (the telecommunications company) – which has solar installations on each atoll – and the University of the South Pacific (USP) which has installed solar PV at its facility at Atafu.

At least 90% of Tokelau's electricity demand is already being supplied by solar. To achieve 100% renewable generation, Tokelau plans to convert all back-up diesel generators and local boats that have diesel engines to run on coconut oil.

The Tokelau Renewable Energy Project (TREP).

In 2012, the Tokelau Renewable Energy Project installed solar arrays on each atoll and Tokelau now already produces over 90% of its electricity from solar energy.

The TREP process

The process used by Tokelau to reach the goal of 100% renewable generation is a model for similar efforts in the Pacific Islands region. First, the government of Tokelau developed an energy policy and strategy that included concepts for reaching the 100% renewables goal. They then undertook a small-scale, 10 kilowatts-peak (kWp) trial of a solar installation on Fakaofo to determine the ability of the solar resource to provide the power needed as well as evaluate the suitability of the power utility to run and maintain the installation.

In 2005, the development of the 10 kWp solar array with an associated battery and inverter system was trialled to supplement the Fakaofo electricity grid with PV-generated power, with a view to later installing a much larger PV system to replace the diesel generator. Although there were some technical problems with the inverters, overall the trials were successful and demonstrated that the construction of the solar arrays and battery banks provided a technically reasonable and sustainable way to meet 90% or more of each island's load. This paved the way for the implementation of the large-scale solar installations now in place in Tokelau.

At the same time as the 10 kWp technical trial was underway, consultants were contracted to examine energy use and recommend the best approach to take to reach the 100% renewable electricity generation goal. The Government opted for the recommendation to proceed with an approach that relied mostly on solar, but with diesel engines fuelled by coconut oil as back-up. At around the same time the electricity supply system was rehabilitated so that the solar power coming online would feed an efficient and appropriate grid with a reliable diesel back-up.

The next step was the request for expressions of interest (EOI) for the solar installations. Each company was asked to provide a design concept and approximate cost for the installations. A shortlist was made from EOI respondents based on the quality of their response and appropriateness of their sample design.

Between the pre-EOI period and the completion of the tender, funding was sourced and assigned to the project, so that it could proceed as soon as a tender respondent was selected. The project cost was about NZD 8.5 million (USD 6.95 million) and completed in October 2012.

Solar System Design. As shown earlier in Figure 3, all three islands have sharp load peaks early in the morning and in the evening. The curves profile does not change much over the week since air-conditioning is not used.

All three islands have solar installations based on a cluster design, with multiple clusters connected in parallel to reach the required capacity (Table 2). In the case of Tokelau, the three-phase cluster design incorporates a combination of alternating current (AC) and direct current (DC) bus charging[2]. The AC bus component includes 20 kWp of solar driving seven SMA Sunny Boy 3000 inverters. The DC bus includes 13 kWp of solar driving four SMA SI 50 48V 50A MPPT controllers with outputs connected in parallel, and with three Sunny Island 5048 inverters operating off the battery. Each cluster requires a battery bank consisting of pairs of 2 V cells in parallel with a capacity of 3200 Ah if discharged over 20 hours (C20), connected in a string to make a

2 http://www.tokelau.org.nz/Solar+Project.html. Further details of the Tokelau solar project can be found in the case study report available for download from: http://www.itpau.com.au/wp-content/uploads/2013/05/TREP-case-study.pdf

Table 2. Solar installation characteristics

Island	kWp of solar	Total battery Ah capacity at 48V
Fakaofo	330	70 400
Atafu	297	57 600
Nukunonu	264	51 200
TOTAL	**891**	**179 200**

Source: Provided through communication by Government of Tokelau (2012).
Where Ah is Ampere-hour; V is volts.

48 V 6 400 Ah (or larger) battery at C20 discharge rate (Figure 4). Thus each cluster represents 33 kWp of solar.

The way forward. With the commissioning of the last of the three solar PV island power systems in 2012, a high percentage of the 100% renewable energy goal was reached. However, to reach a true 100%, Tokelau must now focus on developing the ability to locally produce the fuel needed for transport and for the diesel engines that back up the solar installations.

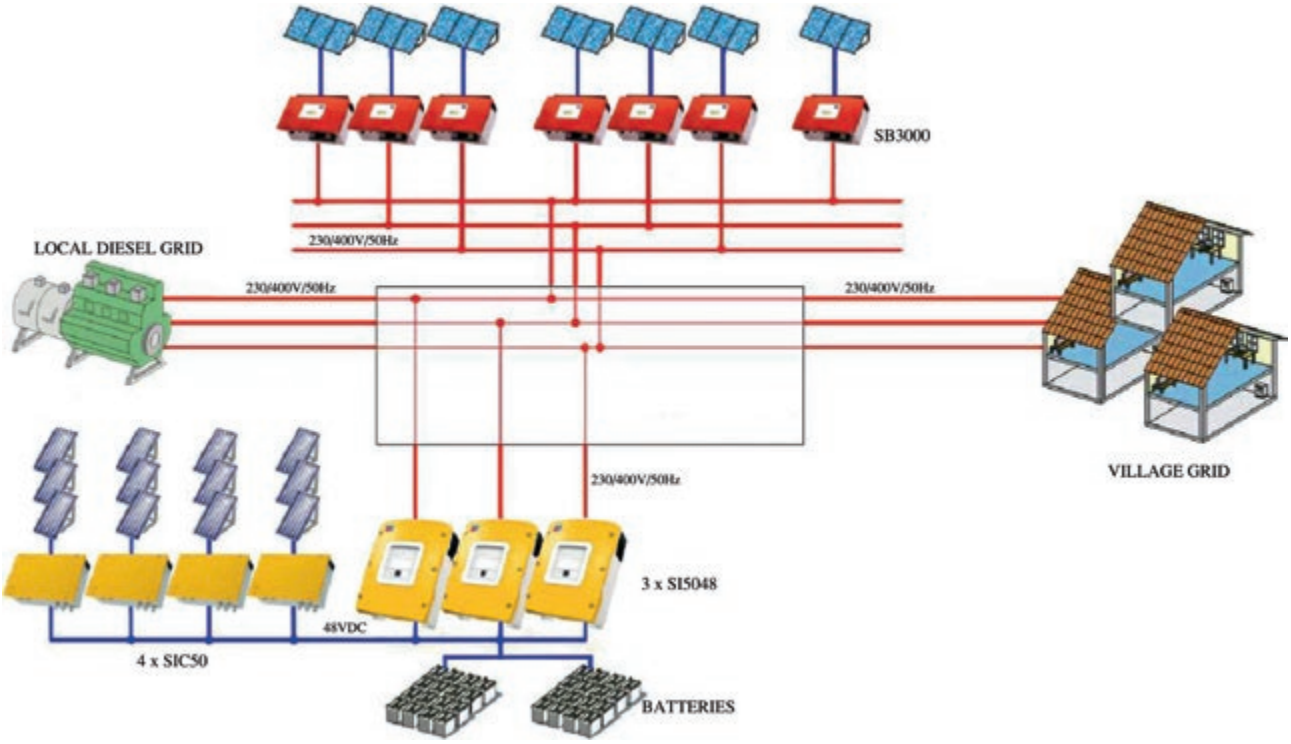

Figure 4. Cluster block diagram for Tokelau solar project
Source: SMA.

5. Challenges for renewable energy deployment

Challenges for renewable energy deployment in Tokelau are known to include:

- Separate management of utility operations for each island, with the need to maintain technical capacity for operation and maintenance on each island.
- High cost of access to the islands.
- To develop the capacity to produce fuel-quality coconut oil in sufficient quantity to replace the fuel needed for backing up the solar PV installations and for diesel powered transport.
- Land tenure issues that could affect the bioenergy development.
- Difficult climate conditions for electrical and mechanical equipment.
- Need for substantial capacity building to assure sufficient management and technical capacity for management, maintenance and repair of renewable energy systems.
- Very small population, limited shipping and lack of economies of scale.

IRENA can suggest pathways to overcome these challenges through its Global Renewable Energy Islands Network (GREIN) and believes that regional and national roadmaps should reflect such pathways. IRENA will continue to work with existing regional and national stakeholders to achieve the transition to renewable energy for a secure and sustainable energy supply.

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In the preparation of this report, primary sources were used as much as possible. Some information was obtained through written questionnaires, some through interviews and some through email correspondence. Where primary sources were not available, the following secondary and tertiary sources were used.

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