Report

IRENA
International Renewable Energy Agency

Pacific Lighthouses

Renewable energy opportunities and challenges in the Pacific Islands region

Tonga

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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Note on currency:
On 23 October 2012, one United States dollar (USD) exchanged for Tonga Pa'anga (TOP) 1.749.

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

ADB	Asian Development Bank
AusAID	Australian Agency for International Development
EPU	Energy Planning Unit
GDP	Gross domestic product
GWh	Gigawatt-hours (Thousand Million kilowatt-hours)
HPS	High Pressure Sodium (street light)
JICA	Japan International Cooperation Agency
kg	Kilogrammes
kWh	Kilowatt-hours (1000 Watt-hours)
kV	Kilovolts
kVA	Kilovolt-ampere
ML	Megalitres
MW/ MWh	Megawatt (Million Watts)/ megawatt-hours
NZAID	New Zealand Aid
PREFACE	Pacific Rural/Renewable Energy France-Australia Common Endeavour
PV	Solar Photovoltaic
RPM	Revolutions per minute
SHS	Solar Home Systems
TEPB	Tonga Electric Power Board
TERM	Tonga Energy Road Map
TERM-IU	Tonga Energy Road Map Implementation Unit
TOP	Tonga Pa'anga (Currency)
TPL	Tonga Power Limited
USD	United States dollar (Currency)
Wp/kWp	Watts Peak/kilowatt-peak (Solar PV)

1. Country context

Figure 1. Map of Tonga

Source: Asian Development Bank (ADB).

Physical Description. Tonga consists of 176 islands, 36 of which are inhabited, with a total area of 748 square kilometres (km^2) and surrounded by an Exclusive Economic Zone of about 700,000 km^2. Tonga is located between 15° and 23°50¢ south latitude and 173° to 177° west longitude. There are five groups of islands: Tongatapu, Vava'u, Ha'apai, 'Eua and Niuas. Most islands have a limestone base formed from an uplifted coral formation, although some have limestone overlying a volcanic base. Volcanic activity still occurs and there have been several eruptions over the past years. The largest island is the capital island of Tongatapu, which is a mostly flat, raised coral island.

Population. Although 2011 was a census year for Tonga, the data is not yet fully available. The preliminary count observed 103 036 people. The Tongatapu population increased by about 0.8%, while all outer island groups showed a decrease. Tongatapu has the predominant share (73%) of the total population, followed by Vava'u at 15%, Ha'apai 6%, 'Eua 5% and Niuas 1%. About 23% of the population can be classified as urban.

Environment. Tonga's climate is tropical maritime with some differences between the southern and northern island groups. Tongatapu's high population density and a continuing influx from the outer islands have created environmental problems including waste disposal, deforestation and damage to the coral reefs. In addition, cyclones are common and can cause damage to infrastructure and crops.

Economic overview. Tonga has a small open economy. A high proportion of its food is imported, mainly from New Zealand. Remittances are important to the economy. Tourism is also important to the economy of Tonga, though at a much smaller scale than remittances. Tonga's Strategic Development Plan emphasises private sector development. The basic infrastructure is reasonably sound and the country has well-developed social services. Fisheries and tourism are considered to offer the best potential for further economic growth though for the near term, agriculture is likely to remain the most important source of export earnings. Tonga's major export commodities include fish, squash, taro, yams, sweet potatoes, vanilla, coconuts, bananas, cassava and kava. Agriculture has contributed around 30% of gross domestic product (GDP) for years, although the volume of agricultural exports has varied during the past decade, with an average value of about TOP 18.8 million (USD 11.5 million) annually between 2008 and 2012, The total export value averaged only about TOP 14 million (USD 6.9 million) between 2007 and 2009. The market for squash peaked in 2003, but since then has virtually disappeared. The value of exports covered about 17% of imports during 2003–2004, but this fell to less than 6% of imports in 2012 partly due to dramatically increased fuel costs. Petroleum imports accounted for about 23% of the value of all imports in 2012. Although Tonga's GDP figures have been rising for about a decade, the upward trend is largely due to inflation, with currency-adjusted calculations showing an essentially static economy (Table 1).

Table 1. Economic statistics (Extracted from Tonga Department of Statisitcs' economic data 2011/2012[1])

Industry	2005-06r	2006-07r	2007-08r	2008-09r	2009-10r	2010-11r	2011-12p
Agriculture sector							
Agriculture	76,3	82,1	80,6	85,2	95,1	107,6	109,1
Forestry	2,2	2,3	2,6	2,7	2,7	5,0	4,0
Fishing	14,6	16,0	14,7	13,9	19,1	19,4	20,8
Total	**93,1**	**100,4**	**98,0**	**101,8**	**116,9**	**132,0**	**133,8**
Market	*35,2*	*38,2*	*38,1*	*38,5*	*44,6*	*50,2*	*53,1*
Non-market	*57,9*	*62,3*	*59,8*	*63,3*	*72,3*	*81,8*	*80,8*
Industry sector							
Mining and quarrying	1,5	1,6	2,1	2,4	5,8	6,1	8,4
Manufacturing	41,4	42,8	44,4	43,3	43,2	45,9	44,9
Electricity and water supply	13,9	14,2	16,7	18,0	17,3	20,4	22,4
Construction	34,5	36,2	39,2	46,7	61,6	75,3	74,4
Total	**91,3**	**94,9**	**102,5**	**110,4**	**127,9**	**147,7**	**150,1**
Market	*64,5*	*64,1*	*68,5*	*77,0*	*93,2*	*113,7*	*115,8*
Non-market	*26,8*	*30,8*	*34,0*	*33,4*	*34,7*	*34,0*	*34,3*
Services sector							
Wholesale and retail trade	47,9	51,6	65,0	71,0	69,3	78,1	80,4
Hotels and restaurants	14,4	14,4	15,9	16,6	17,8	22,9	23,3
Transport and communication	32,7	33,1	37,7	44,2	48,9	47,9	49,5
Financial intermediation	42,2	44,0	49,6	41,7	41,3	45,0	44,6
Real estate, renting and business services	9,9	10,3	11,5	11,8	12,8	14,3	14,7
Public administration and services	88,3	71,9	77,3	81,2	89,1	91,8	93,9
Education	16,3	15,5	16,2	17,9	18,3	16,2	17,5
Health and social work	3,8	3,5	3,5	3,8	3,9	4,2	4,7
Recreational, cultural & sporting activities	4,7	4,5	5,1	5,1	5,4	6,8	6,9
Other community and personal services	13,3	13,0	14,0	15,2	15,6	17,6	19,1
Ownership of dwellings	58,7	64,8	67,6	72,3	73,8	72,4	72,4
Total	**332,3**	**326,6**	**363,4**	**380,8**	**396,2**	**417,3**	**427,0**
Market	*273,5*	*261,8*	*295,8*	*308,5*	*322,4*	*344,9*	*354,6*
Non-market	*58,7*	*64,8*	*67,6*	*72,3*	*73,8*	*72,4*	*72,4*
Less imputed bank service charge	12,5	14,7	15,4	13,6	13,2	13,4	12,7
GDP at factor cost	**504,2**	**507,2**	**548,4**	**579,3**	**627,8**	**683,6**	**698,2**
Plus taxes on products	93,6	99,6	112,2	88,2	86,4	93,4	101,4
Less subsidies on products	3,4	4,0	1,4	3,2	2,0	2,0	0,4
GDP at market prices (TOP)	**594,3**	**602,8**	**659,3**	**664,3**	**712,2**	**775,0**	**799,3**
GDP at market prices (USD)	**289,1**	**292,3**	**337,3**	**314,4**	**368,6**	**422,6**	**470,7**
Exchange rate $US/$TOP	0,486	0,485	0,512	0,473	0,518	0,545	0,589

p - Preliminary estimates.

r - Revised estimates.

Source: National Accounts Report, Statistics Department (2013).

2. Energy landscape

Institutional and regulatory arrangements for energy.

Energy Planning Unit (EPU). The Ministry of Lands, Environment, Climate Change and Natural Resources includes an Energy Planning Unit (EPU) that deals with energy planning, policy development and project co-ordination. Over the years, the EPU was instrumental in developing rural electrification through solar energy. It is currently monitoring the JICA-funded Vava'u solar home systems project, overseeing solar on the Tonga outer islands and also working in the area of energy efficiency in parallel with programmes being carried out under the Tonga Energy Road Map Implementation Unit (TERM-IU). In late 2012 the TERM-IU was designated by government as the focal point for all Tonga energy projects.

Tonga Electric Power Board (TEPB). Until 1998, the main customer groups on Tongatapu, 'Eua, Lifuka (Ha'apai) and Neiafu (Vava'u) received grid-delivered electricity services from the Tonga Electric Power Board (TEPB), a government company. In 1998, Shoreline, a private registered company, took over generation by leasing existing TEPB generation infrastructure and upgrading power plants. In 2000, Shoreline also took over distribution responsibility from TEPB, leaving TEPB with only a regulatory function. In 2008 the Government concluded an agreement with the Shoreline Group to purchase the utility and formed Tonga Power Limited.

Tonga Power Ltd (TPL). Electricity in the urban islands is provided by Tonga Power Ltd (TPL) – a government-owned corporate entity that operates under a concession agreement monitored by the Tonga Electricity Commission, the electricity regulator. The rural areas in Tongatapu have TPL-operated diesel grids, while the outer islands have either solar power or community-managed diesel mini-grids.

Electricity Commission. Along with the change in ownership in 2008, the TEPB was dissolved. A new regulator, the Electricity Commission, was introduced under the Electricity Act of 2007 to reflect the best international practice for public utility regulation and, since privatisation of the utility remains a long-term government goal, to facilitate a possible future sale of the government's interest in TPL. The reforms of the 2007 Utility Act balanced the interests of consumers regarding fair tariffs and receipt of high-quality power, against the need for private investors to minimise their risks regarding earning a fair return on their investment. The Electricity Commission is legally required to regulate tariffs, consumer service standards and electrical safety. The regulatory framework employed is of the concession-contract type. Tariffs, tariff adjustment formulas, operational efficiency benchmarks, consumer service standards and penalties for non-achievement are all specified in a contract between the Electricity Commission, representing the government, and the electricity provider, TPL, which, although owned by the government, is an independent commercially operated business, with a board consisting of local and foreign members appointed by the government.

National Renewable Energy Policy. Tonga's National Renewable Energy Policy was established in 2006 with the aim of assisting renewable energy development in the Kingdom. This was followed by the Government adopting a policy in 2009 for 50% of electricity generation to be from renewable resources by 2012, the Renewable Energy Act (2009) and subsequently the Tonga Energy Roadmap 2010-2020.

The Tonga Energy Road Map. The Tonga Energy Road Map (TERM) is a ten-year work plan for 2010-2020 intended to reduce oil imports and Tonga's vulnerability to oil price shocks; increase access to modern energy services in an environmentally sustainable manner; and meet international requirements for reducing carbon emissions. In 2009, the government of Tonga approved a goal of supplying 50% of electricity from renewable energy sources by 2012. Although this was an over-ambitious goal for a three-year period, it did set events in motion that resulted in a well-defined, technically and economically feasible process that will reduce fuel imports for electricity generation by the desired 50%. After careful examination of the original goal, planners recognised that increasing the efficiency of electricity generation and distribution, petroleum fuel management and the electricity end-use would be more cost-effective. Improved access to energy on the outer islands through renewable energy development was also added to the plan. The time scale for achieving the goal was extended to a more plausible deadline of 2020 and, based on a joint effort and a series of analyses by several different cooperating development agencies, a

detailed programme of action was prepared with indicative funding sources and costs for each action.

In its final form, the TERM contains many different components and crosses the traditional boundaries of ministries and agencies. The Tonga Energy Road Map Agency (TERM-A) was created under the authority of Cabinet as a Government Agency. The TERM-A is the central single Agency responsible for Energy and is made up of the Tonga Energy Road Map Implementation Unit, headed by a Director who is responsible for the management of the TERM, including all aspects of energy within the Kingdom. The TERM-IU is under the management oversight of the Government's TERM Committee (TERM-C), chaired by the Honourable Prime Minister (Chairman) and the Honourable Minister for Lands, Environment, Climate Change & Natural Resource as alternate Chair. The Director TERM-IU is the focal point for all Development Partners for and on behalf of the Government.

Work will be carried out in several phases with technologies piloted before full-scale implementation. Changes in direction are expected since an initiative of this type is new to Tonga and the Pacific region and there are no guidelines to follow. Furthermore, renewable energy technology development is evolving rapidly and so it is essential to have flexibility in implementing the TERM.

As quoted in the TERM Final Report:

"*Flexibility to update and adjust the indicative implementation plan is needed to ensure the TERM remains relevant and responds to evolving circumstances. Recognizing the need for on-going adjustments, key principles of the TERM are set out. These will be adhered to as the specifics of the implementation plan are updated. The key principles are:*

- *Least cost approach to meet the objective of reducing Tonga's vulnerability to oil price increases and shocks;*
- *Managing risk including with respect to the sequencing and timing of new investments and to the extent feasible development of a portfolio of options to meet the demand for electricity;*
- *Long-term financial sustainability in the electricity sector;*
- *Social and environmental sustainability; and*
- *Clear, appropriate and effective definition of roles for government, TPL and the private sector.*"

By the end of 2011, a number of activities related to the TERM had commenced. These included: a commitment from the New Zealand Government and Meridian Energy Ltd of New Zealand to construct a 1.3 megawatt (MW) grid-connected solar station at the site of the existing Popoua power plant; the initiation of a three-year project funded by ADB to improve end-user energy efficiency; rehabilitation of the Solar Home System project in Vava'u by Japan; and an ADB feasibility study and design consultancy for further renewable energy implementations. Additional TERM projects are being developed and some were committed in 2012, including about 500 kWp of solar PV for Vava'u from the Abu Dhabi Fund for Development and 1 MW of additional solar in Tongatapu from Japan through the Japan International Cooperation Agency (JICA).

IRENA assisted in the development of the TERM and supports Tonga through its annual review of renewable energy technologies and costs that will be the basis for power system planning and investments.

Other key legislation. Other key legislation and regulations relating to energy in Tonga include:

- Renewable Energy Act (2008)
- Electricity Act (2007)
- Price and Wages Control Act (1988)
- Environment Impact Assessment Act (2003)
- Cooperative Societies Act (Cap118)
- Petroleum Act (Cap134)
- Forestry Act (Cap126)
- Lands Act (Cap132)
- Foreign Investment Act (2002)

Energy supply and demand

Although biomass remains an important energy source for cooking and crop drying, well over half of Tonga's national energy needs are met by imported petroleum. Solar photovoltaics (PV) currently accounts for less than 4% (May 2013) of the total energy used, although rapid expansion is underway.

Petroleum. Imports of gasoline in 2012 amounted to about 12.7 megalitres (ML) and distillate (No. 2 diesel fuel) about 27 ML, with around half of the imported distillate being used for electricity generation. Petroleum import data are shown in Table 2 and the uses of petroleum fuels are shown in Table 3.

Electricity generation and demand. All electricity in the islands of Tongatapu, 'Eua, Lifuka (Ha'apai) and Neiafu (Vava'u) is generated and distributed by the government-owned national utility, Tonga Power Limited (TPL). Small grid systems for the larger Ha'apai islands ('Uiha, 168 customers; Ha'ano, 106; Ha'afeva, 69; and Nomuka, 110) were constructed with Australian Agency for International Development (AusAID) funding in 2001–2003. The systems are powered by diesel generators and operated by an electricity cooperative on each island. Hours of operation vary by island but typically are less than 12 hours a day. The cost

Table 2. Fuel imports, 2008–2012

Year	Fuel type	Litres
2008	Automobile diesel oil	23 869 846
	Lube oil	40 978
	Petrol (gasoline)	19 051 406
	Kerosene for households	51 646
	Jet fuel	1 167 394
	Aviation gasoline (Avgas)	n/a
2009	Automobile diesel oil	29 600 336
	Lube oil	80 102
	Petrol (gasoline)	17 728 063
	Kerosene for households	730 469
	Jet fuel	1 424 025
	Aviation gasoline (Avgas)	n/a
2010	Automobile diesel oil	27 087 630
	Lube oil	418 196
	Petrol (gasoline)	12 146 854
	Kerosene for households	259 612
	Jet fuel	5 165 141
	Aviation gasoline (Avgas)	1 477 023
	Litres of jet fuel used for in-country travel	294 604
2011	Automobile diesel oil	26 276 876
	Lube oil	528 995
	Petrol (gasoline)	11 363 915
	Kerosene for households	426 878
	Jet fuel	5 084 113
	Aviation gasoline (Avgas)	1 224 587
	Litres of jet fuel used for in-country travel	266 782
2012	Automobile diesel oil	26 991 329
	Lube oil	418 995
	Petrol (gasoline)	12 688 764
	Kerosene for households	337 957
	Jet fuel	4917 025
	Aviation gasoline (Avgas)	1 046 944
	Litres of jet fuel used for in-country travel	138 000

Source: Custom imports data and Statistics Annual Trade Report.

Note: 2010 is directly from Customs data while 2008-2009 are edited data from the Statistics Annual Trade Report.

per kilowatt-hour (kWh) of operation has been higher than predicted, largely due to the actual loading being substantially lower than estimated for the design, causing the engines to operate with poor fuel efficiency. An Asian Development Bank (ADB) project has been proposed to address the difficulty with these small grid systems and determine the feasibility of integrating solar generation with them to reduce fuel usage. There is some private generation of electricity, particularly on church and commercial properties in the outer islands. On the outer islands, solar PV systems provide lighting for most church, school and community hall buildings.

Solar home systems provide power for almost all of the homes in the smaller outer islands with the most recent installations providing 160 watts-peak (Wp) of solar PV capacity. The systems provide 24-hour power (using batteries) for lighting and small communications and entertainment appliances.

TPL has over 15 000 meters in service for consumers. Consumer service standards are regulated and cover the rights and responsibilities of both TPL and its customers. These include the rights and responsibilities to provide proper customer service, good quality power and for disconnection for non-payment of fees.

With the exception of three small island cooperative-operated grids, all grid-supplied electricity in Tonga is generated and distributed by TPL. Table 4 shows the characteristics of the Tongatapu power generators at the Popua power plant. Electricity sales by sector are shown in Table 5 and the statistics of generation, including fuel use, are shown in Table 6. About 97% of the total generation is currently by diesel engines with the rest generated from solar energy. Around 15 000 customers are being served on the four larger islands with over 90% of them on Tongatapu. By Pacific standards, TPL is a mid-sized utility. During the past five years there has been little change in generation with sales remaining in the 40 to 44 gigawatt-hours (GWh) range, a result of economic stagnation and the rising cost of electricity. All loads are metered.

Load patterns for workdays, Saturdays and Sundays are shown in Tables 7, 8 and 9. On all days of the week, the TPL load peaks in the early evening, typically reaching a total of 7 MW. Unfortunately, the solar generation is not able to address this timing of the peak load without adding a substantial storage component. The daytime load changes markedly on the weekend with the noontime peak during the working week and on Saturdays reaching 6 MW, but falling to 5 MW on Sundays. This will need to be considered when increasing the level of solar connected to the grid, as the existing 1.3 MW of solar will already reach 20% grid penetration at noon on weekends, which is a level that starts to cause concerns for grid stability. Since the 1.3 MW of solar is at a single

Table 3. Uses of petroleum fuels (Litres), 2010–2012

Fuel type and usage	2010	2011	2012
Aviation gasoline (Avgas) used for in-country flights	115 000	226 782	115 000
Jet fuel used for in-country flights	1 611 266	1 224 587	1 069 944
Diesel fuel used for electricity generation	13 086 288	13 105 889	12 776 489
Diesel fuel used for land and sea transport	14 001 342	13 170 987	14 214 841

Source: Customs and Statistics Annual Trade report

Table 4. Popua power plant generators (Tongatapu)

Generator Name	Model	Base Voltage (kV)	Base kVA	PMax (kW)	Speed (RPM)	De-rated Power (kW)	Year in Service
UNIT 1	CAT 3516B	11	1525	1400	1500	420–1260	1998
UNIT 2	CAT 3516B	11	1525	1400	1500	420–1260	1998
UNIT 3	CAT 3516B	11	1525	1400	1500	420–1260	1998
UNIT 4	CAT 3516B	11	1525	1400	1500	420–1260	1998
UNIT 5	CAT 3516B	11	1525	1400	1500	420–1260	1998
UNIT 6	CAT 3516B	11	1525	1400	1500	420–1260	1999
UNIT 7	CAT MaK6CM32C	11	3456	2880	600	2448	2006
Trailer Unit	CAT PM3516B	11	1525	1400	1500	Out of service	2010

Source: Provided through communication by TPL (2012) and TERM-IU (2013).
Where kV is kilovolts; kVA is kilovolt-ampere; RPM is revolutions per minute; kW is kilowatts.

Table 5. Electricity sales in kWh, 2007–2012

Year	Sector	Sales in MWh	Year	Sector	Sales in MWh
2007	Residential	22 670	2010	Residential	21 215
	Commercial/industrial	23 018		Commercial/industrial	21 540
	Government	627		Government	587
	Total	46 315		Total	43 341
2008	Residential	22 794	2011	Residential	21 846
	Commercial/industrial	23 144		Commercial/industrial	22 181
	Government	630		Government	604
	Total	46 568		Total	44 631
2009	Residential	21 070	2012	Residential	22 109
	Commercial/industrial	21 393		Commercial/industrial	22 448
	Government	583		Government	611
	Total	43 045		Total	45 168

Source: Provided through communication by TPL (2013).
Comments: Data provided are the combined amounts from four grids, Tongatapu, Vava'u, Ha'apai and 'Eua.

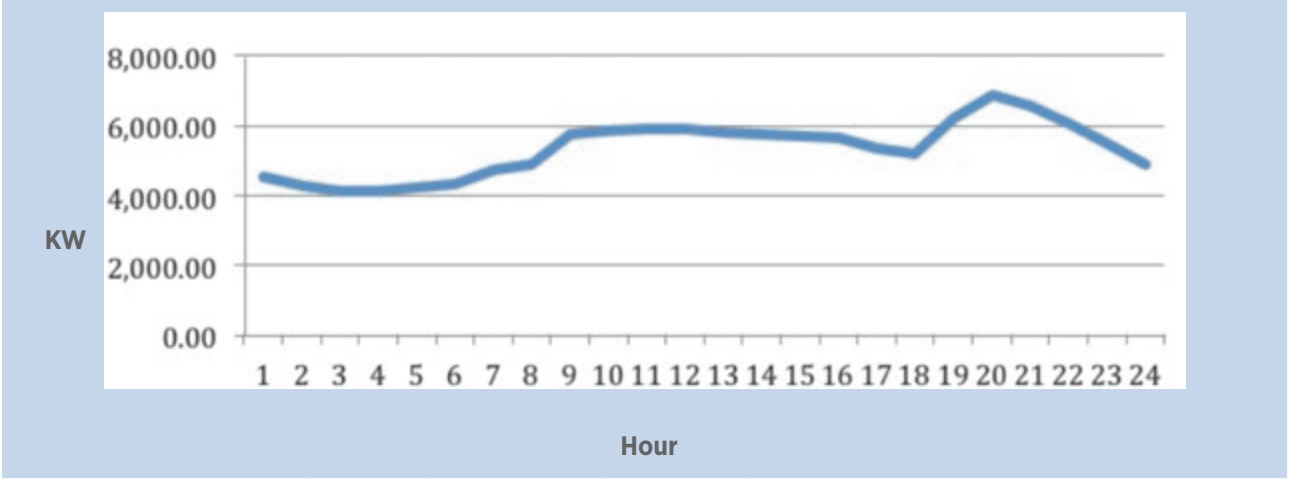
Table 6. Electricity generation statistics, 2006–2012

Year	Actual generation MWh	Fuel used in litres	Station losses MWh	Delivered from the Power House	MWh sold
2006	55 076	13 981 508	9 578	53 877	45 498
2007	56 434	14 115 388	10 120	54 769	46 315
2008	56 782	14 186 248	10 213	54 825	46 568
2009	52 631	13 188 831	9 586	51 398	43 045
2010	52 612	13 086 288	9 271	50 972	43 341
2011	52 846	13 155 923	8 216	51 499	44 631
2012	52 447	12 776 489	7 279	51 212	45 168

Source: Provided through communication by TPL (2013).

Table 7. Typical weekday load pattern

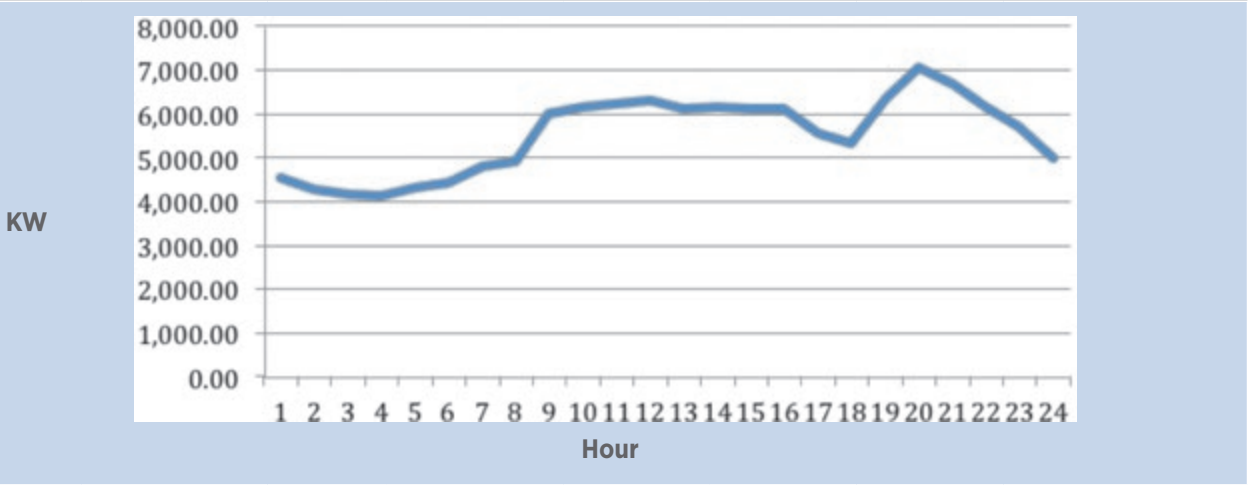
Hour	kW	Hour	kW	Hour	kW	Hour	kW
0100	4 514.0	0700	4 738.8	1300	5 794.4	1900	6 216.6
0200	4 273.2	0800	4 906.2	1400	5 769.8	2000	6 875.2
0300	4 145.8	0900	5 748.6	1500	5 710.6	2100	6 575.8
0400	4 105.4	1000	5 870.4	1600	5 672.6	2200	6 069.4
0500	4 224.0	1100	5 898.2	1700	5 332.0	2300	5 483.8
0600	4 338.6	1200	5 920.8	1800	5 189.4	2400	4 893.0



Source: Provided through communication by Tonga Power Ltd (2012).

Table 8. Typical Saturday load pattern

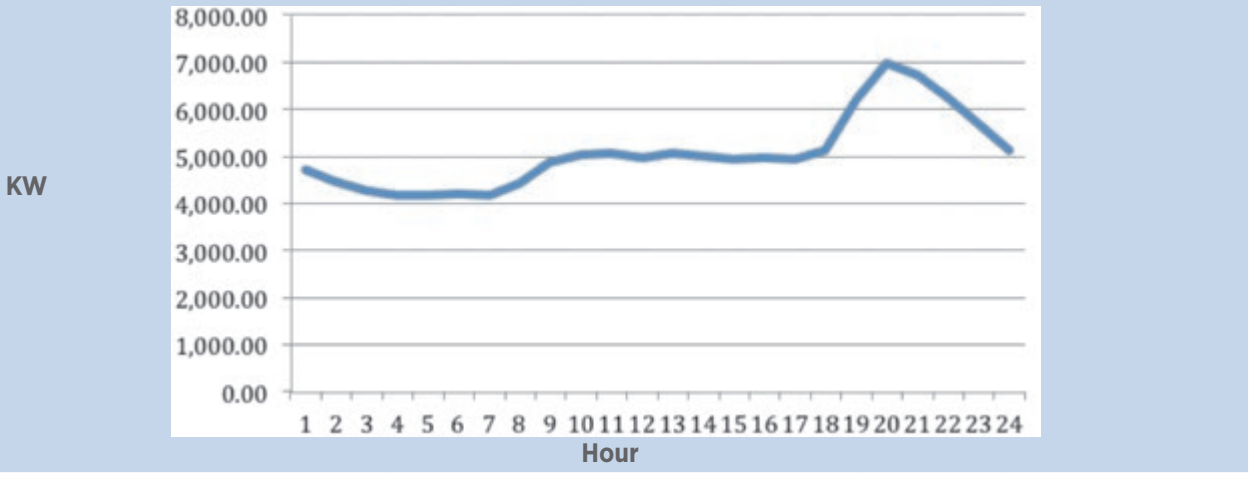
Hour	kW	Hour	kW	Hour	kW	Hour	kW
0100	4 502.0	0700	4 777.0	1300	6 109.0	1900	6 333.0
0200	4 267.0	0800	4 907.0	1400	6 130.0	2000	7 034.0
0300	4 131.0	0900	5 985.0	1500	6 079.0	2100	6 674.0
0400	4 108.0	1000	6 132.0	1600	6 079.0	2200	6 134.0
0500	4 280.0	1100	6 197.0	1700	5 516.0	2300	5 695.0
0600	4 410.0	1200	6 278.0	1800	5 307.0	2400	4 958.0



Source: Provided through communication by Tonga Power Ltd (2012).

Table 9. Typical Sunday load pattern

Hour	kW	Hour	kW	Hour	kW	Hour	kW
0100	4 705.0	0700	4 161.0	1300	5 061.0	1900	6 226.0
0200	4 448.0	0800	4 443.0	1400	5 004.0	2000	6 981.0
0300	4 268.0	0900	4 877.0	1500	4 950.0	2100	6 730.0
0400	4 175.0	1000	5 026.0	1600	4 965.0	2200	6 263.0
0500	4 156.0	1100	5 078.0	1700	4 950.0	2300	5 716.0
0600	4 197.0	1200	4 977.0	1800	5 136.0	2400	5 126.0



Source: Provided through communication by Tonga Power Ltd (2012).

location the speed and size of variations in output will be at a maximum.

The second 1 MW of solar PV, which is expected to be installed in 2013, will be several kilometres from the 1.3 MW plant and will include a form of short-term energy storage to reduce the effects of power fluctuations.

Public street lighting data for Tonga are given in Table 10. The relatively constant evening base load consists largely of street lighting and residential refrigerator and freezer operation. Before the installation of trial LED street lights, street lighting in Tongatapu (Table 10) totalled around 316 kW of load. Although street lighting accounts for only about 10% of the evening load, it offers considerable opportunities for energy efficiency improvements. Trials of high-efficiency LED-type street lights to replace many of the higher wattage lights now in service were completed in 2012 and projects for further replacements of existing streetlights with high-efficiency LED units are in the pipeline for both Tongatapu and outer islands that are served by TPL.

Table 10. Street lighting (2010)

Tongatapu	**1522**	**Vava'u**	**853**
250W HPS	339	70W HPS	853
150W HPS	258	**Ha'apai**	**78**
100W HPS	438	250W HPS	17
70W HPS	159	100W HPS	22
4' Fluorescent tube	104	75W HPS	25
2' Fluorescent tube	202	2X2' Fluorescent tube	14
55W MV	22	**'Eua**	**755**
		70W HPS	755

Source: Provided through communication by Tonga Power Ltd (2012). Where HPS is High Pressure Sodium Lights.

Electricity tariffs. The Electricity Act of 2007 states that the concessionaire has the legal right under the concession contract to pass on fuel costs to consumers and charge an additional inflation-indexed non-fuel tariff. The non-fuel tariff covers agreed-upon operational costs, business overheads, interest payments, depreciation and an allowed return on investment to provide retained earnings for future capital expenditures and/or shareholder dividend payments. The tariff structure is flat and all customers pay the same rate, which is TOP 0.945 as of April 2013. However, since outer island generation is substantially more costly than that of Tongatapu, outer island customers are effectively subsidised by those on Tongatapu.

3. Renewable energy opportunities

Tonga began using solar energy for rural electrification in the late 1980s. Over the years, most of the outer island households have been electrified with solar although a number of installations now need repair or replacement. Biomass remains the primary renewable energy source and is used for cooking and for drying crops, mainly fish and copra. There is no useable hydro resource on the islands. Geothermal is potentially present as there is volcanic activity in Tonga, but it is uneconomical to tap into this resource. The wind resource appears useable but may be difficult to utilise on a large scale due to land issues and the prevalence of coconut trees that interfere with the smooth flow of wind across the island. Biogas can be tapped from landfills at a reasonable cost, but the quantity is modest. Biofuel from coconut oil seems a possibility and could rejuvenate the ailing coconut industry, as well as reducing the use of imported fuel. There appears in the first instance to be a potential tidal resource on Vava'u and there is renewed interest in wave energy although cyclones are a serious problem for both wind and ocean power. The detailed resource potentials are described below.

Biomass. Tonga estimates that 25% of the energy it uses comes from biomass with the rest supplied by petroleum-based fuels and solar energy. The vast majority of the biomass used for energy is for cooking, although drying fish and copra is also a significant use. Even in Tongatapu, where kerosene, electricity or liquefied petroleum gas (LPG) are the main sources of energy for cooking, there is significant use of biomass as the traditional "umu" (an underground oven) is commonly used for special functions and on weekends.

Although biomass waste was once used as an energy source at a Tongatapu coconut processing plant, the plant is no longer functioning and biomass is no longer used for commercial energy in Tonga, even though over 50% of the land area is under tree crops, mostly coconuts. There appears to be little opportunity in the short term for biomass from forest products to become a significant energy resource on Tongatapu.

Timber milling is presently a small-scale industry using logs from the 'Eua Caribbean Pine plantations and ageing coconut trees as raw materials. On 'Eua, waste from log processing is available for energy use and is being considered as a supplement or replacement for the diesel generator powering the island grid. Should coconut oil be designated in the future as a major locally produced biofuel, a large biomass resource will become available from old coconut trees as plantations are being upgraded with new planting. The many tonnes of coconut husks and shells that are a by-product of coconut oil production could also be used for energy generation.

Producing biomass specifically for electricity generation was considered during the preparation of the TERM, but it was decided that the cost of production, feedstock transportation and power generation would not be economical as the land area required would be huge and could be better utilised for food and export crops.

Plantations have been planted with pine and hardwoods for export, and while pine logs are being harvested, it will be many years before the higher value hardwoods mature. At the moment there appears to be sufficient mill waste to provide biomass for energy, although much of the energy produced would be needed for the mill itself.

Biofuels. Of all the possible feedstock for biofuels, coconut oil may make the most sense for Tonga. Coconut production has a long local history and much of Tongatapu and the outer islands have coconut tree canopies, though their productivity is not optimal. In 1995, potential copra production was estimated to be sufficient to produce around 10 ML of coconut oil per year, which is about 75% of the quantity of diesel fuel now used for electricity generation. If the TERM results in a fuel use reduction of 50% the remainder could easily be provided by coconut oil.

If the coconut industry is rehabilitated and revitalised, and barriers to the production and use of biofuels for transport and/or electricity generation eliminated, the maximum offset of diesel fuel by biofuels could be as high as 100% although it would take years of work and substantial investment to develop the coconut industry and further investment by TPL in engines that can burn coconut oil directly.

However, it is clear that an immediate reduction in fuel imports could be made possible by blending coconut oil with diesel fuel. A number of trials in Samoa, Vanuatu and other countries indicate that a 15% coconut oil blend is not a problem with conventional engines. It is likely that after 2020, the next stage of the TERM will need to

include biofuels as a component. However, if that is to happen within a reasonable time, the decision to begin rehabilitating the coconut industry will need to be made soon.

Biogas. There has been no proper assessment of the overall resource, but it seems that sewage, urban waste and animal manure may represent a useful resource, although not sufficient to offset a high percentage of petroleum imports. Estimates made for TERM indicate that tapping existing landfills could offset perhaps as much as 3% of Tongatapu's fuel for electricity generation for a number of years. Should new sewage treatment facilities or landfill facilities be developed, including biogas generation in those facilities could provide enough energy to operate the facilities themselves with any surplus fed to the grid. A number of privately funded or owned biogas digesters have been used for lighting and cooking in remote communities. The Energy Planning Unit (EPU) is currently monitoring their progress.

Solar energy. The solar resource is very good in Tonga, particularly towards the north where satellite measurements indicate that the solar insolation is as much as 5.8 kW/m^2/day. Nearly 25 years of experience with solar-powered rural electrification confirms that there is a useable, cost-effective resource. The solar resource on Tongatapu was documented with an assessment carried out by the Forum Secretariat in 1995–1997 near Cook Point on Tongatapu, but no long-term measurements have been taken on other islands of Tonga or in other areas of Tongatapu.

The only countrywide resource for solar energy system design comes from the U.S. National Aeronautics and Space Administration (NASA), based on many years of satellite measurement data. The data are based on large area measurements that, in many cases, cover far more of the sea around Tonga than land areas on the individual islands. However, the available solar resource may be significantly different, as islands cause local climate effects, most notably clouds due to rising air currents over larger islands. For most of Tonga, the differences are not likely to be great, and the satellite measurements can be used for solar design purposes if the designer assumes a 5–10% lower average solar resource than indicated by the satellite data.

Ground-based solar resource measurements are to be undertaken as part of the TERM. TPL and the EPU of the Ministry of Lands, Environment, Climate Change and Natural Resources have also started collecting solar radiation data at several sites, including the Popua Solar Farm.

Ocean energy. There is a potential tidal energy site on the main island of Vava'u. A bay encompassing around five million square meters of water area has its access to the sea limited by the construction of a jetty across its narrow mouth that includes a central bridge spanning an opening of less than 100 metres. Even though the tidal range is only around 1.5 metres, a large volume of water moves through this small opening twice a day. A pre-feasibility study has been conducted in late 2012. A more detailed feasibility study for wave energy conversion is planned for completion by late 2013.

4. Experience with renewable energy

Rural solar electrification. Tonga has used solar PV for household electrification in rural areas for nearly 20 years (Figure 2). Although early projects did not do well, experience has been gained and each new project has improved in technical and institutional quality. The most recent implementation in the Ha'apai group of islands (a Pacific Rural/Renewable Energy France-Australia Common Endeavour, PREFACE, project) includes 150 Wp of panels, a service fee sufficient to pay for operation and maintenance, an interest-bearing battery replacement fund, and an institutional structure that provides the possibility of good maintenance and customer support. Projects aimed at completing solar electrification to the Niuas and rehabilitating the failed Vava'u Solar Home Systems (SHS) project of the mid-1990s are now underway using a management structure developed from the Ha'apai project experience. The Vava'u project will affect around 500 homes and is expected to be completed by mid-2013.

Each of the programmes has a management committee registered as a non-profit legal entity under the Incorporated Society Act. Committee members are all town officers from the respective islands being electrified and the Governor chairs the committee for Ha'apai and Vava'u. Government representatives chair the committee for the Niuas. Deputy chairs include police magistrates and district officers. Government ministries including Finance; Lands, Environment, Climate Change and Natural Resources; and the Audit Office provide advisory support. Each committee meets once every year to review fees, endorse an annual budget, prepare an annual report, report its financial status and review its office operations.

The committee management structure was built on the long-existing administrative structure of each island group (Figure 3). An office has also been established to provide secretarial duties to the committee and to employ two technicians on each island. The EPU managed the PREFACE project for the first five years in order to reduce operating costs and a similar arrangement will probably be made for the Japan (JICA)-funded project on Vava'u. The Niuas and Ha'apai programmes are currently employing their entire staff from outside government.

Setting the fee level for these remote island electrification projects is more a matter of professional judgement than economic analysis. The fee is set based on a bal-

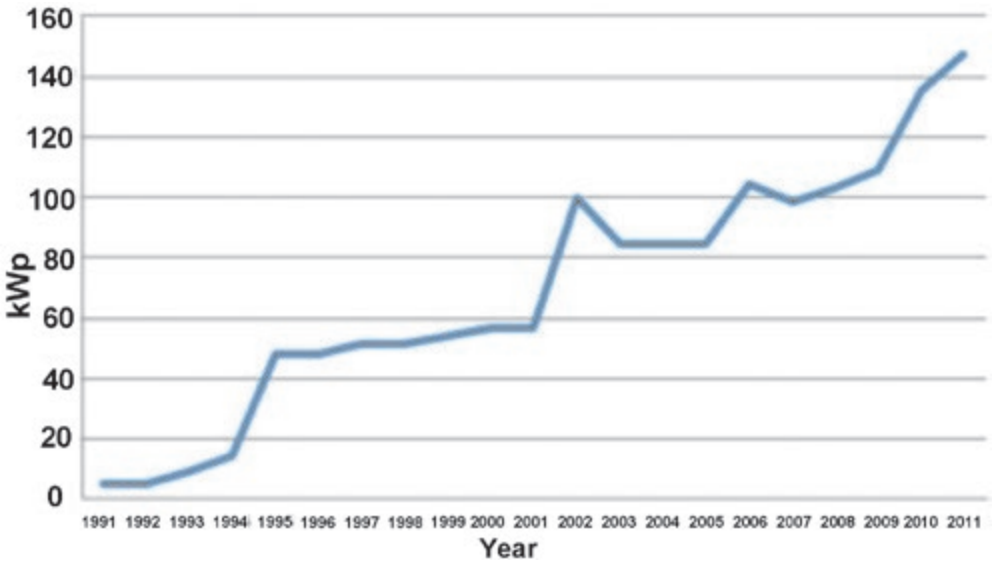


Figure 2. Outer island solar installations 1991–2011

Source: Provided through communication by EPU (2012).

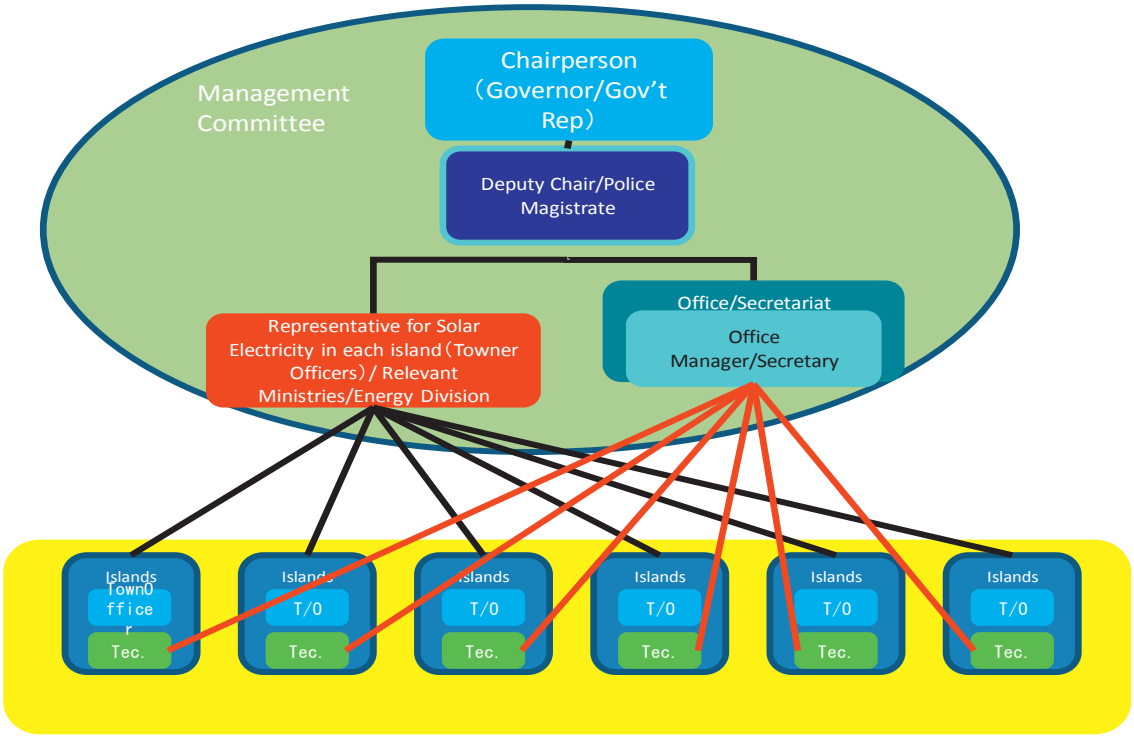


Figure 3. Solar Incorporated Society Management Structure

Source: Provided through communication by EPU (2011).

ance of economics, politics, sensitivity to social issues and common sense. Lessons learnt from past projects highlight the fact that implementers too often set payments on what they think (and rural people say) the households can pay, not what they really pay. Projects in other countries have clearly shown that as long as the services are adequate to the customers' needs and are reliable, fees will be paid. When fees are paid but reliable services are not provided, or when the installations are too small to meet the customers' needs, fee collections decline. The technical designs and options used in the projects also address the issue of affordability and the problems that are currently facing the remote communities where they provide electricity.

Fee collections have been excellent in the Niuas at above 95%. Collections are expected to be the same in Vava'u and off-grid Tongatapu. Ha'apai has been lower at 60–90% at times, due mostly to the remoteness of the islands and the cost of travelling between islands which can be as high as TOP 5800 (about USD 3320) for a single trip. The PREFACE project on Ha'apai has been in operation for 11 years and the first 40 batteries have been replaced using the 60% of collected fees that was set aside for battery replacement. All of the controllers have now been replaced twice using the portion of monthly fees saved for that purpose. Consideration should be given to the local manufacture and use of the Kiribati-style high-reliability controller used in early solar projects in Tonga, as they are well-proven, with some of the 1985 controllers still serviceable.

A power development study by ADB in 2011 highlighted that "[grid-based] electricity supply to the Niuas group of islands was uneconomical at the time. This is still the situation in 2013. Even if the generation and distribution networks are financed by bilateral grant aid, the operation will still have to be subsidised by the utility or Government". Therefore it is expected that the establishment of a grid-based power system in the Niuas will need to be subsidised in the same way as the grids on 'Eua, Ha'apai and Vava'u. Even for solar-based electrification, the government has had to provide assistance, through the EPU, including regular refresher training for local technicians. Training sessions are held in conjunction with annual general meetings of the management committee.

Tonga Telecom also routinely uses solar PV systems to reliably power outer island telephone networks.

Table 11. Recent solar home system PV projects

Location	No. of SHS	Co-Financier	Year
Ha'apai Outer Islands Solar Electricity Society Inc	222	SPC/GoT	2002, 2009
Ha'apai Outer Islands Solar Electricity Society Inc	52 (Lofanga)	IUCN/GoT	2011
Niuatoputapu Solar Electricity Society Inc	27	NZ Aid	2003
Niuafo'ou Solar Electricity Society Inc	169	NZ Aid	2006
Vava'u Solar Electricity Society Inc	495	JICA	2011
Tongatapu Outer Islands Solar Electricity Society Inc	58	JICA	2011
TOTAL	**1023**		

Source TERM IU

Note: JICA has not yet confirmed that the above number of installations is final.

A number of lessons were learnt through the solar home systems projects in Ha'apai, Vava'u and the Niuas (Table 11). These include:

- The amount of money that people are willing to pay for PV electrification can be substantially greater than conventional "ability to pay" surveys would suggest.
- The rate of collection of user fees is directly related to quality of service and meeting customers' needs.
- Community-based institutions are not adequate to ensure sustainable operations and maintenance (O&M).
- Components must survive under very difficult environmental conditions and it has been shown that simple but well-made equipment has a better chance of long-term survival than complicated, state-of-the-art components.
- Projects need to build on previous experience, not only from Tonga but from other Pacific islands as well.
- The more remote the site, the greater the need for high-quality, long-life components.
- Long battery life and customer satisfaction (and therefore fee payments) depend largely on having ample solar panel capacity. Oversizing panels makes good economic sense.
- Preventive maintenance greatly improves long-term reliability.

Solar and solar/diesel mini-grids. The first solar mini-grid in Tonga was installed in 2010 at the Fafa Island Resort off the coast of Tongatapu. The installation is designed to supply the resort with 15 kWp of solar panels and lead-acid batteries for storage. The diesel engine that provided power before the installation of the solar panels is now used to back up solar generation.

Plans are being considered to convert the four small village-scale diesel grids on Nomuka, Ha'afeva, 'Uiha and Ha'ano in the Ha'apai group to solar/diesel hybrids. Additionally, the proposed grid for the Niuas could be solar- rather than diesel-powered.

Solar power for public lighting and water supply. Solar-powered street lights are being tested for village use in Tongatapu but the results are not yet available. Before they are accepted for use, questions regarding ownership and cost recovery must be addressed.

Solar energy has also been used for water-pumping systems in remote villages, which account for about 14% of bore holes used in Tonga, not including the several solar installations of the Tonga Water Board. The TERM-IU and the EPU have identified potential donor partners to finance PV installations to avoid the use of diesel-powered water-pumping engines in remote, rural villages. Water pumping accounts for approximately 1.2% of national diesel consumption. A project under the Japan-financed Pacific Energy Community (PEC) fund will convert the remaining diesel pumps to solar power and will also install community-based, solar-powered freezers on outer islands.

Grid-connected solar. A 1.3 MWp array at the Tongatapu powerhouse was completed in 2012 with funding from NZAID, the European Investment Bank (EIB) and

Table 12. Roof-top grid-connected solar on Tongatapu

PV (kWp)	Location	Single or Three Phase	Installer
8	Utu'one Bed and Breakfast	Single	Solar Island Technologies
5	St. Andrew's High School	Single	Solar Island Technologies
15	Muller Farm-Nukunuku	3 phase	Solar Island Technologies
8	Takuilau College	3 phase	ECOcare, Rotary NZ, UoC
8.25	Tupou College	3 phase	ECOcare, Rotary NZ, UoC
8	Beulah College	3 phase	ECOcare, Rotary NZ, UoC
8.25	Tailulu College	3 phase	ECOcare, Rotary NZ, UoC
8.25	St Joseph (Apifo'ou) College	3 phase	ECOcare, Rotary NZ, UoC
11.4	Molisi Tonga (Fasi)	3 phase	Molisi Tonga, Transnet NZ, Reid Technologies
80.15	**TOTAL**		

Source: Provided through communication (2012).

Meridian Energy Ltd of New Zealand. The plant is owned and operated by TPL. A second 1 MW solar power plant is being planned for installation to commence in 2013 with funding from JICA. The JICA-funded PV installations will include some energy storage to help stabilise the power from the solar plant, thereby avoiding grid stability problems.

Also under construction is grid-connected solar installations for Vava'u with a 500 kWp installation funded by the Abu Dhabi Fund for Development. Since the noontime Vava'u peak load on the weekend is less than 500 kW, the installations will have to include battery storage and control technology to mitigate the effects of the variability of the solar energy in order to avoid serious grid stability problems. Grid-connected solar installations have also been proposed for the small grids in the Ha'apai and 'Eua groups though specific designs and sizes have not yet been designated.

Various private organisations have funded grid-connected solar on Tongatapu. Table 12 lists those in place as of September 2012. All the installations use inverters manufactured by SMA and conform to TPL requirements for net-metering. Over 200 kWp of additional grid-connected solar is in the pipeline for private installation on Tongatapu.

The first private grid-connected solar was installed in June 2012 at the 'Utu'one Bed and Breakfast in Nuku'alofa. The three-phase, 8 kWp roof-mounted installation uses an SMA TRIPOWER 8 kW three-phase, transformerless inverter. This installation complements the solar water heater already in place.

The total PV installed in Tonga is shown in Table 13.

Solar thermal. Solar water heating has been used for over 20 years in residences and tourist facilities. Many have been manufactured locally. Hotels and some upscale residences use solar water heating. Concentrated solar power (CSP) generation is not considered as economically reasonable as solar PV because of high maintenance costs and the high diffuse radiation content of solar energy in Tonga which lowers their conversion efficiency.

Table 13. Installed solar PV in Tonga

Location	Capacity (MWh)	Year	Location
Popua Solar Farm	1 400	2012	Tongatapu
Vaiola hospital	70	2012	Tongatapu
Molisi Tonga	11.4	2012	Tongatapu
'Utu' one guest house	5	2012	Tongatapu
Muller farm	15	2012	Tongatapu
St Andrew's High School	5	2012	Tongatapu
Takuilau College	8	2012	Tongatapu
Tupou College	8.25	2012	
Beaulah College	8	2012	Tongatapu
Tailulu College	8.25	2012	Tongatapu
St Joseph ('Apifo'ou) College	8.25	2012	Tongatapu
Ha'apai Outer Islands Solar Electricity Society Inc	88.8	2002, 2009	Ha'apai
Ha'apai Outer Islands Solar Electricity Society Inc	20.8	2011	Lofanga
Niuatoputapu Solar Electricity Society Inc	13.2	2006	Niuatoputapu
Fafa Island Resort	15	2010	Tongatapu
Vava'u Solar Electricity Society Inc	198	2011	Vava'u
Tongatapu Outer Islands Solar Electricity Society Inc	23.2	2011	Tongatapu
Total	**1 906.15**		

Source: Provided through communication by TERM -IU (2013).

5. Challenges for renewable energy deployment

- There are a large number of widely separated, small islands.
- The relative cost of renewable energy tends to be high, particularly the initial investment, and the inter-island transportation needed for repairs is expensive.
- There is an almost total dependence on donor funding for energy projects that results in long lead times and adds complexity to implementation and maintenance.
- Most donor-funded projects have a very strict policy on the origin of equipment that may not be optimal for the Tonga environment.
- Duties and taxes are applied inconsistently for renewable energy systems, although project equipment is supposed to be exempted from duty and consumption tax.
- There is limited capacity for energy planning, financial planning and analysis, and project development.
- There is limited availability of energy data. Energy companies and agencies need to improve their record-keeping and data management capacities.
- There is a lack of local training capacity in business management and renewable technologies.
- There is a lack of trained or experienced personnel for management or technical positions in energy companies, especially on the outer islands.
- The environmental conditions (such as high salinity) for energy equipment are difficult.
- Tonga's population is widely dispersed on numerous atoll islands and often further fragmented onto islets within an atoll, making centralised management of outer island energy systems difficult.
- International transportation by air and by sea is neither reliable nor of good quality, and is often expensive, making the delivery of replacement parts slow and costly.
- There is a small and fragmented energy market, which makes it difficult to develop private energy-related businesses.
- There is a lack of public awareness regarding renewable energy and energy efficiency.

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 these 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 in Tonga.

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