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Technical Assistance to Develop Investment Plans for Enhancing Energy Resilience in Pacific Island Power Utilities

Grant N° TF 1505
Contract N° SEIDP/C2.2

Final Report

June 2020

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Glossary

ABC	Aerial Bundled Conductor
ACSR	Aluminium core steel reinforced conductors
ADB	Asian Development Bank
ARI	Annual Return Intervals
BESS	Battery Energy Storage System
CRU	Climatic Research Unit
DFR	Draft Final Report
DIA	Disaster Impact Assessment
ECA	Economic Consulting Associates
EEZ	Exclusive Economic Zone
EFL	Energy Fiji Limited
ENSO	El Niño-Southern Oscillation
EPC	Electric Power Corporation of Samoa
FCCC	Fijian Consumer and Competition Commission
GCM	Global Climate Model
GHG	Greenhouse Gas
HTLS	High temperature Low Sag conductors
IEC	International Electrotechnical Commission
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IRR	Internal rate of return
ITCZ	Inter-Tropical Convergence Zone
masl	metres above sea level
MoTET	Ministry of Transport, Energy and Tourism, Tuvalu
NEX-GDDP	NASA Earth Exchange Global Daily Downscaled Projections
NPV	Net present value
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Planning
PPA	Pacific Power Association
PPL	PNG Power Ltd
PRDR	Pacific Regional Data Repository
PV	Photo-voltaic
RCP	Representative Concentrations Pathway
RMU	Ring-Main Unit (MV switchgear)
SAMET	Samoa Climate Section, Meteorology Division, MNRE
SLR	Sea Level Rise
SHS	Standalone Home Solar Systems
SMEC	SMEC International Pty Ltd
SPCZ	South Pacific Convergence Zone
SPREP	South Pacific Regional Environment Programme
TEC	Tuvalu Electricity Corporation
TPENIP	Tuvalu Photovoltaic Electricity Network Integration Project
UEA	University of East Anglia
VOLL	Value of lost load
WB	World Bank
WPM	West Pacific Monsoon

Executive Summary

Introduction

SMEC International Pty Ltd, in association with Economic Consulting Associates (ECA), has been appointed Consultant for the ***Technical Assistance to Develop Investment Plans for Enhancing Energy Resilience in Pacific Island Power Utilities*** under contract N° SEIDP/C2.2 dated 27 November 2019 with the Pacific Power Association (PPA). The assignment is part of the *Sustainable Energy Industry Development Project* funded by the World Bank.

This report was made possible with the financial support of the Japan-World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries, which is financed by the Government of Japan and receives technical support from the World Bank Tokyo Disaster Risk Management Hub. This funding was made available to the Pacific Power Association through the Sustainable Energy Industry Development Project.

The key objective of this TA study was to provide technical, financial and environmental specialist advice on the resilience of three selected target utilities, being representative as large, medium and small utilities in PPA's membership of 25 power utilities. Site visits by the study team were made to Samoa Electric Power Corporation (EPC) and Tuvalu Electricity Corporation (TEC); the site visit to PNG Power Ltd (PPL) was cancelled due to the onset of Covid-19 pandemic travel restrictions.

The outputs of the TA study include:

- Mapping of vulnerable power infrastructure subject to impacts of climate and natural disasters
- Vulnerability assessment of physical assets and energy supply at the three targeted utilities
- Recommended technical solutions needed to enhance the resiliency of the three power systems
- Recommended investment plans and prioritising a pipeline of climate resiliency projects.

It is also intended that the outputs will also be used by the other utility members as a template or checklist to apply to their own organisations in order to mitigate impacts and improve resiliency.

This Final Report includes (i) the findings of the Task 2 field inspections of the key power infrastructures at each of the three targeted utilities; and (ii) Task 3 recommended climate proofing measures identified in the study. It includes feedback received from TEC, EPC and PPA on the draft Final Report dated 12 June 2020.

Assessment of Climatic and Extreme Weather Events

The study focusses on Extreme Weather Events. These can either be climate change related or can be naturally occurring. In terms of disaster response and planning for resilience it is sensible to consider them together.

The main factor driving climate change is increase in temperature. Associated with this is increase in precipitation, more cyclones leading to floods, strong winds, and coastal storm surge. Equally there can be longer periods of no rain leading to water shortages, fires and droughts. These can be considered short term effects. Long term effects such as sea Level Rise are also included.

Natural hazards include earthquakes, which can lead to tsunamis, and volcanoes. The resilience against both climate change induced hazards and natural hazards may be related, for example coastal defences may protect against sea level rise, storm surge and tsunamis.

Incidents have been identified by looking at historical records. Future likely occurrences have been assessed by examining climate change projections. The most substantial is the PACCSAP study carried out in 2014 which is still regarded as the most reliable source of projected climate change information to date.

For worst case scenarios, a climate change scenario of RCP 8.5 projected out to Year 2100 with the extreme value of the error function has been taken.

Climate Resilient Investments

The study provides an overview of the climate resilient status of EPC and TEC. This includes for each utility the impacts of historic events on their power system, the vulnerability to future climate events and looks at investment needs for future proofing. Based on their experience with past climate events, Both utilities have already implemented various climate proofing measures, which have already reduced the impact of subsequent events on their power system. Table 1 lists the vulnerability and impact assessment risks and provides additional climate proofing measures.

Table 1 Climate Proofing Measures

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
Samoa EPC					
Climate Related					
Global Warming Elevated temperature	Higher daytime ambient temperatures; warmer nights	Equipment operation Higher demand for air conditioning	Compensate higher temperatures with increased cooling on generators Use of HTLS conductors to operate at higher temperatures and avoid derating transmission circuits	None	Not applicable for TEC, as there is no HV transmission in Samoa and all MV subtransmission is well constructed with appropriate sag to maintain ground clearances
Global Warming Elevated temperature	Less annual rainfall	Drought / hydro generation	Large hydro reservoirs Multipurpose dams for flood control, potable water, electricity generation	EPC is implementing Alaoa multi-purpose flood control dam	Alaoa multi-purpose flood control dam will increase storage capacity for cascade hydros on Vaisgano river
Global Warming Elevated temperature	Longer periods without rain	Non-rain days / dusty conditions, obscuration of solar panels	More cleaning of solar panels	None	Implement regular monitoring of panels and cleaning when appropriate
More Intense Cyclones	Strong winds from cyclone or tropical depression	Destroy structures not designed to withstand wind loading factor Render windmills unusable	Design structures to Category 5 Make windmills demountable	EPC wind farm can be lowered to ground when storm warnings issued	Include provisions in future wind farms
More Intense Cyclones	High winds	Blow trees onto assets	Undergrounding of distribution system; Keep trees clear of assets	Minimal undergrounding Some tree trimming	Not practical/ economic to underground all EPC network; identify and focus on most vulnerable sections of Network Increase tree trimming programme
Storms	High winds	Rusting of assets in coastal areas due to salt spray	Use stainless or plastic products in lieu of sheet steel	None	Introduce non-rust options in coastal areas of network
More Intense Cyclones or tropical depressions	Heavy rain cyclonic long duration (days)	Area Flooding due to saturated preconditions	Undergrounding of distribution system; placing live vulnerable equipment above flood levels Minimise use of vulnerable ground level assets	EPC is implementing Alaoa multi-purpose flood control dam	Not practical/ economic to underground all EPC network; identify and focus on most vulnerable sections of Network Alaoa control dam will prevent flood damage on Vaisgano river
More Intense Cyclones or tropical depressions	Intense short duration rainfall (minutes)	Impermeable surfaces quickly flooded	Size drains for 1 in 20 precipitation Effective maintenance and cleaning of blocked drains		
More tropical depressions	Thunderstorms	Lightning	Lightning protection for outdoor equipment and generator buildings Surge divertors on HV system	Fiaga power plant has a lightning rod on the comms tower	Needs more lightning protection throughout the EPC network

Hazard	**Type of Risk**	**Impact and Asset Affected**	**Climate Proofing Measures**		
			Industry Best Practice	**Existing**	**Missing/ Recommended**
More tropical depressions	Storm surge	Short term flooding	Raise +2.5 m in elevation on high water mark Accept temporary flooding (several tidal cycles)	None	Assess and protect vulnerable assets in coastal areas of network
More tropical depressions	Landslips	Destruction of assets	Locate assets away from potential landslip areas Protect assets by barriers Underground overhead lines	None	Assess and protect vulnerable assets in areas of network near potential landslip areas
Sea Level Rise (SLR)	Chronic (slow) Coastal Inundation	Long term Flooding	Move assets back from coast to gain +2 m in elevation on mean sea level	None	Assess and protect vulnerable assets in coastal areas of network
Natural - Non-Climate Related					
Equipment Failure	Oil leakage from power transformers in event of catastrophic failure of tank or cooling radiators	Contamination of environment	Construct oil containment around each power transformer to contain complete volume of oil	None (the oil containment of power transformers at Fiaga power plant have been negated by inserting water drainage holes in the bund)	Assess and provide oil containment for all power transformers
Tsunami	Coastal destruction	Short term flooding High energy waves Destructive force on buildings	Move assets 1.5 kms inland or achieve +15 m in vertical elevation	Existing nation-wide warning system for Tsunamis	Assess and protect vulnerable assets in coastal areas of network
Earthquakes	Seismic shocks	Body waves cause building destruction Surface waves cause tsunamis	Build lightweight structures or design high rise which avoid resonant frequency of EQ Move assets 1.5 km inland or achieve +15 m in vertical elevation Seismic design incorporated in all switchgear and transformer foundations and buildings	None	Ensure seismic design incorporated in all switchgear and transformer foundations and buildings
Volcanoes	Potential eruption if not proven to be dormant	Overland lava flow destroying assets	Avoid building in potential or existing lava fields Protection of assets against ash and rocks	None	Assess and protect vulnerable assets around Mt Matavanu
El Niño	Follows 7 year cycle but highly unpredictable	Warmer weather causes more rain and more cyclones	Plan for inclement weather	None	
La Niña	Follows 7 year cycle but highly unpredictable	Colder weather causes less rain and fewer cyclones	Plan for droughts	None	

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
Tuvalu TEC					
Climate Related					
Global Warming Elevated temperature	Higher daytime ambient temperatures; warmer nights	Equipment operation Higher demand for air conditioning	Compensate higher temperatures with increased cooling on generators Use of HTLS[50] conductors to operate at higher temperatures and avoid derating transmission circuits	None	Not applicable for TEC, as there is no overhead transmission system
Global Warming Elevated temperature	Less annual rainfall	Drought / hydro generation	Large hydro reservoirs Multipurpose dams for flood control, potable water, electricity generation	None	Not applicable for TEC, as no hydropower potential exists
Global Warming Elevated temperature	Longer periods without rain	Non-rain days / dusty conditions, obscuration of solar panels	More cleaning of solar panels	None	Implement regular monitoring of panels and cleaning when appropriate
More Intense Cyclones	Strong winds from cyclone or tropical depression	Destroy structures not designed to withstand wind loading factor Render windmills unusable	Design structures to Category 5 Make windmills demountable	None	Currently not applicable for TEC, as no wind power exists; but applicable for future wind power
More Intense Cyclones	High winds	Blow trees onto assets	Undergrounding of distribution system; Keep trees clear of assets	Network already underground	Not applicable for TEC, as existing underground system already cyclone proof
Storms	High winds	Rusting of assets in coastal areas due to salt spray	Use stainless or plastic products in lieu of sheet steel	None	Replace all rusting assets with non-rust options
More Intense Cyclones or tropical depressions	Heavy rain cyclonic long duration (days)	Area Flooding due to saturated preconditions	Undergrounding of distribution system; placing live vulnerable equipment above flood levels Minimise use of vulnerable ground level assets	Network already underground but needs upgrade	External meter boxes exposed to weather; need to be weatherproofed; LV Link boxes to be raised above flood levels
More Intense Cyclones or tropical depressions	Intense short duration rainfall (minutes)	Impermeable surfaces quickly flooded	Size drains for 1 in 20 precipitation Effective maintenance and cleaning of blocked drains		
More tropical depressions	Thunderstorms	Lightning	Lightning protection for outdoor equipment and generator buildings Surge divertors on HV system	Funafuti Power Station has two lighting rods on building	OK as is
More tropical depressions	Storm surge	Short term flooding	Raise +2.5 m in elevation on high water mark Accept temporary flooding (several tidal cycles)		

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
More tropical depressions	Landslips	Destruction of assets	Locate assets away from potential landslip areas Protect assets by barriers Underground overhead lines	None	Not applicable for TEC, as entire country has elevation <5 m (refer footnote 57)
Sea Level Rise (SLR)	Chronic (slow) Coastal Inundation	Long term Flooding	Move assets back from coast to gain +2 m in elevation on mean sea level	None	Locate link boxes and ground mounted transformers, switchgear, etc., on foundations at higher than present levels
Natural - Non-Climate Related					
Equipment Failure	Oil leakage from power transformers in event of catastrophic failure of tank or cooling radiators	Contamination of environment	Construct oil containment around each power transformer to contain complete volume of oil	None	Not applicable for TEC, as there are no HV power transformers
Tsunami	Coastal destruction	Short term flooding High energy waves Destructive force on buildings	Move assets 1.5 kms inland or achieve +15 m in vertical elevation	Network already underground	
Earthquakes	Seismic shocks	Body waves cause building destruction Surface waves cause tsunamis	Build lightweight structures or design high rise which avoid resonant frequency of EQ Move assets 1.5 km inland or achieve +15 m in vertical elevation Seismic design incorporated in all switchgear and transformer foundations and buildings	None	Not applicable for TEC, as not in earthquake zone (refer Table 14)
Volcanoes	Potential eruption if not proven to be dormant	Overland lava flow destroying assets	Avoid building in potential or existing lava fields Protection of assets against ash and rocks	None	Not applicable for TEC, as no volcanoes in country
El Niño	Follows 7 year cycle but highly unpredictable	Warmer weather causes more rain and more cyclones	Plan for inclement weather	None	
La Niña	Follows 7 year cycle but highly unpredictable	Colder weather causes less rain and fewer cyclones	Plan for droughts	None	

Evaluation of Investments

An investment that improves the climate resilience of a power system is viable if its benefits outweigh its costs. These benefits and costs should be evaluated in economic terms, i.e. from the perspective of society as whole, rather than be evaluated in purely financial terms.

The evaluation is concerned with the ‘incremental’ costs and benefits, which represents the difference between the without and with scenarios:

- **Without climate resilience** – the business as usual investment. For example, replacing an aged generator housing.
- **With climate resilience** – spending more to climate proof the asset. For example, upgrading the generator housing specifications to make it flood proof.

There are two common costs to be quantified when evaluating an investment's viability in the context of improving climate resilience:

- **Incremental investment costs**. The upfront cost of making an investment, i.e. how much extra needs to be spent upfront to make the investment more climate resilient?
- **Incremental operating costs**. The annual cost of operating and maintaining the assets, i.e. how much extra is it going to cost to operate and maintain the more climate resilient asset?

The two most common benefits relating to climate resilient investments in the power system are likely to be:

- **Avoided costs of replacement/repair**. Each time there is a climatic or extreme weather event, how much will it cost to replace or repair assets? Climate resilient investments are likely to be less adversely affected, and therefore will require less replacement/repair.
- **Avoided cost of outages.** Each time there is a climatic or extreme weather event, how many customers are likely to face a power outage? Climate resilient investments are likely to be less adversely affected, and therefore will lead to fewer outages. The cost of outages should be quantified **from** the perspective of society, rather than from the narrow perspective of the utility. Therefore, the cost of each kWh of energy not served (due to an outage) should be valued at the 'Value of Lost Load' (VOLL) rather than the electricity tariff.

The results of the analysis of the investments identified in this report are summarised in Table 2 below. For the Base Case scenario, all the investments are considered viable because they are greater than or equal to the hurdle rate of 9% (the ADB social discount rate). Two of the investments are right on the cusp of viability, but sensitivity testing confirms their likely viability, given that the range of results under different input scenarios is generally skewed towards the positive side and because of deliberately conservative assumptions in the base case.

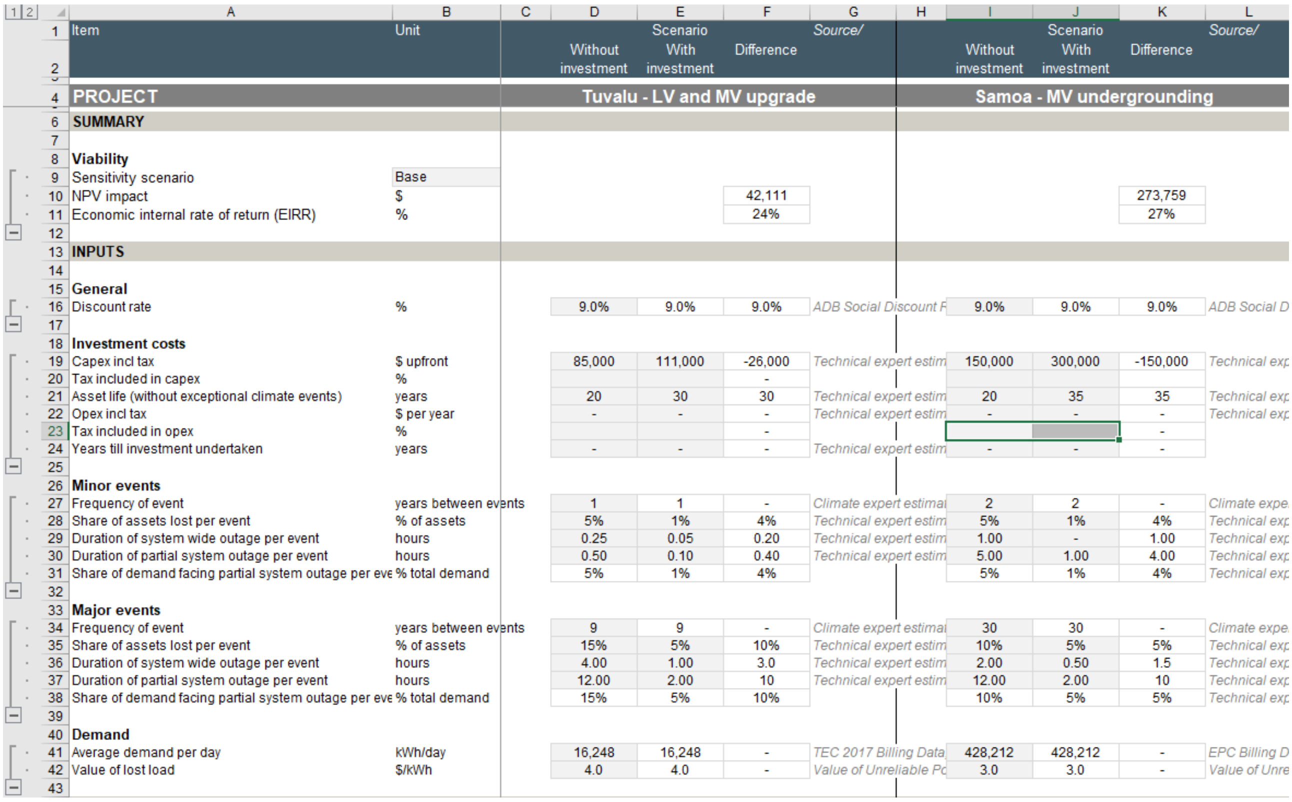
Table 2 Analysis Results of Investments for EPC and TEC

		Samoa				**Tuvalu**
		MV undergrounding	**LV ABC Programme**	**Lightning protection**	**Back-Up Control System**	**LV and MV upgrade**
Benefits						
Avoided cost of replacement and repair - minor event	$ /y	2,250	48,745	-	-	4,250
Avoided cost of replacement and repair - major event	$ /y	-	16,872	-3,250	-417	911
Avoided outage cost - minor event	$ /y	33,186	26,763	-	27,299	609
Avoided outage cost - major event	$ /y	4,639	75,606	40,145	1,249	2,196
Annual avoided costs	$ /y	40,075	167,987	36,895	28,131	7,967
Costs						
Annual incremental cost	$ /y	-11,959	-177,111	-13,627	-24,334	-7,820
Viability						
Annual net impact	$ /y	28,117	-9,124	23,268	3,797	147
NPV impact	$	273,759	-86,638	219,308	35,786	1,386
Economic internal rate of return (EIRR)	%	**27%**	**9%**	**26%**	**11%**	**9%**

We have developed a Viability Tool that Pacific utilities can use in the future to decide whether improving the climate resilience of a power system investment is justified. In building the Viability Tool we have endeavoured to strike an appropriate balance between keeping it simple enough that it can be used by staff of the Pacific utilities and being complex enough that it captures the main value drivers. In particular, this means that:

- The inputs and assumptions have been simplified to a form that can realistically be estimated by staff of Pacific utilities.
- The Viability Tool calculates all incremental costs and benefits in terms of their average annual effect.

A screenshot of parts of the Viability Tool is provided below.



	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		*Source/*			Scenario		*Source/*
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	**PROJECT**			**Tuvalu - LV and MV upgrade**					**Samoa - MV undergrounding**			
6	**SUMMARY**											
7												
8	**Viability**											
9	Sensitivity scenario	Base										
10	NPV impact	$				42,111					273,759	
11	Economic internal rate of return (EIRR)	%				24%					27%	
12												
13	**INPUTS**											
14												
15	**General**											
16	Discount rate	%		9.0%	9.0%	9.0%	*ADB Social Discount F*		9.0%	9.0%	9.0%	*ADB Social D*
17												
18	**Investment costs**											
19	Capex incl tax	$ upfront		85,000	111,000	-26,000	*Technical expert estim*		150,000	300,000	-150,000	*Technical exp*
20	Tax included in capex	%				-						
21	Asset life (without exceptional climate events)	years		20	30	30	*Technical expert estim*		20	35	35	*Technical exp*
22	Opex incl tax	$ per year		-	-	-	*Technical expert estim*		-	-	-	*Technical exp*
23	Tax included in opex	%				-					-	
24	Years till investment undertaken	years		-	-	-	*Technical expert estim*		-	-	-	
25												
26	**Minor events**											
27	Frequency of event	years between events		1	1	-	*Climate expert estimat*		2	2	-	*Climate expe*
28	Share of assets lost per event	% of assets		5%	1%	4%	*Technical expert estim*		5%	1%	4%	*Technical exp*
29	Duration of system wide outage per event	hours		0.25	0.05	0.20	*Technical expert estim*		1.00	-	1.00	*Technical exp*
30	Duration of partial system outage per event	hours		0.50	0.10	0.40	*Technical expert estim*		5.00	1.00	4.00	*Technical exp*
31	Share of demand facing partial system outage per eve	% total demand		5%	1%	4%			5%	1%	4%	*Technical exp*
32												
33	**Major events**											
34	Frequency of event	years between events		9	9	-	*Climate expert estimat*		30	30	-	*Climate expe*
35	Share of assets lost per event	% of assets		15%	5%	10%	*Technical expert estim*		10%	5%	5%	*Technical exp*
36	Duration of system wide outage per event	hours		4.00	1.00	3.0	*Technical expert estim*		2.00	0.50	1.5	*Technical exp*
37	Duration of partial system outage per event	hours		12.00	2.00	10	*Technical expert estim*		12.00	2.00	10	*Technical exp*
38	Share of demand facing partial system outage per eve	% total demand		15%	5%	10%			10%	5%	5%	*Technical exp*
39												
40	**Demand**											
41	Average demand per day	kWh/day		16,248	16,248	-	*TEC 2017 Billing Data*		428,212	428,212	-	*EPC Billing D*
42	Value of lost load	$/kWh		4.0	4.0	-	*Value of Unreliable Pc*		3.0	3.0	-	*Value of Unre*
43												

Climate Resilient Policies and Processes

Investments that improve climate resilience are unlikely to occur in the Pacific if they are not supported and enabled by robust policies and processes. Policies and processes can also play a key role in ensuring that Pacific utilities do not prepare excessively and over-prescribe solutions to protect against risks that may never occur.

There are five key principles that Pacific utilities should integrate into their planning processes. Ideally these principles are incorporated into a standalone climate resilient plan that each utility prepares and updates. If a standalone plan is deemed too onerous or costly for a utility, it can still address the below principles when preparing its power development plan.

The principles are:

1. **Identify the risks of climatic and extreme weather events** – Pacific utilities need to identify and measure the risks associated with potential disasters and assess the degree of vulnerability of their power system to those risks. A careful analysis of risks can also help countries to prioritize the resilience measures and focus on the ones that target events with a higher likelihood. This is particularly important for countries with limited financial resources that can be channelled towards climate resilience objectives. Section 2 of this report provides an example of how risks can be assessed in the future.
2. **Identify resilience measures that will reduce risk** – Resilience measures either aim to reduce the likelihood of damage in the event of a climate or natural disaster or to minimise the consequences of the damage. This should include:
    - Consider whether hardening of existing assets can make them more resilient, including elevating equipment, undergrounding lines, and reinforcing the network

  - Consider whether decentralised networks can be used to increase flexibility and minimise the extent of impact
  - Consider whether the way in which the power system is operated can be modified to make it more able to handle events. This includes improved maintenance of equipment, optimised use of VRE, and demand management.

   Section 3 of this report provides an example of how resilience measures can be identified in the future.

3. **Screen and select of resilience measures** – The benefits of resilience measures need to be compared with the costs of implementing them, as well as the costs of inaction. Resulting benefits and costs will vary by the type of asset they target, the timing of implementation, the expected impacts and the likelihood of a disaster taking place. The cost and benefit information can be used to rank resilience measures and create a portfolio of resilience measures that meet the goals of the utility/policy makers. Section 4 of this report provides an example of how the Viability Tool can be used to screen resilience measures.
4. **Monitor and evaluate measures, to ensure better responsiveness to potential threats** – Expectations and assumptions that go into utilities' investment plans are likely to change soon after the plans are developed. This is not only because climatic conditions might change, causing a change the likelihood of disasters, but also because technologies, consumer preferences and other energy related policies may change during implementation. For the plan to be robust it needs to incorporate a monitoring programme and the systematic reassessment of resilience.
5. **Put financial protection in place** – The financial sector can play a major role in energy sector resilience planning. It can help fund measures that protect the energy sector from major climate or natural disasters, while also providing ex-post support to help those affected negatively from a disaster. Several Pacific utilities have reported that they are unable to insure their overhead lines against climatic and extreme weather events. Self-insurance programs can provide alternatives, as demonstrated by their adoption in Samoa and Fiji.

1.0 Introduction and Background

1.1 Appointment

SMEC International Pty Ltd, in association with Economic Consulting Associates (ECA), has been appointed Consultant for the ***Technical Assistance to Develop Investment Plans for Enhancing Energy Resilience in Pacific Island Power Utilities*** under contract N° SEIDP/C2.2 dated 27 November 2019 with the Pacific Power Association (PPA). The assignment is part of the *Sustainable Energy Industry Development Project* funded by the World Bank.

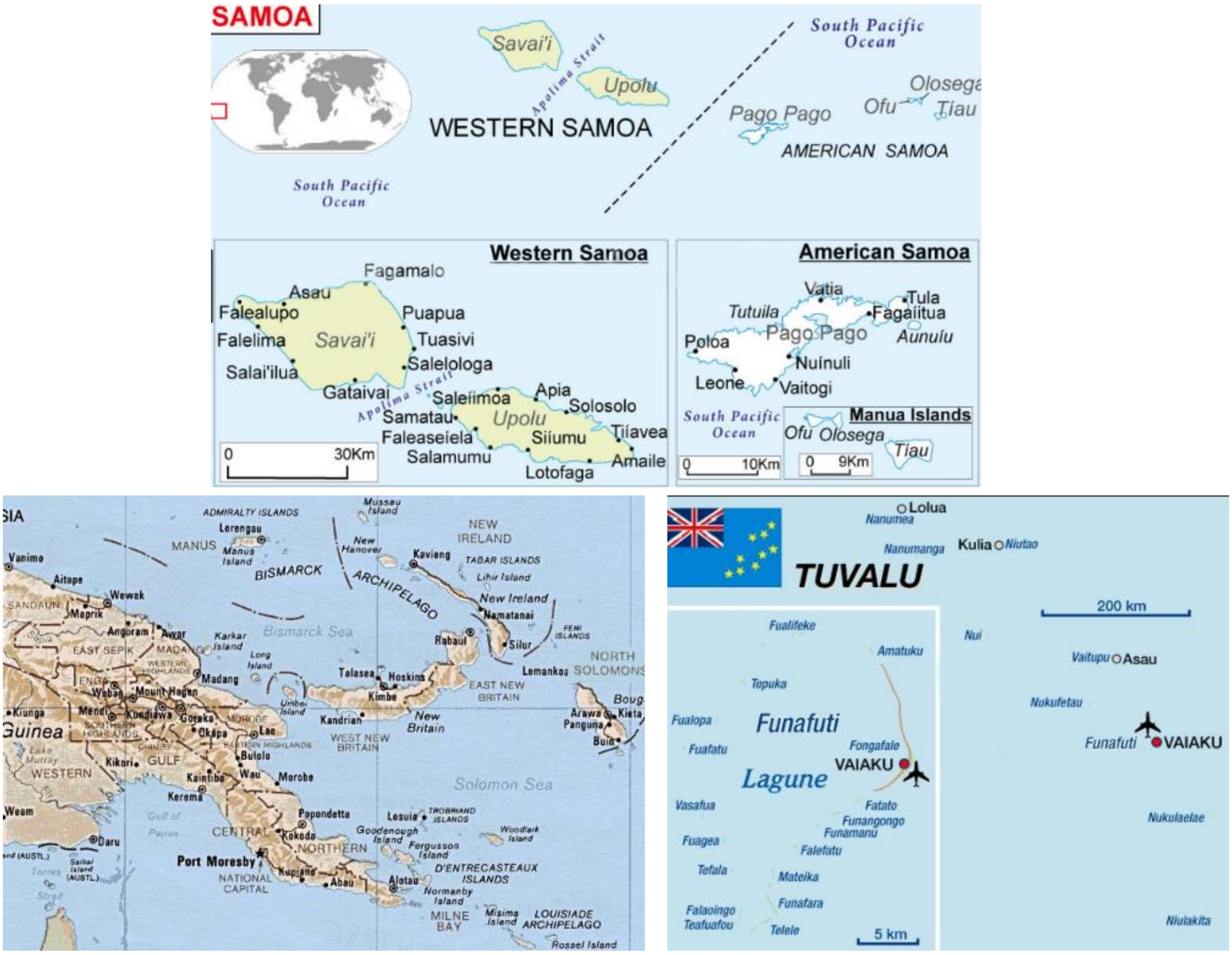
PPA issued their Letter of Contract Effectiveness on 27 November 2019.

The three target utilities, being representative as large, medium and small utilities in PPA's membership of 25 power utilities, are respectively:

- PNG Power Ltd (PPL)
- Samoa Electric Power Corporation (EPC)
- Tuvalu Electricity Corporation (TEC).

The three country maps are shown in Figure 1.

Figure 1: Country Maps of three Targeted Utilities



1.2 Project Objectives

The key objective of this TA study is to provide technical, financial and environmental specialist advice on the resilience of the three selected power utilities for climate change and disaster impacts.

This includes the impact of climate change related incidents (e.g. tropical storms, cyclones, floods, coastal inundation, droughts, etc.) and natural disasters (e.g. fires, earthquakes, etc.).

The outputs of the TA study include:

- Mapping of vulnerable power infrastructure subject to impacts of climate and natural disasters
- Vulnerability assessment of physical assets and energy supply at the three targeted utilities
- Recommended technical solutions needed to enhance the resiliency of the three power systems
- Recommended investment plans and prioritising a pipeline of climate resiliency projects.

It is also intended that the outputs will also be used by the other utility members as a template or checklist to apply to their own organisations in order to mitigate impacts and improve resiliency.

1.3 Final Report

This Final Report includes (i) the findings of the Task 2 field inspections of the key power infrastructures at each of the three targeted utilities; and (ii) Task 3 recommended climate proofing measures identified in the study.

It also includes feedback received from TEC, EPC and PPA on the draft Final Report dated 12 June 2020.

1.4 Field Visit Programme

Field visits were carried out by the study team as follows:

- 15 - 19 January 2020: In Suva, Fiji; met with PPA
- 19 - 23 January 2020: In Funafuti, Tuvalu; met with TEC
- 23 - 24 January 2020: In Nadi, Fiji; in transit
- 24 - 30 January 2020: In Apia; met with EPC.

The field visit to Tuvalu was delayed by three days due to Cyclone Tino; although this meant that the study team were able to observe first-hand the result of the Category 2 storm on Funafuti. A series of subsequent low pressure systems meant frequent rain and strong wind conditions which prevented travel by the team to the outer islands. This is further discussed in Section 3.3.

Photos of the Tuvalu and Samoa site visits are shown in Appendix 1.

The site visit to PNG, scheduled for the week of 22 March 2020, was cancelled due to international travel restrictions and lockdown due to the Covid-19 pandemic. As the probability of international travel to PNG is unlikely until at least after the completion date of this Study, a field assessment of PPL in PNG was not possible. However, the Study Team have all independently visited PNG on different assignments within the last year, most recently in March 2020 by the Environmental Specialist, so are generally familiar with the Country and have accumulated various relevant data. Consequently, this report still provides a limited Task 2 assessment of PPL, except for a field assessment of PPL assets. Although requested through PPA, PPL were unable to provide their Annual Reports, nor a copy of their draft Least Cost Power Development Plan 2020 - 2034. Consequently, this report excludes any investment plans for PPL.

1.5 Acknowledgements

This report was made possible with the financial support of the Japan-World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries, which is financed by the Government of Japan and receives technical support from the World Bank Tokyo Disaster Risk Management Hub.

This funding was made available to the Pacific Power Association through the Sustainable Energy Industry Development Project.

The Study Team gratefully acknowledge the co-operation and assistance of PPA, TEC, and EPC management and officers in providing all necessary project office facilities, project information, and support resources needed during Task 2.

2.0 Assessment of Climatic and Extreme Weather Events

2.1 Defining Climate Resilience

In this assessment both climate and natural disaster risks are considered.

Climate risks include increased air temperature, droughts, increased mean annual rainfall, extreme rainfall events, high tides, sea level rise, storm surge, tropical cyclones and extreme wind. These can lead to flooding and landslips.

Natural disaster risks included fires, earthquakes and volcanic eruptions, both of which can lead to tsunamis.

Potential risks applicable to the PPA member utilities include:

- Major weather event such as cyclones, extreme winds, heavy rain and consequent flooding, storm and king tide surges and consequent flooding, droughts
- Major earthquake and consequent Tsunamis and/or collapse of buildings and infrastructure
- Lightning strikes and/or consequent fires
- Volcanic eruptions
- Acts of terrorism
- Cyber-attacks and subsequent loss of communications and/or data
- Major plant failures due to plane or heavy vehicle crash.
- Human pandemic and consequent loss of key staff
- Any other emergency events that result in a wide loss of disruption to the power supply.

Management of these risks requires each utility to carry out an assessment of the probability of the event happening, an assessment of the possible consequences of the event or simultaneous events happening, identifying what preventative measures could be taken prior to any event, and documenting standard responses to restore supply after the event or events.

Mitigation of the potential risks may consider the following actions:

- Application of n-2 redundancy[1] for generation[2] and n-1 redundancy for all other transmission and substation system assets
- Provision of back-up supplies to key customers
- Protection of key items against adverse weather and corrosion
- Strengthening of key items against seismic and mechanical impacts
- Establish and maintain minimum stock levels for all critical items of equipment
- Establish disaster recovery facilities independent of existing facilities
- Establish specialist crews for restoration of power in emergency conditions
- Establish standby crews for fire and/or security incidents
- Provision of alternate communication and/or SCADA facilities
- Provision of emergency fuel tanks for diesel generators based on possible period of no diesel deliveries
- With respect to Sea Level Rise (SLR), if one allows for measured increases in sea level, one can protect against sea level rise by adding 0.5 metres extra freeboard on to all platforms constructed next to coastlines, wharves and jetties
- If one allows for a worst case scenario, then according to latest publications from ADB one should allow an increment of 2.0 m on existing high water levels to protect against potential sea level rise by the year 2100.[3]
- By adopting a policy of Protect, Adapt or Retreat. To ensure one is in a tsunami impacts low risk zone move back 1.5 km from the sea, be 15 m above sea level or have access to a “safe haven” in a solid three storey building.

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[1] N-1 redundancy is where each component (n) has at least one independent back-up component to ensure continued system availability in the event of that component failure.

[2] EPC have adopted N-2 redundancy for generating plant under ADB-financed Power Sector Expansion Programme. This is because if the largest generator is down on maintenance or fault then the system has no reserve leading to increased vulnerability.

[3] *Sea level change in the Pacific islands region (PIR) – A literature review to inform Asian Development Bank (ADB) guidance on what projections to use in climate risk and adaptation assessments (CRAs)*”, Final Report, 03 April 2020, A. Kiem, Hydro-climatologist, Project Number: TA-8961 REG

2.2 Papua New Guinea

2.2.1 Country Context

The Independent State of Papua New Guinea (PNG), is an archipelago group of islands located north of Australia in the Pacific, roughly between latitudes 2° S and 12° S. PNG is a tropical country and key areas include the eastern half of the island of New Guinea, together with the main islands of Bougainville, Manus, New Britain and New Ireland. The Capital is Port Moresby; the estimated total population is over 8 million. Total land area is nearly 463,000 km^2, with a very diverse and rugged topography.

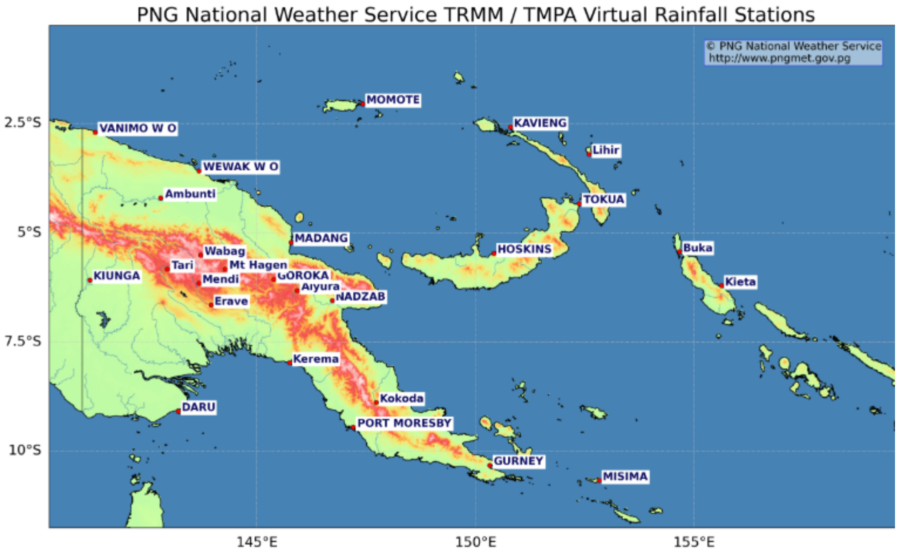
2.2.2 Historical Events

The main climate drivers are the El Niño Southern Oscillation (ENSO) and, to a lesser extent, the position of the South Pacific Convergence Zone. ENSO is considered to have a weaker influence on the northern part of the country. There is little variation over the year in terms of maximum and minimum temperatures. The temperature in Port Moresby rarely rises above 32°C.

The wet season is from November to April and the dry season from May to October, although, the seasonality of rainfall is considered rather weak except for the region around Port Moresby.[4]

PNG's three geographical areas each experience different climates; these are the coastal lowlands, the central highlands and the outer islands. As shown in Figure 2, there are a series of weather stations across the country and three key weather stations are located in Port Moresby on the south coast, Mendi in the Highlands and Kavieng on New Ireland island.

Figure 2: National Weather Service Stations in PNG



2.2.2.1 Highlands

Highlands Topography

The Highlands of PNG is a chain of mountains and high valleys stretching in a generally west to east direction from the border with Indonesia in the centre of the island to the eastern coast. The valleys are typically 1,500 m above sea level and are surrounded by peaks up to 4,000 m. The Highlands are well known for the prevalence of sharp relief. There is very little flat land in the highlands and a large proportion of the land is steep to very steep.

The watersheds are fragmented with much of the Highlands being made up of small catchments. There are large areas with loose soil or clay dominated soil so the water table is very high resulting in damp or swampy areas. These geographical characteristics contributed to historical impenetrability of the Highlands. Until the middle of the 20th century the Highlands were almost entirely isolated from the rest of the country. Despite this the Highlands have been inhabited for many thousands of years and the mountain valleys are relatively densely populated.

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[4] GoPNG, 2014. Papua New Guinea Second National Communication to the United Nations Framework Convention on Climate Change.

Influence of Physiography

The rugged and mountainous nature of the physiography of PNG has a major impact on weather patterns. Two major aspects of physiography - height and alignment - determine local climate. Generally, the summit level of the major mountain chains in PNG lies around 2,500-3,000 m with individual peaks rising as high as 4,500 m. In terms of climatic patterns there are two types of mountain system. The ranges of the islands and northern coast are approximately triangular in section, while the central highlands are more complex, with large intramontane valleys and basins and other internal mountain systems lying within the fringing ranges of the highlands.

These massive mechanical barriers substantially modify air streams in their vicinity. This effect is reinforced by the alignment of the mountain ranges in relation to the dominant south-east/north-west wind regimes. The mountains are aligned either nearly parallel to or transversely across the wind streams. This generates zones of convergence and divergence at the coast, and areas of upslope and downslope winds in relation to the main orographic barriers, which contribute to the major seasonal differences in rainfall found in PNG. In areas of convergence and of upslope winds, rainfall is enhanced, while in areas of divergence and of downslope winds, it is suppressed.

2.2.2.2 Island Influences

Land and sea breezes

Land and sea breezes play a significant part in controlling rainfall in coastal districts of PNG and at some places may completely dominate the seasonal controls. They are thermally driven local diurnal winds caused by the differential heating or cooling of the land relative to the adjacent sea. The sea breeze usually dies out at the coast shortly after sunset but may continue longer inland. The land breeze, the reverse of the sea breeze, usually sets in about midnight (or earlier in mountainous coastal regions) and may continue until two or three hours after sunrise. It is usually much weaker than the sea breeze.

Variations in coastline curvature can affect the direction of the sea breeze. Convective clouds may develop and rapidly become thunderstorms. [5]

Waves

Wind driven waves around Papua New Guinea are typically not large, with markedly different behaviour on the north and south coasts. Waves are seasonally influenced by the trade winds, the West Pacific Monsoon (WPM) the Inter-Tropical Convergence Zone (ITCZ). They correlate timewise with the El Niño Southern Oscillation (ENSO).

2.2.2.3 Temperature

Trends

Annual and half-year air temperatures as recorded at meteorological stations at Port Moresby and Kavieng have been warming since 1943 and 1962 respectively. Minimum air temperature trends are stronger than maximum air temperature trends. Warm temperature extremes have increased and cool temperature extremes have decreased at both sites. All temperature trends are consistent with global warming.

Temperature Change with Altitude

Temperatures differ between the lowlands and the Highlands with the Highlands being markedly cooler. Temperatures in the lowlands are warmer, ranging between 25^{o}C and 35^{o}C and rarely falling below 20^{o}C. The National Weather Service reports a mean annual maximum temperature of 23.7^{o}C and mean annual minimum temperature of 13.0^{o}C for the Mount Hagen area.[6]

Temperature regimes are equable, showing little seasonal variation. Daily mean maximum temperatures on the coast are around 30-32° C, with minima around 23°C. The most marked characteristic of temperature is the drop associated with increasing altitude. A large proportion of the population lives in highland valleys and mountains at altitudes between 1,500 m and 2,000 m, where mean daily maxima are around 22-25°C and night minima are 11-15°C. [7]

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[5] *Ibid.*

[6] http://www.pngmet.gov.pg/

[7] PNG Bureau of Meteorology 2020 http://www.bom.gov.au/pacific/png/index.shtml

Above 2,200 m, frosts can occur and snow may fall and settle above 4,000 m. The combination of relatively high rainfall and temperature is associated with high humidity and cloudiness and moderate rates of evaporation, which range on the coast from 1,500 mm to 2,000 mm per annum. [8]

2.2.2.4 Rainfall

Overview

Rainfall across PNG exhibits high variability both geographically and from year to year. Annual average rainfall in the capital Port Moresby is 1,190 mm, whereas at Kavieng on New Ireland Island, it is 3,150 mm.[9] Year-to-year variability is mostly driven by the El Niño Southern Oscillation which has three phases, two phases El Niño and La Niña being extreme, and a neutral phase.[10]

Generally, El Niño years are drier, and the La Niña are wetter and lead to more flooding and landslides. El Niño is also associated with a late start to the monsoon. At Kavieng, there has been a decrease in the number of days with rainfall since 1957. The remaining annual, half-year and extreme rainfall trends show little change at Kavieng and Port Moresby.

Variation in Rainfall across PNG

Papua New Guinea is situated at the junction of the equatorial Indo-Malayan and South West Pacific regions. To the west lies the large mass of islands of the Indonesian archipelago. To the east are the small scattered islands and atolls of the Pacific. The whole region is known as a ‘maritime continent’. The size of the island of which PNG forms half is the largest, highest and most massive island in this maritime continent. Its size results in significant local modifications to its climate, which would otherwise be equable equatorial, tropical and oceanic in nature. [11]

In Papua New Guinea no location is more than 300 km from the sea and most of the island, except for the main central range, is much closer. The highest point is more than 4500 m above sea level and approximately half the island is above 1000 m. Its height above sea level and the alignment of the island’s physiography in relation to the main weather systems are the major factors which account for the climatic differences found within the island. Altitude is a major factor.[12]

The larger part of the country experiences relatively high annual rainfall of 2500-3500 mm. A few lowland areas are drier, but annual rain falls of less than 1000 mm are unknown except in the capital, Port Moresby.

In contrast large areas of uplands to the north and south of the main central range have average annual rainfalls in excess of 4,000 mm and in some locations these can rise to over 10,000 mm per year.

Rainfall varies seasonally in most areas, but the degree of seasonality is not great. This seasonality is most evident in the drier areas, but even here there is no reliable period of nil or near nil monthly rainfall, as found in true ‘monsoon’ climates.

The seasonal variation of rainfall over most of Papua New Guinea can be described best as a change from ‘fairly wet’ to ‘very wet’. Nevertheless, minor droughts can occur from time to time even in moderately wet regions. The national capital Port Moresby lies in the driest part of the country. [13]

Monsoon Driven Climate Variability

PNG has a monsoonal climate characterised by high temperatures and humidity throughout the year. Two monsoonal seasons are recognised: the northwest monsoons, which occur from December to March, and the southwest Monsoons, which occur from May to October. PNG has one of the wettest climates of the world and rainfall in many areas of the country exceeds 2,500 mm, with the heaviest events occurring in the highlands. Temperatures are relatively steady across the country, and a mean temperature range from 26°C to 28°C.[14]

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[8] Ibid.

[9] Australian Bureau of Meteorology (BoM) 2015

[10] Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2015 (under PACSAP).

[11] Ibid.

[12] Climatic Research Unit (CRU) of University of East Anglia (UEA).

[13] Ibid.

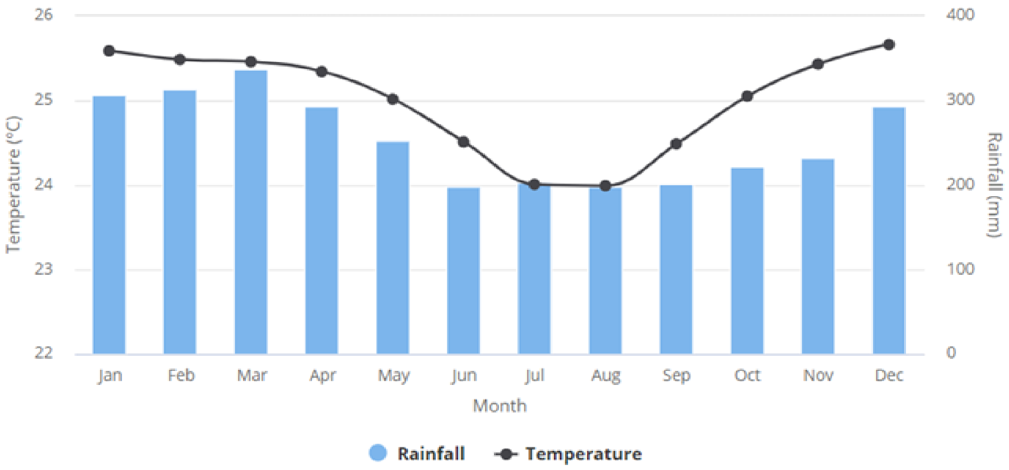
[14] Office of Climate Change and Environmental Sustainability and World Bank, 2009. Climate Change in Papua New Guinea: Framework for the National Climate Change Strategy and Action Plan.

The climate is characterised by high rainfall and humidity and high temperatures which remain generally uniform throughout the year. However, there are significant differences in climatic conditions across the country. The main component of spatial variation in temperature is the difference which occurs with change of altitude.[15]

Figure 3 shows mean historical monthly temperature and rainfall for PNG during the time period 1901-2016.

In order to establish the spatial variation of the climate across PNG archive records have been examined which show historical trends.

Figure 3: Mean historical monthly temperature and rainfall for PNG (1901-2016)

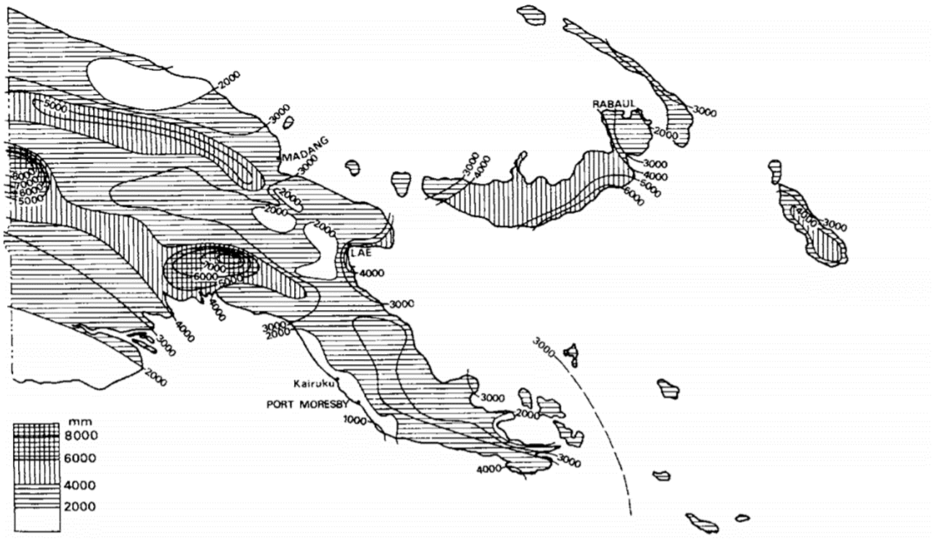


Source: Climatic Research Unit (CRU) of University of East Anglia (UEA).

Rainfall Variability due to Physiography

The interplay of altitude and alignment of mountains combines to give many different rainfall regimes. The distribution of mean annual rainfall over PNG is shown in Figure 4. The bulk of the country lies in the 2000-4,000 mm rainfall zone, with the wettest areas being associated with major topographic barriers to surface flow.[16]

Figure 4: Historical Mean Annual Rainfall over PNG.



The intensity of rainfall varies with location. This can affect erosion, landslides and flash flooding and is shown in Figure 5.

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[15] Climatic Research Unit (CRU) of University of East Anglia (UEA).

[16] PNG Bureau of Meteorology 2020.

The highest daily rain falls generally occur around the islands or in the south-east. In the highlands falls of over 100 mm per day do not occur. Archived data has been analysed to give 1 in 2 year events.[17] This is shown in Figure 6.

Figure 5: Intensity of rainfall

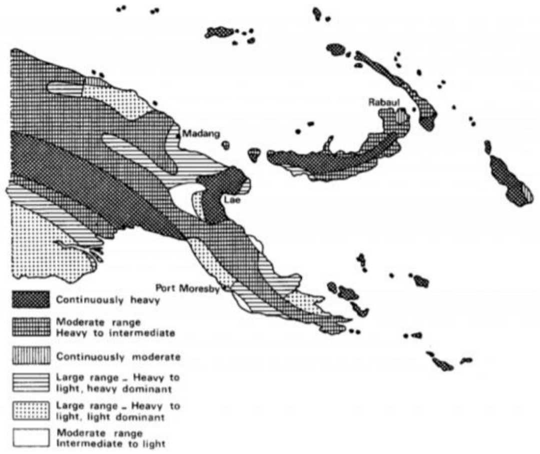
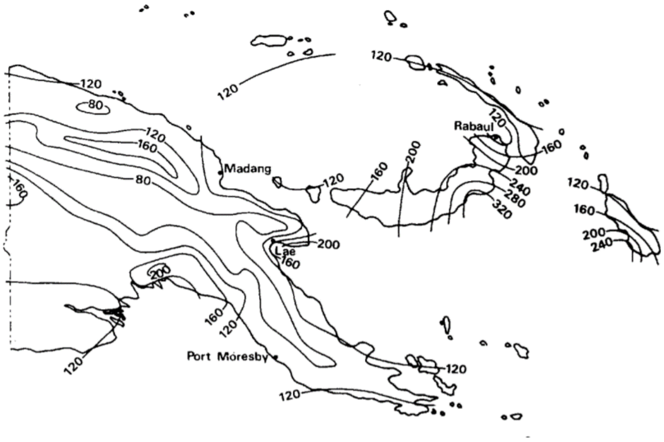


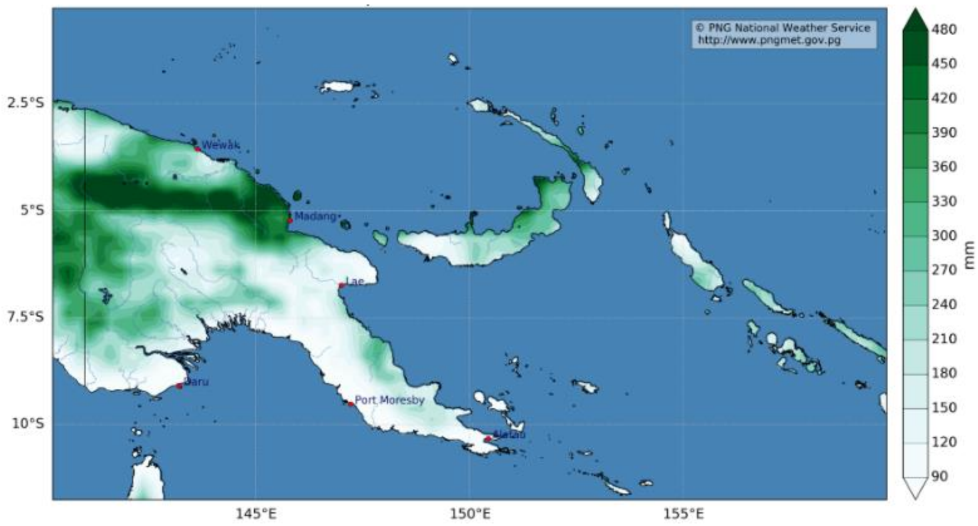
Figure 6: Maximum Daily Rainfalls in mm with ARI 1 in 2 years



Differences in intensity occur. The highlands have lower intensities, as does the drier area near Port Moresby. The heaviest **short term** rainfall occurs in the eastern islands.

There is considerable variation in the spatial distribution of rainfall patterns between the lowlands of PNG, the highlands of PNG and the eastern islands. Rainfall is heaviest in the Hindenberg mountains of northern PNG.

Figure 7: Observed Rainfall over 90 Days in PNG



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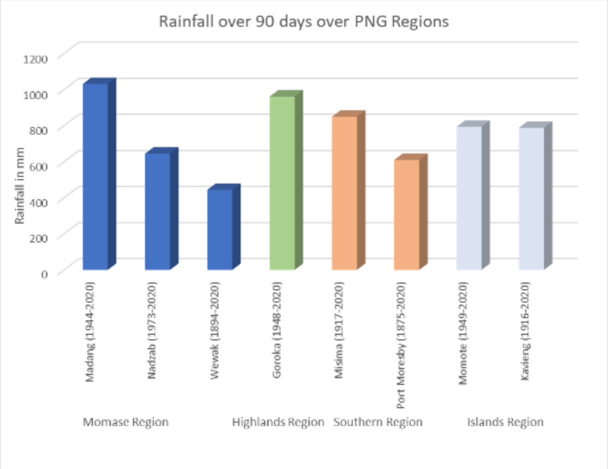
[17] SMEC (1990). *Papua New Guinea Flood Estimation Manual*. Port Moresby, Papua New Guinea, SMEC and Department of Environment and Conservation, Bureau of Water Resources.

Figure 8: Rainfall in Different Regions 90 Days



Rainfall in Highlands

The Highlands region is classified as warm and wet with no marked dry season. The key features are:

- Annual rainfall in the Highlands is highly variable over time. At Mendi, over 52 years from 1951, the annual rainfall ranged from 1,570 mm to 4,015 mm.
- Annual rainfall in the highlands varies with location. Annual rainfall ranged from 1,282 mm at Kainantu to 3,026 mm at Mt. Hagen.
- The Highlands are subject to intensive rainfall events with the highest recorded rainfall being 110 mm within a 24-hour period at Mendi.
- At Goroka, the highest recorded rainfall was 65.6 mm in 24 hours.[18]

There is no data available for rainfall in time lapses shorter than 24 hours.

2.2.2.5 Tropical Depressions and Cyclones

Winds

Although wind patterns are reliable and consistent, and wind speeds can be strong, they are only very rarely destructive. A small proportion of tropical depressions intensify into tropical cyclones, with sustained surface winds of 17 m/sec (34 kt) or greater in the areas affected.

Cyclones

Tropical cyclones affect the Southern Hemisphere portion of Papua New Guinea, mainly between November and April. An average of 15 cyclones per decade developed within or crossed over Papua New Guinea between the 1969 and 2010 seasons. Eleven of the 43 tropical cyclones (26%) between the 1981 and 2010 seasons were severe events at Category 3 or stronger.

PNG experiences **severe** tropical cyclones during the summer months of December to February and is also vulnerable to anomalously long dry spells associated with warm phase of the El Niño-Southern Oscillation (ENSO) phenomenon. Whilst PNG lies just outside of the main Tropical Cyclone belt for the Southwest Pacific region, on average tropical cyclones hit the country at the rate of about one cyclone per year. [19]

The majority of low pressure disturbances in the tropical south-western Pacific develop between November to April. They are characterised by multi-layered cloud with rain, usually with embedded cumulonimbus clouds which produce squally conditions. Typical cloud swirls associated with monsoon depressions observed on satellite photos are 300-600 km in diameter, but often merge with extensive cloud areas in the monsoon current to the north. [20]

Cyclones and Highlands

Tropical cyclones do not significantly affect rainfall in the Highlands.

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[18] Papua New Guinea Second National Communication to the United Nations Framework Convention on Climate Change, GoPNG, 2014.

[19] *Ibid.*

[20] PNG Bureau of Meteorology 2020.

2.2.2.6 Earthquakes and Tsunamis

PNG is in a very active seismic zone and vulnerable to earthquakes which if occurring offshore can have an associated tsunami. The 1998 tsunami which hit Wewak on the northern coast of the main landform caused widespread destruction and may have killed over 2,000 persons. A succession of three waves were reported to be 15 m high on approach and 4 metres high when travelling inland. Damage extended inland a distance of 150 m from the shoreline.

A list of major earthquakes in PNG dating back to the start of reliable records is given in Table 3.

Table 3 Major Earthquakes in PNG

Date	Region	Mag.	Deaths	Injuries	Comments
5/14/2019	New Ireland	7.5 Mw		1	No major damage or deaths reported.
5/6/2019	Morobe	7.2 Mw			Minor damage in Lae
4/7/2018	New Guinea	6.3 Mw	4		Aftershock
3/6/2018	New Guinea	6.7 Mw	25		Aftershock
3/4/2018	New Guinea	6.0 Mw	11		Aftershock
2/25/2018	New Guinea	7.5 Mw	160	500+	Heavy damage / Landslides
1/22/2017	Bougainville Island	7.9 Mw	3	15	Moderate damage / Tsunami (local)
9/9/2002	Sandaun Province	7.6 Mw	4	70	Tsunami (local)
1/10/2002	Sandaun Province	6.7 Mw	1		200 homes destroyed at Aitape
11/16/2000	New Ireland	7.8 Mw			Additional damage / doublet
11/16/2000	New Ireland	8.0 Mw	2		Tsunami (local) / doublet
7/17/1998	Sandaun Province	7.0 Mw	2,700	Thousands	Destructive local tsunami (15 m)
10/13/1993	Morobe Province	6.9 Mw	60	200	Landslides
3/11/1989	southern New Ireland	5.8 Mw	1		Landslide
2/9/1987	Morobe Province	7.4 Ms	3		Landslide
5/11/1985	New Britain	7.2 Mw	1		Landslides
3/27/1984	Karkar Island	6.5 Mw		11	Many buildings destroyed
7/26/1971	PNG / Solomon Islands	8.1 Mw			Tsunami (local) / doublet
7/14/1971	PNG / Solomon Islands	8.0 Mw	2	5	Tsunami (local) / doublet
10/31/1970	North coast	6.9 Mw	5–18	20	3 m (10 ft) tsunami
10/23/1968	North coast	7.5			Moderate damage
2/12/1968	New Ireland	7.8			Minimal damage
8/13/1967	Bismarck Sea	6.4 Ms			Severe damage / tsunami
11/17/1964	New Britain	7.6 Ms			Minimal damage / tsunami
4/23/1953	PNG / Solomon Islands	7.4 Mw			Minimal damage / tsunami
1/13/1941	Bismarck Sea	7.4 Mw	4		Moderate damage / tsunami
1/30/1939	Bougainville Island	7.8 Ms	5	Many	Moderate damage / tsunami
5/12/1938		7.5 Ms			Minimal damage / tsunami
5/28/1937	New Britain		507		Volcanic eruption / tsunami at Tavurvur
12/12/1933					Minimal damage / tsunami
1/19/1922	Bismarck Sea	7.5 Ms			Minimal damage / tsunami
2/2/1920	New Britain	7.7 Ms			Minimal damage / tsunami
5/6/1919	PNG / Solomon Islands	7.8 Mw			Minimal damage / tsunami
1/1/1916	PNG / Solomon Islands	7.9 Mw			Minimal damage / tsunami
10/2/1906	Bismarck Sea	7.2 Mw			Limited damage / tsunami
9/14/1906	New Britain	8.0 Mw			Minimal damage / tsunami
9/10/1900	Bismarck Sea	6.8 Ms	Some		Severe damage / tsunami
1873	Maclay Coast	8.0 Ms	Some		Moderate damage / tsunami
1857	Bismarck Sea	8.0 Ms			Minimal damage / tsunami

2.2.2.7 Volcanoes

Papua New Guinea has the most active volcanoes in the South West Pacific. The volcanoes of PNG are found in 2 principal volcanic arcs, the 1000 km long Bismarck Arc stretching WNW-ESE at north of New Guinea and New Britain Island, from the north coast of New Guinea near the border with Indonesia, to Bougainville Island in the east. This arc is a result of the northward subducting Solomon Sea beneath the

Bismarck Sea plate. The second volcanic arc forms the volcanoes on the south-eastern peninsula of New Guinea and is caused by the northward subduction of the Coral Sea.

2.2.3 Likelihood of Future Events

2.2.3.1 Climate Projections

The latest GCM (global climate model) projections for RCP 8.5 up to 2100 indicate[21]:

- Average rainfall is projected to increase in most areas (medium confidence), along with more extreme rain events (high confidence)
- Droughts are projected to decline in frequency (medium confidence)
- Ocean acidification is expected to continue (very high confidence)
- Sea level will continue to rise (very high confidence)
- No changes in waves along the Coral Sea (south coast) of PNG are projected (low confidence)
- On the northern coasts, December - March wave heights and periods are projected to decrease (low confidence)
- El Niño and La Niña events will continue to occur in the future but there is no information on whether they will change in intensity or frequency

Applying the O'Gorman[22] conclusion that for every one-degree rise in air temperature, short term rainfall would increase by 10%, if one takes a projected increase in temperature by 2050 as 1.6°C (IPCC AR5) then current maximum hourly rainfall data in mm/hour may increase by 16%.

2.2.3.2 Changes in ARI

The PACCSAP report states that, by 2030, the current 1-in-20 year daily rainfall is projected to increase by 12-14 mm; and by 2090, it may increase by 21-55 mm. This means that by 2090 the current 1-in-20 year daily rainfall event may become a 1-in-7 year or even a 1-in-4 year event.

2.2.3.3 Climate Change in Highlands

There is very limited data on projections specifically for the highlands compared with PNG in general.

Until present, the Highlands region is not affected by tropical cyclones. Climate change models do not project a change in this situation.

One can look at rainfall as this is the most significant of all the climate change parameters with respect to the CADIP2 project. The limited data from Mendi is consistent with general findings for the Pacific that annual rainfall may be increasing slightly and that inter-annual variability may be increasing slightly. Daily rainfall data for Goroka airport shows the highest recorded daily rainfall was 65.5 mm. If this is equivalent to the daily rainfall with a 20 year ARI according to PACCSAP there would be increases of 18–21% by 2030 and 32-84% by 2090.

Collectively, if one takes daily rainfall from many separate points in the Highlands the highest daily recorded figure was 110 mm. Assuming this is daily rainfall with a 20-year ARI the increases projected by PACCSAP would be 11-13% by 2030, and 19–50 % by 2090. [23]

2.2.4 Climate Change Effects

The impact and consequences of climate change effects is listed in Table 4. The predicted future occurrence of extreme weather events are shown in Table 5 and worst case scenarios in Table 6.

Table 4 Climate Change Characteristics - PNG

Climate Related Drivers	Effect	Impact and Consequence
Geographical	One main island and several smaller ones which constitute provinces.	Many inland districts only accessible by air or in some cases river but often no roads to move in heavy equipment or fuel for generators. All must be airfreighted in.
	Highly variable topography ranging from sea level coastal plain to central highlands.	Highest point > > 4,000 m. Suitable for small scale hydro plants.

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[21] Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) Program, 2014.

[22] Sensitivity of tropical precipitation extremes to climate change, Nature Geoscience 5, 697-700, O'Gorman, P. A. 2012.

[23] PACCSAP) Program Country Report PNG, 2014 Revised 2015.

Climate Related Drivers	**Effect**	**Impact and Consequence**
	Rainfall very variable; three climatic zone; coastal strip, islands and highlands.	River access to highlands can be interrupted by dry conditions and low river; or floods and turbulent river flows. This can interrupt delivery of diesel fuel.
Chronic (long term) events		
Temperature	Higher maximum temperatures	Affects operating equipment
Temperature	Higher air temperatures	Buildings need more air conditioning
Temperature	Higher air temperatures	Reduces efficiency of solar panels
Temperature	Higher sea temperatures	Reduces efficiency of cooling water for power stations
Temperature	Higher sea temperatures	Desalination plants discharge hot hypersaline brine. May push sea water temperature higher and kill corals, seagrasses etc.
Drought	Reservoirs lower	Impacts hydro electric schemes
Non rain days	More dusty atmosphere	Covers solar panels; need more cleaning; reduces efficiency. There are already extensive solar farms near airport.
Sea Level Rise (SLR)	SLR is 7 mm per year.	This is much higher than the global average 3.2 mm/yr
Acute (short term) Extreme Weather Events		
Tsunami	PNG has experienced tsunami on the north coast of the main island.	Tsunami in 1998 caused > 2,000 fatalities.
Cyclone or tropical depression	Although the mainland of PNG is an island, due to its large size it behaves as a continent. Hence its climate is described as a “maritime continent”.	Highlands experience most annual rainfall due to altitude but storms are usually of short duration. Rainfall intensity may cause landslides.
Cyclone or tropical depression	Storm surge from inverse barometric pressure, together with precipitation	Flooding of coastal assets up to 100 m inland.
Cyclone or tropical depression	Wind and swell generated waves can last for days after cyclone passes.	Ferry service to other islands disrupted. Ports may be unusable. Fuel delivery suspended.
Tropical depression	Strong winds	Impacts on transmission systems.
Heavy rain	If > 200 mm per day classed as extreme.	PNG coastal strips vulnerable to flooding.
Heavy rain	If > 200 mm per day classed as extreme	Flooding of airport runways; cannot fly in spare or replacement parts.
Thunderstorms / lightning	PNG is very prone to thunderstorms and in an area of high lightning strikes.	Lightning protection is required.
Intense short duration rainfall	If > 50 mm per hour classed as extreme	Rainfall occurs in the form of downpours or thunderstorms, which are intense but usually short-lived in the highlands.
Earthquakes	PNG is in a very active seismic zone.	Assets can be damaged.
Volcanoes	Papua New Guinea has the most volcanoes in the South West Pacific.	Volcanoes are active; the most recent eruption was June 2019 near Rabaul, East New Britain.

Table 5 Climate Change Projections in the Future - PNG

Variable	Season	2030	2055	2090	Value	Confidence	
Surface air temperature (°C)	Annual	+0.7 ± 0.3	+1.5 ± 0.4	+2.8 ± 0.6	Pessimistic	High	Confidence
		+0.8 ± 0.4	+1.5 ± 0.5	+2.4 ± 0.8	Base		
		+0.7 ± 0.4	+1.1 ± 0.5	+1.6 ± 0.6	Optimistic		
Maximum temperature (oC)	1-in-20-year event	N/A	+1.5 ± 0.7	+2.7 ± 1.5	Pessimistic	Low	Confidence
			+1.4 ± 0.9	+2.2 ± 1.3	Base		
			+1.0 ± 0.9	+1.3 ± 1.0	Optimistic		
Minimum temperature (oC)	1-in-20-year event	N/A	+1.6 ± 1.8	+2.6 ± 2.1	Pessimistic	Low	Confidence
			+1.7 ± 2.0	+2.4 ± 1.9	Base		
			+1.4 ± 1.8	+1.8 ± 1.8	Optimistic		
Total rainfall (%)	Annual	+5 ± 9	+7 ± 13	+15 ± 21	Pessimistic	Moderate	Confidence
		+3 ± 13	+7 ± 17	+15 ±20	Base		
		+3 ± 13	+8 ± 13	+11 ± 13	Optimistic		
Wet season rainfall (%)	November- April	+6 ±10	+8 ± 12	+15 ± 20	Pessimistic	Moderate	Confidence
		+5 ± 11	+9 ± 17	+16 ± 18	Base		
		+4 ± 12	+10 ± 13	+12 ± 12	Optimistic		
Dry season rainfall (%)	May-October	+4 ± 12	+6 ± 17	+15 ± 26	Pessimistic	Moderate	Confidence
		+1 ± 16	+5 ± 20	+15 ± 24	Base		
		+1 ± 15	+7 ± 16	+10 ± 16	Optimistic		
Sea-surface temperature (°C)	Annual	+0.7 ± 0.5	+1.3 ± 0.5	+2.6 ± 0.7	Pessimistic	High	Confidence
		+0.7 ± 0.4	+1.3 ± 0.5	+2.2 ± 0.7	Base		
		+0.6 ± 0.5	+1.0 ± 0.5	+1.4 ± 0.6	Optimistic		
Mean sea level cms	Annual	+10 (4-15)	+20 (10-29)	+41 (22-60)	Pessimistic	Moderate	Confidence
		+10 (5-14)	+20 (9-30)	+39 (20-58)	Base		
		+9 (4-14)	+18 (10-26)	+31 (17-46)	Optimistic		

Note: Colour code:

High
Medium
Low

Table 6 Climate Change Worst Case Scenarios - PNG

Variable	Season	2055
Surface air temperature (°C)	Annual	+1.9
Maximum temperature (°C)	1-in-20-year event	+2.2
Minimum temperature (°C)	1-in-20-year event	+3.4
Total rainfall (%)	Annual	+20
Wet season rainfall (%)	November- April	+20
Dry season rainfall (%)	May-October	+23
Sea-surface temperature (°C)	Annual	+1.8
Mean sea level cms	Annual	+29

2.2.4.1 Changes in Return Intervals for Rainfall

Figure 9, based on PACCSAP publication project.[24], shows the rainfall return levels through to 2090.

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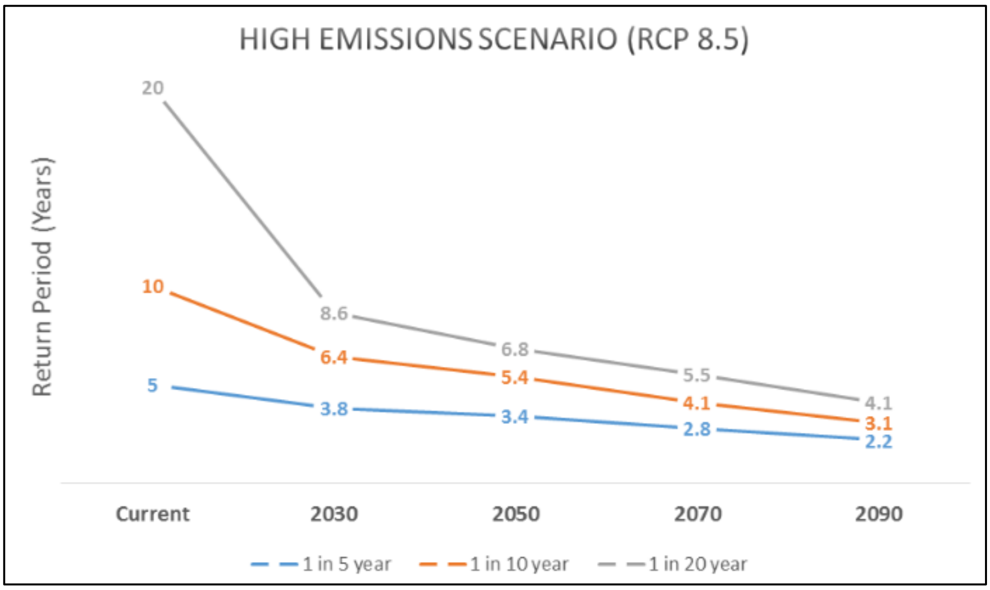
[24] Considering Climate Risks when Managing, Owning and Funding Coastal Assets, Guidance Manual for Commonwealth Agencies, Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Australia, July 2013.

Figure 9 Rainfall Return Levels - PNG



Changes in rainfall ARI are:

- By the year 2050 a 1 in 5 year event will become a 1 in 3.4 year event
- By the year 2050 a 1 in 10 year event will become a 1 in 5.4 year event
- By the year 2050 a 1 in 20 year event will become a 1 in 6.8 year event

At present in PNG occurrence of extreme weather events is as follows:

- Annual rain fall is slowly increasing
- An average of 15 cyclones per decade pass over PNG
- Of these 25% are severe being Category 3 or higher
- When cyclones hit PNG damage can be significant. The cyclone season is December to February. Coastal strips and islands are the most vulnerable. Highlands rarely suffer damage from cyclones.

The future occurrence of extreme weather events, by 2055 under RCP 8.5, are predicted to be as follows:

- Annual average air temperature may increase by 1.9°C and maximum temperature increase by 2.2°C.
- This could lead to 22% increase in short term intensity of rainfall. This is only accurate to + 40%.
- Annual rain fall may change by +20%
- Wet season rain fall may change by +20%
- Dry season rain fall may change by +23%
- Cyclones may lessen in frequency in the future as the cyclone belt moves south but increase in intensity.
- The frequency of cyclones depends on El Niño or La Niña:
  - Most pessimistic case – 1 severe cyclone every 4 years
  - Base case – 3 cyclones every 2 year
  - Optimistic case – 1 cyclone every 1 years
- Sea Level may rise by 290 mm by 2055
- Rainfall – short term intensity will increase by 22% (based on 2.2°C increase)
- PNG is in a very active seismic zone and vulnerable to earthquakes which if occurring offshore can have an associated tsunami. The 1998 tsunami which hit Wewak on the northern coast of the main landform caused widespread destruction and may have killed over 2,000 persons. A succession of three waves were reported to be 15 m high on approach and 4 metres high when travelling inland. Damage extended inland a distance of 150 m from the shoreline.

2.3 Samoa

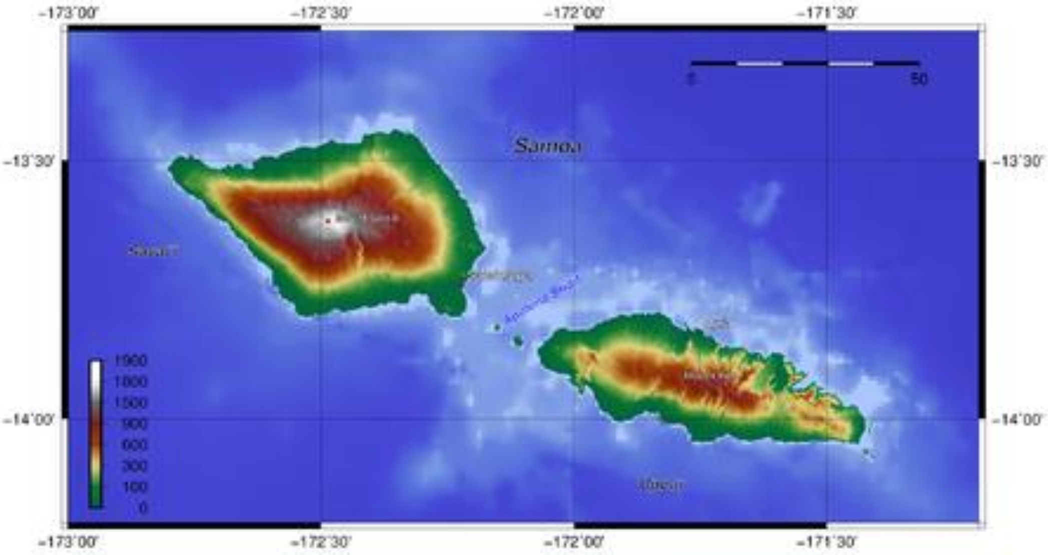
2.3.1 Country Context

Samoa consists of four main inhabited islands Upolu, Savai'i, Manono and Apolima and six smaller uninhabited islands.[25] The islands lie between 13ºS to 14ºS and 170ºW to 173ºW and have a total land area of approximately 2,934 km². More than half of Samoa's resident population live on the island of Upolu, also home to the capital, Apia. Samoa's total population in the last census (2016) was 183,123.[26] The population of Savai'i is ~43,560 people.

Figure 10: Samoa Map

Samoa has a rugged and mountainous topography. On Upolu, the central mountain range runs along the length of the island with some peaks rising more than 1,000 m above sea level. Savai'i has central volcanic peaks reaching 1,860 masl.[27]

Figure 11: Samoa Topography



2.3.2 Historical Events

2.3.2.1 Climate

The Climate Section, Meteorology Division, MNRE (SAMET) maintains many meteorological stations across Samoa and some have Automatic Weather Stations which record 10 minutes sampling of rainfall.

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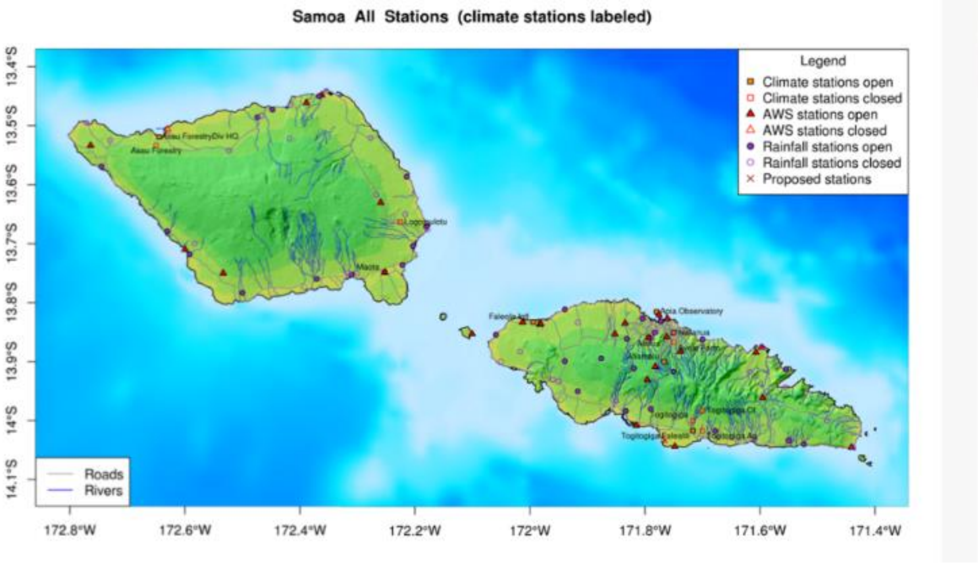
[25] Samoa's First National Communication under the UNFCCC, 2000.

[26] Samoa Bureau of Statistics - Statistical Abstract 2017

[27] Samoa Country Profile, SOPAC, 2000.

Figure 12: SAMET Stations in Samoa



Samoa has a tropical climate that is hot, humid and rainy throughout the year. Samoa has two distinct seasons, the "Hot and Wet" season, is from November to April. The "Cool and Dry" season is from May to October.

2.3.2.2 Temperature

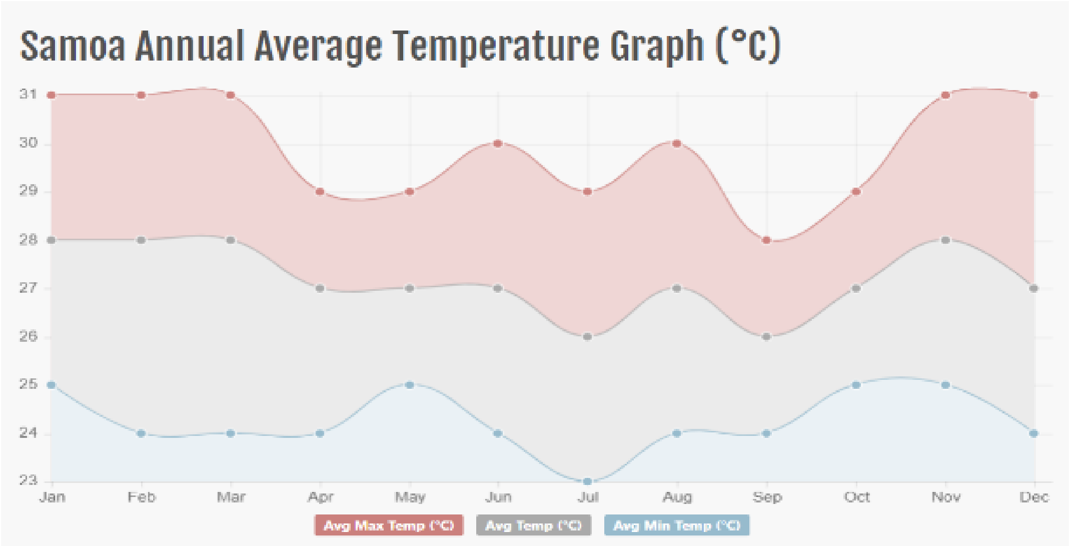
Temperatures are stable, with little variation between the hottest period (December to April), when highs are about 30°C and the coolest period (June to September), when they are around 29°C. Temperatures at night are almost always above 20°C.

There are only very small seasonal temperature differences in Samoa. The south-east trade winds blow steadily throughout the year, having a cooling effect. The coolest month of the year is July when the dry south-east trade winds are strongest. The warmest month is March, which is about 1º C warmer than July.

Table 7 Samoa Annual Average Climate

Averages	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°C)	28	28	28	27	27	27	26	27	26	27	28	27
Min Temp (°C)	25	24	24	24	25	24	23	24	24	25	25	24
Max Temp (°C)	31	31	31	29	29	30	29	30	28	29	31	31

Figure 13: Samoa Temperatures



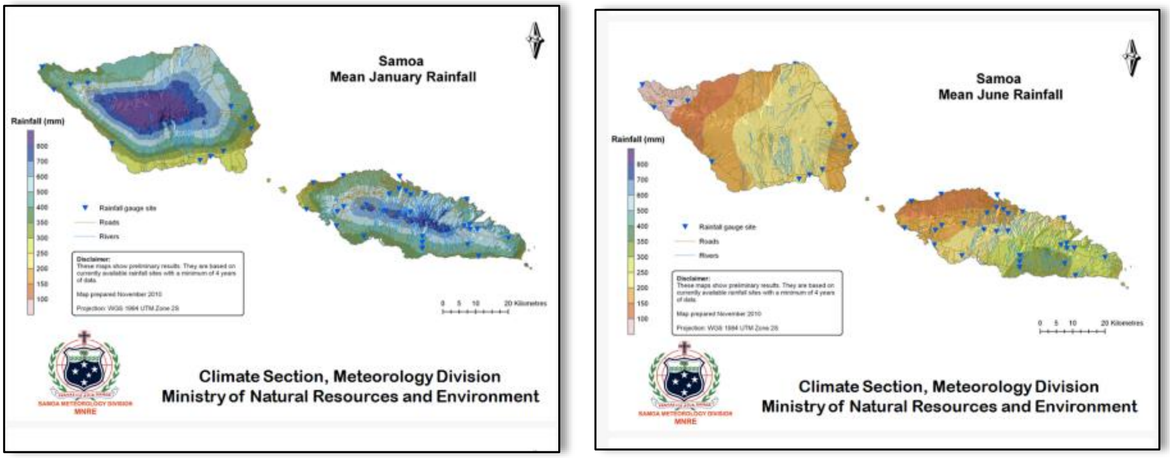
2.3.2.3 Rainfall

Overview

Samoa's annual mean rainfall ranges from 3,000 to 6,000 mm. Rainfall occurs in the form of downpours or thunderstorms, which are intense but usually short-lived, except in the period from December to March, when they can sometimes last for several hours.

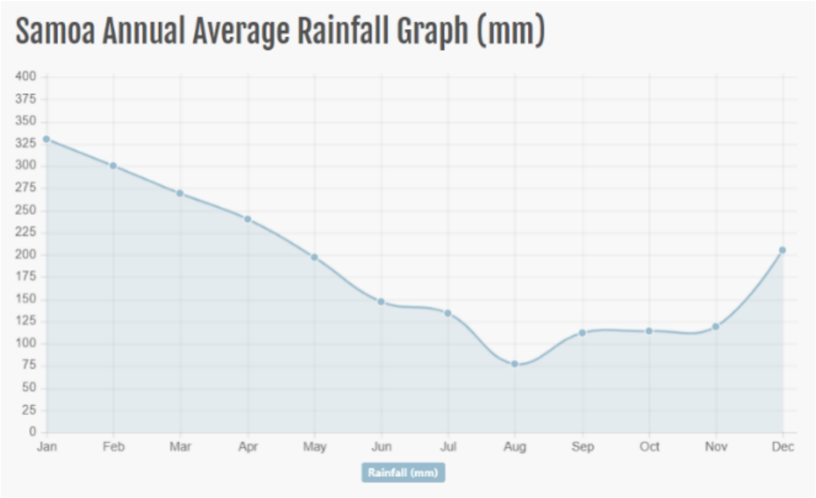
Rainfall is enhanced by the mountains that are found in the interior of the two main islands, and in particular, the largest island, Savai'i, where 1,858 m high Mount Silisili is located. Here, the rains can exceed 5,000 mm per year. Samoa’s topography has a significant effect on rainfall distribution. Wet areas are located in the south-east and relatively sheltered drier areas are in the north-west.

Figure 14: Rainfall in January and June in Upolu and Savaii



Rainfall has a distinct seasonal variation in Samoa. On average 75% of total annual rainfall is received in the wet season, from November to April. Average wet season rainfall amounts to approximately 350 mm per month. On average rainfall is about 150 mm per month in the dry season.

Figure 15: Samoa Average Rainfall



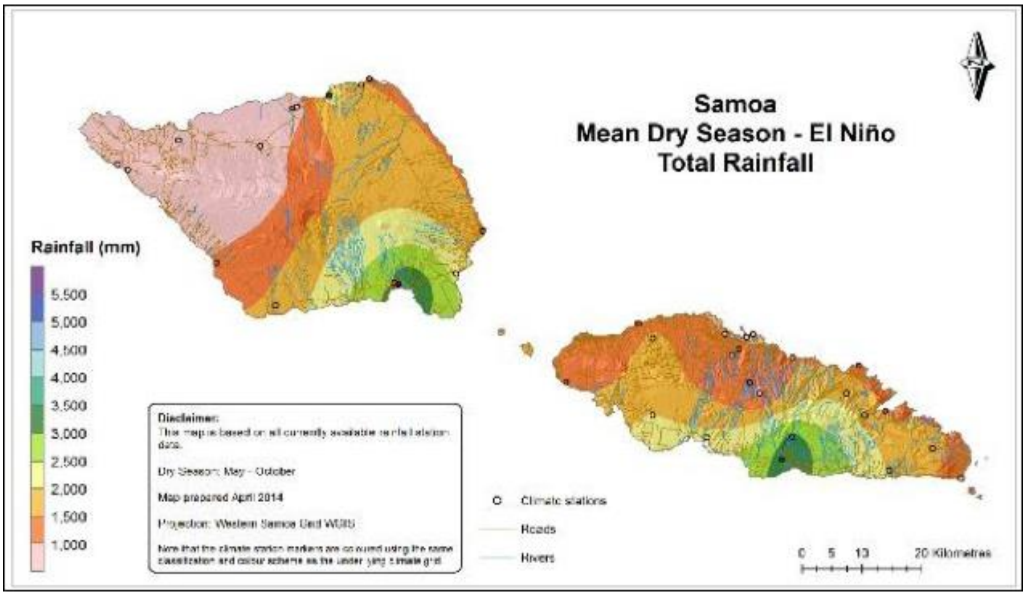
There is significant year-to-year variability in rainfall observed in Samoa. Annual rainfall in the drier years can be approximately half of that observed in wettest years.

Samoa’s rainfall is greatly influenced by the position and strength of the South Pacific Convergence Zone (SPCZ), which lies between Samoa and Fiji during the wet season. In the dry season the SPCZ is normally to the north-east of Samoa, often weak, inactive and sometimes non-existent. The close proximity of the SPCZ to Samoa during summer results in heavy rainfall throughout the country.

El Niño

The year-to-year variability is strongly influenced by the El Niño-Southern Oscillation (ENSO). El Niño is the main driver of Samoa's rainfall. El Niño tends to bring about lower than normal rainfall for Samoa, associated with droughts and forest fires. La Niña on the other hand are generally associated with above normal rainfall, associated with flooding of low-lying areas (in and around Apia).

Figure 16: Rainfall in El Niño season



Apia

In the capital, Apia, on the north side of Upolu Island 2,800 mm of rain falls per year, with a maximum of 450 mm in January and a minimum of 80 mm in July and August.

Table 8 Apia - Average precipitation

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Precipitation (mm)	450	380	350	250	160	120	80	80	130	170	260	370	2,800
Rain Days	19	18	17	15	13	11	8	9	12	14	16	17	169

Source: World Meteorological Organisation

No significant long term trends are evident in the observed daily, monthly, annual or maximum daily rainfall. Currently a daily rainfall of at least 300 mm is a relatively rare event in Apia, with a return period of 10 years.

Rain Shadow

There is a pronounced Rain Shadow effect. Topography plays a vital role in the rainfall distribution, the windward side (south to southeast) of the main islands receive more rainfall than the rain-shadowed side, mainly in the north to northwest regions.

SAMET rainfall stations on the south of both major islands record more rain than those to the north of the islands. This is the well-known rain shadow effect caused by the south westerly trade winds. There is no record as to what extent short term storm rainfall varies in a similar way.

Analysis of the available data shows a 25% difference between north and south, the north being lower.

Elevation Effect on Rainfall

The Climate Risk Profile for Samoa did say storm rainfall increased with elevation, but it was not quantified. The storm rainfall at the highest point in Upolu is 80% higher than in Apia at sea level. On Savai'i, with a maximum elevation of 1858 m, the effect is even more pronounced.

Data for Afiamalu at 796 masl and Nafanua at 113 masl shows that there is a 10% increase in rainfall intensity for every 100 m increase of elevation. The same rate of increase can be used for both islands.

ARIs

There is considerable annual variability in extreme rainfall occurrences. A daily rainfall of at least 300 mm is becoming increasingly common in Apia, with a current return period of approximately 10 years. It is even more common in Afiamalu with a return period of about 5 years.

2.3.2.4 Tropical Depressions and Cyclones

The Samoa Islands are exposed to the tropical cyclones of the South Pacific. Cyclones are usually formed from November to mid-May, though they are most likely from late December to early April. Outside of this period, there has been cyclone Keli, in June 1997. Samoa has a high cyclone hazard classification which means there is a 20% chance of potentially-damaging wind speeds over the next 10 years. (Source: United Nations Office for Disaster Risk Reduction 2019)

Historically cyclones have caused intense damage:

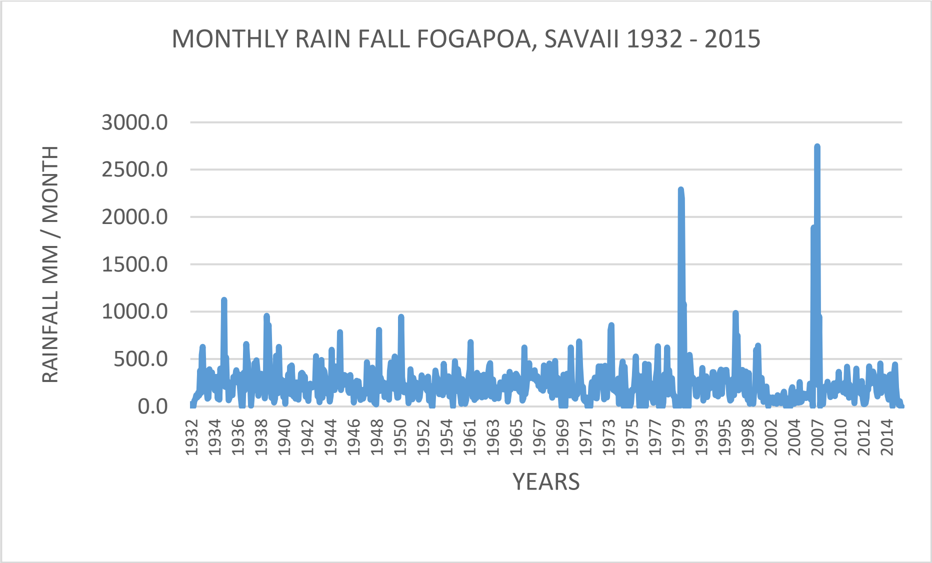
- Cyclone Ofa in 1990 caused winds over 200 km/hr (108 knots)
- Severe Tropical Cyclone Val in 1991 was considered to be the worst tropical cyclone to affect the Samoan Islands since the 1889 Apia cyclone. It lasted 5 days, caused extensive damage to houses and crops and killed 12 people
- Cyclone Evan in 2012 (Category 4) had winds of up to 110 km/h (60 knots) and a total rainfall over 400 m in 24 hours. It affected 7,500 people destroying 2,000 houses and five people died
- It is estimated that cyclones Ofa and Val caused damage exceeding four times the gross domestic product (GDP) of Samoa (UNDP)
- Cyclone Gita in 2018 caused flooding, landslides and debris made main roads impassable. Over 200 people were moved to evacuation centres.

Cyclones are usually more prevalent in El Niño situations. Although Sea Surface temperature (SSTs) are currently warmer than average, the El Niño Southern Oscillation (ENSO) remains in a neutral state which means it is neither El Niño (warmer) nor La Niña (colder). Models suggest that this situation will remain throughout the Tropical Cyclone season 2020-2021. (Source: Samoa Meteorology Division).

2.3.2.5 Extreme Weather Events

The highest annual rainfall ever recorded in Samoa was at Afiamalu of 9,359 mm in 1949. The highest daily rainfall ever recorded in Samoa was at Tapatapao at 671 mm in January 1939. One example of Fogapoa in Savaii is shown in Figure 17 which shows monthly data going back to 1932. This shows occasions when the equivalent of half a year rainfall fell in one month and of course it could have fallen over just a few days.

Figure 17: Monthly Rainfall Savaii 1932 - 2015



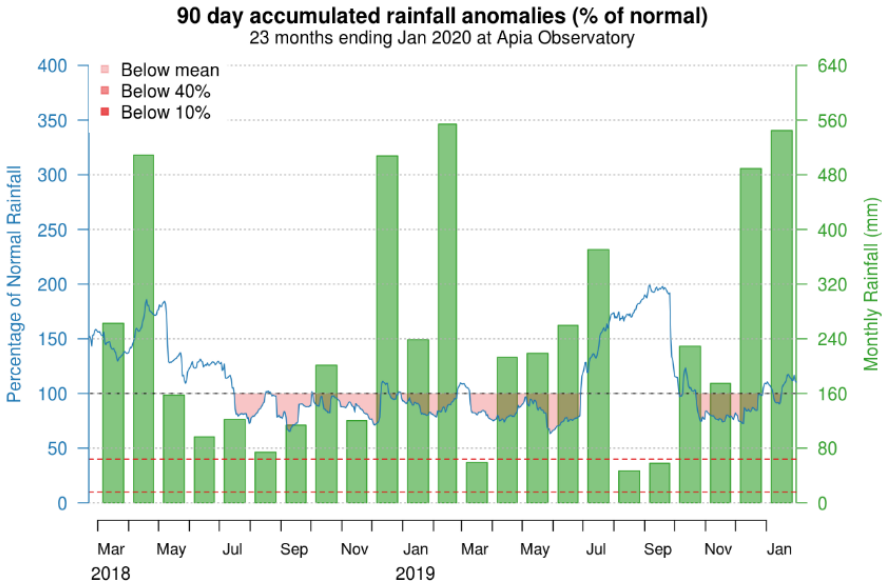
2.3.2.6 Wind

Southeast trade winds dominate all year round. Warm westerly winds are associated with bad weather conditions. The Samoa Meteorology Division predicted that during 2020 cyclone season 2-3 cyclones could pass within 400 km radius of Samoa with at least one cyclone giving wind speeds of up to 178 km/hr (96 knots).

2.3.2.7 Drought

The Samoa Climate Early Warning System (CLEWS) monitors drought and days where rainfall is less than normal. Figure 18 shows rainfall abnormalities leading to the 2019 drought.

Figure 18: Rainfall Abnormalities leading to drought in 2019



2.3.2.8 Earthquakes

The 2009 Samoa M8.1 submarine earthquake and tsunami took place at 06:48:11 local time on 29 September 2009, followed by smaller aftershocks. It was the largest earthquake of 2009. The quake occurred on the outer rise of the Kermadec-Tonga Subduction Zone which is part of the Pacific Ring of Fire, where tectonic plates meet and earthquakes and volcanic activity are common. It killed more than 170 people in the Samoa Islands and Tonga.

The subsequent tsunami caused substantial damage and loss of life in Samoa, American Samoa, and Tonga. The Pacific Tsunami Warning Centre recorded a 76 mm rise in sea levels near the epicentre, and New Zealand scientists noted waves as high as 14 m on the Samoan coast.

Large waves with no major damage were reported on Fiji, the northern coast of New Zealand and Rarotonga in the Cook Islands. People on low-lying atolls of Tokelau moved to higher ground as a precaution.

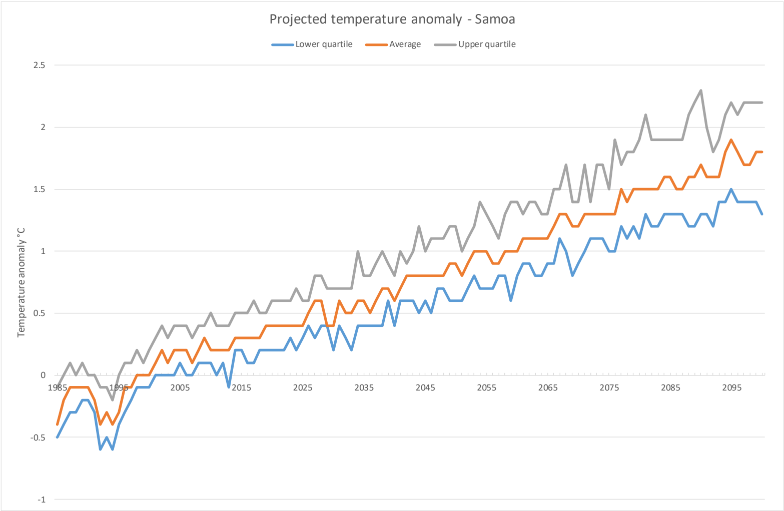
2.3.3 Likelihood of Future Events

2.3.3.1 Climate Projections

Temperature Rise Projections

Figure 19 shows temperature anomalies, that is the difference between average temperature for the period 1985 to 2015 and projected annual average temperature for each year from 1985 to 2100.

Figure 19: Temperature Rise in Samoa up to 2095



The projections suggest that between now and the end of the century, assuming RCP6.0 temperatures are expected to rise by between 1.3°C and 2.3°C.

Higher temperatures are associated with more intense storm rainfalls.

Rainfall Projections

Annual rainfall is not expected to change very much with perhaps a small increase. Whilst annual rainfall is not expected to increase markedly there is a clear trend of increasing daily rainfall. By the end of the century maximum daily rainfall might increase by 17%.

As stated above, higher temperatures create more intense storms because the atmosphere is able to hold more water vapour in a warmer climate.[28] An increase of 10% in intensity of short duration rainfall may occur for every 1°C of temperature increase. Given that temperatures are expected to rise by 1.3°C to 2.3°C the short term rain fall figure may increase by 13% to 23%. These figures must not be considered to be over precise. Plus or minus 50% is possible. [29]

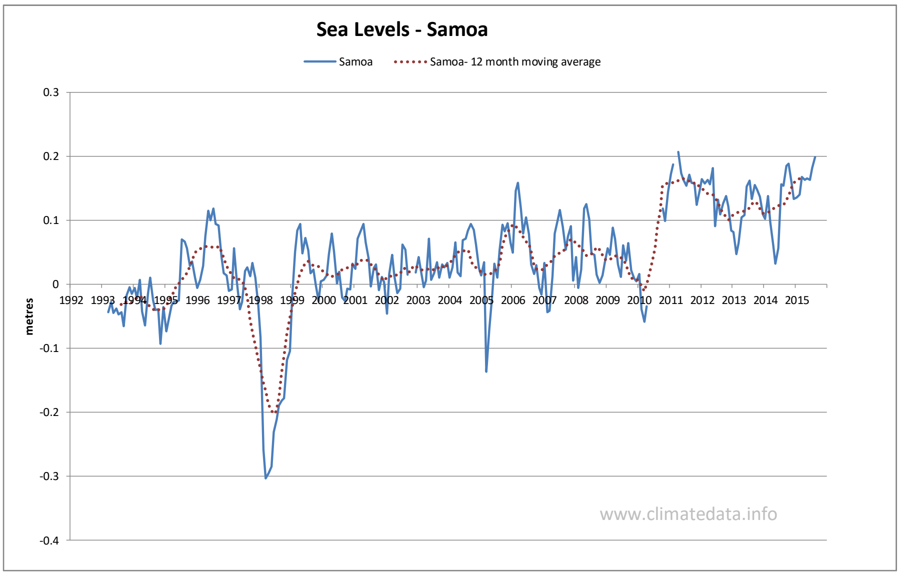
Drought

If daily rainfall increases but annual rain fall does not, then longer periods of drought may be expected.

Sea Level Rise Projections

Observed sea levels for Samoa (refer Figure 20) recorded by the Australian Bureau of Meteorology suggests that sea levels have risen by about 0.1 m over the last 20 years. [30] This is 5 mm / year which in line with IPCC projections.

Figure 20: Sea Level Rise in Samoa



The observed long term trend in sea level for Apia is 5.2 mm/yr. This is greater than the estimated range of global sea-level rise over the past century, namely 1 to 2 mm/yr. This is the **absolute** change in sea level. The National Tidal Centre, Australian Bureau of Meteorology reports a 3.7 mm/yr increase in **relative** sea level at Apia for the period of record, after vertical movements in the observing platform and the inverted barometric pressure effect have been taken into account.

A preliminary analysis of modelled projected changes in barometric pressure indicates a small increasing trend but this is unlikely to be enough to counter sea level rise.

2.3.3.2 Future Climate-related Risk in Samoa

The climate-related risks in Samoa are extreme rainfall events (both six-hourly and daily), drought, high sea levels, extreme winds and extreme high air and water temperatures.

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[28] Allen and Ingram, 2002; IPCC, 2007.

[29] O'Gorman P., 2012, Sensitivity of tropical precipitation extremes to climate change, Nature Geoscience letters.

[30] http://www.bom.gov.au/oceanography/projects/spslcmp/data/monthly.shtml.

Projections of future climate-related risk are based on the output of global climate models, for a range of emission scenarios. The most up to date and reliable source of projections is the PACCSAPP Report[31]. All the likelihood components of the climate-related risks show increases as a result of global warming, though for some the increases are small relative to the uncertainties.

Best estimates of long term, systematic changes in the average climate for Samoa indicate that by 2050 sea level is likely to have increased by 36 cm, annual rainfall by 1.2%, extreme wind gusts by 7% and maximum temperatures by 0.7°C.[32]

There is large uncertainty in the rainfall projections. Global warming may reduce the return periods of extreme daily rainfall events, despite the small change anticipated for the mean rainfall. An extreme daily rainfall of 400 mm is currently a 41-year event. It will likely be a 38-year event by 2050. An extreme six-hourly rainfall of 200 mm is currently a 30-year event. It will likely become a 20-year event by around 2050.

There is no significant difference between the islands. Climate change predictions can be used both in Upolu or Savaii if corrections for wind shadow and altitude are made.

2.3.4 Climate Change Effects

The impact and consequences of climate change effects is listed in Table 9. The predicted future occurrence of extreme weather events are shown in Table 10 and worst case scenarios in Table 11.

Table 9 Climate Change Characteristics - Samoa

Climate Related Drivers	Effect	Impact and Consequence
Geographical	Two main islands about 15 km apart. Four smaller islands	Regular ferry travel between islands
	Similar topography with coastal plain and central mountains	Highest point > 1,000 m asl
	Rainfall similar on both islands	Upolu has northern side in rain shadow.
Chronic (long term) events		
Temperature	Higher maximum temperatures	Affects operating equipment
Temperature	Higher air temperatures	Buildings need more air conditioning
Temperature	Higher air temperatures	Reduces efficiency of solar panels due to drop in OP voltage
Temperature	Higher sea temperatures	Reduces efficiency of cooling water for power stations
Temperature	Higher sea temperatures	Desalination plants discharge hot hypersaline brine. May push sea water temperature higher and kill corals, seagrasses etc. At present there are no thermal desal plants in Samoa. This comment is for future reference.
Drought	Reservoirs lower	Impacts hydroelectric schemes
Non rain days	More dusty atmosphere	Covers solar panels; need more cleaning; reduces efficiency. There are already extensive solar farms near airport.
Sea Level Rise (SLR)	SLR is 3.7 mm per year.	Slightly higher than global average 3.2 mm/yr
Acute (short term) Extreme Weather Events		
Tsunami	Samoa is vulnerable to tsunami on south east coast.	Tsunami has previously caused fatalities. Safe havens are provided with siren warning system. Waves of 14 m reported. Need to be 15 m above sea level
Cyclone or tropical depression	Can generate up to 6 metre waves	Most exposed location is south east coast of Upolu.
Cyclone or tropical depression	Storm surge from inverse barometric pressure, together with precipitation	Flooding of coastal roads on both islands up to 100 m inland.

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[31] Pacific-Australia Climate Change Science and Adaptation Planning Program (PACCSAPP), Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports, 2014.

[32] Climate Risk Profile for Samoa, Wairarapa J. Young, Samoa Meteorology Division March 2007.

Climate Related Drivers	Effect	Impact and Consequence
Cyclone or tropical depression	Wind and swell generated waves can last for days after cyclone passes.	Ferry service to other islands disrupted. Port may be unusable.
Tropical depression	Strong winds	Wind gusts of 70 knots have been measured at Apia. Could damage microwave link from Upolu to Savaii.
Heavy rain	If > 200 mm per day classed as extreme.	Apia town subject to flooding. Bridges have been washed away and Aggie Grays Hotel next to river flooded.
Heavy rain	If > 200 mm per day classed as extreme	Flooding of airport runway; cannot fly in spare or replacement parts.
Thunderstorms	Samoa is prone to thunderstorms	Lightning protection is required.
Intense short duration rainfall	If > 50 mm per hour classed as extreme	Rainfall occurs in the form of downpours or thunderstorms, which are intense but usually short-lived
Earthquakes	Samoa is in an active seismic zone.	Submarine cable can be damaged.
Volcanoes	Samoa is a volcanic island.	Mt Matavanu is an active volcano on north east Savai'i. The most recent eruption was in 1911.

Table 10 Climate Change Projections in the Future - Samoa

Variable	Season	2030	2055	2090	Value	Confidence	
Surface air temperature (°C)	Annual	+0.7 ± 0.3	+1.4 ± 0.4	+2.6 ± 0.7	Pessimistic	Moderate	Confidence
		+0.8 ± 0.4	+1.4 ± 0.5	+2.2 ± 0.7	Base		
		+0.6 ± 0.4	+1.0 ± 0.4	+1.4 ± 0.6	Optimistic		
Maximum temperature (oC)	1-in-20-year event	N/A	+1.5 ± 0.4	+2.6 ± 1.3	Pessimistic	Low	Confidence
			+1.4 ± 0.6	+2.1 ± 1.0	Base		
			+1.0 ± 0.5	+1.3 ± 0.5	Optimistic		
Minimum temperature (oC)	1-in-20-year event	N/A	+1.5 ± 1.9	+2.3 ± 1.9	Pessimistic	Low	Confidence
			+1.6 ± 1.6	+2.0 ± 2.2	Base		
			+1.2 ± 1.6	+1.5 ± 1.6	Optimistic		
Total rainfall (%)	Annual	+4 ± 11	+5 ± 14	+7 ± 24	Pessimistic	Moderate	Confidence
		+2 ± 9	+4 ± 15	+5 ±17	Base		
		+3 ± 9	+3 ± 9	+3 ± 13	Optimistic		
Wet season rainfall (%)	November- April	+3 ±11	+5 ± 11	+8 ± 22	Pessimistic	Moderate	Confidence
		+2 ± 10	+5 ± 15	+6 ± 16	Base		
		+1 ± 8	+4 ± 11	+4 ± 14	Optimistic		
Dry season rainfall (%)	May-October	+4 ± 14	+6 ± 23	+5 ± 36	Pessimistic	Low	Confidence
		+3 ± 15	+4 ± 23	+3 ± 26	Base		
		+2 ± 9	+3 ± 11	+2 ± 14	Optimistic		
Sea-surface temperature (°C)	Annual	+0.7 ± 0.4	+1.3 ± 0.5	+2.4 ± 0.8	Pessimistic	High	Confidence
		+0.7 ± 0.3	+1.2 ± 0.4	+2.0 ± 0.7	Base		
		+0.6 ± 0.4	+0.9 ± 0.3	+1.3 ± 0.4	Optimistic		
Mean sea level cms	Annual	+10 (5-15)	+20 (10-29)	+40 (21-59)	Pessimistic	Moderate	Confidence
		+10 (6-14)	+21 (11-30)	+38 (20-57)	Base		
		+10 (5-15)	+18 (10-26)	+31 (17-45)	Optimistic		

Note: Colour code:

High
Medium
Low

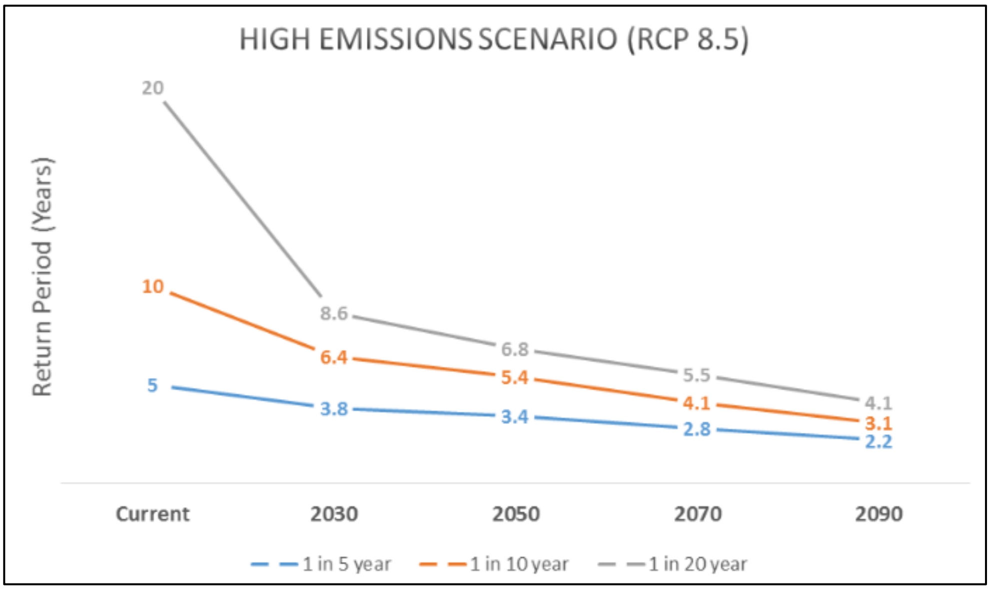
Table 11 Climate Change Worst Case Scenarios - Samoa

Variable	Season	2055
Surface air temperature (°C)	Annual	+1.8
Maximum temperature (°C)	5 percentile event 1-in-20-year event	+1.9
Minimum temperature (°C)	5 percentile event 1-in-20-year event	+3.4
Total rainfall (%)	Annual	+19
Wet season rainfall (%)	November- April	+16
Dry season rainfall (%)	May-October	+29
Sea-surface temperature (°C)	Annual	+1.8
Mean sea level cms	Annual	+29

2.3.4.1 Changes in Return Intervals for Rainfall

Figure 21, based on PACCSAP publication project.[33], shows the rainfall return levels through to 2090.

Figure 21 Rainfall Return Levels - Samoa



Changes in rainfall annual rate of return (ARI) are:

- By the year 2050 a 1 in 5 year event will become a 1 in 3.4 year event
- By the year 2050 a 1 in 10 year event will become a 1 in 5.4 year event
- By the year 2050 a 1 in 20 year event will become a 1 in 6.8 year event.

At present in Samoa occurrence of extreme weather events is as follows:

- Annual rain fall is slowly increasing
- An average of 10 cyclones per decade pass within 400 km of Apia. That is an average of 1 every year.
- In El Niño years there can be 16 cyclones per decade. In La Niña years it may be 10 cyclones per decade.
- Interannual variability is large. That is to say in some seasons there are no tropical cyclones in the vicinity of Apia, yet in other years there can be as many as 5 in one year and in one cyclone season. This has happened twice in the 1980-81 and 2004-05 seasons.
- The cyclone season is November to April, but cyclones can occur outside this time. Tropical Cyclone Keli occurred in June of 1997.
- When cyclones do hit Samoa damage can be significant. Tropical Cyclone Ofa (1990) and Tropical Cyclone Val (1991) caused damage equal to four times Samoa's GDP.
- Flooding from cyclones and La Niña events in 2008 and 2011 caused transportation and water infrastructure to be severely damaged.

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[33] Considering Climate Risks when Managing, Owning and Funding Coastal Assets, Guidance Manual for Commonwealth Agencies, Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Australia, July 2013.

By 2055 under RCP 8.5 the future occurrence of extreme weather events will be as follows:

- Annual average air temperature may increase by 1.8°C and maximum temperature increase by 1.9°C.
- This could lead to 19% increase in short term intensity of rainfall. This is only accurate to + 40%.
- Annual rain fall may change by +19%
- Wet season rain fall may change by +16%
- Dry season rain fall may change by +29%
- If wet season rainfall increases it will be uniform across all Samoa, that is across both major islands.
- If dry season rainfall increases, it will be more pronounced on the eastern sides of Upolu and Savaii and less pronounced on the western side.
- Cyclones may lessen in frequency in the future as the cyclone belt moves south but increase in intensity.
- The frequency of cyclones depends on El Niño or La Niña:
  - Most pessimistic case – 1 cyclone every 0.625 years
  - Base case – 1 cyclone every 1 year
  - Optimistic case – 1 cyclone 1 every 2 years
- Extreme case for cyclones – there has been 5 cyclones in year
- Sea Level may rise by 290 mm by 2055
- Rainfall – short term intensity will increase by 19% (based on 1.9°C increase).

2.3.4.2 Samoa Actions Against Climate Change

Based on historical records, Samoa suffers a severe cyclone at least once a decade and sometimes once every 5 years. Consequently, Samoa is taking several initiatives to develop resilience to climate change.

Under World Bank funding Samoa LTA conducted a Road Vulnerability Assessment to Climate Change and has developed a policy for Climate Resilient Roads. These are now being constructed in Upolu (Coastal Road) and on Savaii (Mali'oli'o Bridge).

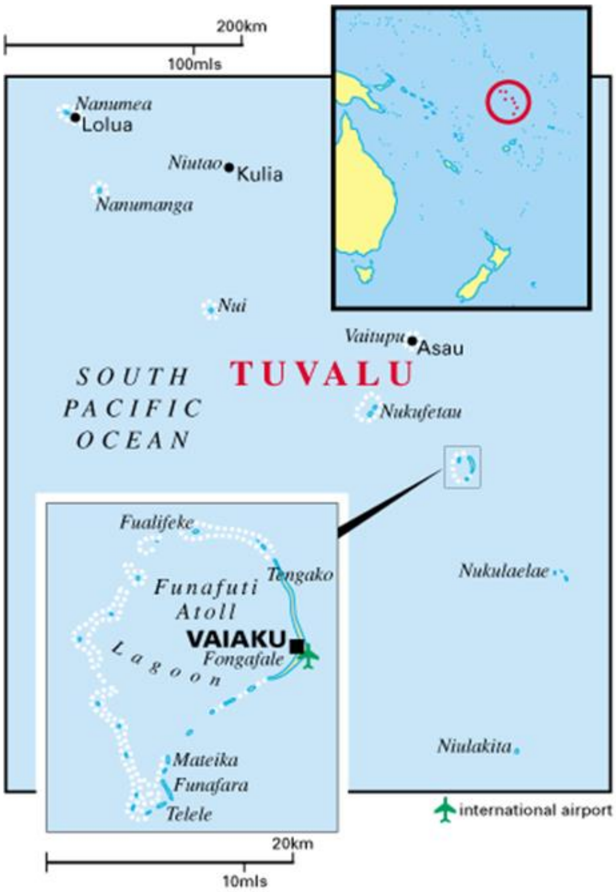
The proposed multi-purpose flood control Alaoa dam by EPC will provide hydroelectric power, flood control during periods of heavy rain, potable water during drought and act as a stilling basin reducing turbidity in potable water during times of heavy rain runoff. The proposed Alaoa dam is 200 m wide by 60 m high and will intercept two main branches of Vaisigano River, covering almost 70% of the total river catchment. The dam design provides for a 1 in 200 years flood; compared to the 2012 flood which was 1 in 100 years flood. Bids for the construction of the Alaoa dam are now in preparation and construction is scheduled to start in 2021, with an estimated 3-year construction period.

More than 70% of Samoa's population lives in 330 rural villages across Upolu and Savaii near the coastline. Under Climate Resilient Sustainable Agricultural Practices (WB/ UNDP) villages are adopting strategies on diversifying food and water sources, being geographically mobile, having more than one place to live, and developing mental preparedness for future extreme events.

2.4 Tuvalu

2.4.1 Country Context

Figure 22: Tuvalu Location



Tuvalu, formerly known as the Ellice Islands, is a Polynesian island country located in in Oceania, about midway between Hawaii and Australia.

Tuvalu is a volcanic archipelago comprising nine small islands stretched over 680 km in the Pacific. Six of them are atoll islands with ponding lagoons, namely Nanumea, Nui, Vaitupu, Nukufetau, Funafuti and Nukulaelae. The remaining three islands, Nanumaga, Niutao and Niulakita, are raised limestone reef islands. Only Funafuti has a large, sheltered lagoon with a deep water entrance.

All the islands are less than five metres above sea level, with the biggest island, Vaitupu, having a land area of just over 524 hectares. The total area is approximately 26 km^2 which makes it the fourth smallest country in the world.

Tuvalu is remote with its closest neighbour Fiji located 1,100 km away. The population of 11,192 (2017 census) is concentrated on Funafuti as people from the outer islands migrated leaving the outer islands sparsely populated. Tuvalu's exclusive economic zone (EEZ) covers an oceanic area of approximately 900,000 km^2.

The land is very low lying and the coral atolls are narrow. Funafuti is the capital and is the largest atoll of the islands and atolls. It has many islets around a central lagoon which stretches 25.1 km north to south by 18.4 km east to west. As the highest height is 4.5 metres above sea level. Tuvalu is the second-lowest highest elevation of any country after the Maldives. At its widest point, Tuvalu only spans about 200 metres.

Tuvalu’s outer islands are largely isolated, hindering communication and making it difficult to provide essential supplies in the face of or following weather-related destruction. Tuvalu is considered a safe country of unspoiled natural beauty and friendly people. However, due to its remoteness, lack of accommodation, limited and high cost of flights, relatively few tourists visit each year.

The predominant vegetation type on the islands of Tuvalu is the cultivated coconut woodland, which covers 43% of the land, the native broadleaf forest is limited to 4.1% of the vegetation types.

The main economy is based on commercial fishing activities in Tuvalu waters, mostly from foreign-based fishing fleets.

Apart from fresh fish, Tuvalu is totally reliant on the import of food, including fresh vegetables and fruit. Because of the lack of soil, agriculture is limited to coconut trees and growing taro in pits of composted waste. Potable water only comes from collected rainwater or from the Government's desalination plant on Funafuti.

2.4.2 Historical Events

2.4.2.1 Climate

The entire country of Tuvalu is widely recognised as one of the most vulnerable countries in the world to the impacts of climate change, including extreme weather events due to its resident’s dependence on ocean resources for their livelihoods, high exposure to climate hazards, and low adaptive capacity. It is also uniformly low, the highest points being only about 4 m above sea level.

Tuvalu has a tropical marine climate with high humidity and mostly uniform temperatures ranging from 26-32°C. From 1942 to 2005, average annual rainfall was 2,875 mm per year, and dry spells and droughts are relatively uncommon.

Tuvalu has seasonal variations as the year has distinct wet and dry seasons. The wet season runs from November to April with winds from the west and northwest; the dry season runs from May to October when the lighter southeast trade winds dominate. Westerly gales and heavy rain are the predominant weather conditions from October to March, the period that is known as Tau-o-lalo, with tropical temperatures moderated by easterly winds from April to November.

The climate patterns throughout Tuvalu follow large-scale patterns across the Pacific. While spread out across roughly 1 million km^2, the islands of Tuvalu all lie within the Southern South Pacific Convergence Zone. The meteorological and oceanographic climate in Tuvalu is driven by strong intra- and inter-annual cycles, such as the El Niño Southern Oscillation (ENSO) and seasonal variations. The interaction with the Pacific Ocean currents plays an important role in shaping climate. Year-to-year climate variations throughout the Southwest Pacific are driven by ENSO. Funafuti experiences wetter, warmer conditions in El Niño years and drier, cooler conditions during La Niña years.[34]

2.4.2.2 Temperature

Tuvalu's climate varies considerably from year to year due to the El Niño-Southern Oscillation. This is a natural climate pattern that occurs across the tropical Pacific Ocean and affects weather around the world. There are two extreme phases of the El Niño-Southern Oscillation: El Niño and La Niña. There is also a neutral phase. In Funafuti, El Niño events tend to bring wetter, warmer conditions than normal, while La Niña events usually bring drier, cooler than normal conditions. This is likely due to the warmer ocean temperatures around Tuvalu in El Niño years.

Table 12 Temperature data for Tuvalu

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C	31	30	30	31	31	30	30	30	30	31	31	31	30.3
Average low °C	27	27	27	27	28	27	27	27	27	27	27	27	26.9

Annual and May–October mean and maximum air temperatures at Funafuti have increased since 1933. The frequency of night-time cool temperature extremes has decreased and warm temperature extremes have increased. These temperature trends are consistent with global warming.

In Funafuti, the capital of Tuvalu, there is little variation in temperature throughout the year. The maximum temperature is between 31–32°C and the minimum temperature between 25–26°C all year round. Air temperatures are strongly tied to the ocean temperatures surrounding the islands and atolls of the country.

Rising sea temperatures are also contributing to coral bleaching and decreasing marine productivity. The marine ecosystem is a vital component of Tuvalu's economy which is dependent on revenue provided by tuna fishing.

2.4.2.3 Rainfall

The country has two distinct seasons – a wet season from November to April and a dry season from May to October. However, rainfall averages more than 200 mm each month of the year in Funafuti and more than 160 mm in Nanumea. This is due to the location of Tuvalu near the West Pacific Warm Pool, where thunderstorm activity occurs all year round. This band of heavy rainfall is caused by air rising over warm water where winds converge, resulting in thunderstorm activity.

Table 13 Rainfall data for Tuvalu

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average precipitation mm	390	350	310	250	240	240	260	250	230	270	280	390	3,500

Average annual rainfall varies from 3,500 mm per year in the southern islands of Tuvalu to 2,700 mm per year in the northern islands.

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[34] BoM and CSIRO, 2011

Annual and half-year rainfall trends show little change at Funafuti since 1927. There has also been little change in extreme daily rainfall since 1961.

2.4.2.4 Tropical Depressions and Cyclones

The number of cyclones varies widely from year to year, with none in some seasons but up to three in others. Cyclones occur more frequently in El Niño years.

An average of 8 cyclones per decade developed within or crossed the Tuvalu EEZ between the 1969/70 to 2010/11 seasons. Tropical cyclones were most frequent in El Niño years (12 cyclones per decade) and least frequent in La Niña years (3 cyclones per decade). Only three of the 24 tropical cyclones (13%) between the 1981/82 and 2010/11 seasons were severe events (Category 3 or stronger) in the Tuvalu EEZ.

The highest elevations are typically in narrow storm dunes on the ocean side of the islands which are prone to overtopping in tropical cyclones, as occurred with Cyclone Bebe, which was a very early-season storm that passed through the Tuvaluan atolls in October 1972. Cyclone Bebe submerged Funafuti, eliminating 90% of structures on the island. Sources of drinking water were contaminated as a result of the system's storm surge and the flooding of the sources of fresh water.

Tuvalu experienced an average of three cyclones per decade between the 1940s and 1970s; however, eight occurred in the 1980s. The impact of individual cyclones is subject to variables including the force of the winds and also whether a cyclone coincides with high tides. Funafuti's Tepuka Vili Vili islet was devastated by Cyclone Meli in 1979, with all its vegetation and most of its sand swept away during the cyclone.

Severe Tropical Cyclone Ofa had a major impact on Tuvalu in 1990 with most islands reporting damage to vegetation and crops. This was made worse by a tropical depression that affected the islands a few days later.

Cyclone Gavin was the first of three tropical cyclones to affect Tuvalu in March 1997 with Cyclones Hina and Keli following later in the season.

In March 2015, winds and storm surge created by Severe Tropical Cyclone Pam resulted in waves of 3 to 5 metres; breaking over the reef of the outer islands, causing damage to houses, crops and infrastructure.

A state of emergency was declared. On Nui, the sources of fresh water were destroyed or contaminated. The flooding in Nui and Nukufetau caused many families to shelter in evacuation centres or with other families.Nui suffered the most damage of the three central islands (Nui, Nukufetau and Vaitupu); with both Nui and Nukufetau suffering the loss of 90% of the crops. Of the three northern islands (Nanumanga, Niutao and Nanumea), Nanumanga suffered the most damage, with from 60 to 100 houses flooded, with the waves also causing damage to the health facility. Vasafua islet, part of the Funafuti Conservation Area, was severely damaged by Cyclone Pam. The coconut palms were washed away, leaving the islet as a sand bar.

A warning system, which uses the Iridium satellite network, was introduced in 2016 in order to allow outlying islands to be better prepared for natural disasters.[35]

2.4.2.5 Extreme Weather Events

Spring tides and tropical cyclones are among the main extreme events that affect Funafuti. As well as high winds and rainfall, tropical cyclones also cause storm surges and swells. The resulting flooding causes saltwater intrusion that sullies the island’s groundwater reserves, making freshwater nearly impossible to drink.

Limited water resources mean residents have minimal drinking water, Persistent droughts mean livestock such as pigs and chickens have no water to drink, crops wither and some such as coconuts no longer bear fruit.

2.4.2.6 Wind and Waves

Wind-waves around Tuvalu do not vary significantly in height during the year. In Tuvalu, wave climate is dependent on regional and local wind climates including those from ENSO, trade winds, tropical cyclones, and storms. Offshore noncyclonic wave climate is predominantly driven by the south-east trade winds and long period south-westerly swell waves from the Southern Pacific Ocean.

Offshore non-cyclonic wave climate is dominated by the combination of south-east trade winds and long period south-westerly swell waves from the Southern Ocean.

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[35] Iridium routes phone calls through space.

Nearshore wave climate differs significantly from offshore wave climate, as waves attenuate as they travel across the reef. The further the wave travels from the reef edge, more attenuation will occur.

Tuvalu is affected by perigean spring tide events which raise the sea level higher than a normal high tide. The highest peak tide recorded by the Tuvalu Meteorological Service is 3.4 metres on 24 February 2006 and again on 19 February 2015. king tide events lead to flooding of low-lying areas, which is compounded when sea levels are further raised by La Niña effects or local storms and waves.

2.4.2.7 Drought

Tuvalu experiences the effects of El Niño and La Niña, which is caused by changes in ocean temperatures in the equatorial and central Pacific. El Niño effects increase the chances of tropical storms and cyclones, while La Niña effects increase the chances of drought.

Typically, the islands of Tuvalu receive between 200 to 400 mm of rainfall per month. However, in 2011, a weak La Niña effect caused a drought by cooling the surface of the sea around Tuvalu. A state of emergency was declared on 28 September 2011, with rationing of fresh water on the islands of Funafuti and Nukulaelae. Households on Funafuti and Nukulaelae were restricted to two buckets of fresh water per day (40 litres).

The governments of Australia and New Zealand responded to the 2011 freshwater crisis by supplying temporary desalination plants and assisted in the repair of the existing desalination unit that was donated by Japan in 2006. In response to the 2011 drought, Japan funded the purchase of a 100 m^3/d desalination plant and two portable 10 m^3/d plants as part of its Pacific Environment Community (PEC) programme.

Aid programmes from the European Union and Australia also provided water tanks as part of a longer-term solution for the storage of available fresh water. The La Niña event that caused the drought ended in April–May 2012.

The main source of freshwater in Tuvalu is rainwater. Groundwater resources are no longer suitable for human consumption due to pollution from saltwater intrusion caused by rising sea levels. Salinity intrusion enhanced by the porosity of soil in Tuvalu has destroyed pulaka crops and decreased the yields of various other fruit trees.

2.4.2.8 Earthquakes

Tuvalu is classified as having a very low earthquake hazard rating. There is less than a 2% chance of potentially-damaging earthquake in the next 50 years. [36]

2.4.3 Likelihood of Future Events

2.4.3.1 Climate Projections

Future changes in El Niño occurrence could have far-ranging, cross-sectoral impacts but projections for how climate change will impact the frequency and intensity of inter-annual cycles is uncertain.

For the period to 2100, the latest global climate model (GCM) projections and climate science findings for Tuvalu indicate[37]:

- El Niño and La Niña events will continue to occur in the future (very high confidence), but there is little consensus on whether these events will change in intensity or frequency
- Annual mean temperatures and extremely high daily temperatures will continue to rise (very high confidence)
- It is not clear whether mean annual rainfall will increase or decrease, the model average indicating little change (low confidence), with more extreme rain events (high confidence)
- Incidence of drought is projected to decrease slightly (low confidence)
- Ocean acidification is expected to continue (very high confidence)
- The risk of coral bleaching will increase in the future (very high confidence)
- Sea level will continue to rise (very high confidence)
- December–March wave heights and periods are projected to decrease slightly (low confidence).

2.4.3.2 Sea Level Rise

Rising sea levels combined with extreme weather events is contributing to the inundation of low lying areas. Coastal erosion is a major problem in Tuvalu, particularly on the western side of the islands. As most

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[36] Pacific Disaster Centre 2020.

[37] Australian Bureau of Meteorology and CSIRO, 2014. Date updated: March 2016.

Tuvaluans live within coastal areas, additional stress is being placed on the already vulnerable marine ecosystem.

Tuvalu faces an existential threat: a rising tide and more frequent and intense rainfall events threaten to sink the nation in 30 to 50 years. The United Nations Intergovernmental Panel on Climate Change predicts a 0.9 m increase in global sea levels by 2100 - degrading up to one metre of Tuvalu's shoreline per year.

In Tuvalu specifically, the rise in sea level will increase by up to 18 cm by 2030. Projections further indicate greater frequency and intensity of rainfall events, including spring tides and tropical cyclones.

As low-lying islands lacking a surrounding shallow shelf, the communities of Tuvalu are especially susceptible to changes in sea level and undissipated storms.

The sea-level rise near Tuvalu measured by satellite altimeters since 1993 is about 5 mm per year.

The atolls have shown resilience to gradual sea-level rise, with atolls and reef islands being able to grow under current climate conditions by generating sufficient sand and coral debris that accumulates and gets dumped on the islands during cyclones.

Gradual sea-level rise also allows for coral polyp activity to increase the reefs. However, if the increase in sea level occurs at faster rate as compared to coral growth, or if polyp activity is damaged by ocean acidification, then the resilience of the atolls and reef islands is less certain.

While some commentators have called for the relocation of Tuvalu's population to Australia, New Zealand or Kioa in Fiji, the government did not regard rising sea levels as such a threat that the entire population would need to be evacuated.

Sea level is expected to continue to rise in Tuvalu. By 2030, under a high emissions scenario, this rise in sea level is projected to be in the range of 4-14 cm. The sea-level rise combined with natural year-to-year changes will increase the impact of storm surges and coastal flooding.

2.4.4 Climate Change Effects

The impact and consequences of climate change effects is listed in Table 14. The predicted future occurrence of extreme weather events are shown in Table 15 and worst case scenarios in Table 16.

Table 14 Climate Change Characteristics - Tuvalu

Climate Related Drivers	Effect	Impact and Consequence
Geographical	Very flat land highest point +4 m asl	Vulnerable to flooding
	Very narrow, less than 500 m wide	Easily inundated
	Islands strung out covers over 680 km North to south	Hard to travel between islands if weather inclement
Chronic (long term) events		
Temperature	Higher maximum temperatures	Affects operating equipment
Temperature	Higher air temperatures	Buildings need more air conditioning
Temperature	Higher air temperatures	Reduces efficiency of solar panels as lower differential temperature reduces output voltage.
Temperature	Higher sea temperatures	Reduces efficiency of cooling water for power stations. Not relevant in Tuvalu at present but may be a consideration in future or in other locations
Temperature	Higher sea temperatures	Desalination plants discharge hot hypersaline brine. May push sea water temperature higher and kill corals, seagrasses etc. Not applicable at present in Tuvalu but should be acknowledged if thermal diesel plants are considered in the future.
Drought	Reservoirs lower	Impacts drinking water supplies; more water may need boiling resulting in increased energy demand.
Non-rain days	More dusty atmosphere	Covers solar panels; need more cleaning; reduces efficiency

Climate Related Drivers	Effect	Impact and Consequence
Sea Level Rise (SLR)	SLR is 5 mm per year; coastal effects	> than global average 3.2 mm / yr
Acute (short term) Extreme Weather Events		
Tsunami	Tuvalu in low seismic zone so odds are small.	Tsunami could be catastrophic as no high ground to run to. Safe haven needs to be strong building more than three floors high.
Cyclone or tropical depression	Can generate 3-5 metre waves	Can inundate whole island if low lying and narrow.
Cyclone or tropical depression	Storm surge from inverse barometric pressure, together with precipitation	Flooding of impermeable surfaces such as roads
Cyclone or tropical depression	Wind and swell generated waves can last for days after cyclone passes.	Solar panels in lagoon can be damaged Could damage future wave power renewable energy generators
Cyclone or tropical depression	Strong winds	Could damage wind farms. If in lagoon windmills may not be collapsible.
Heavy rain	If > 200 mm per day classed as extreme	Leakage through roof of generator house, interruption of power supply.
Heavy rain	If > 200 mm per day classed as extreme	Flooding of airport runway; cannot fly in spare or replacement parts.
Thunderstorms	Tuvalu is in a thunderstorm prone zone	Lightning protection is required.
Intense short duration rainfall	If > 50 mm per hour classed as extreme	Likely to exceed normal runoff abilities and cause localised flooding
Earthquakes	There are no credible risks in Tuvalu	
Volcanoes	There are no credible risks in Tuvalu	

Table 15 Climate Change Projections in the Future - Tuvalu

Variable	Season	2030	2055	2090	Value	Confidence	
Surface air temperature (°C)	Annual	+0.7 ± 0.3	+1.4 ± 0.4	+2.7 ± 0.6	Pessimistic	High	Confidence
		+0.8 ± 0.4	+1.5 ± 0.5	+2.3 ± 0.8	Base		
		+0.7 ± 0.4	+1.1 ± 0.4	+1.5 ± 0.6	Optimistic		
Maximum temperature (oC)	1-in-20-year event	N/A	+1.5 ± 0.5	+2.7 ± 1.3	Pessimistic	Low	Confidence
			+1.5 ± 0.6	+2.1 ± 1.1	Base		
			+1.0 ± 0.6	+1.4 ± 0.7	Optimistic		
Minimum temperature (oC)	1-in-20-year event	N/A	+1.5 ± 1.8	+2.4 ± 1.9	Pessimistic	Low	Confidence
			+1.5 ± 2.0	+2.2 ± 2.0	Base		
			+1.2 ± 1.8	+1.6 ± 1.8	Optimistic		
Total rainfall (%)	Annual	+4 ± 8	+7 ± 12	+11 ± 18	Pessimistic	Moderate	Confidence
		+3 ± 8	+7 ± 10	+12 ± 14	Base		
		+3 ± 8	+7 ± 11	+7 ± 12	Optimistic		
Wet season rainfall (%)	November- April	+4 ± 8	+6 ± 10	+11 ± 16	Pessimistic	Moderate	Confidence
		+3 ± 9	+6 ± 11	+11 ± 14	Base		
		+3 ± 10	+7 ± 9	+7 ± 11	Optimistic		
Dry season rainfall (%)	May-October	+5 ± 13	+8 ± 19	+12 ± 26	Pessimistic	Moderate	Confidence
		+4 ± 11	+7 ± 16	+12 ± 23	Base		
		+3 ± 10	+7 ± 16	+8 ± 18	Optimistic		
Sea-surface temperature (°C)	Annual	+0.7 ± 0.4	+1.3 ± 0.5	+2.5 ± 0.6	Pessimistic	High	Confidence
		+0.7 ± 0.3	+1.3 ± 0.4	+2.1 ± 0.6	Base		
		+0.6 ± 0.4	+1.0 ± 0.3	+1.3 ± 0.5	Optimistic		
Mean sea level cms	Annual	+9 (4-14)	+19 (9-28)	+39 (19-58)	Pessimistic	Moderate	Confidence
		+9 (5-14)	+19 (10-29)	+37 (19-56)	Base		
		+9 (4-14)	+17 (9-25)	+31 (16-45)	Optimistic		

Note: Colour code:

High
Medium
Low

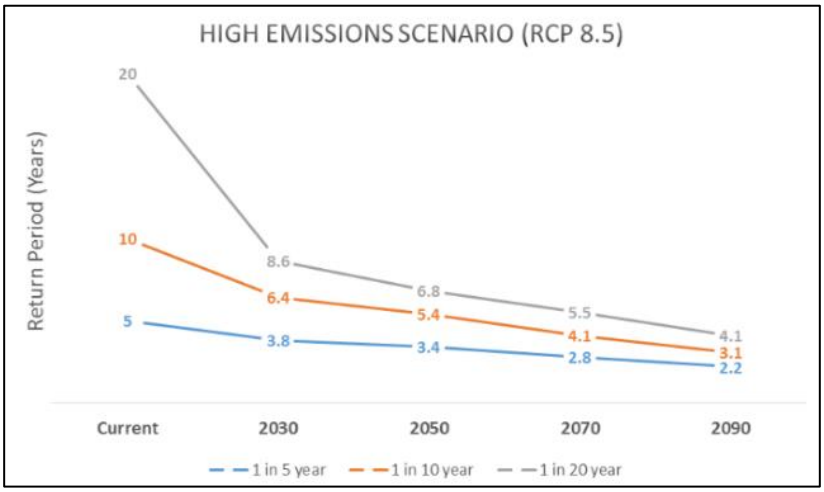
Table 16 Climate Change Worst Case Scenarios - Tuvalu

Variable	Season	2055
Surface air temperature (°C)	Annual	+1.8
Maximum temperature (°C)	5 percentile event (1-in-20-year event)	+2.0
Minimum temperature (°C)	5 percentile event (1-in-20-year event)	+3.3
Total rainfall (%)	Annual	+19
Wet season rainfall (%)	November- April	+16
Dry season rainfall (%)	May-October	+27
Sea-surface temperature (°C)	Annual	+1.8
Mean sea level cms	Annual	+28

2.4.4.1 Changes in Return Intervals for Rainfall

Figure 23, based on PACCSAP publication project.[38], shows the rainfall return levels through to 2090.

Figure 23 Rainfall Return Levels - Tuvalu



Changes in rainfall annual rate of return (ARI) are:

- By the year 2050 a 1 in 5 year event will become a 1 in 3.4 year event
- By the year 2050 a 1 in 10 year event will become a 1 in 5.4 year event
- By the year 2050 a 1 in 20 year event will become a 1 in 6.8 year event.

At present in Tuvalu occurrence of extreme weather events is as follows:

- Annual rain fall is constant over preceding years
- An average of 8 cyclones per decade cross over Tuvalu. That is an average of 1 every 1.25 years
- Cyclones can vary. In El Niño years there can be 12 cyclones per decade. In La Niña years it may be 3 cyclones per decade
- Only 13% of cyclones are severe events (Category 3 or stronger) in Tuvalu region.

The future occurrence of extreme weather events, by 2055 under RCP 8.5, are predicted to be as follows:

- Annual average air temperature may increase by 1.8^{o}C and maximum temperature increase by 2^{o}C
- This could lead to 20% increase in short term intensity of rainfall
- Annual rain fall may change by +19%
- Wet season rain fall may change by +16%
- Dry season rain fall may change by +27%
- More rainfall in dry season means periods of drought may decrease. Now is probability of 0.45 times per annum (8-9 times per 20 years). Will fall to probability of 0.3 times per annum (6-7 per 20 years). This is a reduction of 30% in the likelihood of drought. A drought 1 in every 2.2 years will become 1 in every 3 years
- Cyclone are driven by the sea surface temperature. The higher the temperature the higher the probability of a severe cyclone occurring. Cyclones may lessen in the future as the cyclone belt

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[38] Considering Climate Risks when Managing, Owning and Funding Coastal Assets, Guidance Manual for Commonwealth Agencies, Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, Australia, July 2013

moves south. They may behave more like La Niña years. The frequency of cyclones depending on El Niño or La Niña may be:
  - Most pessimistic case – severe cyclone 1 every 6 years
  - Base case – severe cyclone 1 every 9 years
  - Optimistic case – severe cyclone 1 every 25 years
- Extreme case for cyclones – there has been 3 cyclones in 1 year (1997)
- Sea Level may rise by 280 mm by 2055
- Rainfall – short term intensity will increase by 18% (based on 1.8°C increase)

3.0 Climate Resilient Investments

3.1 Papua New Guinea - PNG Power Limited (PPL)

3.1.1 Overview of Power System

3.1.1.1 Organisation

PNG Power Ltd (PPL) is a fully integrated power authority responsible for generation, transmission, distribution and retailing of electricity, with 30 electricity systems at various centres throughout Papua New Guinea. With the Head Office in Port Moresby, it was corporatised in 2002 as a State Owned Entity. Kumul Consolidated Holdings Limited (KCHL), which holds all shares for corporatised state entities, acts as the sole shareholder on behalf of the Government of PNG. The PNG Power Board comprises eight Directors appointed through KCHL. PPL currently employs around 2,000 employees.

3.1.1.2 Observations

As noted in Section 1.4, the study team were unable to visit PNG because of the global shutdown on international travel because of the Covid-19 pandemic.

This section has been compiled based on the team's knowledge and available background information as well as previous visits to PNG.

3.1.1.3 Generation

PPL has a mixture of diesel, gas turbine and hydro generation, including some from IPPs (Independent Power Producers). Main generation is from hydro, which accounts for 70% of the total electricity generation.

The main source of generation in the Port Moresby power system is the Rouna cascaded hydrostations with a total capacity of 63 MW. PNG Power also operates a 30 MW thermal power station at Moitaka; plus purchases from several IPPs with a combined capacity of 60 MW. The load demand for the Port Moresby System reported to be at generation capacity, but several projects are on-going to increase this capacity. Annual generation of >800 GWh is 70% hydro, 14% light fuel oil, and 16% by IPPs.

Total generation capacity is shown in Table 17 and energy production over the last three years is shown in Table 18. The breakdowns of both are shown in Table 43 and Table 44 in Appendix 3.

Table 17 PPL Generation Summary

Type	Name Plate Ratings MW	Available Ratings MW
PPL Thermal	305	170
PPL Hydro	187	112
Total IPP	139	134
Total Capacity	**631**	**416**

Source: PPL

Table 18 PPL Production Summary

Type	2,017	2018	2019
Total Hydro	504,820	536,615	588,187
Total Thermal	308,530	267,110	301,678
IPP Hydro	85,735	84,325	88,740
IPP Thermal	190,397	276,397	238,412
IPP LNG	211,407	209,555	212,316
IPP Biomass	6,935	4,992	4,731
Total Hydro	590,555	620,939	676,927
Total Thermal	498,928	543,506	540,090
Total LNG	211,407	209,555	212,316
Total Biogas	6,935	4,992	4,731
TOTAL	**1,307,826**	**1,378,993**	**1,434,064**

Source: PPL

3.1.1.4 Transmission and Distribution

PPL's network is split among three separate areas. The Port Moresby system serves both the National Capital District, and the surrounding areas in the Central Province and includes 66 kV transmission and 11 kV medium voltage (MV) distribution. The Ramu network includes 132 kV and 66 kV transmission and 33 kV, 22 kV, 11 kV MV distribution. The Gazelle system comprises a 22 kV network serving Rabaul, Ulagunan and Kokopo. The SLDs are shown in Figure 32 in Appendix 3.

3.1.1.5 Customers

As shown in Table 19, PPL currently has approximately 155,000 customers; the breakdown of customer numbers and consumption by billing area is shown in Table 45 in Appendix 3.

Table 19 PPL Customers

Category	**Total**
Domestic Metered	6,195
Easypay Domestic Customers	124,904
Easypay General Supply Customers	15,968
General Supply	7,800
Ramu Sugar - Special Ttariff	7
Mining - special tariff	2
Industrial Tariff	80
Public Lighting	0
Total	**154,905**

Source: PPL

3.1.2 Impacts of Historical Events on Power System

Completion of this section is awaiting PPL information.

3.1.3 Vulnerability of Power System to Future Climate Events

Completion of this section is awaiting PPL information.

3.1.4 Investment Needs

Completion of this section is awaiting PPL information.

3.1.5 Roadmap for Adoption

Completion of this section is awaiting PPL information.

3.2 Samoa - Electric Power Corporation (EPC)

3.2.1 Overview of Power System

3.2.1.1 Organisation

Samoa's Electric Power Corporation (EPC) was established under the EPC Act as a Corporation in 1972, previously being a division of the Public Works Department. It is an autonomous government owned corporation. EPC's Mission is: *To provide and maintain quality electricity services through innovative, sustainable and environmentally sound practices in developing renewable energy sources, generation and distribution infrastructure network, in partnership with customers and stakeholders to support the development of Samoa*.

EPC's Vision 2025 is: *To be the cheapest electricity provider in the Pacific Region.*

With about 40,000 customers, EPC now provides power to 98 % cent of the population of Samoa, utilising a workforce of nearly 300. EPC's generation includes hydropower, diesel and solar. There are also several Solar IPPs and a 550 kW wind farm with two turbines. EPC also has two BESS (battery energy storage system) of ~14 MWh.

3.2.1.2 Generation

The main generation source in Samoa is from diesel gensets, supplemented by hydro and then solar PV. Details are listed in Table 20. On Upolu, Fiaga power station has four Mitsubishi diesel generators with 2011 Hyundai 7.213 MVA (~5.8 MW) alternators. Previously located at Tanugamanono, the plant was re-sited at Fiaga in 2014. At the same location is a 6 MW / 10.2 MWh Tesla BESS to provide grid stability and back-up supply[39]. A similar BESS rated at 2 MW / 3.75 MWh is located adjacent to Faleolo International Airport.

Table 20 EPC Generation

Location	Type	Capacity MW
Upolu		
Aflolau	Biomass	0.75
Alaoa	Hydro	1.05
Mapu i Fagalele	Solar	0.08
Fale Ole Fee	Hydro	1.75
Faleolo International Airport	Solar[40]	6.7
Faleolo International Airport	BESS	2.0 (3.75 MWh)
Faleseela	Hydro (future)	0.3
Fiaga	Diesel	4 x 5.8
Fiaga	BESS	6.0 (10.2 MWh)
Fuluasou (at NCC)	Hydro	0.68
Gym 3	Solar	0.24
Lalomauga	Hydro	2 x 1.75
Samsoni	Hydro	2 x 0.85
Taelefaga	Hydro	3 x 2
Tafitoala Fausaga	Hydro	0.6
Tanugamanono	Diesel	8
Tanugamanono	Solar	0.15
Tuanaimato Racecourse	Solar[41]	6.2
Vailoa	Wind	0.55
Vaitele	Solar	0.3
Savaii		
Salelologa	Diesel	8
Salelologa	Solar	0.3
Vailoa	Hydro	0.22

Source: EPC

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[39] The Fiaga BESS failed to operate in the January 2020 blackout because the control systems were damaged by the lightning strike.

[40] Green Power IPP 2.5 MW solar; Solar for Samoa IPP 2.2 MW solar; Sun Pacific Harelec 2 MW solar.

[41] Green Power IPP 2.2 MW solar; Solar for Samoa IPP 1.5 MW solar; MFAT-EPC 2.2 MW solar.

EPC have planned additional renewable energy development by IPP companies with bids underway in 2020; this includes 20 MW solar with BESS, 20 MW wind farm with BESS, waste to biodiesel, thermal storage, biomass gasification and a geothermal study in Savaii. EPC's objective is to achieve 100% renewable energy by 2025.

Table 21 shows the production of electricity over the last three financial years; this last year saw an increase of 9% from the previous year, although there was a slight reduction in overall generation the previous year. Contribution from renewable energy sources increased by 12% from the previous year and 27% from the year before.

Table 21 EPC Production 2016-2019

Island/Source	FY 2016-2017		FY 2017 - 2018		FY 2018 - 2019	
	Generation kWh	Contribution %	Generation kWh	Contribution %	Generation kWh	Contribution %
Upolu Island						
Diesel	93,583,712	61	74,936,848	49	80,398,040	48
Hydro	26,425,903	17	42,814,365	28	48,815,938	29
Solar (EPC)	4,145,287	3	2,972,343	2	3,664,755	2
Solar (IPP)	15,673,381	10	17,818,143	12	19,586,448	12
Wind	155,100	0	134,122	<1	216,100	<1
Upolu Total	**139,983,383**	**91**	**138,675,821**	**91**	**152,681,281**	**91**
Apolima Island						
Solar	10,831	<1	9,896	<1	7,955	<1
Apolima Total	**10,831**	**<1**	**9,896**	**<1**	**7,955**	**<1**
Savaii Island						
Diesel	14,033,996	9	14,526,320	9	15,264,755	9
Hydro[42]	-	-	-	-	360,270	<1
Solar (EPC)	339,120	<1	291,855	<1	311,147	<1
Solar (IPP)	8,954	<1	4,001	<1	2,375	<1
Savaii Total	**14,382,070**	**9**	**14,822,176**	**9**	**15,938,547**	**9**
Grand Total	**154,375,784**	**100**	**153,507,893**	**100**	**168,627,783**	**100**

Source: EPC

3.2.1.3 Distribution

EPC's distribution network on Upolu utilises a mainly 22 kV, but with some 33 kV, interconnected ring to provide a versatile system whereby the sections of feeders can be isolated for fault or maintenance requirements, yet still provide alternate routes in order to maintain supply. It is predominately overhead with some underground in Apia. Main conductor type is Wasp[43].

The Savaii distribution network utilises a 22 kV ring circumnavigating the Island around Mt Matavanu, with short radial spurs to supply local areas. The SLD for both islands is shown in Figure 33 and Figure 34.

Key statistics for both islands are as follows:

- Total distribution transformers 923 totalling 160 MVA capacity; refer Table 46 in Appendix 4
- Total 871 km medium voltage distribution
  - 832 km 22 kV
  - 39 km 33 kV
- Total N° poles 30,025.

The LV network is all overhead open wire bare conductor system mounted on tanalised wooden poles and crossarms. The previous use of concrete poles in Samoa was stopped by Government legislation because of public safety concerns.

EPC are considering the introduction of ABC (aerial bundled conductor) for LV distribution. This has many benefits over the conventional open wire system and is now used by most utilities around the world. A big benefit of the use of ABC in Samoa is avoidance of the need to cut food bearing and ornamental trees which

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[42] The Faleata Vailoa 200 kW hydrostation commenced operation in March 2019. Refer photos. The discharge water is also then used to provide potable water via the Vailoa water treatment plant.

[43] Wasp conductor: bare AAC 100 mm^2 7/4.39 mm.

otherwise interfere with overhead open-wire lines, resulting in outages, particularly in adverse weather. The full advantages of ABC are documented in Appendix 6. The ABC installation is included in the proposed energy resilience projects listed in Section 3.2.4.3.

All MV and LV construction and maintenance is done in-house by EPC; tree-clearing from overhead lines, as well as street light installation and maintenance, is out-sourced to contractors.

3.2.1.4 Customers

The number and category of EPC customers at the end of the 2017-2018 FY is shown in Table 22. EPC is currently implementing its smart meter project and is actively promoting its iPay system for customer prepay.

Table 22 EPC Customers 2018

Customer Category	**N° Customers**		
	Pre-Payment	**Normal Payment**	**Total**
Domestic	32,214	1,438	33,652
Commercial	3,722	725	4,447
School	273	38	311
Government	63	340	403
Hotel	24	25	49
Religion	841	304	1,145
Industrial	13	37	50
Streetlights		31	31
Total	**37,150**	**2,938**	**40,088**

Source: EPC 2017-18 Annual Report

3.2.1.5 Equipment

All EPC assets, especially buildings, comply with the National Building Code[44] which a performance based set of standards that provides objectives and descriptions of how a building and site should be constructed to achieve a structurally-sound and sustainable built environment.

The EPC power network system is generally designed to NZ/Australian standards and most equipment is sourced from the Pacific rim (Japan, Asia, NZ and Australia). There is an international airport at Faleolo on Upolu that can accommodate wide body aircraft and Port of Apia serves container and roll-on/roll-off cargo ships, plus small cargo vessels, oil tankers and cruise liners. There is a regular combined passenger and vehicular ferry service between Mulifanua on Upolu and Salelologa on Savaii.

EPC have a stores depot on both islands with an adequate level of key overhead distribution equipment, poles, transformers, conductor, etc. However, it does lack critical control components for the diesel generators as already noted above.

EPC advise that fuel storage for the diesel generators is adequate and not considered an issue.

3.2.1.6 Resources

As of June 2019, EPC has 280 permanent and contract employees.

3.2.2 Impacts of Historical Events on Power System

Observations while in country including lightning strike

As noted in Section 1.4, the study team visited Samoa in January 2020.

The team viewed EPC's key assets on Upolu and Savai'i including:

- Alaoa Hydrostation
- Faleata Hydrostation
- Fiaga Diesel Station
- Samasoni Hydrostation
- Salelologa Diesel and Solar Station, Savaii
- Taelefaga Hydrostation
- Tanugamanono Solar
- Typical distribution circuits.

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[44] National Building Code of Samoa, Ministry of Works, Transport and Infrastructure, 2017.

Of particular relevance during the visit was that during a typical heavy thunderstorm, EPC suffered a direct lightning strike on the communications tower at Fiaga Power Station about 16:00 on 27 January 2020; this caused significant damage to a number of items of equipment at Fiaga, including 22 kV circuit breakers and generator control equipment (see photos in Appendix 1), resulting in a Nationwide blackout lasting several hours. It also destroyed EPC's microwave link between Upolu and Savaii. As reported in the local press, EPC declared a State of Emergency: *EPC General Manager said the disruption has left "only two generators operating at Fiaga and seven hydro power plants" which is not enough to adequately supply Upolu. "We are trying our very best to share what we have at the moment, but if worse comes to worse, we will have to shut off power or apply rationing to some parts of the country."* It is noted that Fiaga power plant is located at 520 masl which makes it particularly vulnerable to lightning strikes.

The outage required a black start of the entire network, using an out-of-service 3 MW diesel generator at Tanugamanono. This was started using an air compressor powered by a small portable 230 V generator; once underway EPC's other generation was able to be synchronised and gradually connected to the network. Thanks to the imitative of the EPC engineers, they were able to mix-and-match damaged with undamaged circuit boards on all four Fiaga diesel generators to get two of the units operating again. The other two units could not be restarted until new spare parts were ordered and received from Japan several weeks later. In the interim, large businesses with in-house generators were asked to run these to relieve the load on EPC's system.

Two lessons to be learnt from this serious incident is (i) the need to create and maintain a minimum stock level of key control equipment for the generator units and BESS system; and (ii) to increase the level of lightning protection on EPC assets. Appendix 2 gives an overview of lightning and some statistics for lightning strikes in the Pacific. It also lists some international standards applicable to the protection of assets in power utilities. Some budget for additional lightning protection is included in the proposed energy resilience projects listed in Section 3.2.3.3.

Samoa's power system has also suffered significant damage and resultant loss of supply on many past occasions due to natural events. EPC's predominately overhead power distribution network is vulnerable to high winds, flooding, tsunamis and lightning.

In addition to the major events described below, in April 2018, a rockfall destroyed a section of the Lotofaga South Coast 22 kV feeder near Lalomanu, effectively breaking the MV ring and resulting in a widespread outage in the area[45]. The line is still not replaced and is included in the list of proposed projects. It is recommended that consideration be given to replacing this with 22 kV underground cable to minimise the risk of future occurrences. This is the same are that suffered serious damage in the 2009 Tsunami.[46]

Cyclone Evan 2012

In 2012, three hydrostations on the Alaoa River were severely damaged by floodwater from Cyclone Evan and remained out of service for over four years. The penstocks to the Samasoni, Fale ole Fee and Alaoa hydropower stations were all severely damaged by the resultant floods resulting in loss of ~4.6 MW generation for almost five years. It was reported[47] that damage *to the transmission and distribution grid included 1,198 power poles damaged, (833 leaning, 245 broken, 120 fallen), 158 power meters destroyed, 6.7 km of power line requiring replacement, 25 transformers destroyed, and significant damage to the radio network. The estimated cost for replacement of damaged power sector infrastructure is SAT 39.1 million. Losses to EPC are estimated at SAT 31.9 million more, mainly from loss of revenue but also from the need to replace low-cost hydropower generation with high-cost diesel generation.*

EPC have subsequently installed flood control protection walls on the banks of the Alaoa River and replaced the above-ground penstocks with fibreglass version installed underground. There is also an on-going project to construct a multi-purpose[48] dam at the headwaters to capture and control future floods.

The estimated direct costs of Cyclone Evan damages were around 39 million SAT, as summarised in Table 23.

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[45] Local residents advised the Study Team that power was off for >2 months, but this is refuted by EPC. Currently the area is served by a long spur feeder and, until such time that the ring feed is restored, suffers reduced reliability of supply.

[46] The tsunami was triggered by a magnitude 8.1 earthquake on 29 September 2009 and caused significant damage and loss of life on the south east coast on Upolu. It was reported that the tourist zone of Lalomanu was crushed by a 6 to 9 m wall of water which scoured cliffs above Lalomanu to a height of 10 - 15 m and at the same time destroying the overhead power network.

[47] *Samoa Post-disaster Needs Assessment Cyclone Evan 2012*, Government of Samoa, March 2013.

[48] The proposed Alaoa dam of 4 m cumec will (i) provide flood control; (ii) potable water supply for Apia; and (iii) source of generation water for downstream hydropower stations.

Table 23: Cost of damaged EPC power system infrastructure due to Cyclone Evans

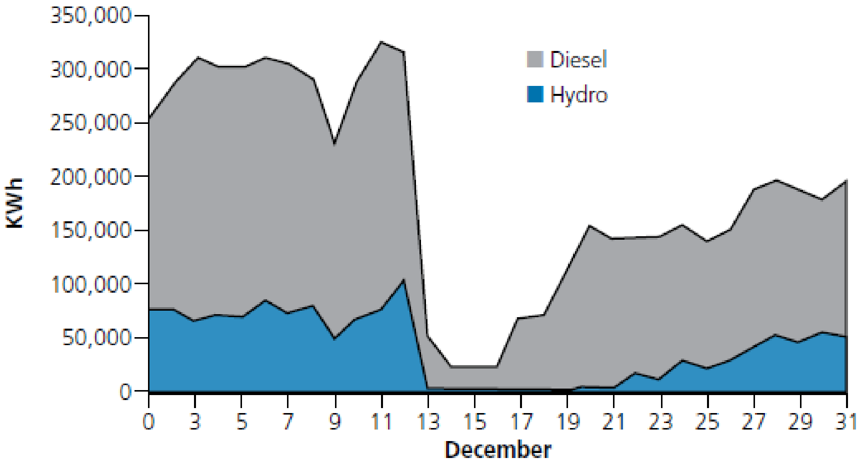
Component	Damage (thousand SAT)
Power generation	
Hydropower plants	
Samasoni	18,000.0
Alaoa	2,076.3
Fale ole Fee	11,780.6
Lalomauga	656.5
Taelefaga	287.8
Thermal plants	
Tanugamanono (diesel)	1,665.0
Savai'i (diesel)	65.0
Transmission and distribution	
Power poles (833 leaning, 245 broken, 120 fallen)	861.5
Power meters (158 meters destroyed)	95.9
Cross-arms (195 broken)	483.7
Power lines (6.7km needing replacement)	1,460.7
Transformers (25 destroyed)	437.7
Radio network (destroyed)	418.8
Total	**39,089.1**

Source: Post-disaster Needs Assessment - Cyclone Evan 2012, Government of Samoa, March 2013

In addition to the above direct costs to replace damaged infrastructure, there were also significantly indirect costs related to outages and increased fuel costs:

- **Costs of outages**: The island of Upolu was without power for four days and it took around two months to restore full service. The figure below shows that by the end of December, approximately two weeks after the cyclone, generation still approximately 40 percent lower than pre-cyclone levels due to both network damage and capacity constraints (EPC faced a significant shortfall until the Fiaga diesel generators were commissioned and the damaged hydrostations recommissioned). The Post-disaster Needs Assessment quantified the cost in financial terms, based on lost revenue to EPC, at around 6 million SAT. The lost revenues to EPC is likely to be significantly less than the damage to the economy from outages. Assuming a value of lost load of 9 SAT/kWh would lead to a cost to the Samoan economy of around 18 million SAT.
- **Cost of additional diesel fuel***:* Several of EPC's hydro generation stations were out of commission for months. As a result, EPC had to run its diesel generators at much higher loads. The Post-disaster Needs Assessment quantified the cost at 21.6 million SAT.

Figure 24: Generation of electricity in December 2012



Source: Post-disaster Needs Assessment - Cyclone Evan 2012, Government of Samoa, March 2013

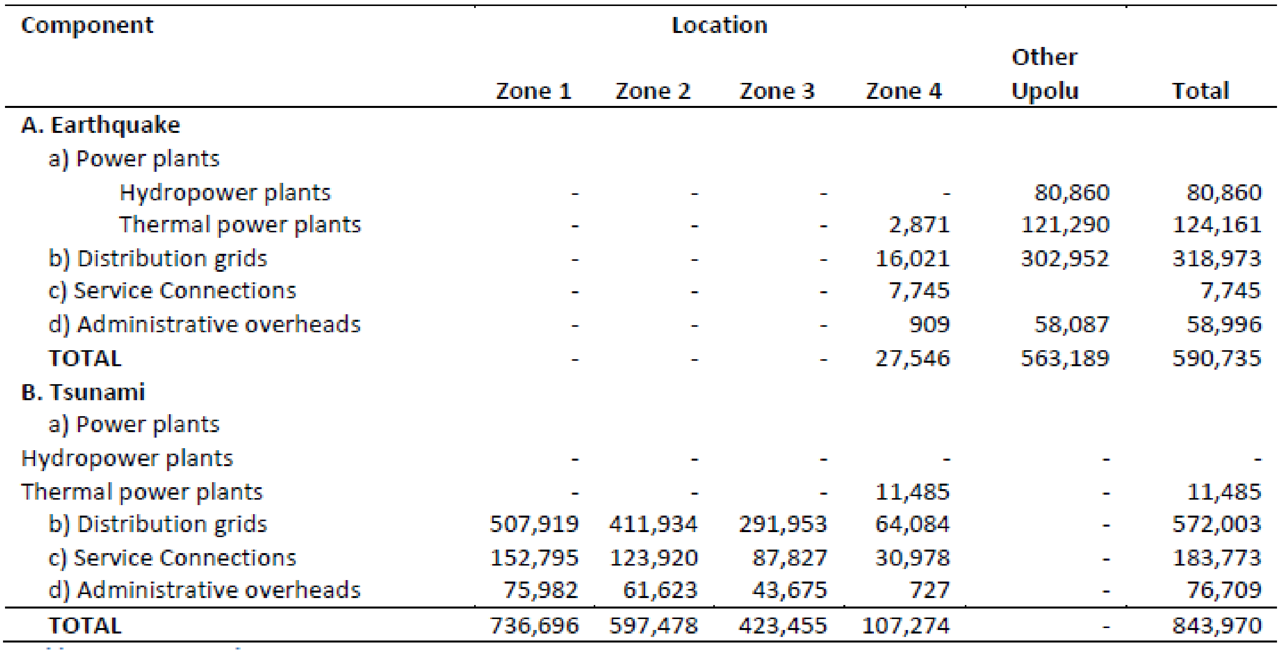
Earthquake and Tsunami 2009

In 2009, the M8.1 submarine earthquake mentioned in section 2.3.2.8 caused a Tsunami resulting in large loss of life and damage to the overhead distribution network in Lalomanu area. Approximately 11 km of power lines and 303 service connections were destroyed by the tsunami.

The Post Disaster Needs Assessment estimated the direct costs of the event to be 0.59 million SAT relating to the earthquake and 0.84 million SAT relating to the Tsunami, as shown in Table 24.

The indirect costs were estimated to be 0.75 million SAT, in the form of lost revenue to EPC. If this energy not served were instead valued at a value of lost load of 9 SAT/kWh, the cost would be around 8.4 million SAT.

Table 24: Cost of damaged EPC power system infrastructure due to 2009 Earthquake and Tsunami



Component	Location					
	Zone 1	Zone 2	Zone 3	Zone 4	Other Upolu	Total
A. Earthquake						
a) Power plants						
Hydropower plants	-	-	-	-	80,860	80,860
Thermal power plants	-	-	-	2,871	121,290	124,161
b) Distribution grids	-	-	-	16,021	302,952	318,973
c) Service Connections	-	-	-	7,745		7,745
d) Administrative overheads	-	-	-	909	58,087	58,996
TOTAL	-	-	-	27,546	563,189	590,735
B. Tsunami						
a) Power plants						
Hydropower plants	-	-	-	-	-	-
Thermal power plants	-	-	-	11,485	-	11,485
b) Distribution grids	507,919	411,934	291,953	64,084	-	572,003
c) Service Connections	152,795	123,920	87,827	30,978	-	183,773
d) Administrative overheads	75,982	61,623	43,675	727	-	76,709
TOTAL	736,696	597,478	423,455	107,274	-	843,970

Source: Post Disaster Needs Assessment - Following the Earthquake and Tsunami of 29 September 2009, Government of Samoa.

3.2.3 Vulnerability of Power System to Future Climate Events

The team notes that EPC have been proactive in future proofing their assets as mentioned above following the 2012 Cyclone Evan.

EPC have recently introduced a system for self-funding of asset insurance; this was approved by Government of Samoa and needs Cabinet approval whenever there is a requirement to draw on the fund of WST 2.5 m (~USD 940 k).

A risk assessment[49] of EPC key assets was carried out in 2018 and ranked each asset in terms of material damage risk (catastrophic, severe or damaging), business interruption risk (prolonged, major or moderate) and assigned a priority (critical, important or best practice) for implementation. Critical risks identified were:

- Alaoa hydro: need to maintain head gate and tailrace (refer section 2.3.4.2 re EPC's Alaoa multi-purpose flood control dam)
- Afulilo hydro: need to repair head gate control
- Tanugamanono: need to upgrade MV switch room and remote monitor 10 MVA transformer.

3.2.4 Investment Needs

3.2.4.1 Historical and Committed Projects

EPC's business-as-usual committed projects and not specifically related to climate events are listed in Table 25.

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[49] *Risk Improvement Report,* September 2018, Willis Towers Watson.

Table 25 EPC Business as Usual Committed Projects 2020

Item	Project	Cost USD k
Transmission & Distribution		
TD1	**Malifa to Port/Wharf**: 2 km underground HV, LV and fibre cable; include tie to overhead and underground transformers	2,000
TD2	**Downtown**: 2 km UG HV, LV; including pad mount transformers with switches	2,000
TD3	**Vailoa to Saina**: 2 km underground HV, LV; including tie to overhead, pad mount transformers and switches	5,000
TD4	**Fuluasou - Tanu 2nd 33 kV tie**: 4 km 33 kV OH tie line Fiaga power station to new substation inside STEC land near Faleolo International Airport	4,000
Generation		
GE1	Diesel Generation Expansion: New powerhouse in another site with new generators: 3 x 3 MW fast speed gens 2 x 4/5 MW medium speed diesels	tbc
GE2	RE development	
GE3	Tiapapata hydro: 1 MW	6,500
GE4	Savaii hydro	tbc
GE5	Alaoa Multi - Purpose Dam	70,000
GE6	Lalomauga head pond upgrade	2,000
GE8	**SCADA spare parts:** Inverters CPUs, Data Loggers, Weather Monitoring Station, Communication UHF/VHF Microwave link	
Buildings		
BLD1	Tanugamanono Powerhouse Upgrade	1,500
BLD2	Vaitele Master Plan	
BLD3	Salelologa Powerhouse Upgrade	
BLD7	Fuluasou Substation Upgrade [National Control Centre]	

Source: EPC

3.2.4.2 Business as Usual Investments

Uncommitted projects needed by EPC for business-as-usual and not specifically related to climate events, but which require funding are listed in Table 26.

Table 26 EPC Business as Usual Uncommitted Projects 2020

Item	Project	Cost USD k
Transmission & Distribution		
TD5	**Fiaga to Faleolo 33 kV OH tie line**: from Fiaga PS to a new substation in Faleolo	2,000
TD6	**Network Automation Upgrade**: Autoreclosers, Fault Indicators, PQ Monitoring	250
TD8	**33 kV Submarine cable from Savaii to Upolu: 15 km**	25,000
TD9	**33 kV tieline Fiaga power station to Airport Substation**	5,000
IT1	**Power system modelling software:** PSS/Adept	50
Generation		
GE7	**SCADA spare parts:** Generator CPUs, Network Cards, Transducers, IEDs.	100
	Subtotal	

Source: EPC

3.2.4.3 Climate Specific Investments

Uncommitted projects needed by EPC to mitigate against climate events and which require funding are listed in Table 27. TD11 and TD12 have been added as a recommendation of the study team.

Table 27 EPC Climate Resilient Uncommitted Projects 2020

Item	Project	Cost USD k
Transmission & Distribution		
TD7	**Aleipata Coastline 22 kV OH Replacement**	300
TD8a	**33 kV Submarine cable from Savaii to Upolu: 15 km** Feasibility	150
TD10	**LV Replacement ABC programme**	3,000
TD11	Increased lightning protection at key EPC generator and substation facilities	150
TD12	Backup Control Centre	250

Source: EPC and SMEC

Item TD7 provides for the undergrounding of the overhead broken 22 kV link on the Lotofaga South Coast which was destroyed in 2018 by a rockfall (refer Section 3.2.2). Replacing the overhead by underground will provide a more reliable supply and a resilient solution to future rockfalls in the area.

Item TD8 climate proofs the LV distribution against the effects of adverse weather, particularly with trees interfering with the conventional open wire system resulting in outages.

Item TD11 provides for additional lightning protection throughout the EPC grid, including lightning rods at all indoor locations, overhead earth wires at outdoor substations, installation of surge diverters on all MV circuits and control systems.

Item TD12 provides for a back-up control centre with associated SCADA controls so that system control for all of Samoa can be maintained in the event of the main NCC at Fuluasou suffering a catastrophic event (fire, lightning, explosion, or losing total communications and/or power, etc.).

It is acknowledged that EPC has already made considerable climate resilient investments as a consequence to earlier events and this reflects the smaller than expected list of projects above.

3.2.5 Roadmap for Adoption

Total implementation will include preparation of specifications (to climate resilient requirements) of the required equipment, manufacture, delivery to Samoa and installation. Assuming that funding becomes available for the uncommitted projects, the implementation should be achieved as follows:

- TD7: installation within 3 months of availability of the underground 22 kV cable
- TD8: installation of the ABC is expected to be a staged project converting existing overhead LV supply to ABC in a sequence of prioritised areas (obviously those areas in worst existing condition and/or having the highest number of outages); total installation over 24 months following staged delivery of ABC conductor and fittings
- TD11: installation of the lightning protection within 12 months of availability of the protection equipment

TD12: is best implemented with the assistance of a suitably experienced consultancy to work closely with the NCC team to scope the project and prepare the detailed design and specifications. Total duration is expected to be about two years.

3.2.6 Summary of Climate Proofing Measures

Table 28 lists the vulnerability and impact assessment risks identified in Section 2.3.4 and their applicability to EPC. Recommended climate proofing measures are shown in the last column.

Based on their experience with past climate events, TEC has already implemented (refer Section 3.2.2) various climate proofing measures, which have reduced the impact of subsequent events on the power system. In addition, EPC is continuing to apply further measures, such as the Alaoa multi-purpose flood control dam. Some additional measures are recommended as shown.

Table 28 Climate Proofing Measures - Samoa EPC

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
Climate Related					
Global Warming Elevated temperature	Higher daytime ambient temperatures; warmer nights	Equipment operation Higher demand for air conditioning	Compensate higher temperatures with increased cooling on generators Use of HTLS[50] conductors to operate at higher temperatures and avoid derating transmission circuits	None	Not applicable for TEC, as there is no HV transmission in Samoa and all MV subtransmission is well constructed with appropriate sag to maintain ground clearances
Global Warming Elevated temperature	Less annual rainfall	Drought / hydro generation	Large hydro reservoirs Multipurpose dams for flood control, potable water, electricity generation	EPC is implementing Alaoa multi-purpose flood control dam	Alaoa multi-purpose flood control dam will increase storage capacity for cascade hydros on Vaisgano river
Global Warming Elevated temperature	Longer periods without rain	Non-rain days / dusty conditions, obscuration of solar panels	More cleaning of solar panels	None	Implement regular monitoring of panels and cleaning when appropriate
More Intense Cyclones	Strong winds from cyclone or tropical depression	Destroy structures not designed to withstand wind loading factor Render windmills unusable	Design structures to Category 5 Make windmills demountable	EPC wind farm can be lowered to ground when storm warnings issued	Include provisions in future wind farms
More Intense Cyclones	High winds	Blow trees onto assets	Undergrounding of distribution system; Keep trees clear of assets	Minimal undergrounding Some tree trimming	Not practical/ economic to underground all EPC network; identify and focus on most vulnerable sections of Network Increase tree trimming programme
Storms	High winds	Rusting of assets in coastal areas due to salt spray	Use stainless or plastic products in lieu of sheet steel	None	Introduce non-rust options in coastal areas of network
More Intense Cyclones or tropical depressions	Heavy rain cyclonic long duration (days)	Area Flooding due to saturated preconditions	Undergrounding of distribution system; placing live vulnerable equipment above flood levels Minimise use of vulnerable ground level assets	EPC is implementing Alaoa multi-purpose flood control dam	Not practical/ economic to underground all EPC network; identify and focus on most vulnerable sections of Network Alaoa control dam will prevent flood damage on Vaisgano river

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[50] Overhead High temperature Low Sag (HTLS) conductors are designed to operate at a higher temperature (up to 200 ºC) than conventional ACSR conductors and have a higher tensile strength. The advantage is that the conductor sags are less, meaning that greater currents can be carried; the disadvantage is that HTLS conductors are about 5 x more expensive. HTLS conductors are often used to upgrade existing HV transmission lines without the need for new right-of-ways..

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
More Intense Cyclones or tropical depressions	Intense short duration rainfall (minutes)	Impermeable surfaces quickly flooded	Size drains for 1 in 20 precipitation Effective maintenance and cleaning of blocked drains		
More tropical depressions	Thunderstorms	Lightning	Lightning protection for outdoor equipment and generator buildings Surge divertors on HV system	Fiaga power plant has a lightning rod on the comms tower	Needs more lightning protection throughout the EPC network
More tropical depressions	Storm surge	Short term flooding	Raise +2.5 m in elevation on high water mark Accept temporary flooding (several tidal cycles)	None	Assess and protect vulnerable assets in coastal areas of network
More tropical depressions	Landslips	Destruction of assets	Locate assets away from potential landslip areas Protect assets by barriers Underground overhead lines	None	Assess and protect vulnerable assets in areas of network near potential landslip areas
Sea Level Rise (SLR)	Chronic (slow) Coastal Inundation	Long term Flooding	Move assets back from coast to gain +2 m in elevation on mean sea level	None	Assess and protect vulnerable assets in coastal areas of network
Natural - Non-Climate Related					
Equipment Failure	Oil leakage from power transformers in event of catastrophic failure of tank or cooling radiators	Contamination of environment	Construct oil containment around each power transformer to contain complete volume of oil	None (the oil containment of power transformers at Fiaga power plant have been negated by inserting water drainage holes in the bund)	Assess and provide oil containment for all power transformers
Tsunami	Coastal destruction	Short term flooding High energy waves Destructive force on buildings	Move assets 1.5 kms inland or achieve +15 m in vertical elevation	Existing nation-wide warning system for Tsunamis	Assess and protect vulnerable assets in coastal areas of network
Earthquakes	Seismic shocks	Body waves cause building destruction Surface waves cause tsunamis	Build lightweight structures or design high rise which avoid resonant frequency of EQ Move assets 1.5 km inland or achieve +15 m in vertical elevation Seismic design incorporated in all switchgear and transformer foundations and buildings	None	Ensure seismic design incorporated in all switchgear and transformer foundations and buildings

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
Volcanoes	Potential eruption if not proven to be dormant	Overland lava flow destroying assets	Avoid building in potential or existing lava fields Protection of assets against ash and rocks	None	Assess and protect vulnerable assets around Mt Matavanu
El Niño	Follows 7 year cycle but highly unpredictable	Warmer weather causes more rain and more cyclones	Plan for inclement weather	None	
La Niña	Follows 7 year cycle but highly unpredictable	Colder weather causes less rain and fewer cyclones	Plan for droughts	None	

3.3 Tuvalu - Tuvalu Electricity Corporation

3.3.1 Overview of Power System

3.3.1.1 Organisation

Tuvalu Electricity Corporation (TEC), part of the Ministry of Transport, Energy and Tourism (MoTET), is responsible for providing electricity on Funafuti and seven of the outer islands. TEC Head Office is at the Funafuti Power Station adjacent to the airport runway. The Board of Directors, comprising Chairman plus four members, are elected and appointed by the Cabinet every two years and hold monthly meetings.

Photo 1: TEC Head Office and Funafuti Power Station

3.3.1.2 Generation

Tuvalu has committed to generating 100% of its electricity from renewable energy sources by 2025. A summary of the existing electricity generation is shown in Table 47. This is 58% diesel and production relies heavily on imported diesel fuel[51], transported by sea and subject to climate change-related supply disruptions. This heightened climate change and energy security problems and caused high per capita greenhouse gas emissions. One focus of the government is to increase the renewable energy penetration on the outer islands to 100%, to be followed by Funafuti. Up to 10 % of GDP is spent on imported fuel, making energy the costliest sector of Tuvalu's economy.

Table 48 lists the number of TEC customers and their consumption over the last four years.

On the main island of Funafuti, TEC provides a 24/7 supply of electricity using both diesel and solar generation. The main source of generation is three Daihatsu 600 MW automotive diesel generators located within the TEC compound beside the airport runway. These were commissioned in 2007 under a Japanese grant.[52] These units have a 20-year design life, so have ~6 years life remaining. Fuel storage is in 2 x 150,000 ℓ tanks which provides about 8 weeks[53] of reserve generation.

Eight outer islands are each powered by solar hybrid system running 24 hours per day, with diesel generators on standby. Some of the outer islands have battery storage and two islands have standalone home solar systems (SHS).

TEC's existing solar plants total 756 kW_p in Funafuti and 1,352 kW_p in the Outer Islands. All solar panels belong to TEC, including those mounted on non-TEC buildings.

Table 49 records the diesel and solar generation 2015-2018.

Several other grid-connected PV plants funded by donor partners are due to be constructed with some to be commissioned in 2021. This includes:

- Increasing Access to Renewable Energy Project funded by the Asian Development Bank (ADB):
    - Funafuti - 500 kW plus 1 MW/3 MWh BESS (battery energy storage system)
    - Nui - 100 kW
    - Nukulaelae - 45 kW

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[51] Pacific Energy is the current supplier of fuel to Tuvalu.

[52] *Upgrading of Electric Power Supply in Funafuti Atoll -Grant Aid from the People of Japan as a token of Friendship and Co-operation between Japan and Tuvalu 2006*.

[53] Average weekly diesel usage is 36,800 ℓ per week (4 road tanker trips); 300,000/36,800 = 8.15 weeks.

    - Nukufetau - 78 kW
- Tuvalu Energy Sector Development Project funded by the World Bank (WB)
    - Funafuti - 700 kW plus 1 MW/2 MWh BESS
- Tuvalu Photovoltaic Electricity Network Integration Project (TPENIP) Phase II
    - Vaitupu - Motufoua Secondary School - 70 kW.

TEC's energy losses are reported[54] to be 8.15% of annual generation, comprising 3.62% technical, 3.53% non-technical and 1% unbilled for street lighting.

For future generation and eventual replacement of the diesel generators at Funafuti Power Station, it is recommended that the installation of a floating solar farm in Funafuti Lagoon be considered by TEC as an alternative to acquiring new and scarce land.[55] The feasibility of a wind farm in Funafuti Lagoon could also be assessed.

3.3.1.3 Distribution

MV distribution is at 11 kV and the LV system three phase 400/230 V. All distribution is underground since 1982; there is no overhead distribution which ensures no disruption to supply due to wind and trees.

The 11 kV system in Funafuti is shown in Figure 36; from the 11 kV switchboard at the generating station, there is a 7.4 km ring circuit using 3-core 50 mm^2 Cu XLPE insulated underground cable passing through 7 RMUs (ring-main units); this allows the system to be sectionalised and fed from either direction to maintain power supply. Four of the RMUs supply a radial feeder using 3-core 25 mm^2 Cu XLPE insulated underground cable.

There are 15 11/0.4 kV distribution transformers, rated at 100 kVA, 150 kVA, 160 kVA, 200 kVA, 400 kVA sizes. These supply a network of underground 3 phase LV cables connected together at ground mounted link boxes. There are a total of 196 link boxes; each supplies a maximum of 10 to 15 customers, with an average of 5 customers per box.

3.3.1.4 Customers

Customers are supplied from the LV link boxes by LV single and three phase underground service cables, with the service fuse in the link box and the tariff meter mounted in a weatherproof meter box on the exterior of the customer's house.

TEC are about to replace in 2020 the existing tariff meters for all domestic customers with electronic pre-pay smart meters. These meters will be installed inside customer's houses; this will eliminate the vulnerability of the outside meters to rain during bad weather. TEC predict that installation of pre-payment meters will reduce demand by about 3%. Government and essential services will retain the existing meters with monthly billing.

For domestic customers, electricity is only used for lighting and appliances; all cooking is done using bottled LPG gas. There is no electric water heating.

3.3.1.5 Equipment

TEC uses specifications to NZ/Australian standards for the procurement of all major equipment. Ordering of new equipment is subject to availability of finance and usually takes between 1 to 3 months by sea. Regional cargo ships provide a monthly service to Funafuti Port from Auckland via Fiji. Small items of spare parts can be delivered by airfreight, usually within one to two weeks. TEC's store warehouse, adjacent to Head Office, holds a limited quantity of key items, such as distribution transformers, cables, LV pillars, tariff meters and similar. It uses a simple Excel-based stock N° system.

There are no spare 11 kV RMUs. The Study Team noticed that the outdoor RMU adjacent to the Funafuti Power Station had lost its SF_6 gas and therefore would have been dangerous to operate.[56]

In general, all equipment suffers from continual exposure to corrosion from the salt air and the harsh tropical environment; there was much evidence of rusted equipment needing replacement in the short term.

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[54] *Quantification of the Power System Energy Losses in South Pacific Utilities* Report, May 2012 Kema International.

[55] PPA report that both WB and ADB are exploring the feasibility of floating solar farm in the lagoon.

[56] It was recommended to TEC that a Do NOT OPERATE sign be immediately put on the RMU and urgent steps be taken to replace the unit. The RMU was installed in 2015. After consultation with third parties, the issue was identified as being a manufacturing fault in a batch of ABB 11 kV SF_6 switchgear whereby the tank seams were failing and allowing the SF_6 gas to escape. Even if the unit is re-gassed, the same issue would repeat itself. The same fault has occurred in other Pacific Countries with Rarotonga being the most affected PPA utility.

Because of the threat from flooding during severe weather, it is recommended that all new equipment be mounted on concrete pedestals at least 0.3 m above ground level and that all live LV terminals within link boxes be a minimum of 1.0 m above the known tide wash levels to mitigate any risk to the public of electric shock. All 11 kV terminals must be insulated using heat shrink or similar.

3.3.1.6 Resources

TEC's organisation chart is shown in Figure 35; as of January 2020, currently there are 42 employees (26 staff on Fogafale and 16 in the Outer Islands) in four divisions - Generation, Distribution, Finance and Renewable Energy - reporting to the General Manager.

TEC's Outer Islands organisation comprises seven groups of staff, each group reporting to an Outstation Supervisor and providing appropriate technical service to their local customers.

TEC has two working vehicles and four motorbikes used by staff and at times staff use their own motorbikes. MoTET provides vehicle transport for carrying large items of equipment.

3.3.2 Impacts of Historical Events on Power System

As noted in Section 1.4, the study team visited Tuvalu immediately after Cyclone Tino had passed and were able to observe first-hand the result of the Category 2 storm on Funafuti. Unfortunately though, the subsequent weather was dominated by a series of low pressure systems with frequent rain and strong wind conditions which prevented travel to the outer islands.

The team viewed all of TEC's key assets on Funafuti including:

- Funafuti Power Station
- Funafuti solar installations
- 11 kV distribution system
- LV household connections
- Damage to houses, trees, etc., due to high winds and waves sweeping across the low-lying land[57] due to Cyclone Tino.

To the credit of TEC and illustrating the benefit of an all-underground system, the power supply on Funafuti during Cyclone Tino was fully maintained without disruption. However, some customers lost power due to water short-circuiting supply in the external meter boxes and it was observed that a number of pillar boxes had seawater damage. On the outer islands, there were some outages due to generator issues and flooding of pillars, which were disconnected from the supply as a precaution.

3.3.3 Vulnerability of Power System to Future Climate Events

TEC's all-underground system in general provides a reliable power supply. Although there were some customers who lost power in the January 2020 cyclone, this was localised and due to the vulnerability of their external meter boxes to rain causing short circuits.

It is recommended TEC implements a programme to replace and improve the susceptibility of their distribution assets to both storm damage and also corrosion from seawater and salt-laden air. This is included in the following section on Climate Specific Investments.

New equipment such as LV distribution pillars should be positioned to shield the electrical equipment from prevailing wind and/or waves, with mounting bases of sufficient height to be above previous flood and wave levels. Live equipment inside the pillars should be mounted as high as practical.

3.3.4 Investment Needs

3.3.4.1 Historical and Committed Projects

A list of historic renewable energy and energy efficiency projects implemented by TEC over the last ten years is shown in Table 29. These were all categorised as either energy efficiency or renewable energy projects without specific mention of energy resilience. Pipeline energy efficiency or renewable energy projects are listed in Table 30.

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[57] The highest point in Tuvalu is Niulakita being about 4.6 metres above sea level; on Funafuti the highest point is <2 m asl.

Table 29 TEC Renewable Energy and Energy Efficiency Projects 2008-2019

N°	Location	Project Description	Installed PV Capacity (kWp)	Generator (kVA)	Installed Battery Capacity (kWh)	Objective	Donor	Status	Start	End	Executing Agency	Implementing Agency	Total Funding	Remarks
Renewable Energy Projects														
1	Stadium	e8 Tuvalu Solar Project	40		Nil	Demonstration	Japan Gov/ e8 Group	completed	2008	2008		TEC	*Costs unavailable*	
2	Motufoua Secondary School, Vaitupu	Tuvalu Photovoltaic Integration Project (TVIP)	46		576	To provide the school with quality and 24/7 Power Supply	Italy Govt.	completed	2009	2009	IUCN	TEC	USD 700,000	
3	PWD, Funafuti	Grid-connected Solar PV Desalination Plant	66		Nil	To provide clean power supply to the desalination plant	Japan Govt.	completed	2013	2013	Hitachi	PWD	USD 5,000,000	
4	Rooftop- Govt. Building and Tuvalu Media building, Funafuti	Tuvalu Energy Project	170		Nil	To reduce diesel oil consumption	NZ Aid	completed	2015	2015	NZ MFAT	TEC		Rooftop installation - 130 kW Govt. building and 40 kW Tuvalu Media building
5	Funafuti - TEC Compound Rooftop Hospital and Marine Warehouse	Solar Space Creation Project	500		Nil	To create space and reduce diesel consumption	UAE	completed	2015	2015	MASDAR	TEC	USD 4,000,000	
6	Nukulaelae	Improving reliable access to modern energy services through solar PV systems for rural (outer islands) of Tuvalu	45	164	586	To reduce diesel oil consumption	EU	completed	2014	2015	MPUI	TEC	€ 1,857,000	
7	Nukufetau	Improving reliable access to modern energy services through solar PV systems for rural (outer islands) of Tuvalu	87	164	1,008	To reduce diesel oil consumption	EU	completed	2014	2015	MPUI	TEC		

N°	Location	Project Description	Installed PV Capacity (kWp)	Generator (kVA)	Installed Battery Capacity (kWh)	Objective	Donor	Status	Start	End	Executing Agency	Implementing Agency	Total Funding	Remarks
8	Nui	Improving reliable access to modern energy services through solar PV systems for rural (outer islands) of Tuvalu	70	164	864	To reduce diesel oil consumption	EU	completed	2014	2015	MPUI	TEC		
9	Vaitupu	Tuvalu Energy Project	400	260	2,880	To reduce diesel oil consumption	NZ Aid	completed	2015	2015	NZ MFAT	TEC	NZ 19,000,000	
10	Niutao	Tuvalu Energy Project	230	160	1,728	To reduce diesel oil consumption	NZ Aid	completed	2015	2015	NZ MFAT	TEC		
11	Nanumaga	Tuvalu Energy Project	205	160	1,584	To reduce diesel oil consumption	NZ Aid	completed	2015	2015	NZ MFAT	TEC		
12	Nanumea	Tuvalu Energy Project	195	160	1,440	To reduce diesel oil consumption	NZ Aid	completed	2015	2015	NZ MFAT	TEC		
13	Amatuku-rooftop	Solar PV Hybrid System	8	120	96	To reduce diesel oil consumption	Finland	completed	2017	2017	MPUI	TEC	USD 18,000	
14	Niulakita/ Funafala	Solar Home Standalone (SHS) Systems and PV Cooling Storage Facility	300 W for home and 800 W for refrigerators			To provide the resident with quality lighting and derive economic activities	Italy Govt.	completed	2017	2017	MPUI	TEC	USD 300,000	
Energy Efficiency Projects														
1	TEC Compound, Funafuti	RE and EE Demonstration Fale				To showcase most efficient appliances	SIDS Dock	Completed	2016	2017	SPREP	TEC	*Costs unavailable*	
2	Development Bank of Tuvalu, Funafuti	Subsidy Scheme				To replace inefficient appliances	Italy Govt	On-going	2016		IUCN	DBT	*Costs unavailable*	
3	All of Tuvalu	Prepayment Meters				To improve TEC cash flow and minimise bad debtors	World Bank	Arrived; installation by May 20	2018	2019	WB	TEC	USD 750,000	
4	Government Building, Funafuti	Window Tinting				To minimise the heat gains in the Govt. building	World Bank	Completed	2018	2018	WB	TEC	USD 200,000	

Source: TEC

Table 30 TEC Renewable Energy and Energy Efficiency Pipeline Projects 2020

N°	Location	Project Description	Installed PV Capacity (kWp)	Generator (kVA)	Installed Battery Capacity (kWh)	Objective	Donor	Status	Start	End	Executing Agency	Implementing Agency	Total Funding
1	Nukulaelae, Nukufetau, Nui and Funafuti	Increasing Access to Renewable Energy Project	Nukulaelae - 45 kW, Nukufetau - 78 kW, Nui - 100 kW, Funafuti - 500 kW, BESS 1 MW/ 2 MWh			To increase PV and storage capacity at N/lae2, N/fetau, Nui and Funafuti	ADB	Going through the ADB approval processes	2020	2021	MPUI	TEC	USD 6,000,000
2	Funafuti	Tuvalu Energy Sector Development Project	700 kW PV BESS 1 MW/1 MWh Prepayment meters etc			To reduce diesel oil consumption and contributing to achieve Tuvalu 100% target by 2020	World Bank	Contract signed and implementation 2020	2020	Sep 2020	MPUI	TEC	USD 7,000,000
3	Motufoua Secondary School, Vaitupu	Tuvalu Photovoltaic Electricity Network Integration Project (TPENIP) Phase II	70 kW PV	120		To increase PV capacity to 90%	Italy	Recruit TA for feasibility study	2020	2020	MPUI	TEC	USD 427,000
4	Funaota, Nukufetau	Solar Home Standalone (SHS) Systems and PV Cooling Storage Facility	300 W for home and 800 W for refrigerators			To provide resident with quality lighting and accelerate economic activities.	India UN Partnership Fund	Working on the design report	2019	2020	UNDP, Fiji	TEC	USD 213,151
5	Funafuti Power Station	Supply of spare alternator winding				To provide quick replacement if existing windings fail	Japanese Aid		tbc			TEC	USD 600,000

Source: TEC

Key initiatives include:

- Installation of prepayment meters funded by World Bank; this objective being to improve TEC cash flow and minimise bad debtors (also refer Section 3.3.1.4)
- Additional 700 kWp of solar PV and 1 MW, 2 MWhr BESS funded by World Bank
- Additional 500 kWp of solar PV and 1 MW, 3 MWhr BESS funded by Asian Development Bank
- Supply of spare alternator winding for Funafuti Power Station ($600 k, including $200 k installation) funded by Japanese Aid.

3.3.4.2 Business as Usual Investments

Uncommitted projects needed by TEC for business-as-usual and not specifically related to climate events, but which require funding are summarised in Table 31.

Table 31 TEC Business as Usual Uncommitted Projects

Item	Project	Cost USD k
1	Funafuti Power Station recladding	100
2	Funafuti Power Station generator maintenance	150
3	Funafuti Power Station cooling tower	45
4	Funafuti Power Station fuel pipes	20
5	Increase minimum stock levels of key equipment	250

Source: TEC

#1 Recladding of Funafuti Power Station generator house and offices; currently the building leaks and exposes the generators to possible rain damage[58] - see photo in Appendix 1.

#2 Major and staged maintenance of the three Daihatsu 600 MW automotive diesel generators at Funafuti Power Station, 60 k hours service overdue but deferred to cashflow. The Government has assisted TEC in procuring the spare parts for the 60,000 hour overhaul. The arrival of the spare parts is pending the lifting of travel bans due to the Covid-19 restrictions.

#3 Replacement of one cooling tower (two towers already replaced) at Funafuti Power Station- estimated budget $45 k. The Government has also assisted in the procurement of the replacement radiator which will be delivered similar to above

#4 Replacement of fuel pipes at Funafuti Power Station and cleaning of fuel tanks

#5 Increase minimum stock levels of key spare parts and equipment for generators, Fogafale and Outstations, including:

- Spare parts for all generator units
- Spare 11 kV circuit breaker at Funafuti Power Station switchboard
- Spare 11 kV RMU
- Spare distribution transformers
- Spare transformer insulating oil
- Spare 11 kV cable jointing kits
- Spare solar PV parts
- Spare batteries for Outer Islands
- Selected test equipment
- New truck with crane for transporting transformers
- New 4WD pick-up.

3.3.4.3 Climate Specific Investments

TEC's underground network and the optimum siting of the main generation station already demonstrates some future proofing of their assets and results in only minimal investments needed for further climate mitigation.

Uncommitted projects needed by TEC to mitigate against climate events and which require funding are listed in Table 32.

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[58] The Study Team observed that the generator units were covered in tarpaulins to prevent rain from the adverse weather shorting the generator windings (refer Photo 19).

Table 32 TEC Climate Resilient Uncommitted Projects

Item	Project	Cost USD k
1	Spare 11 kV circuit breaker at Funafuti Power Station	6
2	Replacement of rusted LV pillars	30
3	Replacement of rusting 11 kV RMUs	60
4	Replacement of rusting distribution transformers	80

Source: TEC

The objective here is not to replace the existing assets with the same standard of equipment, but instead to upgrade the distribution system with climate resilient equipment that will provide a much longer assert life compared with the existing. In particular, to install equipment constructed from suitable plastic materials stainless steel or that can stand up to the harsh environment.

3.3.5 Roadmap for Adoption

Assuming that funding becomes available for the uncommitted projects, the implementation should be achieved with twelve months. This includes preparation of specifications (to climate resilient requirements) of the required equipment, manufacture, delivery to Tuvalu and installation. It is expected that installation of equipment can be done by TEC staff and will involve minimal disruption of power.

3.3.6 Summary of Climate Proofing Measures

Table 33 lists the vulnerability and impact assessment risks identified in Section 2.4.4 and their applicability to TEC. Recommended climate proofing measures are shown in the last column.

In summary, TEC has already implemented a number of climate proofing measures, which have reduced the impact of recent events on the power system, but some additional measures are recommended as shown.

Table 33 Climate Proofing Measures - Tuvalu TEC

Hazard	Type of Risk	Impact and Asset Affected	Climate Proofing Measures		
			Industry Best Practice	Existing	Missing/ Recommended
Climate Related					
Global Warming Elevated temperature	Higher daytime ambient temperatures; warmer nights	Equipment operation Higher demand for air conditioning	Compensate higher temperatures with increased cooling on generators Use of HTLS[50] conductors to operate at higher temperatures and avoid derating transmission circuits	None	Not applicable for TEC, as there is no overhead transmission system
Global Warming Elevated temperature	Less annual rainfall	Drought / hydro generation	Large hydro reservoirs Multipurpose dams for flood control, potable water, electricity generation	None	Not applicable for TEC, as no hydropower potential exists
Global Warming Elevated temperature	Longer periods without rain	Non-rain days / dusty conditions, obscuration of solar panels	More cleaning of solar panels	None	Implement regular monitoring of panels and cleaning when appropriate
More Intense Cyclones	Strong winds from cyclone or tropical depression	Destroy structures not designed to withstand wind loading factor Render windmills unusable	Design structures to Category 5 Make windmills demountable	None	Currently not applicable for TEC, as no wind power exists; but applicable for future wind power
More Intense Cyclones	High winds	Blow trees onto assets	Undergrounding of distribution system; Keep trees clear of assets	Network already underground	Not applicable for TEC, as existing underground system already cyclone proof
Storms	High winds	Rusting of assets in coastal areas due to salt spray	Use stainless or plastic products in lieu of sheet steel	None	Replace all rusting assets with non-rust options
More Intense Cyclones or tropical depressions	Heavy rain cyclonic long duration (days)	Area Flooding due to saturated preconditions	Undergrounding of distribution system; placing live vulnerable equipment above flood levels Minimise use of vulnerable ground level assets	Network already underground but needs upgrade	External meter boxes exposed to weather; need to be weatherproofed; LV Link boxes to be raised above flood levels
More Intense Cyclones or tropical depressions	Intense short duration rainfall (minutes)	Impermeable surfaces quickly flooded	Size drains for 1 in 20 precipitation Effective maintenance and cleaning of blocked drains		
More tropical depressions	Thunderstorms	Lightning	Lightning protection for outdoor equipment and generator buildings Surge divertors on HV system	Funafuti Power Station has two lighting rods on building	OK as is

Hazard	**Type of Risk**	**Impact and Asset Affected**	**Climate Proofing Measures**		
			Industry Best Practice	**Existing**	**Missing/ Recommended**
More tropical depressions	Storm surge	Short term flooding	Raise +2.5 m in elevation on high water mark Accept temporary flooding (several tidal cycles)		
More tropical depressions	Landslips	Destruction of assets	Locate assets away from potential landslip areas Protect assets by barriers Underground overhead lines	None	Not applicable for TEC, as entire country has elevation <5 m (refer footnote 57)
Sea Level Rise (SLR)	Chronic (slow) Coastal Inundation	Long term Flooding	Move assets back from coast to gain +2 m in elevation on mean sea level	None	Locate link boxes and ground mounted transformers, switchgear, etc., on foundations at higher than present levels
Natural - Non-Climate Related					
Equipment Failure	Oil leakage from power transformers in event of catastrophic failure of tank or cooling radiators	Contamination of environment	Construct oil containment around each power transformer to contain complete volume of oil	None	Not applicable for TEC, as there are no HV power transformers
Tsunami	Coastal destruction	Short term flooding High energy waves Destructive force on buildings	Move assets 1.5 kms inland or achieve +15 m in vertical elevation	Network already underground	
Earthquakes	Seismic shocks	Body waves cause building destruction Surface waves cause tsunamis	Build lightweight structures or design high rise which avoid resonant frequency of EQ Move assets 1.5 km inland or achieve +15 m in vertical elevation Seismic design incorporated in all switchgear and transformer foundations and buildings	None	Not applicable for TEC, as not in earthquake zone (refer Table 14)
Volcanoes	Potential eruption if not proven to be dormant	Overland lava flow destroying assets	Avoid building in potential or existing lava fields Protection of assets against ash and rocks	None	Not applicable for TEC, as no volcanoes in country

Hazard	**Type of Risk**	**Impact and Asset Affected**	**Climate Proofing Measures**		
			Industry Best Practice	**Existing**	**Missing/ Recommended**
El Niño	Follows 7 year cycle but highly unpredictable	Warmer weather causes more rain and more cyclones	Plan for inclement weather	None	
La Niña	Follows 7 year cycle but highly unpredictable	Colder weather causes less rain and fewer cyclones	Plan for droughts	None	

4.0 Evaluation of Investments

4.1 Methodology

4.1.1 Overall approach

Economic analysis rather than financial analysis

An investment that improves the climate resilience of a power system is viable if its benefits outweigh its costs. These benefits and costs should be evaluated in economic terms, i.e. from the perspective of society as whole, rather than be evaluated in purely financial terms.

The difference been economic analysis (which is how we recommend investments should be evaluated) and financial analysis is further described as follows:

- **Financial analysis evaluates costs and benefits from the perspective of the entity** making the investment – i.e., the electricity utility – and asks whether the financial revenues accruing from the investment over its life are likely to outweigh the upfront costs of making the investment.
- **Economic analysis evaluates costs and benefits from the perspective of society as a whole** (i.e. the economy) and considers a range of benefits beyond financial transactions. For example, if an investment results in fewer electricity outages, the benefit to society is typically larger than increased tariff revenues for the utility. Economic analysis also requires quantifying costs and benefits based on 'shadow prices', which reflect the underlying economic value, rather than market prices. This means excluding transfers from one group within society to another – for example, taxes should be excluded from economic costs because they are a transfer from individual taxpayers to the Government and back to society. Similarly, distortions such as minimum wages should be adjusted for, as they can artificially inflate the value of labour.

Throughout this economic analysis, we are guided by the Asian Development Bank's *Guidelines for the Economic Analysis of Projects*.

Comparing costs and benefits with and without investments

This evaluation is therefore concerned with the 'incremental' costs and benefits, which represents the difference between the without and with scenarios:

- **Without climate resilience** – the business as usual investment. For example, replacing an aged generator housing.
- **With climate resilience** – spending more to climate proof the asset. For example, upgrading the generator housing specifications to make it flood proof.

Key viability metrics

An investment is viable if its incremental benefits outweigh it incremental costs over its useful life. We use two indicators to determine this:

- **Net present value (NPV)** of benefits less costs**.** This is in effect the sum of all benefits less the sum of costs, with future benefits and costs discounted at the social discount rate to reflect the time value of money. We use the NPV rather than an arithmetic sum because it correctly reflects the fact that 'a dollar spent today is more expensive than a dollar spent in the future', or put differently, 'consumers prefer to consume today rather than in the future'. An investment is viable if the NPV is greater than zero.
- **Internal rate of return (IRR**)*.* This is a different indicator than NPV, but it is interrelated. It represents the discount rate at which the NPV of benefits less costs equals zero. An investment is viable if the IRR is greater than the social discount rate. We use a value of 9% for the social discount rate, which is the Asian Development Bank's default social discount rate[59].

4.1.2 Calculating costs and benefits

There is a wide range of possible investments that improve the climate resilience of power systems, including elevating assets, undergrounding lines, reinforcing towers, creating microgrids, and adding backup power supplies. In this methodology, it is difficult to describe all the costs and benefits applying in all cases and therefore in the following text we focus on those that are likely to be most significant and common.

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[59] Guidelines for the Economic Analysis of Projects, Asian Development Bank, 2017

Types of costs

There are two common costs to be quantified when evaluating an investments viability:

- **Incremental investment costs**. The upfront cost of making an investment, i.e. how much extra needs to be spent upfront to make the investment more climate resilient?
- **Incremental operating costs**. The annual cost of operating and maintaining the assets, i.e. how much extra is it going to cost to operate and maintain the more climate resilient asset?

Both estimates should exclude tax, which – as discussed above – is a transfer from one group of society to another. And both estimates should adjust for any market distortions such as minimum wages and fixed exchange rates, although in most cases these are likely to be minor.

Types of benefits

The two most common benefits relating to climate resilient investments in the power system are likely to be:

- **Avoided costs of replacement/repair**. Each time there is a climatic or extreme weather event, how much will it cost to replace or repair assets? Climate resilient investments are likely to be less adversely affected, and therefore will require less replacement/repair.
- **Avoided cost of outages.** Each time there is a climatic or extreme weather event, how many customers are likely to face a power outage? Climate resilient investments are likely to be less adversely affected, and therefore will lead to fewer outages. The cost of outages should be quantified from the perspective of society, rather than from the narrow perspective of the utility. Therefore, the cost of each kWh of energy not served (due to an outage) should be valued at the 'Value of Lost Load' (VOLL) rather than the electricity tariff.

We describe the calculations of these benefits, including VOLL, in more detail in Section 4.2.

Adjusting for difference in timing and life of assets

It is important to take account of differences in the timing and life of assets in the with and without climate resilience scenarios. For example:

- Constructing distribution boxes out of stainless steel rather than zinc plated steel may not make a significant difference to ability of the boxes to withstand a single weather event. But it will protect them from chronic effects of climate change – i.e. rusting from exposure to semi-frequent weather events. This difference should be reflected in a longer asset life for the climate resilient asset.
- To evaluate whether or not to underground MV lines, it may not be fair to only assess the cost of undergrounding. The existing overhead lines may already be old and need replacing soon anyway, in which case the fair comparison would be the cost of new underground lines today versus the cost of new overhead lines in the future (e.g. 10 years' time).

Difficult to quantify costs and benefits

In addition to the costs and benefits described above, some types of climate resilient investments may result in environmental impacts, such as fewer carbon emissions. In some cases, the 'without climate resilience' scenario may lead to higher emissions, for example due to increased standby diesel generation. Valuing carbon emissions can be difficult because there is no global consensus on the cost of future climate change impacts, although one commonly used value is the prevailing price of carbon (or a long-term average) under the EU Emissions Trading System.

Other difficult to quantify benefits, such as visual impacts, can be included in the analysis as a qualitative 'add-on' to the quantitative analysis. For example, if the quantitative analysis demonstrates that the investment is borderline viable, then the presence of qualitative benefits could tip the balance in favour of the investment.

More guidance is available in the Asian Development Bank's *Guidelines for the Economic Analysis of Projects*.

Sensitivity analysis

Quantifying the incremental costs and benefits is inherently challenging and requires a lot of professional judgement, both with respect to the frequency of future weather events and to the impact of those weather events on the system (i.e. damages and outages).

It is therefore important to incorporate some sensitivity testing of the key inputs and assumptions. As implemented in Section 4.3 below, we recommend calculating the NPV and IRR under at least three different scenarios:

- Base Case
- Optimistic / Low Case
- Pessimistic / High Case.

In this context, we define 'Optimistic' with respect to future weather events and their impacts. The Optimistic Case will lead to a lower viability because events are assumed to occur less frequently, with less severity, and therefore have less impact on the power system.

The results under the Base Case should be the primary driver of the investment decision, but the range of results observed in the Optimistic and Pessimistic Cases also deserves consideration. For example, if Base Case is borderline viable, yet the Pessimistic Case results in only slightly higher viability than the Base Case and the Optimistic Case much worse, then perhaps on balance the project is not viable (or needs to be redesigned or deferred).

4.2 Viability Tool

We have developed a Viability Tool that Pacific utilities can use to decide whether improving the climate resilience of a power system investment is justified.

Balancing ease of use and complexity

When conducting economic analyses, it can be tempting to build sophisticated models that give the appearance of being robust, despite the outputs hinging a few key inputs that are inherently uncertain. This is especially true when evaluating the impact of future climatic events, for which there is a wide range of possible future outcomes. The downside to complex models is that they quickly become more difficult to use, understand, and check for errors.

Therefore, in building the Viability Tool we have endeavoured to strike an appropriate balance between keeping it simple enough that it can be used by staff of the Pacific utilities and being complex enough that it captures the main value drivers. In particular, this means that:

- **The inputs and assumptions have been simplified to a form that can realistically be estimated by staff of Pacific utilities**. For example, rather than inputting the frequency and impacts of a complex array of different climatic events (flooding, cyclones, earthquakes, tsunamis, etc), the user only needs to define inputs for two types of events: (1) Major events, and (2) Minor events. What constitutes a major event is specific to the type of investment being evaluated – for example a major event, in the context of whether or not to elevate a generator, would be events that cause surface flooding. In the context of investing in lightning protection, a major event would be one that causes a severe lightning strike.
- **The Viability Tool calculates all incremental costs and benefits in terms of their average annual effect.** This means that the evaluation of an investment occurs in three columns – without climate resilience, with climate resilience, and difference – rather than entire worksheets. These three columns can be copied as many times as required to evaluate several investments on the same worksheet. We avoid adding a spurious level of detail and do not estimate incremental costs and benefits that change over time – for example the frequency of events will likely increase over the life of an investment, but modelling this would only layer uncertain assumptions on top of other uncertain assumptions and is unlikely to make a decisive impact on the result (especially given that future effects are discounted – at 9% discount rate a benefit in year 20 is only worth 18% of the benefit in year 1). Instead, we have opted to keep the model and assumptions simple and estimate average effects over the life of the asset.

Model functionality

Below are a series of screenshots that illustrate the functionality of the Tool. To keep it useable, the Tool is entirely contained within a single Excel worksheet, which is separated into six sections:

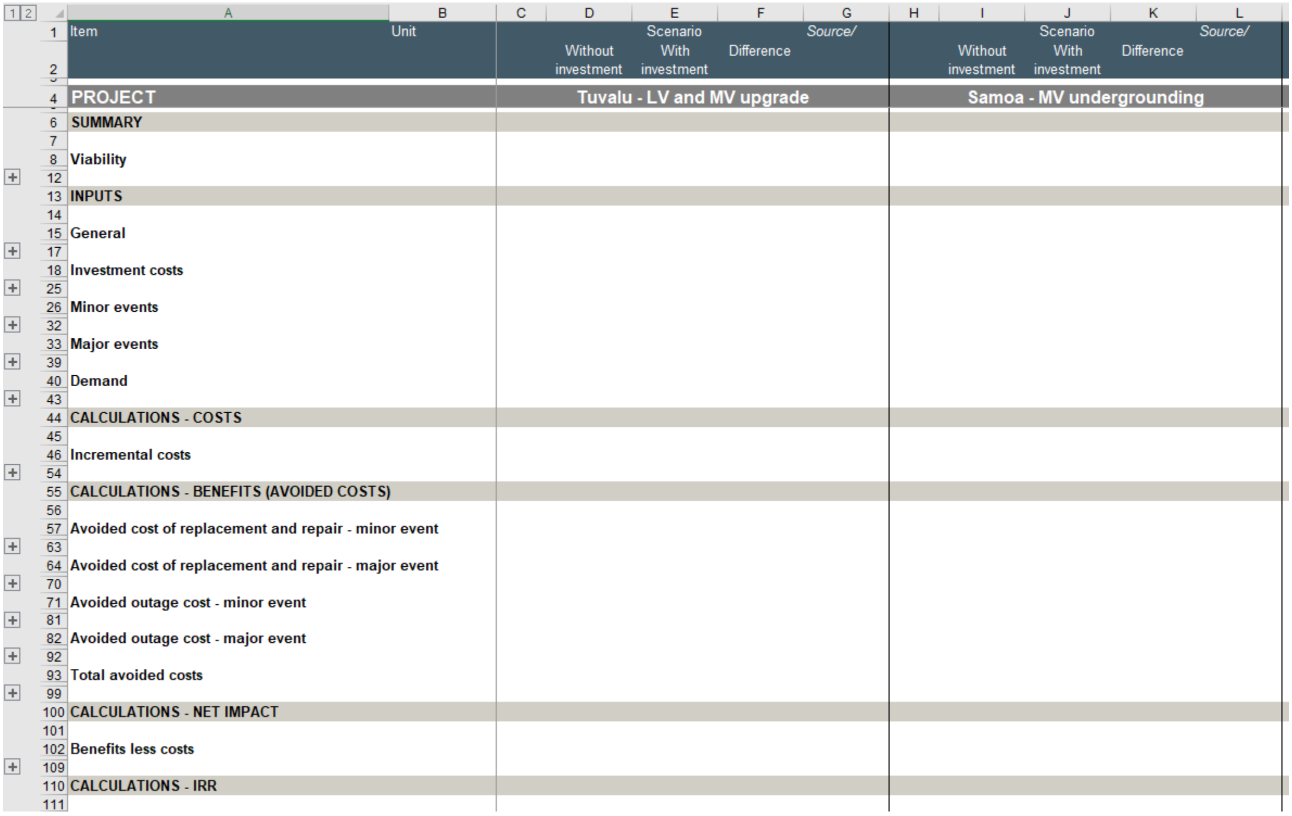
- **Summary of outputs.** Shows the NPV and IRR of the investment
- **Inputs and assumptions**. Where the user inputs key inputs and assumptions, including the investment cost, operating cost, frequency of major and minor events, impacts of major and minor events, and demand for power.

- **Calculations – costs**. The annual incremental costs are calculated by converting the upfront investment costs into annual costs (i.e. an annuity over the life of the asset), adding the annual operating costs, and calculating the difference in the with and without climate resilience scenarios.
- **Calculations – benefits.** Calculates two types of incremental benefits – avoided cost of replacement and repair and avoided cost of outages:
  - Estimate the avoided cost of replacement and repair per event, based on the proportion of assets that will be damaged in each major and minor event respectively. Multiply this by the frequency of those events.
  - Estimate the duration of outages per event, split into two parts – (a) system wide outages (if the whole system is impacted for a short time) and (b) partial outages (for those customers directly affected by the damaged infrastructure. Also estimate the share of demand affected under partial outages, which alongside average hourly demand, allows estimating unserved energy per event. This is multiplied by the value of each kWh not served. The value of each kWh not served should be set equal to the value of lost load (VOLL), which is an estimate of the economic impact of the outages. It is usually calculated either by econometric techniques to assess the relationship between changes in GDP growth and changes in electricity consumption, or by directly surveying electricity consumers. It is typically many multiples higher than the electricity tariff. We describe the calculation of VOLL for Tuvalu and Samoa in Section 4.3 below.
- **Calculations – net impact.** Calculated as annual incremental benefits less annual incremental costs. Also calculates the net present value.
- **Calculations – IRR**. Shows the incremental benefits and costs by year, which serves as a check of the annual calculations (they should produce the same NPV) and allows calculation of the IRR.

Screenshots

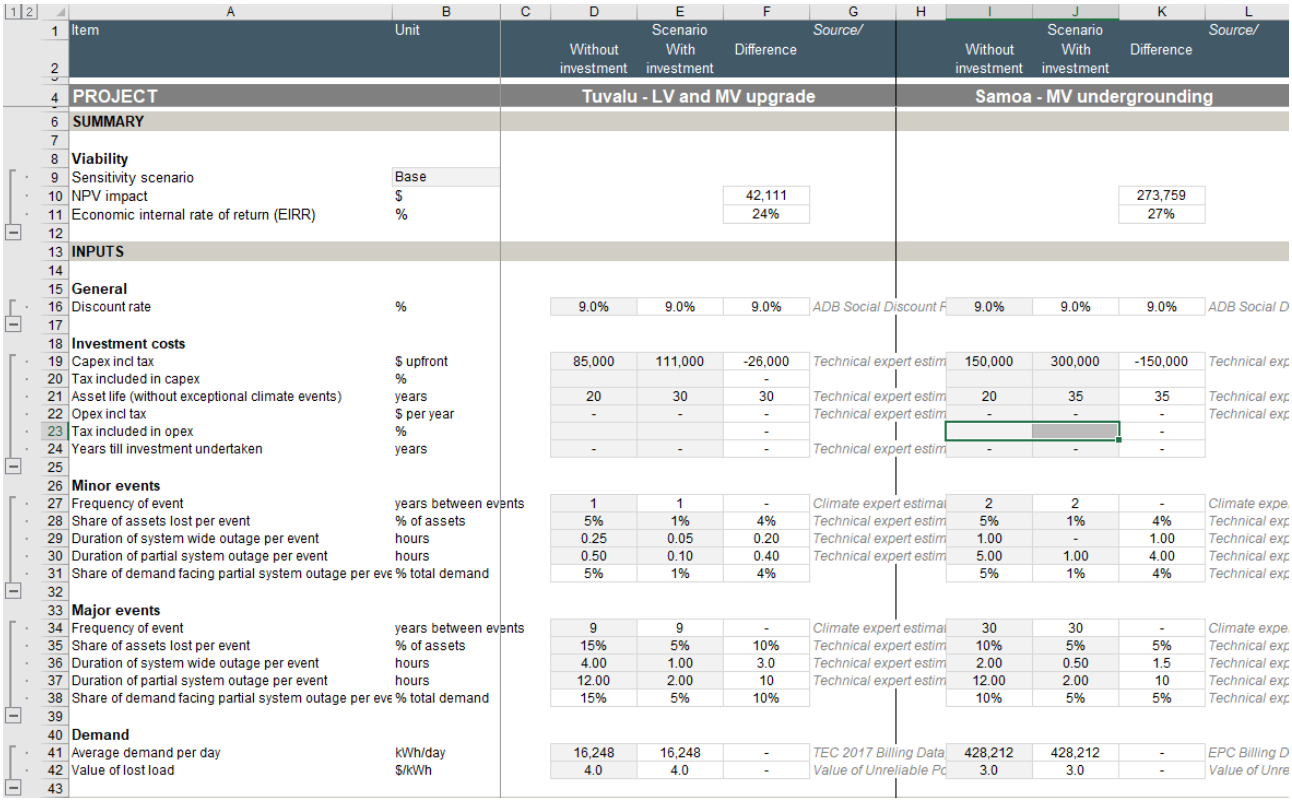
A series of screenshots are provided below that illustrate the functionality of the Tool, including inputs, calculations and results.

Figure 25 Viability Tool – Overall (grouped sections)



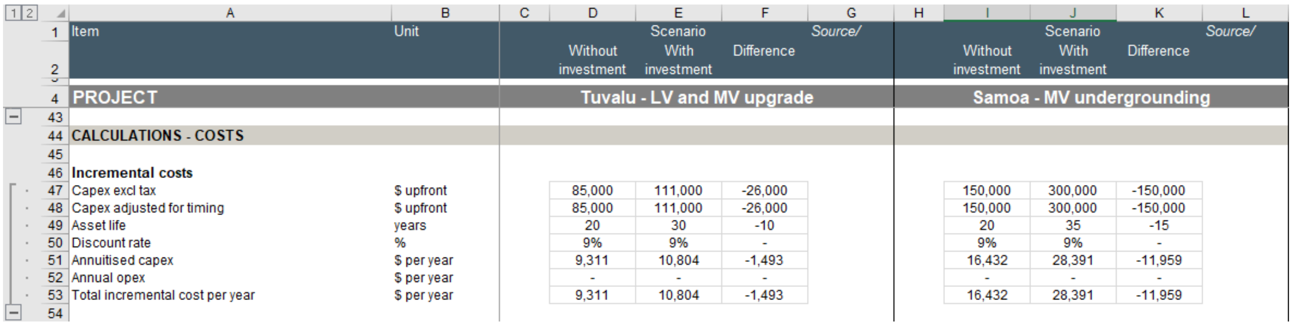
	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		*Source/*			Scenario		*Source/*
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	PROJECT				Tuvalu - LV and MV upgrade					Samoa - MV undergrounding		
6	SUMMARY											
7												
8	Viability											
12												
13	INPUTS											
14												
15	General											
17												
18	Investment costs											
25												
26	Minor events											
32												
33	Major events											
39												
40	Demand											
43												
44	CALCULATIONS - COSTS											
45												
46	Incremental costs											
54												
55	CALCULATIONS - BENEFITS (AVOIDED COSTS)											
56												
57	Avoided cost of replacement and repair - minor event											
63												
64	Avoided cost of replacement and repair - major event											
70												
71	Avoided outage cost - minor event											
81												
82	Avoided outage cost - major event											
92												
93	Total avoided costs											
99												
100	CALCULATIONS - NET IMPACT											
101												
102	Benefits less costs											
109												
110	CALCULATIONS - IRR											
111												

Figure 26 Viability Tool – Summary and Inputs



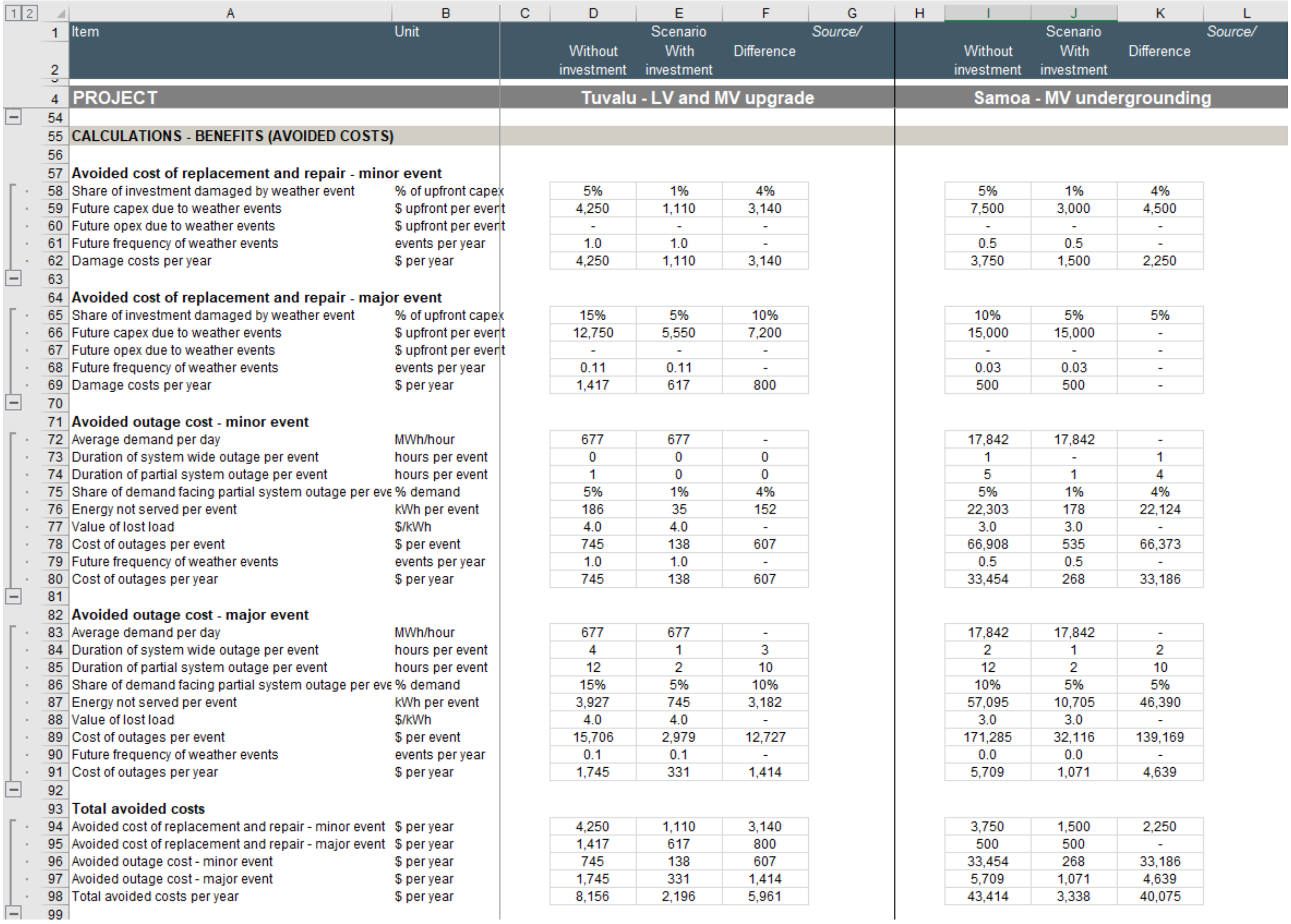
	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		*Source/*			Scenario		*Source/*
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	**PROJECT**				**Tuvalu - LV and MV upgrade**					**Samoa - MV undergrounding**		
6	**SUMMARY**											
7												
8	**Viability**											
9	Sensitivity scenario	Base										
10	NPV impact	$				42,111					273,759	
11	Economic internal rate of return (EIRR)	%				24%					27%	
12												
13	**INPUTS**											
14												
15	**General**											
16	Discount rate	%		9.0%	9.0%	9.0%	*ADB Social Discount F*		9.0%	9.0%	9.0%	*ADB Social D*
17												
18	**Investment costs**											
19	Capex incl tax	$ upfront		85,000	111,000	-26,000	*Technical expert estim*		150,000	300,000	-150,000	*Technical exp*
20	Tax included in capex	%				-						
21	Asset life (without exceptional climate events)	years		20	30	30	*Technical expert estim*		20	35	35	*Technical exp*
22	Opex incl tax	$ per year		-	-	-	*Technical expert estim*		-	-	-	*Technical exp*
23	Tax included in opex	%				-					-	
24	Years till investment undertaken	years		-	-	-	*Technical expert estim*		-	-	-	
25												
26	**Minor events**											
27	Frequency of event	years between events		1	1	-	*Climate expert estimat*		2	2	-	*Climate expe*
28	Share of assets lost per event	% of assets		5%	1%	4%	*Technical expert estim*		5%	1%	4%	*Technical exp*
29	Duration of system wide outage per event	hours		0.25	0.05	0.20	*Technical expert estim*		1.00	-	1.00	*Technical exp*
30	Duration of partial system outage per event	hours		0.50	0.10	0.40	*Technical expert estim*		5.00	1.00	4.00	*Technical exp*
31	Share of demand facing partial system outage per eve	% total demand		5%	1%	4%			5%	1%	4%	*Technical exp*
32												
33	**Major events**											
34	Frequency of event	years between events		9	9	-	*Climate expert estimat*		30	30	-	*Climate expe*
35	Share of assets lost per event	% of assets		15%	5%	10%	*Technical expert estim*		10%	5%	5%	*Technical exp*
36	Duration of system wide outage per event	hours		4.00	1.00	3.0	*Technical expert estim*		2.00	0.50	1.5	*Technical exp*
37	Duration of partial system outage per event	hours		12.00	2.00	10	*Technical expert estim*		12.00	2.00	10	*Technical exp*
38	Share of demand facing partial system outage per eve	% total demand		15%	5%	10%			10%	5%	5%	*Technical exp*
39												
40	**Demand**											
41	Average demand per day	kWh/day		16,248	16,248	-	*TEC 2017 Billing Data*		428,212	428,212	-	*EPC Billing D*
42	Value of lost load	$/kWh		4.0	4.0	-	*Value of Unreliable Po*		3.0	3.0	-	*Value of Unre*
43												

Figure 27 Viability Tool – Incremental cost calculations



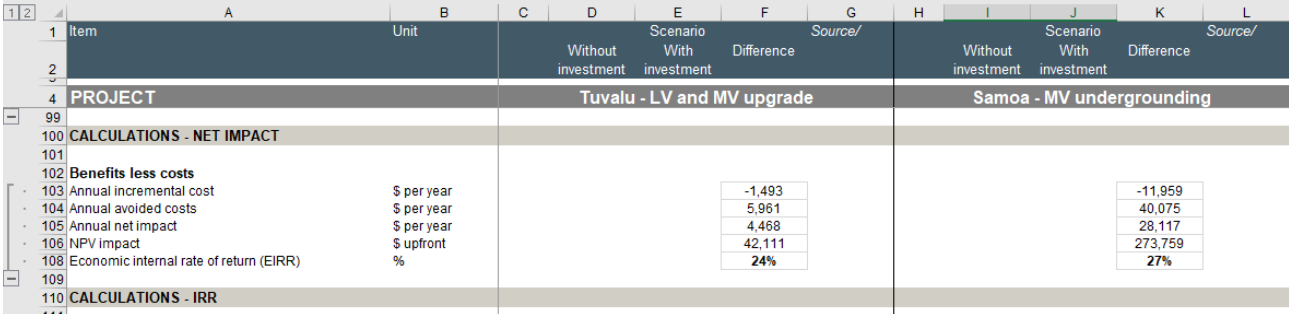
	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		*Source/*			Scenario		*Source/*
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	**PROJECT**				**Tuvalu - LV and MV upgrade**					**Samoa - MV undergrounding**		
43												
44	**CALCULATIONS - COSTS**											
45												
46	**Incremental costs**											
47	Capex excl tax	$ upfront		85,000	111,000	-26,000			150,000	300,000	-150,000	
48	Capex adjusted for timing	$ upfront		85,000	111,000	-26,000			150,000	300,000	-150,000	
49	Asset life	years		20	30	-10			20	35	-15	
50	Discount rate	%		9%	9%	-			9%	9%	-	
51	Annuitised capex	$ per year		9,311	10,804	-1,493			16,432	28,391	-11,959	
52	Annual opex	$ per year		-	-	-			-	-	-	
53	Total incremental cost per year	$ per year		9,311	10,804	-1,493			16,432	28,391	-11,959	
54												

Figure 28 Viability Tool – Incremental benefit calculations



	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		Source/			Scenario		Source/
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	PROJECT			Tuvalu - LV and MV upgrade					Samoa - MV undergrounding			
54												
55	CALCULATIONS - BENEFITS (AVOIDED COSTS)											
56												
57	**Avoided cost of replacement and repair - minor event**											
58	Share of investment damaged by weather event	% of upfront capex		5%	1%	4%			5%	1%	4%	
59	Future capex due to weather events	$ upfront per event		4,250	1,110	3,140			7,500	3,000	4,500	
60	Future opex due to weather events	$ upfront per event		-	-	-			-	-	-	
61	Future frequency of weather events	events per year		1.0	1.0	-			0.5	0.5	-	
62	Damage costs per year	$ per year		4,250	1,110	3,140			3,750	1,500	2,250	
63												
64	**Avoided cost of replacement and repair - major event**											
65	Share of investment damaged by weather event	% of upfront capex		15%	5%	10%			10%	5%	5%	
66	Future capex due to weather events	$ upfront per event		12,750	5,550	7,200			15,000	15,000	-	
67	Future opex due to weather events	$ upfront per event		-	-	-			-	-	-	
68	Future frequency of weather events	events per year		0.11	0.11	-			0.03	0.03	-	
69	Damage costs per year	$ per year		1,417	617	800			500	500	-	
70												
71	**Avoided outage cost - minor event**											
72	Average demand per day	MWh/hour		677	677	-			17,842	17,842	-	
73	Duration of system wide outage per event	hours per event		0	0	0			1	-	1	
74	Duration of partial system outage per event	hours per event		1	0	0			5	1	4	
75	Share of demand facing partial system outage per eve	% demand		5%	1%	4%			5%	1%	4%	
76	Energy not served per event	kWh per event		186	35	152			22,303	178	22,124	
77	Value of lost load	$/kWh		4.0	4.0	-			3.0	3.0	-	
78	Cost of outages per event	$ per event		745	138	607			66,908	535	66,373	
79	Future frequency of weather events	events per year		1.0	1.0	-			0.5	0.5	-	
80	Cost of outages per year	$ per year		745	138	607			33,454	268	33,186	
81												
82	**Avoided outage cost - major event**											
83	Average demand per day	MWh/hour		677	677	-			17,842	17,842	-	
84	Duration of system wide outage per event	hours per event		4	1	3			2	1	2	
85	Duration of partial system outage per event	hours per event		12	2	10			12	2	10	
86	Share of demand facing partial system outage per eve	% demand		15%	5%	10%			10%	5%	5%	
87	Energy not served per event	kWh per event		3,927	745	3,182			57,095	10,705	46,390	
88	Value of lost load	$/kWh		4.0	4.0	-			3.0	3.0	-	
89	Cost of outages per event	$ per event		15,706	2,979	12,727			171,285	32,116	139,169	
90	Future frequency of weather events	events per year		0.1	0.1	-			0.0	0.0	-	
91	Cost of outages per year	$ per year		1,745	331	1,414			5,709	1,071	4,639	
92												
93	**Total avoided costs**											
94	Avoided cost of replacement and repair - minor event	$ per year		4,250	1,110	3,140			3,750	1,500	2,250	
95	Avoided cost of replacement and repair - major event	$ per year		1,417	617	800			500	500	-	
96	Avoided outage cost - minor event	$ per year		745	138	607			33,454	268	33,186	
97	Avoided outage cost - major event	$ per year		1,745	331	1,414			5,709	1,071	4,639	
98	Total avoided costs per year	$ per year		8,156	2,196	5,961			43,414	3,338	40,075	
99												

Figure 29 Viability Tool – Net impact calculations



	A	B	C	D	E	F	G	H	I	J	K	L
1	Item	Unit			Scenario		Source/			Scenario		Source/
2				Without investment	With investment	Difference			Without investment	With investment	Difference	
4	PROJECT			Tuvalu - LV and MV upgrade					Samoa - MV undergrounding			
99												
100	CALCULATIONS - NET IMPACT											
101												
102	**Benefits less costs**											
103	Annual incremental cost	$ per year				-1,493					-11,959	
104	Annual avoided costs	$ per year				5,961					40,075	
105	Annual net impact	$ per year				4,468					28,117	
106	NPV impact	$ upfront				42,111					273,759	
108	Economic internal rate of return (EIRR)	%				**24%**					**27%**	
109												
110	CALCULATIONS - IRR											

4.3 Evaluation of Investment Plans

4.3.1 Samoa

Inputs

The inputs prepared by our team, relating to the identified climate resilient investments above, are summarised in Table 34 for the Base Case.

Table 34 Inputs to viability evaluation – Samoa (Base Case)

		Samoa - MV undergrounding		**Samoa - LV ABC Programme**		**Samoa - Lightning protection**		**Samoa - Back-Up Control System**	
		Without investment	***With investment***	***Without investment***	***With investment***	***Without investment***	***With investment***	***Without investment***	***With investment***
Investment costs									
Capex incl tax	$ upfront	150,000	300,000	1,500,000	3,000,000	10,000	150,000	-	250,000
Tax included in capex	%								
Asset life (without exceptional climate events)	years	20	35	20	35	30	30	30	30
Opex incl tax	$ per year	-	-	-	-	-	-	-	-
Tax included in opex	%								
Years till investment undertaken	years	-	-	5	-	-	-	-	-
Minor events									
Frequency of event	years between	2	2	2	2	1	1	2	2
Share of assets lost per event	% of assets	5%	1%	10%	-	-	-	2%	-
Duration of system wide outage per event	hours	1.00	-	1.00	1.00	-	-	1.00	-
Duration of partial system outage per event	hours	5.00	1.00	10.00	10.00	-	-	1.00	-
Share of demand facing partial system outage per event	% total demand	5%	1%	10%	-	-	-	2%	-
Major events									
Frequency of event	years between	30	30	20	20	2	2	30	30
Share of assets lost per event	% of assets	10%	5%	50%	5%	10%	5%	10%	5%
Duration of system wide outage per event	hours	2.0	0.5	5.0	0.5	2.0	1.0	1.0	0.5
Duration of partial system outage per event	hours	12.0	2.0	48.0	5.0	6.0	2.0	2.0	-
Share of demand facing partial system outage per event	% total demand	10%	5%	50%	5%	10%	5%	10%	5%
Demand									
Average demand per day	kWh/day	428,212	428,212	428,212	428,212	428,212	428,212	428,212	428,212
Value of lost load	$/kWh	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

The inputs shown above were prepared based on the professional judgement of our team. In the case of average demand per day, this is based on EPC billing data from 2019 and escalated by one year of growth[60]. The estimate of value of lost load (VOLL) of $3/kWh is based on the average parameters determined as part of a recent study commissioned by the Pacific Power Association.[61]

As a crosscheck of this estimate of VOLL, we prepared an approximate estimate of the cost of standby diesel generation in Samoa. The result, as shown in Table 35, is that if there are 30 outage hours per year (which is likely to be on the high side for Samoa), then the cost of standby generation is approximately $2.9/kWh. This confirms our expectation that a VOLL estimate of $3/kWh is conservative, given that the cost of standby generation would typically define the lower bound on VOLL estimates – the full economic impacts are likely to be significantly higher (not household and business can afford one, and there is still an interruption while the standby generator is started).

Table 35 Estimated cost of standby diesel generation in Samoa

Inputs	**Value**
Price of diesel per litre (USD/l)	2.3
Heat rate (l/kWh)	0.3
Investment cost ($/kW)	250
Life (years)	5
Discount rate	9%
Oil & filter cost ($/outage hr)	1
Outage hours per year	30
Calculated costs	
Investment cost per year ($/kW/yr)	64.3
Investment and oil costs per kWh ($/kWh)	2.2
Fuel cost of diesel generation (USD/kWh)	0.7
Total cost ($/kWh)	**2.9**

Results

The results of our analysis in our Base Case are summarised in Table 36. It shows that the investments' IRRs all pass the hurdle rate of 9% (the social discount rate) and are therefore viable. However, the programme to convert LV line to Aerial Bundled Cable (ABC) only just meets the hurdle rate and therefore may warrant further analysis – we discuss this further under our sensitivity tests below.

Table 36 Results of viability evaluation – Samoa (Base Case)

		MV undergrounding	**LV ABC Programme**	**Lightning protection**	**Back-Up Control System**
Benefits					
Avoided cost of replacement and repair - minor event	$ /y	2,250	48,745	-	-
Avoided cost of replacement and repair - major event	$ /y	-	16,872	-3,250	-417
Avoided outage cost - minor event	$ /y	33,186	26,763	-	27,299
Avoided outage cost - major event	$ /y	4,639	75,606	40,145	1,249
Annual avoided costs	$ /y	40,075	167,987	36,895	28,131
Costs					
Annual incremental cost	$ /y	-11,959	-177,111	-13,627	-24,334
Viability					
Annual net impact	$ /y	28,117	-9,124	23,268	3,797
NPV impact	$	273,759	-86,638	219,308	35,786
Economic internal rate of return (EIRR)	%	**27%**	**9%**	**26%**	**11%**

---

[60] Demand will grow over the life of the asset, but we have intentionally taken a conservative approach and just used current demand

[61] Value of Unreliable Power for Kiribati and Tuvalu, Interim Report, 2019. This study does not cover Samoa, so we took an average of the relationship between GDP and electricity consumption as estimated for Kiribati, Tuvalu, Solomon Islands, Papua New Guinea and Vanuatu. Using 2018 estimates of Samoa's GDP and consumption results in a VOLL of approximately $3/kWh. We expect that this is a conservative (low) estimate, given that the countries for which the study was conducted generally have less energy intensive economies than Samoa.

Sensitivity tests

We test the sensitivity of our analysis by changing the key inputs and assumptions. The key changes we make are as follows:

- **Pessimistic / High Case** – In this case climate change effects are assumed to be worse than in the Base Case and therefore the return on climate resilient investments is likely to be higher. The frequency of weather events is set based on historical records and climate change projections to 2050 under RCP 8.5 as given in the PACCSAP studies. Also, an adverse El Niño event is assumed and the upper bounds taken of the error functions on the projections. And the impacts of weather events (with regards to damage and outages) are assumed to be 50% higher. We also assume that investment costs are 20% lower and that the value of lost load is $6/kWh.
- **Optimistic / Low Case** – In this case climate change effects are assumed to be better than in the Base Case and therefore the return on climate resilient investments is likely to be lower. The frequency of weather events is set based on historical records and climate change projections to 2050 under RCP 8.5 as given in the PACCSAP studies but with a neutral or favourable La Niña event. And the impacts of weather events (with regards to damage and outages) are assumed to be 50% lower. We also assume that investment costs are 20% higher and that the value of lost load is only $2/kWh.

The results are provided in the tables below. They show that the IRR ranges between -6% and 4% in the low case, and between 75% and 1,492% in the high case, which far exceed the hurdle rate. Given that the ABC programme was borderline viable in the Base Case, it is reassuring that it is extremely viable in the Pessimistic / High Case (more so than it is unviable in the Optimistic / Low Case). On balance, we conclude that all four investments are all likely to be economically viable.

Table 37 Results of viability evaluation – Samoa (Optimistic / Low Case)

		MV undergrounding	LV ABC Programme	Lightning protection	Back-Up Control System
Benefits					
Avoided cost of replacement and repair - minor event	$ per year	900	11,699	-	-
Avoided cost of replacement and repair - major event	$ per year	-	2,700	-390	-188
Avoided outage cost - minor event	$ per year	4,014	5,353	-	3,604
Avoided outage cost - major event	$ per year	914	3,896	2,230	268
Annual avoided costs	$ per year	5,829	23,647	1,840	3,684
Costs					
Annual incremental cost	$ per year	-14,351	-212,533	-16,353	-29,201
Viability					
Annual net impact	$ per year	-8,522	-188,887	-14,512	-25,517
NPV impact	$	-81,187	-1,828,951	-136,783	-240,504
Economic internal rate of return (EIRR)	%	**4%**	**1%**	**-6%**	**-6%**

Table 38 Results of viability evaluation – Samoa (Pessimistic / High Case)

		MV undergrounding	LV ABC Programme	Lightning protection	Back-Up Control System
Benefits					
Avoided cost of replacement and repair - minor event	$ per year	7,200	155,984	-	-
Avoided cost of replacement and repair - major event	$ per year	-	53,992	-41,600	-1,000

		MV undergrounding	LV ABC Programme	Lightning protection	Back-Up Control System
Avoided outage cost - minor event	$ per year	316,877	428,212	-	222,670
Avoided outage cost - major event	$ per year	39,610	1,113,352	1,712,849	9,635
Annual avoided costs	$ per year	363,687	1,751,539	1,671,249	231,305
Costs					
Annual incremental cost	$ per year	-9,567	-141,689	-10,902	-19,467
Viability					
Annual net impact	$ per year	354,120	1,609,850	1,660,347	211,838
NPV impact	$	3,433,903	15,607,876	15,649,386	1,996,650
Economic internal rate of return (EIRR)	%	**303%**	**75%**	**1,492%**	**116%**

4.3.2 Tuvalu

Inputs

The inputs prepared by our team, relating to the climate resilient investments identified in Section 3.3.4 are summarised in Table 39 for the Base Case. Note that we group the four investments identified in Section 3.3.4.3 above (Spare 11 kV circuit breaker at Funafuti Power Station switchboard, Replacement of rusted LV pillars by stainless steel type, Replacement of rusting 11 kV RMUs and Replacement of rusting distribution transformers) into a single programme of investments, because they are unlikely to be implemented independently of one another (doing so would leave a weak point in the chain of infrastructure and many of the benefits would not be realised).

Table 39 Inputs to viability evaluation – Tuvalu (Base Case)

Tuvalu - LV and MV upgrade		***Without investment***	***With investment***
Investment costs			
Capex incl tax	$ upfront	85,000	176,000
Tax included in capex	%		
Asset life (without exceptional climate events)	years	20	30
Opex incl tax	$ per year	-	-
Tax included in opex	%		
Years till investment undertaken	years	-	-
Minor events			
Frequency of event	yrs between events	1	1
Share of assets lost per event	% of assets	5%	0%
Duration of system wide outage per event	hours	0.25	0.05
Duration of partial system outage per event	hours	0.50	0.10
Share of demand facing partial system outage per event	% total demand	5%	0%
Major events			
Frequency of event	yrs between events	9	9
Share of assets lost per event	% of assets	20%	5%
Duration of system wide outage per event	hours	6.0	1.0
Duration of partial system outage per event	hours	12.0	2.0
Share of demand facing partial system outage per event	% total demand	20%	5%
Demand			
Average demand per day	kWh/day	16,248	16,248
Value of lost load	$/kWh	4.0	4.0

The inputs shown above were prepared based on the professional judgement of our team. In the case of average demand per day, this is based on TEC billing data from 2017 and escalated by three year of growth[62]. The estimate of value of lost load is based on a recent study commissioned by the Pacific Power Association.[63]

Results

The results of our analysis in our Base Case are summarised in Table 40. It shows that the investment's IRR just passes the hurdle rate of 9% (the social discount rate) and is therefore indicatively viable, although we discuss sensitivity tests below.

Table 40 Results of viability evaluation – Tuvalu (Base Case)

		Tuvalu - LV and MV upgrade
Benefits		
Avoided cost of replacement and repair - minor event	$ per year	4,250
Avoided cost of replacement and repair - major event	$ per year	911
Avoided outage cost - minor event	$ per year	609
Avoided outage cost - major event	$ per year	2,196
Annual avoided costs	$ per year	7,967
Costs		
Annual incremental cost	$ per year	-7,820
Viability		
Annual net impact	$ per year	147
NPV impact	$	1,386
Economic internal rate of return (EIRR)	%	**9%**

Sensitivity tests

We test the sensitivity of our analysis by changing the key inputs and assumptions. The key changes we make are as follows:

- **Pessimistic / High Case –** In this case climate change effects are assumed to be worse than in the Base Case and therefore the return on climate resilient investments is likely to be higher. The frequency of weather events is set based on historical records and climate change projections to 2050 under RCP 8.5 as given in the PACCSAP studies. Also an adverse El Niño event is assumed and the upper bounds taken of the error functions on the projections. And the impacts of weather events (with regards to damage and outages) are assumed to be 50% higher. We also assume that investment costs are 20% lower and that the value of lost load is $6/kWh.
- **Optimistic / Low Case** – In this case climate change effects are assumed to be better than in the Base Case and therefore the return on climate resilient investments is likely to be lower. The frequency of weather events is set based on historical records and climate change projections to 2050 under RCP 8.5 as given in the PACCSAP studies but with a neutral or favourable La Niña event. And the impacts of weather events (with regards to damage and outages) are assumed to be 50% lower. We also assume that investment costs are 20% higher and that the value of lost load is only $2/kWh.

The results are provided in the tables below. They show that the IRR is -8% in the low case and 61% in the high case. On balance, these results confirm our conclusion that the package of investments is likely to be economically viable, given that:

- the range of results is skewed towards the positive side
- the low case represents a combination of unfavourable factors that are unlikely to eventuate
- we have been deliberately conservative with our assumptions in the base case, for example a using a low estimate of VOLL and current levels of demand.

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[62] Demand will grow over the life of the asset, but we have intentionally taken a conservative approach and just used current demand

[63] Value of Unreliable Power for Kiribati and Tuvalu, Interim Report, 2019. We adopt the value determined using the Econometric Approach, which is more conservative than the value added approaches which produce results ranging from 5 to 15 dollars per kWh.

Table 41 Results of viability evaluation – Tuvalu (Optimistic / Low Case)

		Tuvalu - LV and MV upgrade
Benefits		
Avoided cost of replacement and repair - minor event	$ per year	850
Avoided cost of replacement and repair - major event	$ per year	197
Avoided outage cost - minor event	$ per year	59
Avoided outage cost - major event	$ per year	167
Annual avoided costs	$ per year	1,273
Costs		
Annual incremental cost	$ per year	-9,384
Viability		
Annual net impact	$ per year	-8,111
NPV impact	$	-76,450
Economic internal rate of return (EIRR)	%	**-8%**

Table 42 Results of viability evaluation – Tuvalu (Pessimistic / High Case)

		Tuvalu - LV and MV upgrade
Benefits		
Avoided cost of replacement and repair - minor event	$ per year	13,600
Avoided cost of replacement and repair - major event	$ per year	2,187
Avoided outage cost - minor event	$ per year	6,770
Avoided outage cost - major event	$ per year	21,664
Annual avoided costs	$ per year	44,220
Costs		
Annual incremental cost	$ per year	-6,256
Viability		
Annual net impact	$ per year	37,964
NPV impact	$	357,828
Economic internal rate of return (EIRR)	%	**61%**

5.0 Climate Resilient Policies and Processes

5.1 Introduction

Power infrastructure throughout the entire value chain—from upstream generation to downstream distribution networks—is prone to climate and natural disaster risks, the occurrence of which has been increasing due to climate change. Such disasters can cause severe damages to physical assets, potentially leading to loss of service. The magnitude of the impact of such disasters is a function of several parameters, including the design and condition of assets and the interconnectedness of the different parts of the electricity system[64].

Investments that improve climate resilience are unlikely to occur in the Pacific if they are not supported and enabled by robust policies and processes. Policies and processes can also play a key role in ensuring that Pacific utilities do not prepare excessively and over-prescribe solutions to protect against risks that may never occur.

In the remainder of this section we describe five key principles that Pacific utilities should integrate into their planning processes. Ideally these principles are incorporated into a standalone climate resilient plan that each utility prepares and updates. If a standalone plan is deemed to onerous or costly for a utility, it can still address the below principles when preparing its power development plan. Utilities should also endeavour to integrate the principles into their asset management systems, so that climate resilience is regularly monitored and re-evaluated. The detailed implementation steps that each utility should take will vary based on the characteristics of their power system and their existing planning processes, but the principles will be common throughout.

The principles, described in more detail below, are:

1. Identify the risks of climatic and extreme weather events
2. Identify resilience measures that will reduce risk
3. Screen and select of resilience measures
4. Monitor and evaluate measures, to ensure better responsiveness to potential threats
5. Put financial protection in place.

5.2 Identify the risks of climatic and extreme weather events

As a first step when designing a resilience plan for the power sector, Pacific utilities need to identify and measure the risks associated with potential disasters and assess the degree of vulnerability of their power system to those risks. A careful analysis of risks can also help countries to prioritize the resilience measures and focus on the ones that target events with a higher likelihood. This is particularly important for countries with limited financial resources that can be channelled towards climate resilience objectives.

Section 4.3 above provides a detailed examples (for Tuvalu, Samoa, and Papua New Guinea) of how the likelihood of future events and the vulnerability of the power system can be assessed, as described in steps below.

Step 1: Assess the likelihood of future events, which allows for a better assessment of its risk

Analysis of the average probability of extreme events occurring within a given timeframe requires detailed historical climate data and information[65], which can sometimes be hard to obtain. Such information may include key climate variables (e.g. extreme rainfall events, or very high temperatures) and projections regarding climate change in the target region. Climate projections depend on several assumptions, such as carbon emissions, which in combination with their complexity, requires the consideration of a range of scenarios that cover several possible outcomes. Common practices for identifying the risk associated with a disaster include the collection and analysis of hydrological and meteorological data as well as medium range weather forecasting.

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[64] ESMAP 2016. Enhancing power sector resilience emerging practices to manage weather and geological risks.

[65] Metrics for measuring the probability of a disaster occurring within a given timeframe can be express in terms of an average return interval (ARI) or annual exceedance probability (AEP).

Step 2: Assess the vulnerability of power sector assets and operations

A critical input when assessing the exposure of a Pacific country's power system to a climate or natural risk is the inventory of assets and operations that may be affected by such risks.

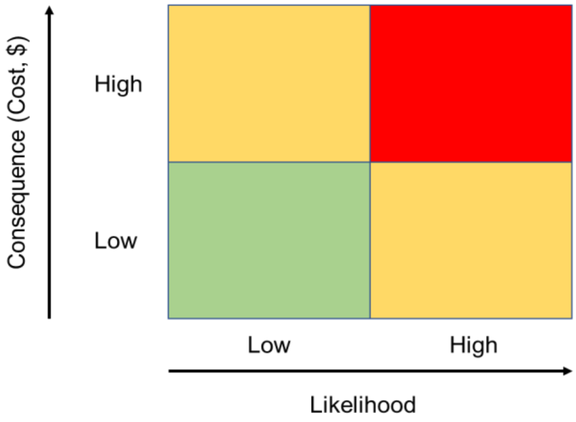
Information included in such an inventory should include the age and lifetime of the assets, their geographical location, their elevation, current and historical performance, cost of replacing the asset, as well the cost of maintaining the asset.

Following the completion of the inventory, utilities can determine the vulnerability of assets to potential threats and decide which resilience measure to adopt.

Step 3: Evaluate the potential consequences of future events

The prioritisation of risks does not only depend on their likelihood of occurrence, but also on the potential consequences that might result from the occurrence of a natural hazard. For instance, while distribution outages are more frequent than disruptions in the transmission network, the latter are generally more costly[66]. The owner of the assets that are affected negatively by the disaster will bear a direct cost, while consumers and other stakeholders will incur indirect costs. The estimation of such costs is useful when prioritizing resilience measures (section 5.3). The direct and indirect costs can be determined in terms of:

- The extent of service disruption
- The potential health and environmental impacts
- The impact on resource availability (e.g. water).



Assets or operations that may be affected by a disaster can be displayed in a two-dimensional matrix, reflecting the likelihood- consequence of the event on that particular asset.

The matrix (shown on the right) can be used by policy makers in Pacific countries to screen and decide which risks to prioritize. A disaster that has a higher likelihood of occurrence, but which will result in insignificant damages might be less of a priority in terms of resilience planning, than an event that has lower likelihood, but which might have catastrophic consequences.

5.3 Identify resilience measures that will reduce risk

Resilience measures either aim to reduce the likelihood of damage in the event of a climate or natural disaster or to minimise the consequences of the damage. These are briefly discussed below.

Step 1: Consider whether hardening of existing assets can make them more resilient

Hardening of assets refers to the adoption of initiatives aimed at making power sector assets less susceptible to potential threats, including retrofitting or reinforcing existing structures, relocating assets or developing barriers. Hardening assets in Pacific countries may include:

- **Elevation of assets and equipment**: This provides protection against flooding, inundation and rising sea levels. For example, this measure was adopted in the Ha'apai islands of Tonga following Cyclone Ian in 2014.
- **Undergrounding lines**: This reduces exposure to lightning, tree and storm damage
- **Reinforcing transmission and distribution lines**: Structural changes to lines, poles and wires (e.g. steel poles) provides better protection in case of system failure.

The screening of hardening measures will depend on their effectiveness in providing resilience against potential damages in relation to the cost of implementing them.

Step 2: Consider whether decentralised networks can be used to increase flexibility and minimise the extent of impact

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[66] US Department of Energy 2016. Climate change and the electricity sector: Guide for climate change resilience planning.

In centralised networks a relatively small damage can affect the entire network and cause significant damages. In regions where disasters occur frequently, such as the Pacific, decentralised networks can help avoid several of the transmission risk issues that centralised grids are facing. Although in many Pacific Island countries, which already have very small power systems, scope for further decentralisation will be limited. Nevertheless, potential solutions include:

- **Expansion of distributed generation**: Can provide backup power during major outages, while also limiting the number of customers affected
- **Microgrids**: These can connect and disconnect from the grid and can therefore operate independently during outages
- **Local backup power supplies**: Local generation, such as diesel gensets, which are common in developing countries where the grid might be unreliable, can provide electricity access during a power outage.

Step 3: Consider whether the way in which the power system is operated can be modified to make it more able to handle events

The following initiatives can improve the flexibility of the power system to cope with climatic and extreme weather events:

- **Good maintenance of assets and equipment**: Keeping equipment well maintained reduces their vulnerability to damages.
- **Fuel reserve capacity**: Several countries in the Pacific lack sufficient reserve capacity and as such are more prone to major power outages resulting from climate or natural damages. Generation planning involving fuel flexibility can provide some protection during such events.
- **Better management of variable renewable energy (VRE) technologies**: Variability risks can be better managed through improved meteorological and hydrological services that allow for real-time weather monitoring, installation of energy storage facilities, as well as diversification of supply resources.
- **Transmission and distribution network risk reduction:** Transmission and distribution lines are the assets most susceptible to damages caused by disasters. Measures to improve the resilience of these assets to flooding, fire, strong wind and other damages include the adoption of internationally acceptable standards for the design and development of new lines, poles, substations and other distribution equipment. Another important measure is vegetation management, which is particularly important for countries in the Pacific with above-ground lines that come into contact with vegetation, often causing line strikes.
- **Demand management:** Load management can help to reduce the risk of outages during or after a disaster. This can be in the form of direct load control, or indirect through the use of time-of use tariffs.
- **Supporting infrastructure**: Poorly maintained or insufficient supporting infrastructure can lead to major delays when dealing with a disaster. It is therefore important to maintain roads, water supplies, firefighting facilities and other emergency services in order to minimize the response time during major events.
- **Effective and fast communication**: Communication is key when a disaster strikes, as it allows the efficient and quick coordination between the various agencies involved. Information can be provided quickly via the internet and text messaging. Also, during the Christchurch (New Zealand) and Gorkha (Nepal) earthquakes, social media proved to be a useful channel for sharing information.

5.4 Screen and select of resilience measures

The benefits of resilience measures need to be compared with the costs of implementing them, as well as the costs of inaction to determine the right course of action. Resulting benefits and costs will vary by the type of asset they target, the timing of implementation, the expected impacts and the likelihood of a disaster taking place. The cost and benefit information can be used to rank resilience measures and create a portfolio of resilience measures that meet the goals of the utility/policy makers. A methodology for evaluating/screening investments is provided in Section 4.1 above. It is simple enough that it can be readily adopted by the Pacific utilities as part of their investment planning.

Other qualitative and quantitative metrics that should be considered alongside the quantitative methodology described above include:

- **Other difficult to quantify benefits to the economy**: Other positive impacts on the economy that go beyond the energy sector, such as reduction in unemployment, should be taken into consideration.
- **Robustness**: The degree of robustness of a resilience measure against a range of climate scenarios should be considered when estimating the cost of a potential measure.
- **Reversibility**: It is important that resilience measures can be reversed in response to changes in priorities or the regulatory environment.
- **Time for results to be realised**: It is important when screening potential resilience measure to take into consideration the amount of time necessary for a measure to be implemented and therefore for an asset to be protected from a potential disaster.
- **Resource availability**: Human and financial capital available to support the selected measures.

5.5 Monitor and evaluate measures, to ensure better responsiveness to potential threats

Expectations and assumptions that go into utilities' investment plans are likely to change soon after the plans are developed. This is not only because climatic conditions might change, causing a change the likelihood of disasters, but also because technologies, consumer preferences and other energy related policies may change during implementation[67].

Monitoring progress and evaluating outcomes should therefore be a key component of building climate resilience. For the plan to be robust it needs to incorporate the following elements:

- **Monitor progress**: To ensure not only that implementation milestones are met, but also that the cost of implementation does not exceed the estimated one.
- **Reassessment of resilience plan(s)**: To ensure that the plan continues to meet current priorities and that the ranking of resilience actions incorporates any potential technological, climatic, or other changes. The plan should be reassessed at regular intervals and should incorporate feedback from all units implementing the plan. The reassessment should be done periodically with the frequency defined by the availability of new relevant information and the resources available for such an update to take place.

5.6 Put financial protection in place

The financial sector can play a major role in energy sector resilience planning. It can help fund measures that protect the energy sector from major climate or natural disasters, while also providing ex-post support to help those affected negatively from a disaster.

Financial protection options, such as insurance policies, also help in mitigating the direct impacts of a disaster away from consumers. For instance, in the case of the Great East Japan earthquake, insurance that covered almost a quarter of the financial losses allowed for faster recovery than would otherwise be possible. Developing countries, on the other hand, usually rely on post-disaster financing, mostly coming from donor assistance, but that may not be sustainable[68].

Several Pacific utilities have reported that they are unable to insure their overhead lines against climatic and extreme weather events. Self-insurance programs can provide alternatives. Samoa currently has a self-insurance fund of around US$16.5 m in place. Another example that may be of relevance to other Pacific Island countries is that of Fiji, where the Fijian Consumer and Competition Commission (FCCC) recently approved, as part of a new Tariff Methodology, the implementation of a self-insurance fund. Each year, Energy Fiji Limited (EFL) is allowed to set aside funds which can only be drawn on in the case of an 'extra-ordinary event' and with approval from FCCC. EFL's tariff is set to pay for this fund, rather than requiring EFL to finance it out of their cash reserves. But in the case of an extra-ordinary event, any new expenditure from the fund will not enter EFL's asset base and therefore will not earn a return. The Fiji example is particularly valuable because the mechanism is clearly set out in the regulatory framework.

Outside of the power sector specifically, there is the Pacific Disaster Risk Financing and Insurance programme, which is a joint initiative of the World Bank, SPC, and the Asian Development Bank, with financial support from the Government of Japan, the Global Facility for Disaster Reduction and Recovery and the European Union. It was launched in 2007 and provides Pacific nations with advisory services

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[67] US Department of Energy 2016. Climate change and the electricity sector: Guide for climate change resilience planning

[68] Ibid

relating to disaster risk management and a risk pooling mechanism that allows countries to access insurance at competitive prices.

Appendix 1 Photographs

Samoa - Upolu

Photo 2: Fiaga Power Station

←Note drain from oil retention bund

Photo 3: Fiaga Power Station Generator

Photo 4: Fiaga Control Room

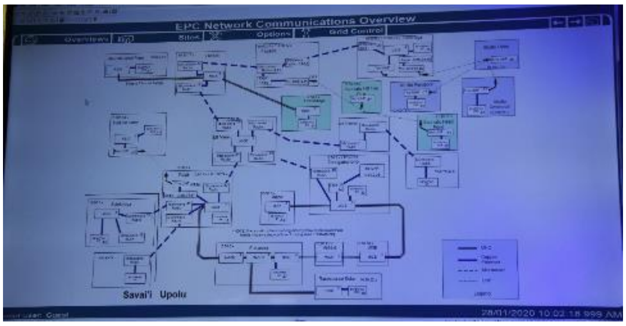

Photo 5: Fiaga Power Station BESS

Photo 6: Fiaga Power Station Comms Tower

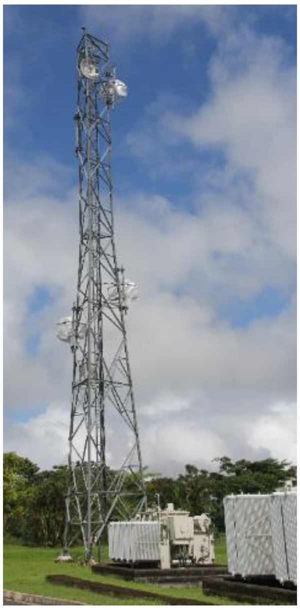

Photo 7: Damage from Lightning Strike on Comms Tower

Photo 8: Alaoa 1.25 MVA Hydro Plant

Photo 9: Samsoni 2.0 MVA Hydro Plant

Photo 10: Tsunami Siren and Retreat area Halfway up Cliff

Photo 11: Typical Overhead Distribution

Samoa - Savai'i

Photo 12: Salelologa Generating Station & EPC Offices

Photo 13: Salelologa 22 kV Panel and Control Console

Valloa.Generator Protection
Status | Metering | Reports

Metering
A Phase Current 291.3 A
B Phase Current 303.0 A
C Phase Current 302.9 A
A Phase Voltage 249.0 V
B Phase Voltage 249.0 V
C Phase Voltage 248.0 V
Frequency 50.00 Hz
Power Factor 0.88
Real Power 201 kW
Reactive Power 101 kVAr
Real Energy 309.42 MWh pu

Photo 14: Salelologa Solar Farm

Photo 15: Salelologa Diesel Generators

Photo 16: Salelologa Fuel Storage

Photo 17: Spare Transformers

Photo 18: Faleata 200 kW Hydro

Photo 19: Typical Overhead Distribution

Tuvalu

Photo 20: Funafuti Power Station - Alternators Protected from Rain

Photo 21: Funafuti Power Station - Rusted Cooling Tower

Photo 22: Funafuti Power Station - Fuel Storage Tanks

Photo 23: Funafuti Power Station - Control Panel and Control Desk

Photo 24: Rusted 11 kV RMU

Photo 25: LV Distribution Pillars

Photo 26: Buckets Protecting Live Cables

Photo 27: Area where waves had washed across Funafate and Storm Damage

Photo 28: Typical Road - Underground Distribution & LED Street Lights

Photo 29: Customer Meter

Photo 30: 11 kV RMU with SF_6 Gauge on Zero

Photo 31: TEC Stores

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Appendix 2 Lightning

Lightning is a sudden high-voltage discharge of electricity that occurs within a cloud, between clouds, or between a cloud and the ground. Globally, there are about 40 to 50 flashes of lightning every second, or nearly 1.4 billion flashes per year.

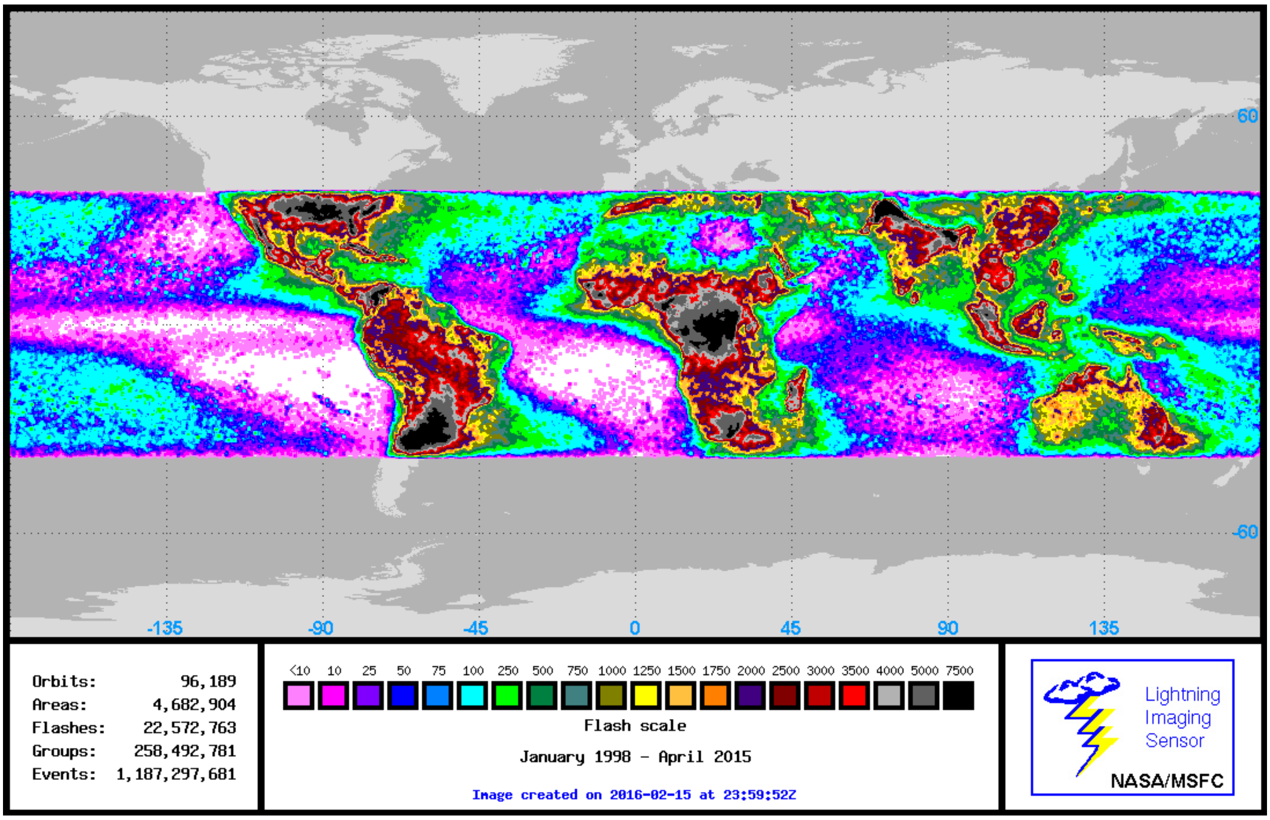
Each year, lightning strikes kill people, livestock and is responsible for billions of dollars in damage to buildings, communication systems, power lines, and electrical equipment.

The distribution of lightning on Earth is far from uniform. The ideal conditions for producing lightning and associated thunderstorms occur where warm, moist air rises and mixes with cold air above. These conditions occur almost daily in some parts of the Earth, particularly in the tropics, but only rarely in other places.

Much more lightning occurs over land than over the ocean because daily sunshine heats the land surface faster than the ocean. The heated land surface warms the air above it, and that warm air rises to encounter cold air aloft. The interaction between air masses of different temperature stimulates thunderstorms and lightning.

More lightning occurs near the equator than at the poles. NASA satellites show the world's principal lightning hotspot is Lake Maracaibo, north-western Venezuela in South America. It has an annual lightning flash rate density of 232.52 flashes of lightning per square kilometre. Figure 30 from NASA shows lightning strikes worldwide. Of more relevance, Figure 31 shows the annual average lightning strikes per square kilometre for the Pacific.

Figure 30 Lightning Flashes Worldwide 1998-2015



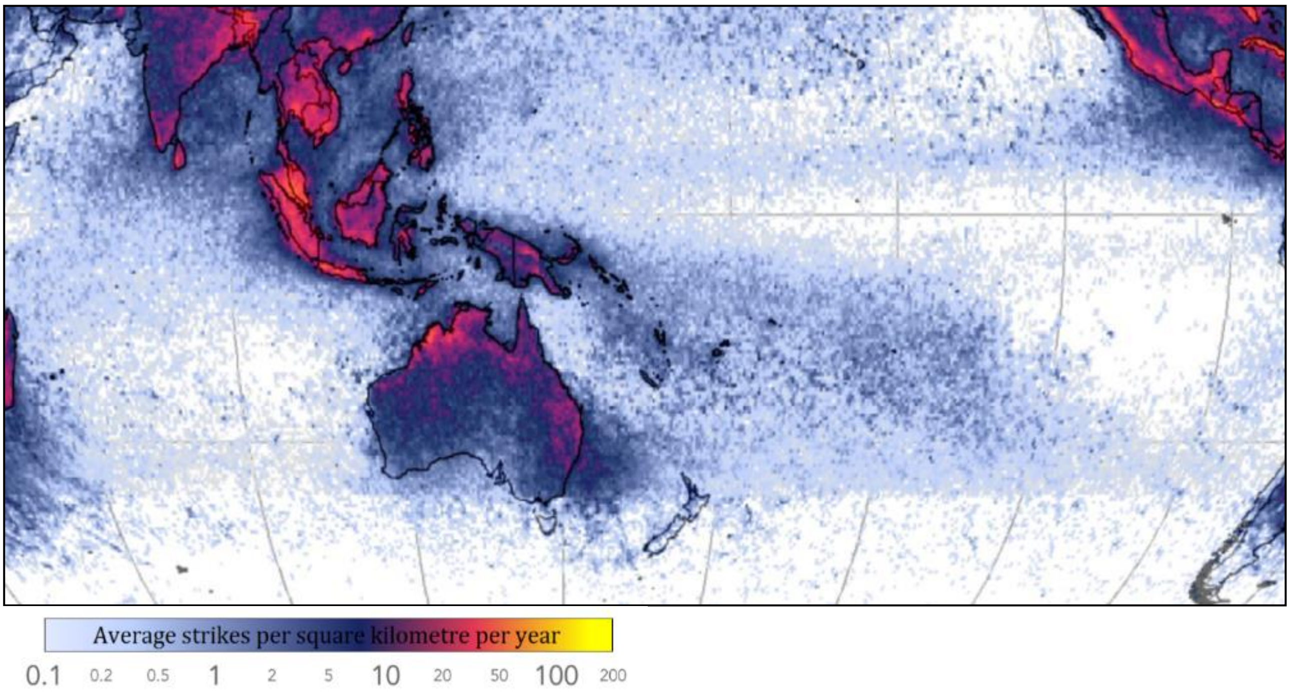
Source NASA

For the three target power utilities, the figures indicate that Tuvalu has a lightning strike rate of around 2 strikes /km^2/yr; Samoa is around 5 strikes /km^2/yr and PNG is much higher with 20-50 strikes /km^2/yr in the Highlands.

Based on land area, this indicates that Tuvalu can expect over 100 lightning strikes per year and Samoa over a thousand strikes per year across the whole country. In PNG during the rainy season lightning strikes are a daily occurrence, often several times a day.

These are average figures. Lightning occurs during thunderstorms which are restricted to the rainy season and are of only a few hours duration, sometimes even minutes.

Figure 31 Lightning Flashes in Pacific



Source NASA

The following international standards published by the International Electrotechnical Commission (IEC) are applicable to the protection of assets in power utilities:

- IEC 61643: Low-voltage surge protective devices- (includes various parts
- IEC 62305: Protection against lightning - includes various parts
- IEC 62561: Lightning protection system components (LPSC) - includes various parts
- IEC 62713: Safety procedures for reduction of risk outside a structure
- IEC 62793: Protection against lightning - Thunderstorm warning systems
- IEC 62858: Lightning density based on lightning location systems - General principles.

Appendix 3 PNG Supporting Information

Table 43 PPL Generation Details

Type	Name Plate Ratings MW	Available Ratings MW
Gazelle		
PPL Hydro	10	**0**
PPL Thermal	17	11
Subtotal	**27**	**11**
Port Moresby		
PPL Hydro	66	58
PPL Thermal	138	89
IPP LNG Gas	96	89
Subtotal	**300**	**236**
Ramu		
PPL Hydro	108	52
PPL Thermal	84	33
IPP Hydro	10	12
IPP Thermal	34	32
Subtotal	**300**	**236**
Isolated Systems		
PPL Hydro	2	2
PPL Thermal	65	38
IPP Biogass	1	1
Subtotal	**68**	**41**
Total	**631**	**416**

Source: PPL

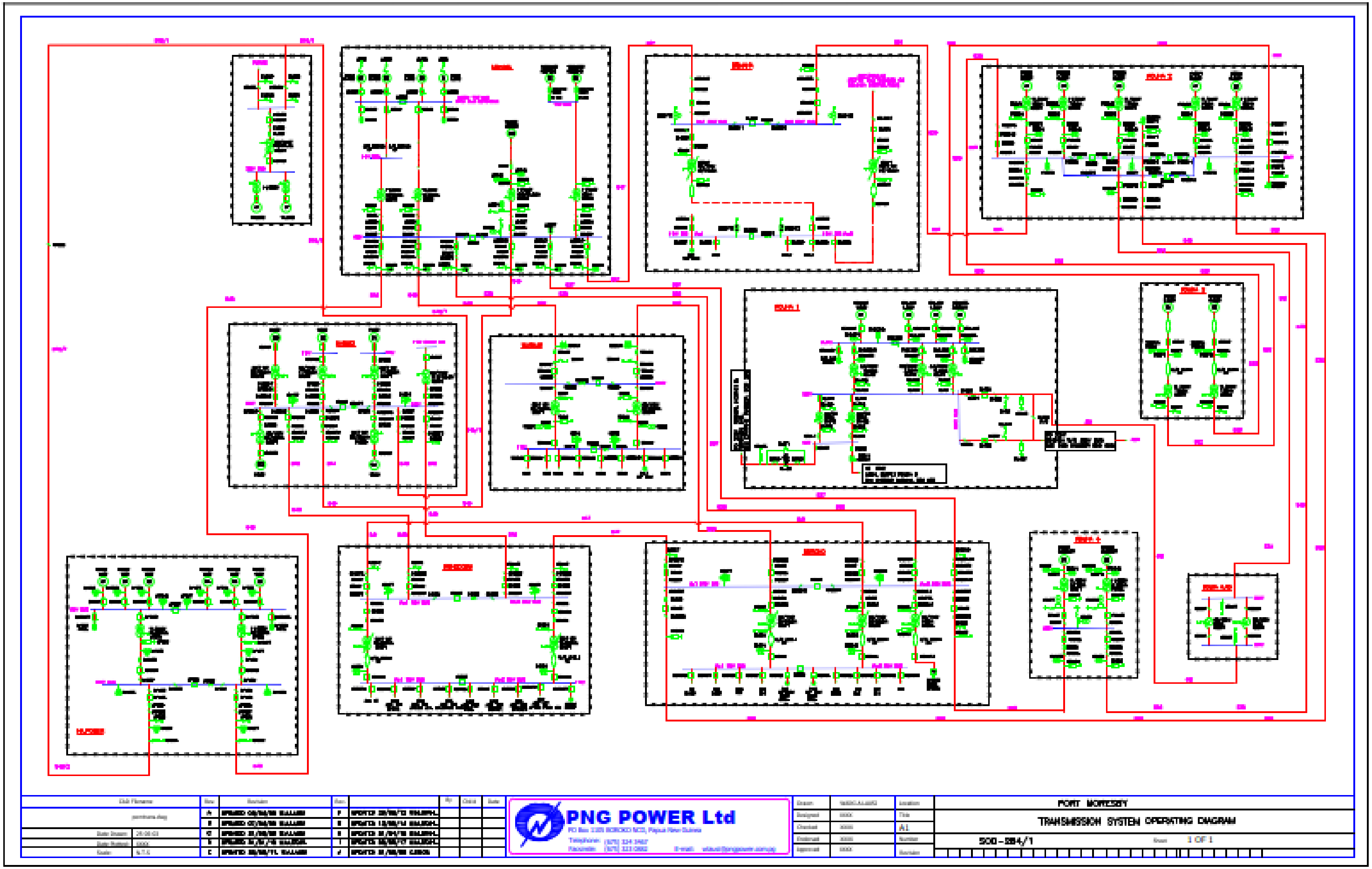
Table 44 PPL Production Summary

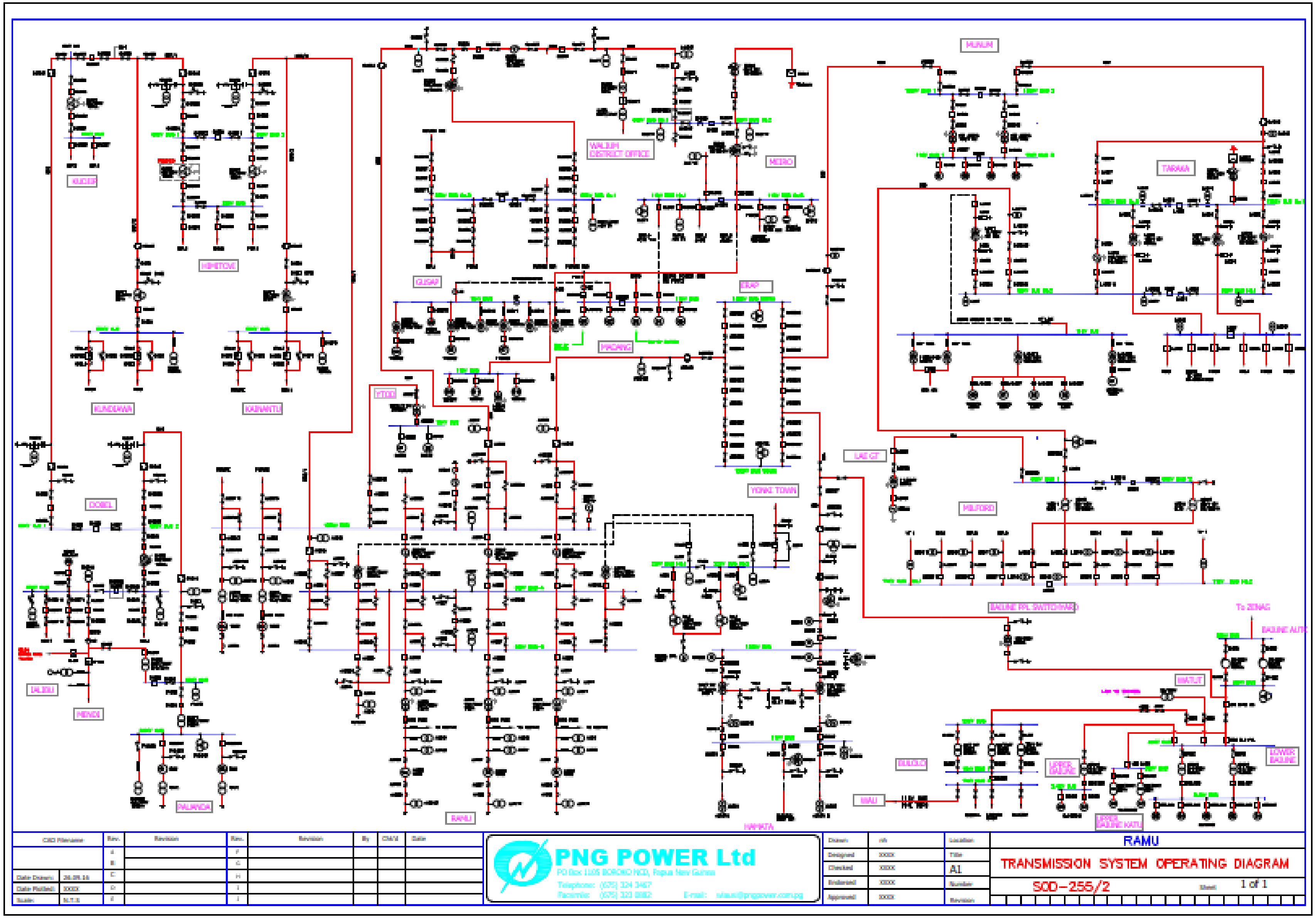
Type	2017	2018	2019
PPL Hydro	504,820	536,615	588,187
PPL Thermal	308,530	267,110	301,678
Hydro + Thermal Gen.	813,351	803,724	889,865
Purchases	494,475	575,269	544,199
System Total	1,307,826	1,378,993	1,434,064
Rouna.1	4,388	5,565	9,866
Rouna.2	115,915	130,801	146,027
Rouna.3	64,209	64,497	41,811
Rouna.4	56,831	62,582	73,380
Sirinumu	73	113	284
Total POM Hydro	241,416	263,558	271,368
Moitaka Gt.2	17,314	25,494	5,725
Moitaka Diesel.1	6,604	0	0
Moitaka Diesel.2	0	0	0
Moitaka Diesel.3	1,244	592	0
Moitaka Diesel.4	800	0	0
Aggreko Lease Unit	43,774	40,207	48,439
Moitaka Total	69,737	66,293	54,164
Kanudi Gt.1	17,300	9,624	10,729
Kanudi Gt.2	4,178	17,215	27,240
Kanudi Gt.3	18,745	8,082	20,077
Hanjung Kanudi Diesel 1 (IPP)	60,671	58,873	62,535
Hanjung Kanudi Diesel 2 (IPP)	62,916	60,158	45,262
Exxon Mobil Png (IPP)	211,407	209,555	185,476
Niupower IPP	0	0	26,840
POM Purchase Total	334,995	328,586	320,113
Total Pom Thermal	444,954	429,801	405,483
Port Moresby System	686,370	693,359	676,852
Ramu Hydro	184,326	199,102	258,614
Yonki Tod	1,333	0	0
Pauanda Hydro	33,371	33,722	46,890

Type	**2017**	**2018**	**2019**
Total Ramu Hydro	219,030	232,823	305,504
Lae Diesels	2,966	4,231	4,737
Taraka Diesels	4,152	7,266	8,243
Taraka Lease	30,683	0	0
Lae Port Ge	28,255	2,753	2,193
Madang Diesel	2,036	5,155	9,889
Mendi - Diesel	975	920	1,533
Wabag - Diesel	871	2,261	2,928
Dobel Lease	5,088	8,739	0
Goroka - Diesel	98	366	135
Kundiawa - Diesel	0	329	32
Total Ramu Thermal	75,123	32,020	29,690
Baiune Wau	1,288	1,529	1,310
Baiune Lae Line	0	0	0
Baiune Zenag Line	84,447	82,796	87,430
Munum (IPP)	66810.1	157,366	130,616
Pogera			0
Total Ramu Purchased	152,545	241,690	219,356
Ramu System	446,698	506,534	554,550
Rabaul			0
Ulagunan	11,300	5,910	10,449
Ulagunan Lease	358	10,345	26,743
Takubar			0
Kerevat Diesel	910	1,941	7,719
Kerevat Lease			0
Toboi			0
Warangoi Diesel			0
Warangoi Hydro	41,885	37,135	7,768
Gazelle System	54,453	55,331	52,678
Lake Hargy Hydro	2,490	3,099	3,211
Bialla Diesel	934	464	207
Bialla System	3,424	3,563	3,417
Ru - Creek Hydro	0	0	336
Kimbe Diesel	11,389	16,200	16,121
Mosa	6,152	4,992	4,731
Kumbago	783	0	0
Total Kimbe Purchase	6,935	4,992	4,731
Kimbe System	18,324	21,192	21,188
Aitape	1,448	1,148	938
Alotau	13,883	12,816	12,686
Arawa	4,237	4,044	4,243
Bainyik/Maprik	2,017	2,368	3,065
Buka	9,348	10,183	10,490
Daru	4,625	4,915	3,973
Finschhafen	827	710	789
Kavieng	10,957	11,097	11,013
Kerema	2,509	2,329	1,780
Lombrum/Lorengau	8,581	8,754	9,170
Popondetta	7,343	8,095	8,749
Samarai	229	220	220
Tari	2,681	2,085	2,828
Vanimo	7,600	7,682	7,435
Wewak	22,706	22,568	21,159
Total Other Diesels	98,991	99,015	98,539

Source: PPL

Figure 32: PPL System Diagram




WALIUM DISTRICT OFFICE
MUNUM
TARAKA
KUNDIAWA
KAINANTU
GUSAP
MADANG
ERAP
YONKI TOWN
LAE GT
MILFORD
DOBEL
IALIBU
MENDI
RAMU
HAMATA
BULOLO
WAU
WATUT
UPPER BAIUNE
LOWER BAIUNE
UPPER BAIUNE KATU
BAIUNE PPL SWITCHYARD
To ZENAG
PNG POWER Ltd
PO Box 1105 BOROKO NCD, Papua New Guinea
Telephone: (675) 324 3467
Facsimile: (675) 323 0082
E-mail:
RAMU
TRANSMISSION SYSTEM OPERATING DIAGRAM
A1
SOD-255/2
1 of 1

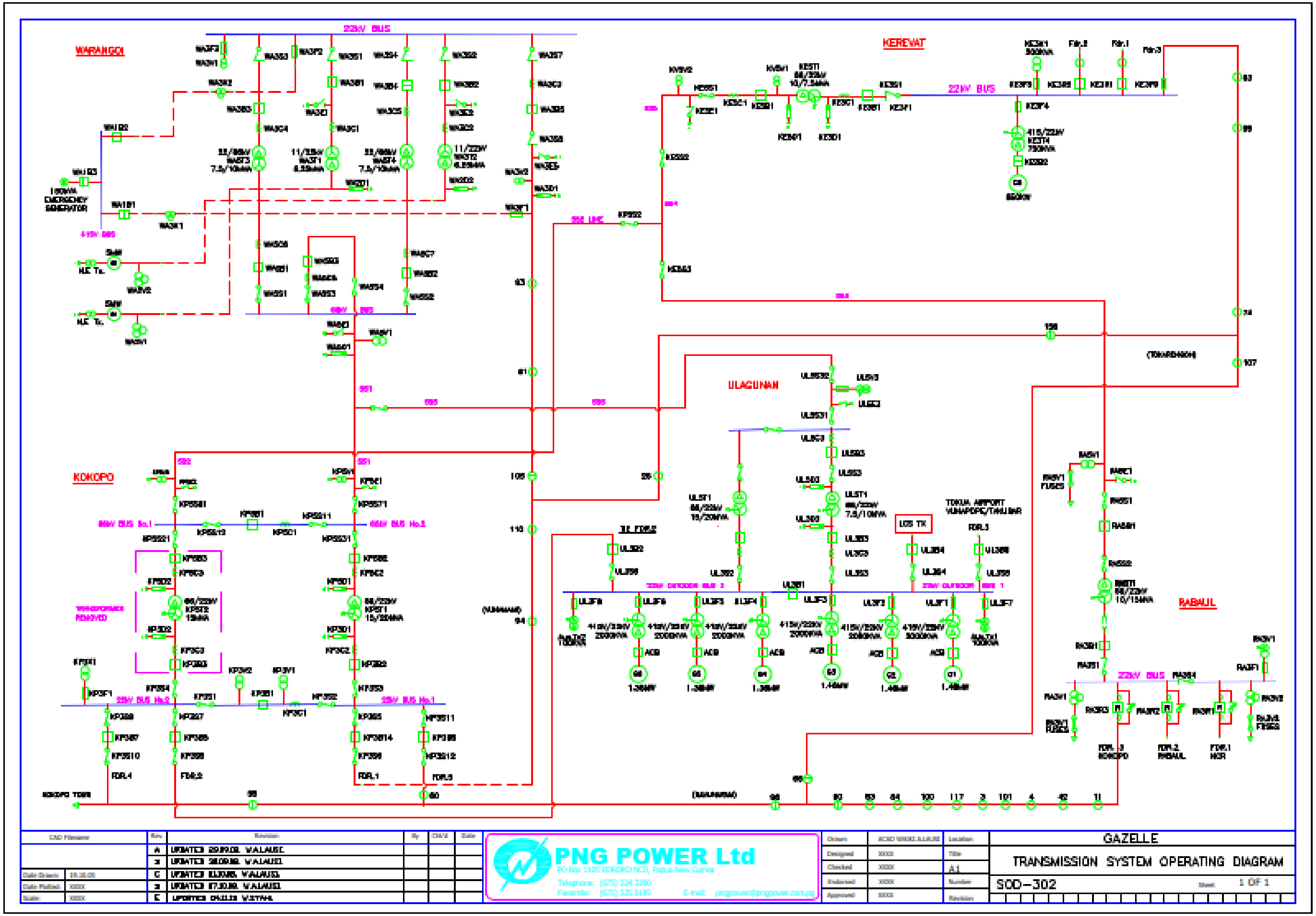

22kV BUS
WARANGOI
KEREVAT
22kV BUS
ULAGUNAN
KOKOPO
RABAUL
22kV BUS
PNG POWER Ltd
GAZELLE
TRANSMISSION SYSTEM OPERATING DIAGRAM
A1
SOD-302
1 OF 1

Table 45 PPL Customers and Usage 2019

	Domestic			General Supply		Ramu Sugar - Special Tariff		Mining - special tarrif		Industrial Tariff		Public Lighting		Easypay				Total	
Centres	**Customers**	**kWh (0.4987)**	**kWh (0.8475)**	**Customers**	**kWh (0.9871)**	**Customers**	**kWh (0.53)**	**Customers**	**kWh (0.4880)**	**Customers**	**kWh (0.6331)**	**Customers**	**kWh**	**Domestic Customers**	**kWh (0.6968)**	**General Supply Customers**	**kWh (0.9627)**	**Customers**	**kWh**
Aitape	199	78,672	328,149	89	645,467		0.00		0.00		0	0	0		0.00	0	0	288	1,052,288
Alotau	31	15,893	188,932	142	6,104,559		0.00		0.00		0	0	0	1366	2,764,740.00	369	2,206,367	1,908	11,280,491
Arawa	1	365	3,696	11	464,965		0.00		0.00		0			422	672,881.00	105	621,803	539	1,763,710
Bialla	18	8,198	44,702	48	1,881,708		0.00		0.00		0	0	0	549	595,765.00	102	203,956	717	2,734,329
Buka	-	0	0	30	1,901,060		0.00		0.00		0			3,742	5,470,254.00	674	3,188,648	4,446	10,559,962
Central	1	711	11,218	40	2,976,940		0.00		0.00		0		0	3,427	2,484,997.00	64	267,449	3,532	5,741,315
Daru	39	12,278	65,999	56	1,742,846		0.00		0.00		0	0	0	792	985,480.00	114	304,188	1,001	3,110,791
Finschaffen	7	3,268	11,296	31	420,610		0.00		0.00		0	0	0	318	219,947.00	22	40,333	378	695,454
Goroka	94	31,573	441,287	236	11,850,783		0.00		0.00		0	0	0	6,627	6,689,243.00	975	2,632,818	7,932	21,645,704
Gusap(K92 Mining Ltd	8	548	17,523	18	1,099,699	7	5,964,016.00	1	0.00	1	12,686,622	0	0	54	75,898.00	14	25,113	103	19,869,419
Ialibu	340	160,272	342,047	141	643,664		0.00		0.00		0			0	0.00	0	0	481	1,145,983
Kainantu	73	25,141	121,441	127	2,559,237		0.00		0.00		0	0	0	2,446	765,479.00	358	87,775	3,004	3,559,073
Kavieng	114	54,198	335,180	254	6,392,025		0.00		0.00		0	0	0	1,117	1,918,666.00	101	307,907	1,586	9,007,976
Kerema	17	6,903	59,505	37	1,156,181		0.00		0.00		0	0	0	553	917,830.00	35	79,856	642	2,220,275
Kimbe	162	138,473	783,449	337	9,430,977		0.00		0.00		0	**0**	0	2,489	3,117,755.00	227	1,476,266	3,215	14,946,920
Kokopo	19	13,737	456,822	554	23,884,001		0.00		0.00	1	0	0	0	10,799	10,043,816.00	2,391	4,981,559	13,764	39,379,935
Kundiawa	1,354	319,567	647,534	567	3,702,505		0.00		0.00		0	0	0	0	0.00	0	0	1,921	4,669,606
Lae	123	43,985	637,662	786	90,786,002		0.00		0.00	22	56,447,080	0	0	14,653	23,531,228.00	2,241	9,881,722	17,825	181,327,679
Lorengau	59	40,662	253,075	114	5,770,778		0.00		0.00		0	0	0	1,253	1,928,710.00	225	843,996	1,651	8,837,221
Madang	44	37,284	647,950	367	21,330,038		0.00		0.00	6	13,643,600	0	0	5,715	6,900,169.00	376	1,053,319	6,508	43,612,360
Maprik	312	119,094	447,410	162	2,226,115		0.00		0.00		0	0	0	4	3,396.00	0	0	478	2,796,015
Mendi	873	263,672	756,265	243	1,738,196		0.00		0.00		0	0	0	2	406.00	0	0	1,118	2,758,539
Minj	612	283,356	411,453	228	2,774,445		0.00		0.00	1	322,080			0	0.00	0	0	841	3,791,334
Mumeng (Zenag)	.	0	0	4	35,146		0.00		0.00	1	6,012,000			619	182,503.00	25	22,206	598	6,251,855
Mt.Hagen	87	47,584	541,018	309	13,396,444		0.00		0.00	1	1,477,520	0	0	8,310	3,381,331.00	1,305	2,124,711	10,012	20,968,608
Popondetta	15	9,132	77,794	138	5,110,034		0.00		0.00		0	0	0	2,626	1,797,108.00	88	254,296	2,867	7,248,364
Port Moresby	382	157,362	3,523,043	1909	274,355,599		0.00		0.00	46	105,074,520	0	0	51,439	96,315,527.00	5,277	26,482,708	59,053	505,908,759
Samarai	54	16,938	28,087	24	63,468		0.00		0.00		0	0	0	1	682.00	0	0	79	109,175
Tari	34	11,991	87,701	32	947,643		0.00		0.00		0			828	711,293.00	191	252,447	1,085	2,011,075
Vanimo	567	233,922	1,278,381	220	4,330,237		0.00		0.00		0	0	0	0	0.00	0	0	787	5,842,540
Wag/Wapen	463	289,263	865,682	182	1,962,934		0.00		0.00		0	0	0	4	3,107.00	0	0	649	3,120,986
Wau	44	15,888	43,016	34	642,723		0.00	1	119,344,000.00		0	0	0	900	553,470.00	186	92,124	1,165	120,691,221
Wewak	22	9,254	221,815	290	11,622,710		0.00		0.00	1	1,004,000	0	0	3,198	4,037,733.00	455	993,595	3,966	17,889,107
Yonki	27	9,970	102,256	40	1,159,507		0.00		0.00		0	0	0	651	277,227.00	48	11,680	766	1,560,640
TOTAL	**6,195**	**2,459,154**	**13,781,390**	**7,800**	**515,109,246**	**7**	**5,964,016**	**2**	**119,344,000**	**80**	**196,667,422**	**0**	**0**	**124,904**	**176,346,641**	**15,968**	**58,436,842**	**154,905**	**1,088,108,711**

Source PPL

Appendix 4 Samoa Supporting Information

Figure 33: EPC Upolu System Diagram

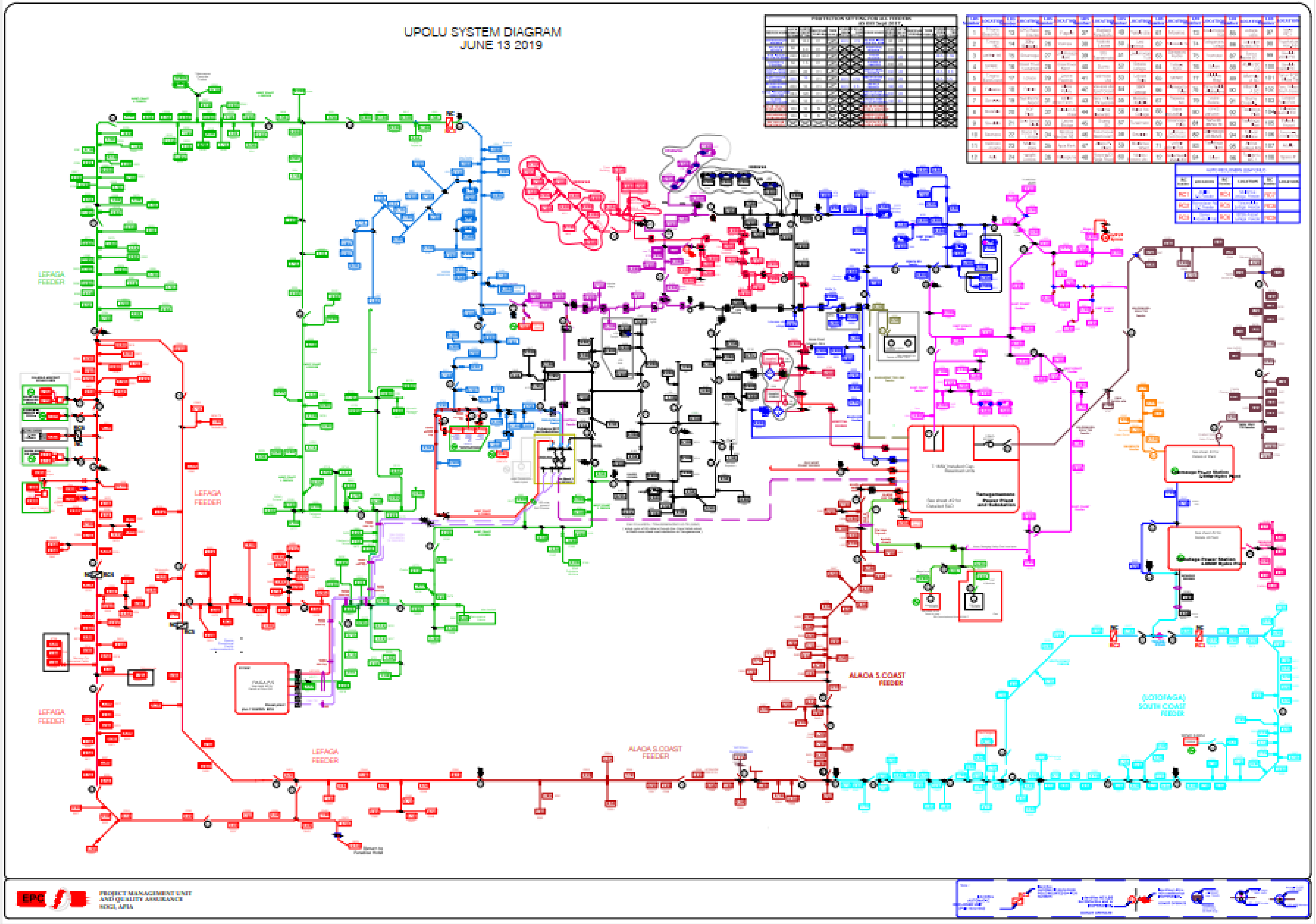


Figure 34: EPC Savai'i System Diagram

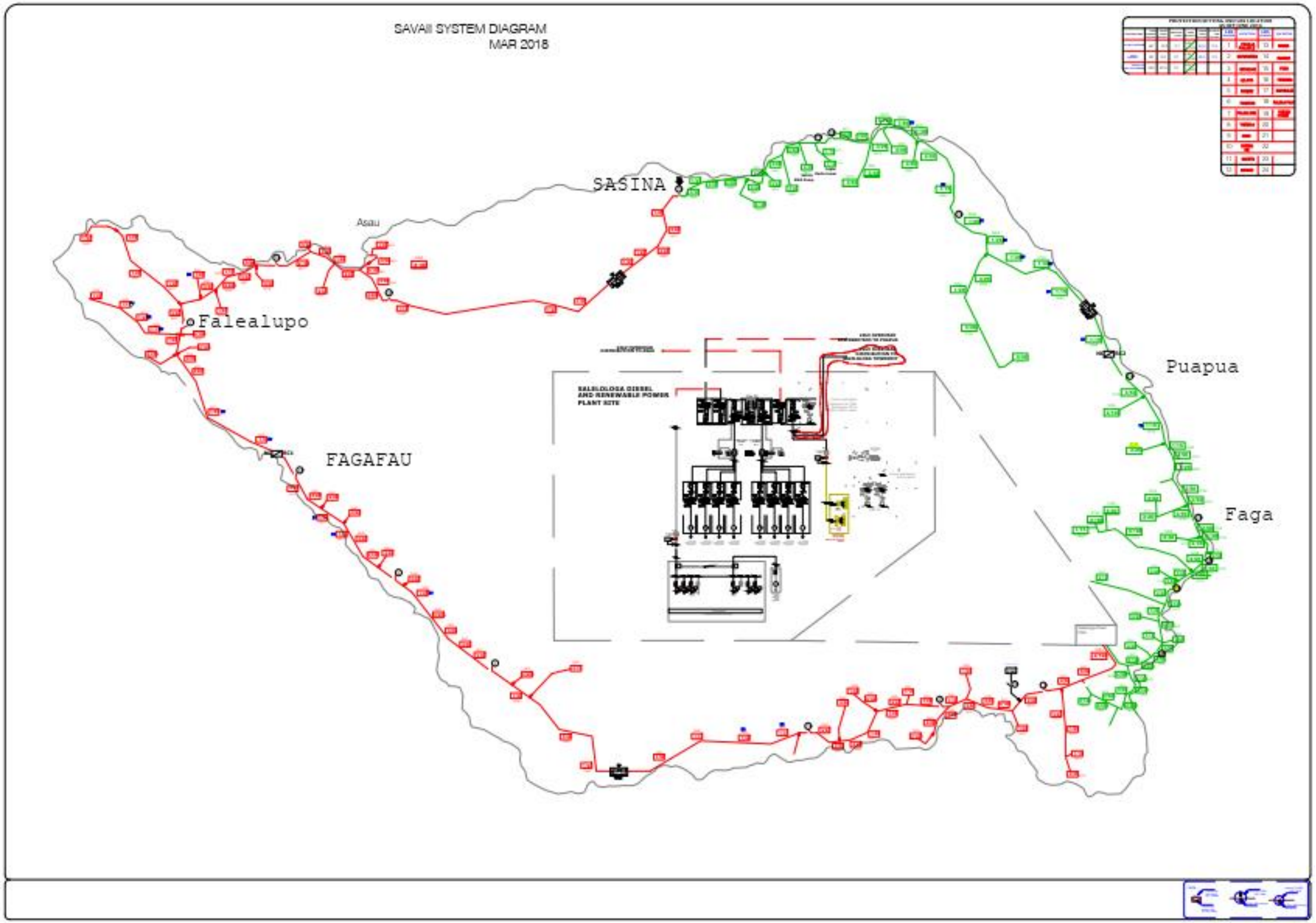


Table 46: EPC Distribution Transformers

Transformer Capacity kVA	Quantity	Total Capacity kVA
5	1	5
10	1	10
15	98	1,470
25	128	3,200
30	135	4,050
50	202	10,100
75	7	525
100	129	12,900
150	4	600
200	90	18,000
250	1	250
300	2	600
350	33	11,550
500	54	27,000
650	2	1,300
750	4	3,000
1,000	22	22,000
1,250	2	2,500
1,500	2	3,000
2,000	1	2,000
3,000	2	6,000
6,000	1	6,000
12,000	2	24,000
Total	**923**	**160,060**

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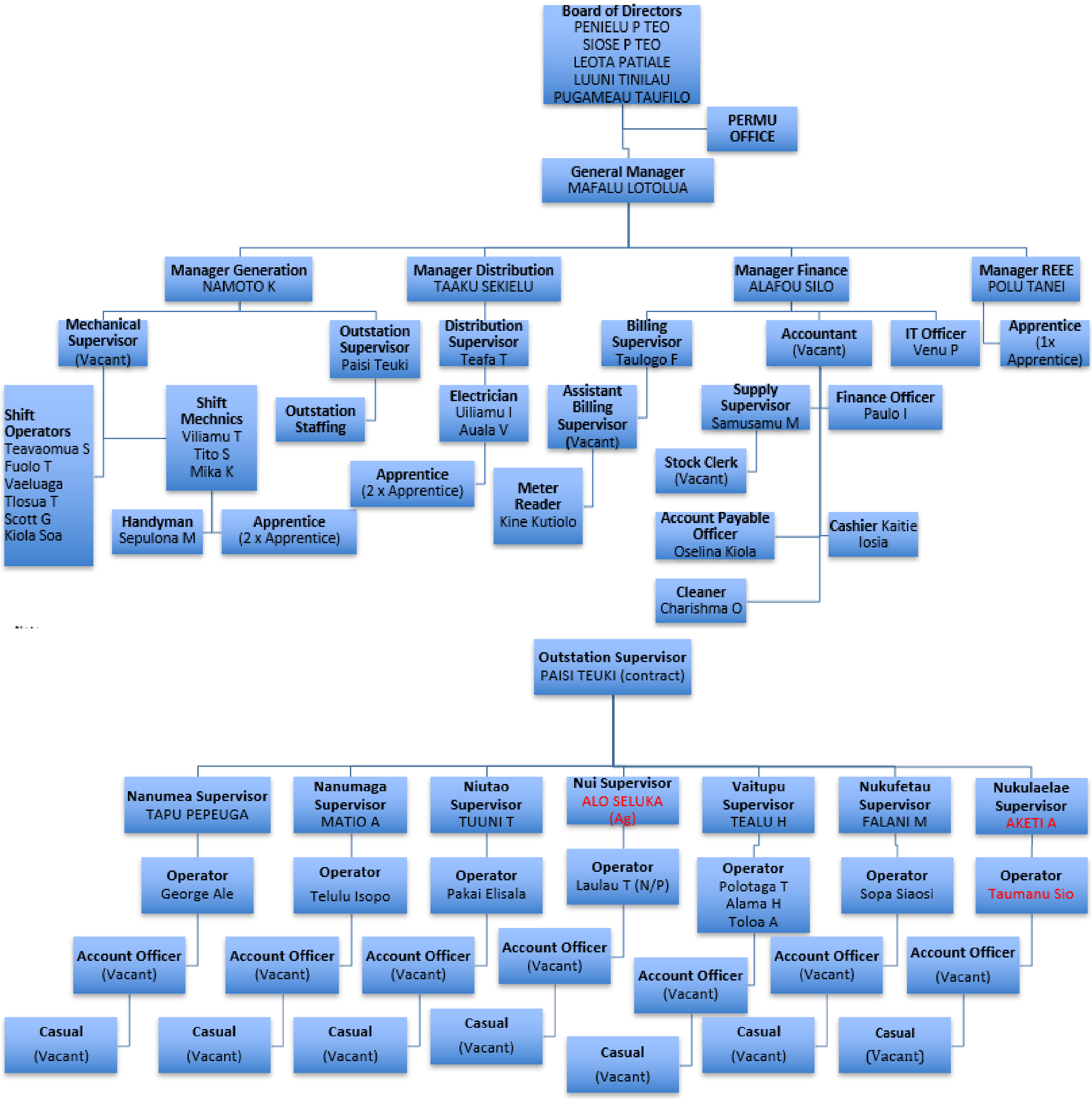
Appendix 5 Tuvalu Supporting Information

Figure 35: TEC Organisation Structure 2020



Source: TEC

Table 47 TEC Existing Generation Capacity

Type	Location	Size	Total	
Funafati				
Diesel kW	Funafuti Power Station	3 x 600	1,800	36 %
Solar kW$_p$	Government Buildings	130		
	Hospital	75		
	Marine Warehouse	75		
	Media Building	40		
	Sports Field[69]	20		
	TEC Integrated	350		
	PWD Compound	66	756	15 %

---

[69] The Sports Field solar PV is out of service due to damaged panels.

Type	Location	Size	Total	
		Subtotal Funafuti	**2,556**	**51 %**
Outer Islands				
Diesel 40 kW sets x 14	Vaitupu =1; Nukulaelae = 3 5 other islands = 2 each	560		
Diesel 80 kW sets x 7	Vaitupu =2; 5 other islands = 1 each	560	1,120	22 %
Solar	Amatuku-rooftop	120		
	Nanumaga	160 (or 205?)		
	Nanumea	160 (or 195?)		
	Niutao	160 (or 232?)		
	Nui	164 (or 60?)		
	Nukufetau	164 (or 77?)		
	Nukulaelae	164 (or 45?)		
	Vaitupu	260 (or 410?)	1,352	27 %
		Subtotal Outer	**2,472**	**49 %**
		Total	**5,028**	**100 %**

Source: TEC

Table 48 TEC Customers and Consumption 2015-2018 (kWh)

Customers	**2015**		**2016**		**2017**		**2018**	
	N°	**Units**	**N°**	**Units**	**N°**	**Units**	**N°**	**Units**
Government	37	1,409,931	48	1,746,277	52	1,709,776	64	1,292,455
Commercial	164	1,505,754	208	1,861,599	172	1,668,209	185	1,762,295
Private	865	1,808,602	943	2,114,430	870	1,990,475	776	2,491,848
Subtotal	***1,066***	***4,724,287***	***1,189***	***5,722,306***	***1,094***	***5,368,460***	***1,025***	***5,546,598***
Government	30	63,205	29	46,323	39	182,806	27	133,339
Commercial	79	69,388	97	107,008	109	181,713	101	185,866
Private	1,042	796,766	986	841,826	1,145	915,088	939	923,366
Subtotal	***1,151***	***929,359***	***1,112***	***995,157***	***1,293***	***1,279,607***	***1,067***	***1,242,571***
Total N° of Users	**2,217**		**2,301**		**2,384**		**2,092**	
Total Consumption (kWh)		**5,653,646**		**6,717,463**		**6,647,967**		**6,789,169**

Source: TEC

Table 49 TEC Production 2015-2018

Type	**2015**	**2016**	**2017**	**2018**
Diesel				
Energy Produced (kWh)				
Fogafale	na	6,168,47	6,255,720	6,790,514
Energy Exported (kWh)				
Fogafale	4,912,020	5,189,135	5,663,910	5,949,380
Outstation	641,323	231,685	267,512	339,685
Subtotal	**5,553,343**	**5,420,820**	**5,931,422**	**6,289,065**
Peak Load (kW) Fogafale	na	1,372	1,238	1,364
Average Load (kW) Fogafale	na	731	776	846
Station Usage (kWhr) Fogafale	na	763,955	537,280	437,084
TEC Main Office (kWhr)	na	324,286	107,348	138,386
Fuel Consumed (ℓ)				
Fogafale	1,402,076	1,497,996	1,593,012	1,722,023
Outstations	238,803	80,028	75,555	101,059
Total	**1,640,879**	**1,578,024**	**1,668,567**	**1,823,082**
Solar PV				
Fogafale				
40 kWp Sport Field	8,700	14,056		With solar at TEC
65 kWp-PWD	4,619	Incl. in UAE	Incl. in UAE	Incl. in UAE
42 kWp Kavatoetoe		Out of Service during cyclone PAM in 2015		
130 kWp Govt. Buiild	90,292	180,795	168,887	172,137
40 kWp Media Build	22,209	59,050	108,500	44,567

Type	2015	2016	2017	2018
350 kWp TEC comp	195,464	366,232	384,917	265,556
75 kWp PMH	33,000	111,487	104,042	87,350
75 kWp Marine W/house	39,763	96,247	36,770	Out of Service
Subtotal	**394,047**	**827,857**	**803,116**	**569,610**
Outer Islands				
Vaitupu - Motufoua-46 kWp	44,721	46,136	19,797	27,724
Vaitupu -Village - 400 kWp	36,970	310,822	493,671	432,002
Nu kulaelae - 45 kWp	34,121	64,232	53,741	58,466
Nu kufetau - 77 kWp	112,579	139,339	134,110	90,704
Nui - 60 kWp	77,903	121,684	79,009	65,910
Nanumea - 195 kWp	53,696	140,526	164,570	155,946
Nanumaga - 205 kWp	42,126	214,735	139,544	155,092
Niutao - 230 kWp	4,212	106,952	81,889	127,767
Subtotal	**404,328**	**1,144,426**	**1,166,331**	**1,113,611**
Grand Total	**6,351,718**	**7,393,103**	**7,900,869**	**7,402,676**

Source: TEC

Figure 36 Funafuti 11 kV Distribution System

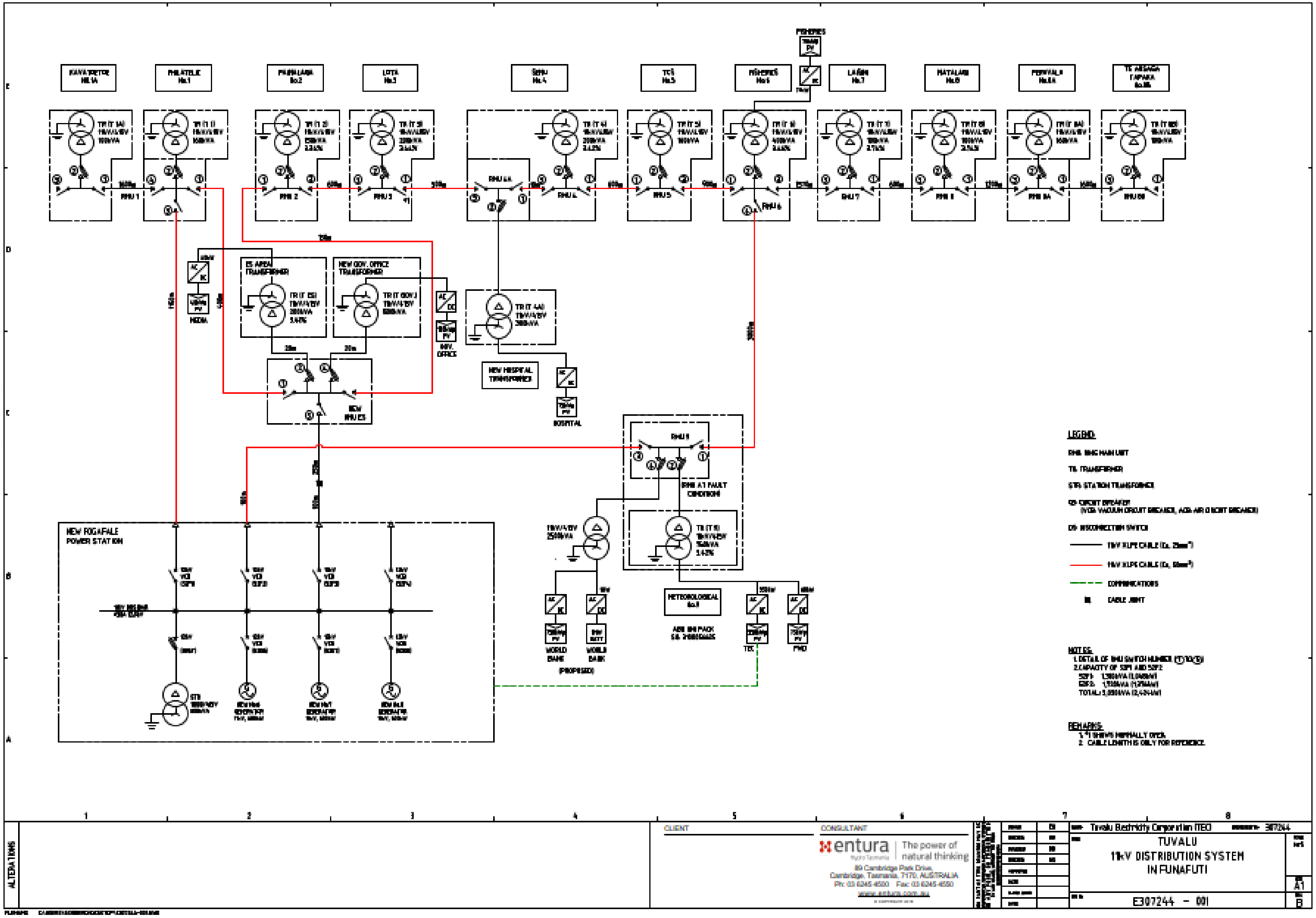


Table 50 Share of Renewable Energy 2018-2019

Station	Supplied Energy by DEG (kWh)	Supplied Energy by PV (kWhr)	Share of RE (%)	Supplied Energy by DEG (kWh)	Supplied Energy by PV (kWhr)	Share of RE (%)	Supplied Energy by DEG (kWh)	Supplied Energy by PV (kWhr)	Share of RE (%)	Supplied Energy by DEG (kWh)	Supplied Energy by PV (kWhr)	Share of RE (%)	Supplied Energy by DEG (kWh)	Supplied Energy by PV (kWhr)	Share of RE (%)
Quarter:	**2018 Q1**			**2018 Q2**			**2018 Q3**			**2018 Q4**			**Tuvalu Overall**		
Nanumea	2,869	36,507	93%	2,451	38,370	94%	2,114	39,277	95%	4,004	41,792	91%	11,438	155,946	93%
Nanumaga	1,984	40,020	95%	1,311	37,990	97%	2,593	37,806	94%	5,006	39,276	89%	10,894	155,092	93%
Niutao	14,117	30,852	69%	12,286	32,190	72%	9,565	34,955	79%	8,931	29,770	77%	44,899	127,767	74%
Nui	31,920	9,300	23%	26,220	14,130	35%	23,340	18,750	45%	23,863	23,730	50%	105,343	65,910	38%
Vaitupu	12,285	112,100	90%	8,361	114,850	93%	12,998	108,921	89%	23,863	96,131	80%	57,507	432,002	88%
Nukufetau	18,658	24,124	56%	17,670	23,429	57%	20,989	19,179	48%	18,315	19,179	51%	75,632	85,911	53%
Nukulaelae	6,217	17,721	74%	6,297	14,103	69%	3,449	14,964	81%	9,035	11,678	56%	24,998	58,466	70%
O/Islands Total	**88,050**	**270,624**	**75%**	**74,596**	**275,062**	**79%**	**75,048**	**273,852**	**78%**	**93,017**	**261,556**	**74%**	**330,711**	**1,081,094**	**77%**
Funafauti Total	**1,411,400**	**198,052**	**12%**	**1,482,180**	**176,123**	**11%**	**1,444,470**	**92,378**	**6%**	**1,611,330**	**103,057**	**6%**	**5,949,380**	**569,610**	**9%**
Tuvalu Overall	**1,499,450**	**468,676**	**24%**	**1,556,776**	**451,185**	**22%**	**1,519,518**	**366,230**	**19%**	**1,704,347**	**364,613**	**18%**	**6,280,091**	**1,650,704**	**21%**
Quarter:	**2018 Q1**			**2018 Q2**			**2018 Q3**			**2018 Q4**			**Tuvalu Overall**		
Nanumea	6,096	37,393	86%	5,100	38,585	88%	7,165	29,042	80%	na			11,438	155,946	93%
Nanumaga	13,249	32,486	71%	7,349	40,860	85%	7,129	35,648	83%				10,894	155,092	93%
Niutao	12,284	29,510	71%	7,890	35,400	82%	8,370	31,665	79%				44,899	127,767	74%
Nui	10,943	14,616	57%	23,067	25,963	53%	30,924	9,445	23%				105,343	65,910	38%
Vaitupu	32,715	84,510	72%	60,988	72,201	54%	48,391	64,283	57%				57,507	432,002	88%
Nukufetau	23,020	18,693	45%	23,967	23,967	50%	21,972	23,536	52%				75,632	85,911	53%
Nukulaelae	11,588	14,489	56%	15,627	15,627	50%	15,040	17,457	54%				24,998	58,466	70%
O/Islands Total	**109,895**	**231,697**	**68%**	**143,988**	**252,603**	**64%**	**138,991**	**211,076**	**60%**				**330,711**	**1,081,094**	**77%**
Funafauti Total	**1,496,870**	**206,324**	**12%**	**1,557,720**	**204,934**	**12%**	**1,705,500**	**203,955**	**11%**				**5,949,380**	**569,610**	**9%**
Tuvalu Overall	**1,606,765**	**438,021**	**21%**	**1,701,708**	**457,537**	**21%**	**1,844,491**	**415,031**	**18%**				**6,280,091**	**1,650,704**	**21%**

Source: TEC

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Appendix 6 LV Aerial Bundled Conductors

Aerial bundled conductors (ABC) are overhead power lines using several insulated conductors bundled tightly together. The conductors are AAAC (all-aluminium alloy conductor), insulated with XLPE (cross-linked polyethylene) insulation. The phases are identified by one, two or three ribs running longitudinally along the insulation. There are two types of ABC; one using a neutral/messenger to support the phase conductors; the other uses all conductors share the support function. The neutral/messenger size is determined by the mechanical and electrical conditions and is sometimes less than the phase size.

First introduced in the early 1960's, ABC is now widely used throughout the world and especially in the ASEAN region; since it is particularly suitable for both tropical and developing countries to reduce both technical and non-technical losses.

ABC is most commonly used in LV systems, but is also available in MV ratings. Public lighting is achieved by having one extra conductor, (usually smaller, say 16 mm^2.

The disadvantages of the old 4-wire bare conductors, all of which are eliminated with ABC, include:

- Prone to disruptions during wet and windy monsoon conditions
- Inherent danger to linemen when working with live conductors
- Danger to public and property in the event of fallen conductors.

ABC is widely accepted throughout the world because of its simplicity of construction, its advantage in areas with trees and improved security it offers against theft of electricity. In addition, its construction design is simplified, pole heights can be shortened and installation time and costs reduced. The frequency of outages with ABC due to short circuits is almost eradicated and physically uneven sagging and clashing of individual phases is eliminated.

As the total ABC system, including connectors and neutral is fully insulated, there is no risk of touching live conductors. Consequently, the safety of both linemen and public is enhanced. Corrosion problems which can occur in coastal areas are reduced due to the insulation covering.

ABC can be readily installed on the walls of buildings or across shop fronts which makes it beneficial in crowded commercial areas where the installation of poles and associated guys is not possible. Due to its completely insulated nature, the clearances of ABC over buildings and other obstructions may often be safely reduced. ABC has a versatility advantage in that more than one circuit can be attached to the same pole, or to poles carrying HV circuits or telecommunication lines. The pole attachment fittings are designed with a safety-link to enable the line to fall away, rather than break, in the event of accidental loads such as falling trees.

The reactance of ABC is typically 25% of separate circuits resulting in improved voltage regulation characteristics.

ABC accessories include:

- Suspension assemblies, including angles up to 45^o
- Large angle assemblies for angles > 45^o
- Dead-end (tension) assemblies
- Insulated compression sleeves for joining of ABC
- IPC (insulated piercing connectors) for service and tee-off connections.

Pole assemblies can be connected to poles either by bolting with galvanised bolts (where pole holes exist) or by fixing with stainless steel strap. The same fittings can be attached onto the sides of buildings. ABC compression sleeves are fully insulated and are designed to develop the full rated tensile strength of the ABC on which they are fitted. The connectors are pre-filled with anti-oxidant jointing paste to ensure satisfactory electrical connection.

The IPC connectors are also fully insulated suitable for application onto live phases. The teeth of the contact plates inside the IPC penetrate the ABC insulation to establish contact without the need to first strip the ABC insulation. The bolt head is designed to be tightened to a specific torque or sometimes to shear off at that torque. The service side of the IPC can still be undone if necessary, in the event of the service being removed.

The procedure to erect ABC is similar to any other conductor. The drum must be mounted on a drum stand so that the ABC can unwind off the drum without kinking. ABC conductor rollers with a large groove suitable for the ABC diameter are mounted on each pole so that the ABC can be strung without physical damage, particularly to avoid running over sharp objects or against the concrete pole itself. The ABC can be pulled out manually. After pulling, the ABC is strained and sagged to the requisite tension and transferred from the rollers to the pole fittings.

Examples of ABC (four equal sized cables type) shows IPC connections for service wire which goes to isolating switches and then digital meters in pole mounted box. In these phots taken by SMEC in Myanmar, old open wire LV with hooked connections were to be removed once the ABC was commissioned.

The overall capital cost of ABC is estimated to be >5% cheaper than equivalent rated conventional open wire uninsulated system. ABC is about 3% more expensive than equivalent rated conventional open wire insulated system. Apart from the upfront capital cost, the following should also be considered in the comparison:

- Service and maintenance costs are typically 20% to 30% lower than those incurred with bare overhead lines
- Increased sales due to more reliable supply
- Increased load capacity due to the lower impedance; this allows longer circuit lengths to be used to supply customers at the specified voltage service standards.

The immediate benefits of ABC can be summarised as follows:

- Shorter installation times
- Reduced pole heights
- Lower costs of installation
- Increased quality of supply to the customer
- Reduction in outages due to external factors
- Increased safety to pubic and line staff
- Less cluttered appearance
- Can be installed in a narrower right-of-way.

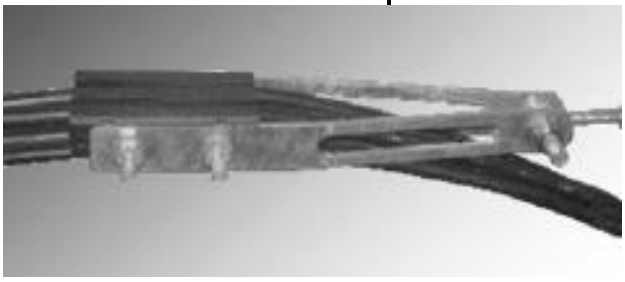
Long term benefits include:

- Lower service and maintenance costs
- New connections can be done alive without need to first deaden the lines
- Not affected by trees, vegetation and wet weather
- Elimination of illegal connections
- Better voltage regulation.

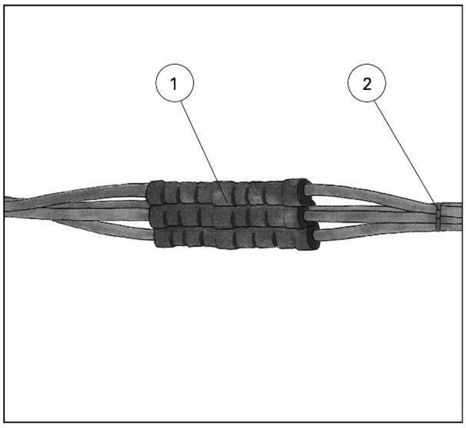
Typical ABC fittings and accessories include:

Anchor clamp

Anchor bracket



Anchoring clamp



LV ABC joint

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