Resilience Assessment Tool and Disaster Readiness Indicator for Pacific Island Utilities

Final Report

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Submitted to the **Pacific Power Association (PPA)**

Contributors

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Contents

Tables and figures

Tables

Figures

Boxes

1 Introduction

1.1 Background

Economic Consulting Associates (ECA) of the United Kingdom, in association with SMEC International (SMEC) of Australia has been contracted by the Pacific Power Association (PPA) under the Sustainable Energy Industry Development Project to deliver the assignment ***Resilience Assessment Tool and Disaster Readiness Indicator for the Pacific Island Utilities.***

Owing to the unique characteristics of the Pacific countries and territories, the Pacific utilities are particularly exposed to various hazards, caused both by climatic events and natural disasters. These have the potential to cause serious impacts on the assets and operations of the utilities, and consequently the supply of power to customers.

As global climate change is expected to increase the frequency of many of these hazards, and as reliance on electricity increases, it is vital that the Pacific utilities take steps to improve their resilience to climate change and disasters. Indeed the 2021-2030 Framework for Energy Security and Resilience in the Pacific (FESRIP) highlights the urgency of supporting the development and management of climate-resilient and disaster-resilient energy infrastructure[1].

This assignment follows on from, and builds upon previous work completed by SMEC and ECA for PPA in 2019, which developed Climate Resilience Investment Plans for Samoa, Tuvalu and Papua New Guinea[2], including a Resilience Viability Tool to support utilities in assessing the economic viability of investments to improve their resilience.

1.2 Objectives

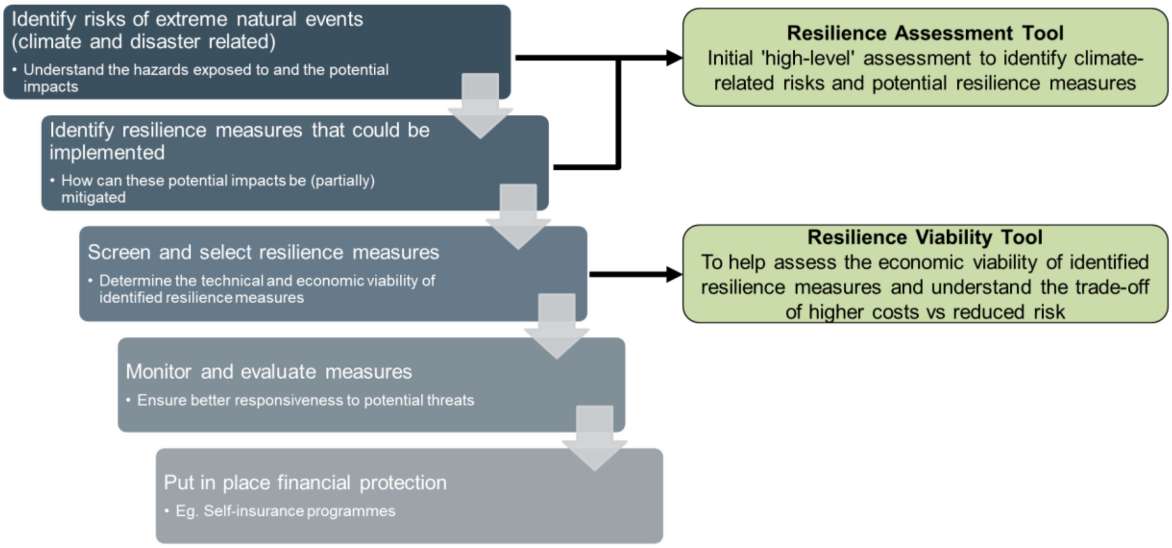
The objective of this assignment is to provide the Pacific utilities with a tool, the *Resilience Assessment Tool,* which they can use to better understand their exposure and resilience to a range of climatic and natural hazards. This builds upon the recommendations of the previous assignment.

As part of the previous assignment, we recommended that the Pacific utilities develop their own *Climate Resilience Plans,* which are to be updated regularly. For smaller utilities, where this may not be feasible, we proposed that climate and disaster resilience considerations are explicitly included in the utilities' power development plans. We identified five key principles that utilities should follow to improve their climate resilience, as shown in the figure below.

[1] Pacific Community (SPC), 2021, Framework for Energy Security and Resilience in the Pacific (FESRIP) 2021-2030; Volume 1

[2] Analysis was also conducted for Papua New Guinea, but more limited as the proposed visit was not possible due to the onset of the Covid-19 pandemic and associated travel restrictions. These utilities were chosen by PPA to be representative of a small (Tuvalu), medium (Samoa), and large (Papua New Guinea) PPA member utility.

Figure 1 Principles to improve climate resilience of Pacific utilities



Source: ECA and SMEC

While the previous assignment identified various resilience measures that could be implemented and developed using the *Resilience Viability Tool* to assist utilities in screening and selecting resilience measures, the focus of this follow-on assignment is to provide another tool to support the Pacific utilities with the first step – identifying the risks of extreme natural events to the utilities' assets and operations.

It is intended that the *Resilience Assessment Tool* will be used by utility staff to guide their self-assessment of their exposure to a range of hazards, and consequently assist the utilities identifying priority areas for resilience measures, and investments. It can also be used for benchmarking the climate resilience of the utility over time and comparing the relative resilience of different Pacific utilities.

As part of this assignment, a two-day workshop of the use of *Resilience Assessment Tool* and the *Resilience Viability Tool* developed under the previous assignment was provided to staff of the PPA member utilities in Apia, Samoa in February 2023.

1.3 Report structure

The remainder of this report is structured as follows:

- **Section 2** offers a framework for thinking about hazards, risk, and resilience and defines key terminology used throughout this report and in the tools; and
- **Section 3** provides an overview of the *Resilience Assessment Tool,* including its objectives and a summary of the required inputs. It also provides guidance on how it can be used by Pacific utilities.

The subsequent sections elaborate on the different components of the *Resilience Assessment Tool* and provide guidance on the required inputs:

- **Section 4** elaborates on the hazards facing the Pacific power systems and includes a list of the relative impact of these hazards on the power systems of the Pacific utilities;
- **Section 5** discusses the exposures and vulnerabilities of the Pacific utilities and includes a list of the potential system impacts of the different hazards; and
- **Section 6** provides a discussion of the mitigation measures that may be implemented by the Pacific utilities to improve their resilience.

2 Framework and definitions

The terminology of the various concepts related to hazards, risk, and vulnerability can be confusing, and even established international organisations and practitioners often use different terms to mean the same thing. To ensure a common understanding among the Pacific utilities, we have prepared a framework of the key concepts and provides associated definitions. These are set out below.

- **Extreme natural events –** These are events which give rise to a range of *hazards.* The *Resilience Assessment Tool* focuses on assessing the hazards related to two broad types of extreme natural events:
    - **Climate-related events –** This covers any events which are caused or affected by global climate change and includes tropical cyclones, storms, sea level rises, and rising ambient temperatures.
    - **Geophysical events –** This includes events such as earthquakes, tsunamis, and volcanic eruptions.
- **Hazards –** These are specific events, generally attributable to the extreme natural events listed above (either *climate-related events* or *geophysical events*), which have the potential to cause harm to property and life (specifically, damage to utilities' assets and disruption of power system operations). Hazards includes events such as strong winds, flooding, and droughts.
- **Exposures –** This refers to the presence of power system assets that may be adversely affected by the hazards. For example, overhead lines in a wind-prone area have a higher degree of exposure to the hazard of strong winds than underground lines. It may also refer to areas of a utility's operations (eg regular maintenance) that may be affected by hazards.
- **Vulnerabilities –** The potential for adverse effects of hazards on exposed power system assets. For example, overhead power lines may be vulnerable to damage by strong winds, which could cause a power outage. Note that an asset might be 'exposed', but may have minimal vulnerability due to mitigation measures being undertaken.
- **Risks –** This refers to the likelihood that a hazard leads to adverse impacts on the power system. Said differently, it is the combination of ***hazards*** and ***vulnerabilities***.
- **Mitigation measures –** These are actions that can be taken by the utility to reduce the vulnerability of their systems and operations to hazards. These measures can include both capital projects, such as undergrounding the distribution system, as well as changes to operating practices, such as regularly pruning and clearing trees that are in close proximity to assets. They may also be referred to as resilience measures.
- **Resilience –** The ability of the power system to cope with the hazards. It is effectively the inverse of risk. Therefore, low risk indicates high resilience and

vice-versa. In the *Resilience Assessment Tool* we refer to resilience when we discuss all the different risks from differed hazards and vulnerabilities.

The table below provides an example of this framework.

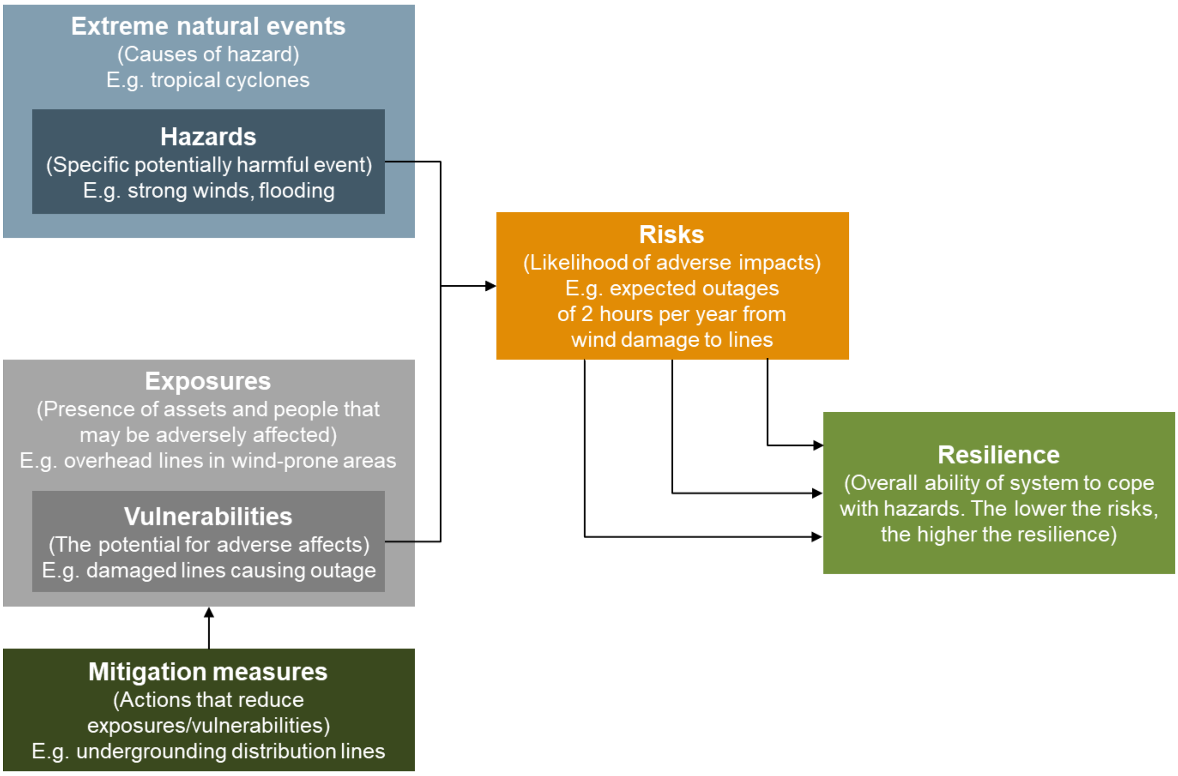
Table 1 Example of framework

Term	Example
Extreme natural events	Cyclone
Hazard	Strong winds
Exposures	Overhead lines
Vulnerabilities	Overhead lines blown over by strong winds, leading to outages
Risk	Likelihood that strong winds lead to overhead lines being blown over by strong winds, leading to outages
Mitigation measures	Undergrounding of distribution lines
Resilience	Ability of system to cope with strong winds (along with other hazards and risks)

Source: ECA

The figure below illustrates how these terms fit together to define resilience, which forms the framework underpinning the Resilience Assessment Tool.

Figure 2 Defining resilience based on hazards, vulnerabilities, and risks



Source: ECA

3 Resilience Assessment Tool

3.1 Tool objectives

The *Resilience Assessment Tool* aims to support Pacific utilities in assessing their current level of resilience to various climate-related and geophysical hazards. In designing the tool, we aimed to ensure that the tool can be used for the following purposes:

- **Assess current resilience –** Act as a tool to support the Pacific utilities in assessing their current level of resilience, including determining which hazards pose the greatest risk, and which aspects of the system are most exposed. The initial assignment identified the need for Pacific utilities to carefully assess their own climate and disaster resilience as a crucial first step.

- **Evaluate impact of mitigation measures –** Pacific utilities may wish to invest in projects or programmes (or adapt their day-to-day operating practices) to improve their climate and disaster resilience. The tool can be used to assess the impact of introducing such measures on the utilities' resilience relative to the status quo.

- **Track resilience over time –** We anticipate that utilities will update the tool on a regular basis. This will allow them to track how their resilience changes over time. It may improve as additional mitigation measures are deployed, or it may worsen as the intensity of hazards increases or an expansion of the system leads to more assets being exposed.

- **Benchmark resilience –** The tool can be used by all PPA member utilities to determine their resilience. Subject to a thorough review of the inputs and ensuring they are set following standard principles, the tool can allow for utilities to benchmark their resilience relative to their peers.

3.2 Tool overview

To ensure that it can be used with relatively minimal training, and by those who may not have a deep understanding of modelling and Excel, we have aimed to keep the tool relatively simple and user-friendly. It contains several key steps, which are also shown in the *Guidance* sheet of the model.

1. **Determine hazard rating –** Identify the hazards to which the country is exposed to and determine how severe they are. This is a combination of the frequency and intensity, and is expressed in the model as a hazard rating. Although the model is pre-populated with hazard ratings for the different countries and territories, Section 4 of this report provides additional details.

2. **Input impact ratings –** As a second step, the user is encouraged to think about and determine how severe the impact of each hazard is on the power system, if no mitigation measures are taken. This involves identifying the assets or aspects of operations exposed to the hazard and then determining the severity of the potential impact. This is explained in more detail in Section 5 of this report.

3. **Input mitigation ratings –** Following on, the user must identify what mitigation measures are in place to reduce the potential impact of the hazard and assign a mitigation rating, which assesses to what extent the potential impact(s) of each hazard have been mitigated. Further details are provided in Section 6 of this report.

4. **Review calculated vulnerability ratings –** The model will automatically calculate the vulnerability rating, which shows how severe the impact of each hazard is on the power system, after mitigation measures are implemented.

5. **Review calculated risk scores –** The model will also automatically calculate the risk score, which determines the risk of each hazard to the power system, calculated as the product of the hazard rating and the vulnerability rating. It also calculates an *unmitigated risk score* which determine the risk of each hazard to the power system with no mitigations in place. This is calculated as the product of the hazard rating and the potential impact rating.

6. **Review calculated overall risk score –** The average of the risk scores across all hazards considered in the model are combined to provide the overall level of risk to the power system, after allowing for different severity of different hazards, their expected impacts, and mitigations.

7. **Review calculated resilience indicator –** Finally, the model will determine the overall resilience indicator which is an indication of the power system's overall resilience to climate events and natural disasters.

The table below provides an overview of the different ratings and scores included in the model and their ranges.

Table 2 Overview of *Resilience Assessment Tool* calculation process

#	Aspect	Input type	Description	Scale
1	Hazard rating	Pre-populated in model for Pacific countries and territories, but can be changed by user	Measure of severity of hazard for the country, which is combination of frequency and intensity	Scale 0-10: 0= never occurs 10= occurs with very high frequency and intensity
2	Impact rating	User inputted	Measure of severity of potential impact of hazard on power system	Scale 0-10: 0= no impact 10= severe impact
3	Mitigation rating	User inputted	Measure of the extent to which potential impacts of each hazard have been mitigated	Scale 0-100%: 0%= not at all 100%= completely mitigated
4	Vulnerability rating	Calculated as impact rating multiplied by 1 minus the mitigation rating	Measures severity of impact of hazard on power system after mitigation is taken into account	Scale 0-10: 0= no impact 10= severe impact
5	Risk score	Calculated as hazard rating multiplied by vulnerability rating	Indicator of the risk of each type of hazard to the power system after combining hazard severity and the potential/expected impacts	Scale 0-100: 0= No risk 100= Very high risk

#	Aspect	Input type	Description	Scale
6	Overall risk score	Calculated as the average of risk scores across all hazards	Indicator of the overall level of risk to the power system, accounting for the different severity of hazards, their potential impacts, and mitigations	Scale 0-100: 0= No risk 100= Very high risk
7	Resilience indicator	Calculated as 100 minus the overall risk score	Indicator of the power system's overall resilience to climate events and natural disasters	Scale 0-100: 0= No resilience/very low resilience (worst) 100= Very high resilience (best)

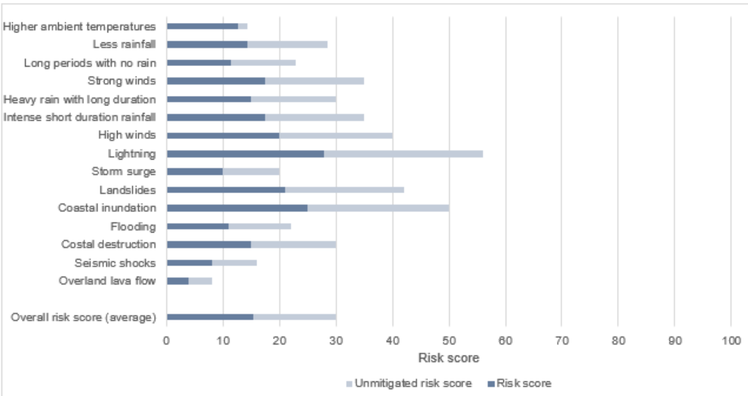
Source: SMEC and ECA

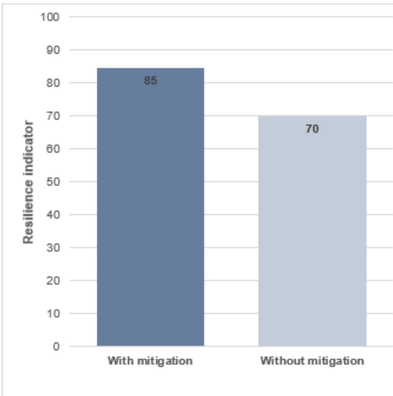
The model includes a summary sheet which provides an overview of the hazards and risk scores for the different hazards, highlighting the impact of the mitigation measures on the overall risk score. It also provides an overview of the resilience indicator.

We note that the reliance on user inputs means that the outputs should not automatically be taken at face value. Instead, the value of the tool lies in the process of filling it out and using it, as this encourages each user to think carefully about hazards, potential impacts applicable to their power system, and how they might be mitigated.

Figure 3 Screenshot of *Summary* sheet in Resilience Assessment Tool

Hazards				Risk without mitigation		Risk with mitigation		
#	Extreme natural event	Hazard	Hazard rating	Impact rating	Unmitigated risk score	Mitigation rating	Vulnerability rating	Risk score
1	Rising temperatures	Higher ambient temperatures	3	5	14	12%	4	13
2		Less rainfall	5	6	29	50%	3	14
3		Long periods with no rain	4	6	23	50%	3	11
4	Tropical cyclones	Strong winds	5	7	35	50%	4	18
5		Heavy rain with long duration	6	5	30	50%	3	15
6		Intense short duration rainfall	7	5	35	50%	3	18
7	Storms	High winds	8	5	40	50%	3	20
8		Lightning	8	7	56	50%	4	28
9		Storm surge	4	5	20	50%	3	10
#		Landslides	6	7	42	50%	4	21
#	Sea level rise	Coastal inundation	10	5	50	50%	3	25
#	Tsunami	Flooding	4	6	22	50%	3	11
#		Costal destruction	5	6	30	50%	3	15
#	Earthquakes	Seismic shocks	2	8	16	50%	4	8
#	Volcanoes	Overland lava flow	1	8	8	50%	4	4
		Overall risk score (average)			30			15
		Resilience indicator (100 minus overall risk score)			70			85





Cover | Guidance | Example | Hazards | Impacts & Mitigation | Summary

Source: ECA

4 Hazards facing the Pacific utilities

4.1 Overview

This assignment considers a range of extreme natural events which could cause a series of hazards. A hazard is an event that has the potential to cause harm to property and life (in this case specifically, damage to utilities' assets and a disruption of power system operations). The extreme natural events that give rise to these hazards include climate-related events as well as geophysical events.

The table below provides an overview of the hazards included in the *Resilience Assessment Tool* and the extreme natural event that gives rise to them. These hazards have been selected on the basis of being the most common and prominent hazards which are likely to have an impact on the Pacific utilities' systems. Of course, not all of these hazards may be applicable to each Pacific utility. For example, those in countries with no volcanoes will not face the associated hazards.

Table 3 List of hazards

Extreme natural event	Hazards
Climate-related	
Rising temperatures	Higher ambient temperatures
	Less rainfall
	Long periods with no rain
Tropical cyclones	Strong winds
	Heavy rain with long duration
	Intense short duration rainfall
Storms	High winds
	Lightning
	Storm surge
	Landslides
Sea level rise	Coastal inundation
Geophysical	
Tsunami	Flooding
	Coastal destruction
Earthquakes	Seismic shocks
Volcanoes	Overland lava flow
	Volcanic ash contamination

Although the focus of this assignment is on climate-related and geophysical hazards, utilities may also be affected by other hazards, including those caused by humans or other factors. This can include hazards such as acts of vandalism or terrorism, vehicle collisions and crashes impacting utility assets, or disease and pandemic outbreaks affecting the operations of the utility. Supply chain disruptions or cyberattacks are also legitimate hazards and in many jurisdictions some of the utilities' largest concerns.

The Resilience Assessment Tool has been developed with flexibility in mind and users are able to add additional hazards, which may include any of those noted here. The general framework and approach for assessing resilience to such hazards (eg. supply chain disruptions) is the same as that of geophysical hazard, with the user identifying the potential severity of the hazard, the potential impacts on the utility's assets or operations, and mitigation measures that may or may not have been implemented.

4.2 Assessing hazards

4.2.1 Framework

By definition, a hazard has the potential to cause damage to life and property. However, some hazards may be more likely to cause such damage than others. This is due to a combination of two main factors:

- **Frequency –** An indication of how often, on average, the hazard can be expected to occur. Some hazards may occur frequently (eg strong winds from storms), while others may occur very rarely (eg a volcanic eruption). For other hazards, the frequency may refer to how the hazard is expected to develop over time. An example is higher ambient temperatures from global climate change, which are expected to increase gradually.

- **Intensity –** Indicates the 'strength' of the hazard, given that this varies across countries (and sometimes also within countries). For example, some countries tend to experience stronger cyclones and tropical storms than others.

It is important to note that frequency and intensity are not necessarily directly correlated. Some hazards, such as a volcanic eruption, may be relatively infrequent but intense when it does occur, while high winds from storms may be relatively frequent but not that intense. On the other hand, some countries may experience frequent and intense cyclones.

4.2.2 Hazard rating

For the purpose of the Resilience Assessment Tool we determine a **hazard rating** based on a combination of frequency and intensity. This takes a value between 0 and 10, whereby 10 is the highest (most severe) and 0 is the lowest (least severe/does not occur). As indicated above, there is not necessarily a direct correlation between frequency and intensity which means that a degree of judgement must be used to determine the hazard score. The table below provides a guide to setting the hazard score.

Table 4 Hazard rating

Hazard rating	Frequency	Intensity
0	Does not occur	N/A
1	Very rare occurrence	Very low
2	Rare occurrence	Low
3	Occasional occurrence	Low
4	Combination of either frequent event with low intensity, or intense event with relatively low frequency	
5		
6		
7		
8	Frequent occurrence	
9	Very frequent	
10	Extremely frequent	Intense

The Resilience Assessment Tool includes pre-determined hazard ratings for several Pacific countries. These have been calculated based on exert knowledge and a range of sources, which are detailed in the next Section.

4.2.3 Determining the hazard rating

The first step for Pacific utilities to determine their climate resilience is to assess the hazards that they face in their country. This involves determining the frequency of the extreme natural events and consequent hazards, as well as their intensity. This will depend not on only climatic and geographic conditions, but also the characteristics of the country. For example, countries with many low-lying islands (eg 4 metres below sea level) will be much more exposed to sea level rises or coastal flooding.

The frequency and intensity of hazards can be determined based on a range of publicly available data and research, as shown in the figure below. Based on our assessment of these sources and our own understanding of the context in which the Pacific utilities operate, we have pre-determined this and the resulting hazard score for each Pacific country.

Box 1 Sources to help determine the hazard rating

1. Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program, Australian Government Bureau of Meteorology http://www.bom.gov.au/climate/pacific/index-pacific.shtml

2. Climate Change Knowledge Portal (CCKP), World Bank, Washington DC USA. https://climateknowledgeportal.worldbank.org/

3. Technical Assistance to Develop Investment Plans for Enhancing Energy Resilience in Pacific Island Power Utilities, SMEC /ECA, Contract # SEIDP/C2.2, September 2020

4. Climate Change and Disaster Risk Management, ADB, 2023, https://www.adb.org/what-we-do/themes/climate-change-disaster-risk-management/main

Source: ECA and SMEC

However, Pacific utilities should be encouraged to critically engage with this data and make adjustments if necessary. In particular, they may wish to consider regional disparities within a country and how this affects the overall hazard score.

5 Potential impacts

5.1 Overview

Following on from the assessment of hazards, the Pacific utilities need to determine the potential impacts of these hazards on their systems. The potential impacts of hazards on the systems of the Pacific utilities are wide-ranging, and often severe. This is illustrated by the fact that several Pacific utilities' struggle to obtain market-based insurance for their assets. As climate changes make hazards more frequent and/or intense, and as reliance on the electricity supply increases, it is important for Pacific utilities to engage with the potential impacts of hazards on their systems to identify areas where mitigation measures may need to be prioritised.

Potential impacts can vary significantly, and utilities should ensure that they do not restrict their focus to commonly discussed impacts of hazards, such as overhead lines. It is also important to remember that in addition to physical damages to assets resulting from hazards, there can also be disruptions to the utilities' day-to-day operations. For example, flooding may prevent staff from accessing assets to conduct repair work and/or routine maintenance.

Furthermore, focus should be paid to ensure that potential impacts on the full value chain of electricity supply are considered. This includes generation, transmission, distribution, retail, and system operations.

The table below provides an overview of potential impacts to different assets and areas of operations from different hazards. Note that this table is not exhaustive, and that there will be differences in the potential impacts for different utilities. This will depend on the characteristics of the country and the network.

Table 5 Overview of potential impacts by exposed assets and hazard

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts
Rising temperatures	Higher ambient temperatures	Control equipment	Impacts operating equipment
		Transformers	Reduces output capacity
		MV & LV Conductors and cables	Reduces circuit ratings
			Increases conductor sag which reduces ground clearance
		Solar generation	Reduces efficiency of solar equipment with less generation output
	Less rainfall	Overhead network	Possible flashover on insulators due to salt and/or dust build up
		Solar generation	Reduces efficiency of solar panels due to getting dirty
	Long periods with no rain	Overhead network	Possible flashover on insulators due to salt and/or dust build up
		Solar generation	Reduces efficiency of solar panels

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts
Tropical cyclones	Strong winds	Overhead network	Overhead equipment (towers, poles, overhead assets) is damaged or destroyed
			Falling trees bring down overhead conductors
			Wind turbines are damaged or destroyed
	Heavy rain with long duration	Overhead network	Localised flooding and water damage
	Intense short duration rainfall	Overhead network	Localised flooding and water damage
Storms	High winds	Overhead network	Overhead equipment (towers, poles, overhead assets) is damaged or destroyed
			Falling trees bring down overhead conductors
	Lightning	Overhead network	Damage to key power system assets, with SCADA controls (eg circuit boards) destroyed by voltage surges. Long restoration time if no spare parts
	Storm surge	Overhead network	Localised flooding and water damage
			Coastal erosion
	Landslides	Overhead network	Distribution equipment destroyed
Sea level rise	Coastal inundation	Ground mounted equipment	Ground mounted equipment vulnerable to flooding and water damage
Tsunami	Flooding	Ground mounted equipment	Flooding and water damaged
		Overhead network	Poles and transformers knocked over by inertia of large floating debris
	Coastal destruction	Ground mounted equipment	Flooding and water damaged
		Overhead network	Poles and transformers knocked over by inertia of large floating debris
Earthquakes	Seismic shocks	Substations	Buildings destroyed
		Entire network	Power transformers shaken off their foundations and put out of action
			Mechanical protection relays malfunction to disrupt supply
		Buildings	Substandard buildings destroyed
Volcanoes	Overland lava flow	Substations	Destruction of assets
		Entire network	Damage to exposed assets due to ingress of volcanic dust
		Buildings	Outdoor assets destroyed by the blast of air and debris
	Volcanic ash contamination		

Source: ECA and SMEC

Note that we consider potential impacts as what could happen if no mitigation/resilience measures are taken to reduce the potential impact. These mitigation/resilience measures are discussed in more detail in the next Section.

Pacific utilities should be encouraged to think about the potential impacts of applicable hazards on their systems and should adjust and/or expand on this list as appropriate. We also expect that the model be a 'living' document which Pacific utilities can expand over time as new potential impacts are identified.

5.2 Impact rating

5.2.1 Framework

The impact rating is a required input to the Resilience Assessment Tool. This is an indicator of the potential impact of the hazard on the utilities' assets and/or operations. As each hazard may have several impacts on different assets or aspects of the utilities' operations, there may be several impact scores for each hazard. For example, there are separate impact scores for the hazard *less rainfall from increasing temperatures* for the overhead network (impact of possible flashover due to salt and/or dust build up) and solar generation (reduced efficiency of solar panels).

As a result, we calculate an impact score for each potential impact. In addition, users must provide an *impact weighting* which indicates the relative importance of the impacts. For example, impacts upon solar panels in a system with relatively little solar generation may be less important than impacts on the overhead network. The sum of the impact weightings must be equal to 100%.

5.2.2 Impact score

Similar to the hazard rating, the impact rating takes a value of 0 to 10, whereby:

- **10** is the maximum rating and represents a major and catastrophic impact on the utilities' operations, considered as a entire network blackout lasting over six hours.
- **0** is the minimum rating and means that the impact has no tangible impacts upon the operations.

The table below provides an indicative guide on how to rate the potential impact. Note that this may need to be adjusted by the Pacific utilities depending on the size of their network. For example, large utilities may fish to raise the thresholds for affected areas, while smaller utilities may wish to lower them. In some cases, a different approach may need to be taken to calculate the rating. For example, although the build-up of dust on solar panels may not lead to system outages, it may have an impact on the efficiency of generation, which should be captured.

Table 6 Impact rating

Potential impact rating	Impact	Affected Area	% of Customers Affected	Expected Restoration Time Hours

0 (best case)	None	None	0	na
1	Minimal	1 Customer with no power	≤ 1	≤ 0.5
2	Minor	≤ 10 Customers with no power	≤ 2	≤ 1
3	Minor	1 LV Feeder tripped	≤ 2	≤ 0.5
4	Significant	≥1 LV Feeders tripped	≤ 5	≤ 1
5	Significant	1 MV Feeder tripped	≤ 10	≤ 0.5
6	Serious	≥1 MV Feeders tripped	≤ 20	≤ 1
7	Serious	≤ 50% of generation unavailable	≤ 50	≤6 hours
8	Severe	≥ 50% of generation unavailable	≥ 50	≥6 hours
9	Severe	Entire network blackout	100	≤6 hours
10 (worst case)	Severe	Entire network blackout	100	≥6 hours

Note that the potential impact may, of course, vary within a country. For example, the potential impact of coastal flooding may be quite severe on assets located in coastal areas. However, if the areas affected reflect a relatively minor share of total customers and load, the potential impact to the utility as a whole is relatively low.

This exercise should be taken seriously by the Pacific utilities as it will allow them to identify which hazards and assets/areas of operations are most likely to have a significant impact on the system, and consequently which may warrant the most urgent actions to improve resilience.

6 Mitigation and resilience measures

6.1 Reducing vulnerability

The vulnerability of Pacific utilities to hazards is not necessarily equal to the potential impact. This is because, although they are exposed to various hazards and potential impacts, they are able to reduce their vulnerability to hazards through a range of mitigation measures, which reduce the vulnerability of the utilities' systems and operations to hazards and makes them more resilient.

These mitigation measures can take different forms. Crucially, it includes both capital investments as well as changes to operating procedures. The initial phase of this assignment focussed on identifying different mitigation measures that Pacific utilities could take to improve their resilience.

The table below provides a non-exhaustive overview of potential resilience measures that could be taken by the Pacific utilities in response to different potential impacts.

Table 7 Potential mitigation measures

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts	Potential mitigation measures
Rising temps	Higher ambient temps	Control equipment	Impacts operating equipment	Provide air-conditioning for vulnerable equipment
		Transformers	Reduces output capacity	Specify/use transformers rated for higher ambient temperatures

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts	Potential mitigation measures
		MV & LV Conductors and cables	Reduces circuit ratings	Ensure new construction designed for higher ambient temperatures
			Increases conductor sag	Ensure new construction designed for higher ambient temperatures
		Solar generation	Reduces efficiency of solar equipment with less generation output	Effective mitigation difficult
	Less rainfall	Overhead network	Possible flashover on insulators due to salt and/or dust build up	Specify/use insulators rated for polluted conditions
		Solar generation	Reduces efficiency of solar panels due to getting dirty	Implement regular cleaning of solar panels
	Long periods with no rain	Overhead network	Possible flashover on insulators due to salt and/or dust build up	Specify/use insulators rated for polluted conditions
		Solar generation	Reduces efficiency of solar panels	Implement regular cleaning of solar panels
Tropical cyclones	Strong winds	Overhead network	Overhead equipment (towers, poles, overhead assets) is damaged or destroyed	1) Design overhead equipment for applicable maximum wind speeds 2) Consider undergrounding vulnerable sections of overhead distribution
			Falling trees bring down overhead conductors	1) Design overhead equipment for applicable maximum wind speeds 2) Consider undergrounding vulnerable sections of overhead distribution
			Wind turbines are damaged or destroyed	
	Heavy rain with long duration	Overhead network	Localised flooding and water damage	1) Mount equipment above ground 2) Use water-proof enclosures
	Intense short duration rainfall	Overhead network	Localised flooding and water damage	1) Mount equipment above ground 2) Use water-proof enclosures
Storms	High winds	Overhead network	Overhead equipment (towers, poles, overhead assets) is damaged or destroyed	1) Design overhead equipment for applicable maximum wind speeds 2) Consider undergrounding vulnerable sections of overhead distribution
			Falling trees bring down overhead conductors	1) Design overhead equipment for applicable maximum wind speeds 2) Consider undergrounding

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts	Potential mitigation measures
				vulnerable sections of overhead distribution
	Lightning	Overhead network	Damage to key power system assets, with SCADA controls (eg circuit boards) destroyed by voltage surges. Long restoration time if no spare parts	1) Install lightning arrestors on overhead network at high risk locations 2) Install ground wire (or OPGW) on HV overhead circuits 3) Install lightning protection at all HV substations 4) Stock adequate quantity of spare parts for all electronic equipment
	Storm surge	Overhead network	Localised flooding and water damage	1) Mount equipment above ground 2) Use water-proof enclosures
			Coastal erosion	1) Mount equipment above ground 2) Use water-proof enclosures
	Landslides	Overhead network	Distribution equipment destroyed	1) Design ring circuits so that damaged sections can be isolated and back-fed to maintain supply 2) Design substations to n-1 contingency
Sea level rise	Coastal inundation	Ground mounted equipment	Ground mounted equipment vulnerable to flooding and water damage	1) Mount equipment above ground 2) Use water-proof enclosures
Tsunami	Flooding	Ground mounted equipment	Flooding and water damaged	1) Mount equipment above ground 2) Use water-proof enclosures
		Overhead network	Poles and transformers knocked over by inertia of large floating debris	Design network with protective barriers in susceptible areas
	Coastal destruction			
Earthquakes	Seismic shocks	Substations	Buildings destroyed	Design all buildings and structures to applicable seismic standards
		Entire network	Power transformers shaken off their foundations and put out of action	Bolt down all power transformers to their foundations
			Mechanical protection relays operate to disrupt supply	1) Install seismic rated Buchholz relays on power transformers 2) Replace all mechanical protection relays with digital versions
		Buildings	Substandard buildings destroyed	Design all buildings and structures to applicable seismic standards

Extreme natural event	Hazard	Exposed assets/ operations	Potential impacts	Potential mitigation measures
Volcanoes	Overland lava flow	Substations	Destruction of assets	Prepare contingency plans
		Entire network	Damage to exposed assets due to ingress of volcanic dust	Prepare contingency plans
		Buildings	Outdoor assets destroyed by the blast of air and debris	Prepare contingency plans
	Volcanic ash contamination			

Source: ECA and SMEC

6.2 Assessing mitigation measures

A final input to the tool is to determine to what extent the mitigation measures in place actually mitigate the potential impact. This will rely on holistic consideration of the potential impacts and the proposed measures, which may need to include a high-level technical assessment of the proposed measures. The table below provides a guide to determining the appropriate mitigation score.

Table 8 Mitigation score

Mitigation rating	Mitigation result
100 % (full mitigation)	Potential impact can be fully mitigated with no consequence to normal power supply
90 %	Potential impact can be mostly mitigated with minimal effect on normal power supply
80 %	Potential impact can be partly mitigated with minor effect on normal power supply
70 %	Potential impact can be partly mitigated with some effect on normal power supply
60 %	Potential impact can be partly mitigated with significant effect on parts of normal power supply momentarily
50 %	Potential impact can be partly mitigated with significant effect on parts of normal power supply for short period
40 %	Potential impact can be partly mitigated with serious effect on parts of power supply for short period
30 %	Potential impact can be partly mitigated with serious effect on entire power supply for say 1 hour
20 %	Potential impact cannot be mitigated resulting in severe effect on entire power supply for say ≤ 5 hour
10 %	Potential impact cannot be mitigated resulting in severe effect on entire power supply for say 1 day
0 % (no mitigation)	Potential impact cannot be mitigated resulting in severe and prolonged effect on entire power supply

Source: ECA and SMEC

For example, undergrounding the entire overhead network is likely to fully mitigate the potential impact of high winds on these assets (hence reducing the vulnerability to zero). On the other hand, adding protective barriers to susceptible assets may only mitigate the potential impact of a tsunami by a certain degree.

In addition to assessing the impact of the mitigation measures currently in place, Pacific utilities can also use the tool to assess the impact that implementing different mitigation measures would have on their resilience.

6.3 Viability of mitigation measures

While the importance of climate-resilient and disaster- resilient infrastructure to Pacific utilities is clear, we note that various mitigation measures can be costly and that there may be a range of barriers to implementation. As outlined in the principles that guide climate resilience, planning, after an assessment of their current level of resilience and the identification of appropriate mitigation measures, Pacific utilities should screen and select appropriate measures to implement. Part of this screening process should include identifying whether the measure is *economically* viable.

In discussing economic viability, it is important to note the distinction between financial analysis and economic analysis:

- **Financial analysis** focuses on the costs and benefits from the perspective of the entity making the investment (ie the utility), determining whether the revenues accruing from the investment over its life are likely to outweigh the upfront costs of making the investment.

- **Economic analysis** focuses on the costs and benefits from *the perspective of society as a whole,* considering a range of benefits beyond the financial transactions. For example, a reduction in electricity outages has benefits beyond the increased tariff revenue for the utility. Further information on economic analysis is provided in the previous report.

As part of the previous assignment we prepared a *Resilience Viability Tool* which can support Pacific utilities in determining whether a mitigation measure is economically viable. The tool compares a scenario *without climate resilience* (ie business-as-usual) with a scenario *with climate resilience* (ie with mitigation measures being implemented). It calculates the net present value (NPV) and internal rate of return (IRR). These concepts, as well as the functionality of the *Resilience Viability Tool* are described in detail in the previous report.

In addition to determining the economic viability, utilities should also perform a screening of technical viability (ie can it be implemented from a technical perspective, which may also include issues such as land acquisition and material availability) and assess how the measures may be funded.