Renewable Energy Costs in the Pacific

Collation of renewable energy infrastructure project cost data in the Pacific

March 2019

The Pacific Region Infrastructure Facility (PRIF) is a multidevelopment partner coordination, research and technical assistance facility that supports infrastructure development in the Pacific. PRIF members include the Asian Development Bank, Australian Department of Foreign Affairs and Trade, European Investment Bank, European Union, Japan International Cooperation Agency, New Zealand Ministry of Foreign Affairs and Trade, United States Department of State and the World Bank Group.

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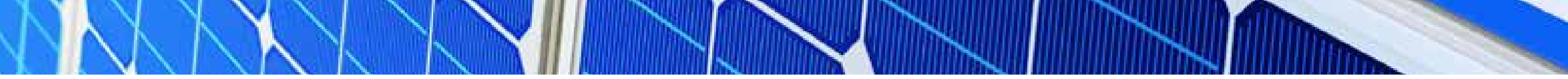
Renewable Energy Costs in the Pacific - Final Report
Collation of Renewable Energy infrastructure project cost data in the Pacific

ADB | Australian Aid | European Union | JICA | New Zealand Aid Programme | U.S. Department of State | World Bank Group

Cover Photo - Philippe McCracken, ITP. *The Tokelau Renewable Energy Project involved the installation of solar photovoltaic and battery systems on the three atolls of Tokelau in 2012.*
All other photos courtesy of ADB.



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Abbreviations

ADB	Asian Development Bank
ARENA	Australian Renewable Energy Agency
CAPEX	Capital Expenditure
DoD	Depth of Discharge for a battery bank
DFAT	Australian Department of Foreign Affairs and Trade
EIB	European Investment Bank
EU	European Union
FSM	Federated States of Micronesia
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
kW	kilowatt, unit of power
kW_p	kilowatt peak, photovoltaic DC power output under standard test conditions
kWh	kilowatt hour, unit of energy
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
IPP	Independent Power Producer
ITP	IT Power Australia Pty Ltd, trading as ITP Renewables
JICA	Japan International Cooperation Agency
LCOE	Levelised Cost of Electricity
MFAT	New Zealand Ministry of Foreign Affairs and Trade
OPEX	Operations and Maintenance Expenditure
PCO	PRIF Coordination Office
PIC	Pacific Island Countries
PNG	Papua New Guinea
PPA	Pacific Power Association (or Power Purchase Agreement)
PRIF	Pacific Region Infrastructure Facility
PV	Photovoltaic
PV-B	Photovoltaic and battery project
RAR	Regional Australia's Renewables, ARENA program
RE	Renewable Energy
SPC	Secretariat of the Pacific Community
TA	Technical Assistance
ToR	Terms of Reference
USD	United States Dollars
W	Watt, unit of power, W_p or W_{DC} is Direct Current, W_{AC} Alternating Current, where there is no subscript, the reference hasn't specified.
WB	World Bank

Definitions

LCOE	is the average price ($/kWh) over a generation project's lifetime such that the project breaks even.
RE penetration	instantaneous RE power (kW) divided by instantaneous total power (kW).
RE contribution	annual RE generation (kWh) divided by annual total generation (kWh).

Executive Summary

The *Renewable Energy Costs in the Pacific* study analysed the capital costs of large solar photovoltaic, wind and hydro generation projects built in the Pacific over the past decade.

There is a large range of project costs for renewable generation projects in the Pacific. This is due to a variety of factors including remoteness, scale, local capacity, perceptions of risk, design parameters and any upgrades for existing infrastructure included in the project scope. There are numerous challenges in obtaining cost breakdown data and making like-with-like comparisons. Insufficient cost breakdown data was obtained from wind and hydro generation projects to analyse trends.

This report focuses on capital costs (CAPEX) while the importance of operation and maintenance costs (OPEX) and Levelised Cost of Electricity (LCOE) are acknowledged. This is particularly so in the PV-battery-diesel mini-grid sector where there are examples of CAPEX being minimised in a manner that increases OPEX and LCOE. As the deployment of batteries is expected to increase in the Pacific region, the issue of assessing forecast lifecycle costs and battery life are likely to increase in importance. In addition, the impacts and costs of disposing of solar PVs and batteries is a growing concern in the Pacific. It is being investigated in a separate PRIF study on "Pacific Region Solid Waste Management and Recycling."

The key overall findings from the PV systems analysis include:

- The average, total installed cost of PV systems has fallen from around USD $12/W in 2008 to $3/W in 2018. Key factors affecting installed costs include scale, location, and footing type (rooftop, concrete or piled), as well as the need for fencing, civil works and any requirements to bring in sand and repair/upgrade existing infrastructure.
- The average, total installed cost of PV-battery systems has fallen from around $11/W in 2014 to $5 to $8/W in 2018. Key factors affecting costs are similar to PV only systems with the added factors of battery type and inverters sizing plus function, as well as any requirements for new control systems and buildings to house battery banks and inverters.

Analysis of the commercial in-confidence, system cost breakdowns obtained for this report provides the following generalised insights for component and other costs:

- PV modules have fallen from around $3/W_{DC}$ in 2012 to $1/W_{DC}$ by the end of 2013 and now can be as low as approximately $0.5/W_{DC}$.
- PV frames, show less of a downwards cost trend, possibly because this category sometimes includes footing components, with prices in the range $0.20 to $0.85/W_{DC}$.
- Grid-connected PV inverters have a range from around $0.15 to $0.40/W_{DC}$, with inverters for PV-battery systems being 30 to 75% more expensive. A better parameter for inverters is $/W_{AC}$.
- Where listed separately, civil costs show a wide range ($0.05 to $0.61/W for PV systems and $0.28 to $0.90/W for PV-battery systems, with two outliers at $3.52 and $9.88/W) with no clear trends over time. This indicates the location specific nature of preparing a site for a PV array and, if required, a new battery and inverter building plus the high costs of bringing in sand and earth moving equipment.
- Where listed separately, transport and insurance costs vary from $0.09 to $0.56/W (4% to 14% of total project costs) for PV systems and $0.31 to $3.19/W (6% to 15% of total project costs) for PV-battery systems. The wide range indicates the different logistical challenges of various locations in the Pacific, particularly outer islands.
- Large batteries and battery inverters varied from 22% of project costs to 42% of project costs. Small batteries varied from 14% of project costs to 38% of project costs.
- Batteries were costed between $200 to $750/kWh in the tenders examined, with no clear time-based trend. However, this range may be misleading for a variety of factors including that tenders were often unclear in their methodology for documenting inclusions/exclusions and specifying the capacity of the battery bank.

There are also significant economies of scale factors applying to renewable generation projects.

1. Introduction

In the last decade, investment in Renewable Energy (RE) generation infrastructure has significantly increased in many parts of the world, including in the Pacific region.

In 2018, all the nations in the Pacific have established RE targets for their electricity sector An overview of the countries examined in this report is shown in the following table.

Table 1: Pacific Island Countries' Electricity Sector Overview[1]

	Geography	Population	Electricity Access	Generation GWh pa	RE Target	RE Target by Year
Cook Islands	14 islands	15,200	99%	31.8	100%	2020
Fiji	320 islands, 106 inhabited	888,400	87%	900	100%	2030
FSM	607 islands	105,300	65%	72	> 30%	2020
Kiribati	32 widely scattered atolls	120,100	>65%	23	23 - 40%	2025
Marshall Islands	34 islands, mostly atolls	55,500	87%	101	20%	2020
Nauru	single island	11,000	100%	31.7	50%	2020
Niue	single island	1,520	99%	3.3	80%	2025
Palau	596 islands, 12 inhabited	17,900	98%	89.3	45%	2025
PNG	Over 600 islands	8,558,800	12%	217.3	100%	2030
Samoa	10 islands	196,700	100%	140	100%	2025
Solomon Islands	~1000 islands, 350 inhabited	682,500	23%	78	79%	2030
Tokelau	3 atolls	1,400	100%	1.2	100%	long-term
Tonga	176 islands, 36 inhabited	100,300	89%	55.4	50%	2020
Tuvalu	9 atolls	10,200	98%	5.2	100%	2020
Vanuatu	>80 islands, 65 inhabited	304,500	33%	66.3	100%	2030

Power utilities are frequently making investments in renewable generation infrastructure and increasingly signing renewable Power Purchase Agreements in order to:

i) reduce reliance on high cost diesel generation,
ii) improve energy security, and
iii) reduce greenhouse gas emissions.

This *Renewable Energy Costs in the Pacific* report aims to analyse the capital costs of large solar photovoltaic (PV), wind and hydro generation projects built in the Pacific over the past decade. The objective is to improve renewable energy project design and implementation through the provision of reliable, comparable capital cost data.

All costs in this report are USD unless otherwise specified.

1 ITP analysis from various sources, including Pacific Energy Country Profiles, NZ MFAT 2016, geography from *Fuelling the Pacific: Aid for renewable energy across Pacific Island countries*, C Betzold, 2015, estimated 2018 population data from SPC's 2018 Pocket Statistical Summary.

2. Methodology

An overview of the approach to developing this report was to:

- undertake a relevant literature review,
- develop a project data specification and target projects list,
- consult with stakeholders to obtain cost breakdowns, and
- analyse and graph key trends.

Further details on these activities follows.

2.1 Literature Review

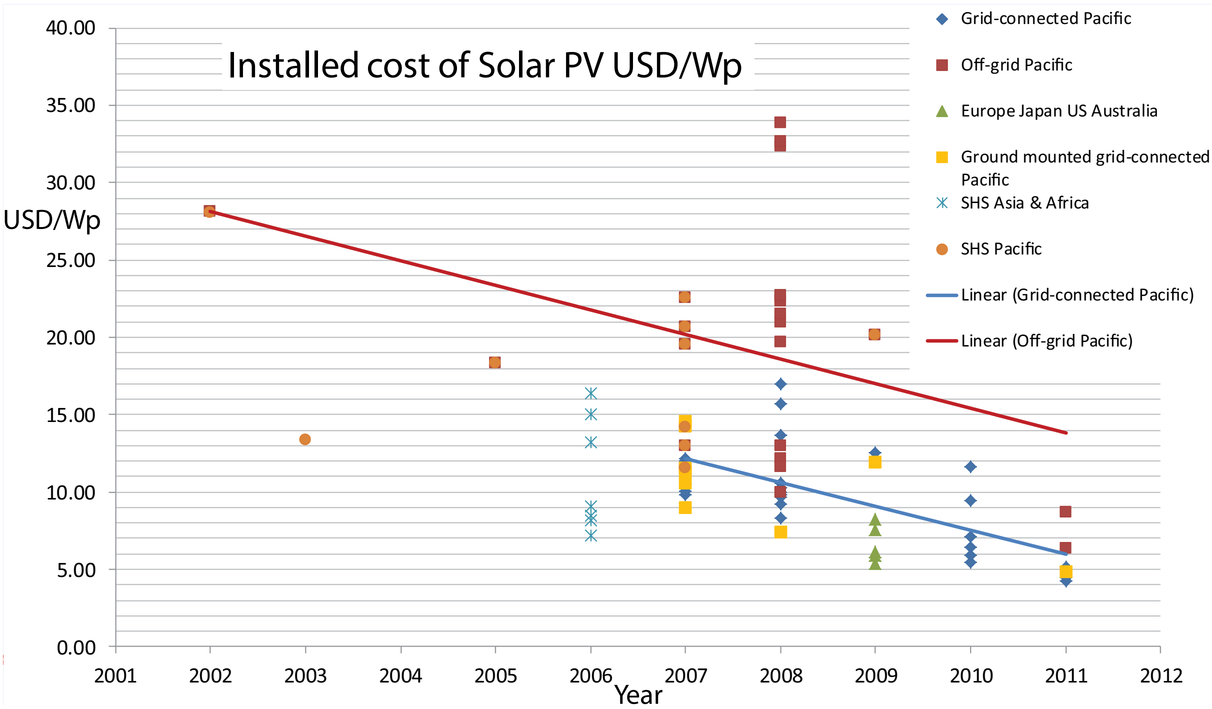
➔ *Costs of Renewables in Pacific Island Countries*, ITP presentation, Oct 2011

This presentation to an IRENA workshop in Sydney identified:

- data gaps as a key challenge for analysing renewable generation project costs, 'information on real, on-site costs of RE technologies in the Pacific is very limited',
- data is not systematically collected and is difficult to access from utilities and private companies due to confidentiality,
- cost data is not consistent due to inclusions and exclusions and different methodologies for itemising costs, and
- long supply chains and limited transport options, along with small markets and harsh environments lead to increased costs.

The research examined solar home systems (SHS), off-grid PV systems and grid-connected PV. A key figure from the presentation is shown below.

Figure 1: PV costs over time, from ITP, 2011



The analysis found the average cost of installed, grid-connect PV at just under \$10/W_{DC} (range \$4.5 to \$14/W_{DC}), while 'off-grid' PV cost just under \$20/W (range \$10 to \$34/ W_{DC}), highlighting the much higher costs when integrating PV and batteries on diesel mini-grids. For grid-connected PV, the costs of PV panels were just under 60% of the total project costs.

The analysis only had two wind projects and these were \$4.0/W_{AC} (Cooks 40 kW_{AC}, 2003) and \$3.3/W_{AC} (Fiji 10 MW_{AC}, 2006). The analysis had seven hydro generation projects in the Pacific and categorised their costs as micro-hydro \$4 to \$23/W_{AC} and small-hydro \$1.8 to \$4/W_{AC}.

The report concluded that:

- costs are not always directly comparable,
- it is not feasible to generalise across PICs as there is so much variability across countries (transport and logistics, labour, environment etc),
- institutional and regulatory environment and technical capacity have a big impact on costs, and
- transaction costs are high and hard to predict.

➔ *Grid-connected PV Systems in the Pacific Island Region*, GIZ_SPC, Aug 2013

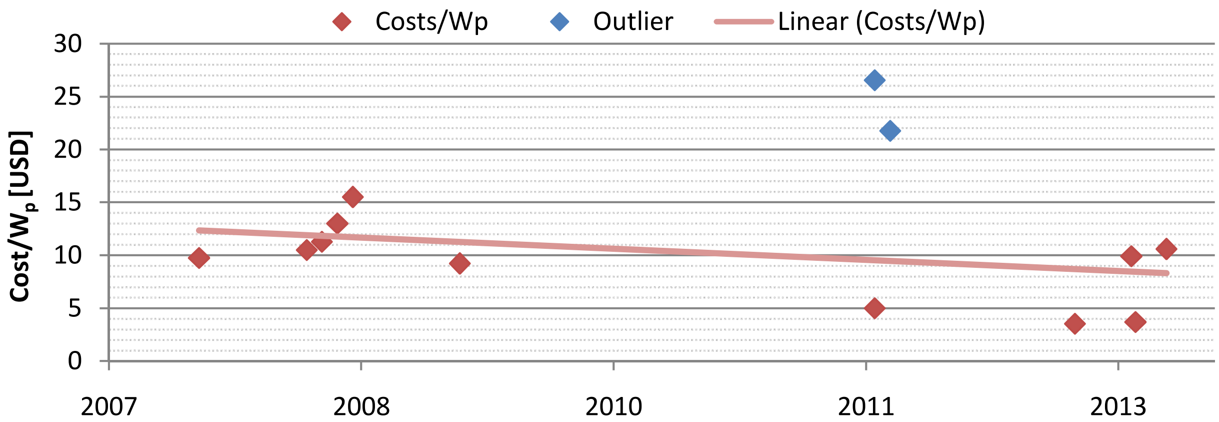
This report estimated there was a total of 3.2 MW of PV in the Pacific region as of July 2013. It also estimated that this would increase to a total of 10 MW by the end of 2015. It found, 'where data is available, the capital costs ranged from USD \$3.5 to \$15.5/W_{DC}, (excluding outliers) with an average of \$6.55/W_{DC}.'

The analysis reported the 1.3 MW_{DC} Maama Mai solar farm in Tonga, installed in November 2011 as costing \$5/W_{DC}. The contract for this project included 5 years of support for Tonga Power Limited for management and maintenance advice.

This report also documented the cost of three Japanese funded PV systems but their \$/W costs are not listed here as they are considered to be above market value.

This report indicated that the average capital cost for PV systems in 2014-15 was expected to be \$8.9/W_{DC} and provided the following figure on the installed costs of PV.

Figure 2: Cost per W_p, from GIZ_SPC, Aug 2013



Though the report noted that, 'since the analysis is relying on a small amount of projects (14 from 27 projects provided usable data), and even less when taking outliers out of consideration, the limited sample size precludes the possibility of finding a statistically significant relationship.'

The report analyses the performance of 10 PV systems where data was available. Though it also noted that 'polycrystalline panels are most common in the region, but for more than 40% of the systems, the panel technology was unknown'.

➔ ***Second Pacific Energy Investors Forum Final Report***, Pacific Power Association, Aug 2016

This report aimed to assist governments and utilities of 13 PICs to increase access to renewable energy through private sector investments. It examined the many barriers to private sector investment in the Pacific.

It listed the following costs for Independent Power Producer projects that had been built:

- PNG Bulolo 15 MW_{AC} Hydro, Morobe, commissioned March 2013, cost $3.33/$W_{AC}$,
- Samoa Upolu airport 2 MW PV, commissioned 2015, cost $3/W,
- Samoa Upolu racecourse 2 MW PV, commissioned 2016, cost $3/W,
- Vanuatu Devils Point 3.5 MW_{AC} wind farm, commissioned December 2008, $2.33/$W_{AC}$,
- Vanuatu Undine Bay 0.5 MW PV, commissioned April 2016, $2.28/W.

The report provides a list of six recommendations aimed at addressing barriers to IPP investments and provides the following four project proposals to be presented to potential investors:

- 2 MW_{AC} hydro, Savai'I, Samoa,
- 2.75 MW_{AC} wind, Savai'I, Samoa,
- 1.5 MW solar, Pohnlangas, Pohnpei FSM, and
- 80 MW_{AC} hydro, Naoro Brown, PNG.

The report provided estimated costs for these projects but, as they are estimates, they haven't been summarised here.

➔ ***Price of Solar PV Electricity in Developing Countries***, Global Solutions Group, Nov 2016

This paper focuses on the cost of utility-scale PV generated electricity on a cents/kWh basis. It forecasts that module costs are expected to be below $0.3/$W_{DC}$ within the next two years, though this is the manufacturing cost not the retail price.

The analysis is based on the 37 winning bids for utility-scale PV plants in 13 developing countries. The projects examined were estimated to have costs from $2.7/W (75 MW, South Africa, 2013) to $0.75/W (800 MW, UAE, to be commissioned in 2018).

None of the projects are in the Pacific and only one is below 10 MW. In addition, it is unclear how the authors have dealt with the issue of fixed PPA rates vs rates that are indexed through a variety of ways.

The analysis indicates that module costs are around one third of the cost. Adding in the inverters and balance of plant takes this to around 60% of total costs. The remaining 40% for engineering, procurement and construction plus other is described as very transaction, site and country specific.

The authors are optimistic for further cost reductions and encourage Multilateral Development Banks to assist driving PV electricity prices down by reducing financing costs through de-risking projects by assisting with structuring of procurement and/or providing guarantees.

➔ *Renewable Power Generation Costs in 2017*, IRENA, Jan 2018

This report focuses on the LCOE (c/kWh) of utility-scale generation projects. It claims that PV module prices have decreased by 81% since the end of 2009. The report provides the global weighted average of total installed costs of utility-scale RE generation projects showing:

- PV declining from $4.4/W to $1.4/W between 2010 and 2017,
- Onshore wind declining from $1.8/W to $1.5/W between 2010 and 2017, and
- Hydropower increasing from $1.2/W to $1.5/W between 2010 and 2017.

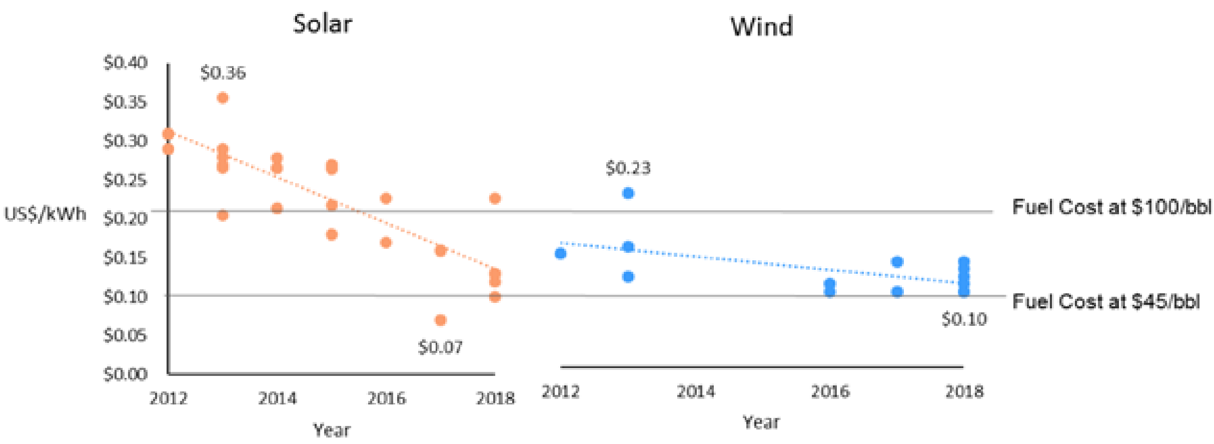
Though it is important to note that there is a wide range of project costs. This report is also optimistic about cost reductions for PV and wind continuing out to 2020.

➔ *Renewable Energy Island Index and Marketplace*, Castalia, Oct 2017.

This presentation to the Caribbean Renewable Energy Forum (CREF) 2017 discusses Castalia's spreadsheet that tracks the enabling environment and renewable projects in the Caribbean.

It contains the following figure examining PV (22 projects) and wind generation (13 projects) electricity costs ($/kWh) in the Caribbean.

Figure 3: USD per kWh levelised cost of renewable generation in the Caribbean, Castalia, 2017



This figure should be seen as illustrative only as examining the raw data indicates that significant assumptions are required to generate the $/kWh LCOE estimates. It also appears that many outliers have also been removed from the analysis.

➔ *IRENA Pacific SIDS Project Funding spreadsheet*, Dec 2017.

A copy of IRENA's Pacific projects spreadsheet was obtained for this report. The IRENA spreadsheet contains limited information on 150 funding allotments totaling around $1,108 million with an announced project capacity of 359 MW.

2.2 Project Cost Template

A cost template was developed, which was used to attempt to develop consistent cost breakdowns for the projects being examined. The cost template allows for detailed, itemisation of the project components and cost breakdowns.

2.3 Target Projects List

The IRENA spreadsheet was used to commence the process of developing a target project list for this assignment. The information in the IRENA spreadsheet was checked through web searches and updated by identifying renewable generation projects that had not been captured. This led to the development of a list of 71 renewable generation projects that could be targeted for this report. The target projects list is provided in Annex A.

Subsequent consultations reduced the target project list for detailed cost breakdowns which left a list of 43 target projects which, in practice, would most likely yield detailed cost breakdown information. However, by September 2018, complete cost breakdowns were obtained for only 16 projects and partial cost breakdowns for a further four. There are a range of challenges in obtaining cost breakdown data and these include:

- contracts requiring the written consent of suppliers before cost breakdowns are shared with third parties,
- inadequate physical and electronic filing systems for some stakeholders, and
- the additional work involved in attempting to find historical data.

Subsequent consultations reduced the target project list for various reasons. This left a list of 43 target projects, for which attempts were made to obtain detailed cost breakdown information. The analysis of the cost breakdowns is commercial in-confidence and is not provided in this report.

2.4 Data Issues

In addition to the challenges in obtaining cost breakdown data, there are also significant data gaps in information that is published on websites. For some projects, these include inadequate information on:

- exact location(s) of new generation infrastructure,
- clear dates and details on whether the date is funding approval, tender close, contract sign, full commissioning or launch event,
- whether PV is monocrystalline, polycrystalline or thin-film,
- whether PV power capacity figures are DC or AC, ideally both should be reported due to the trend to higher DC to AC ratios for PV systems,
- battery type, voltage, power capacity, energy storage size and rate, design depth of discharge, maximum depth of discharge and prime function,
- other infrastructure that may be included in the total project costs, such as gensets, network upgrades, new buildings, and
- key forecast parameters such as expected annual generation, maximum instantaneous RE penetration and annual RE contribution.

Some projects also have different key parameters published on various websites. There also appears to be incorrect information published on some websites.

To improve future research in this area, the following could be considered:

- tender specifications and contracts be changed so that cost breakdown data or percentages can be published,
- development of a standard template to allow for consistent cost data collection and publication, and
- any future work includes forecast and actual performance and OPEX, so that lifecycle costs can also be analysed.

PV DC/AC Ratios

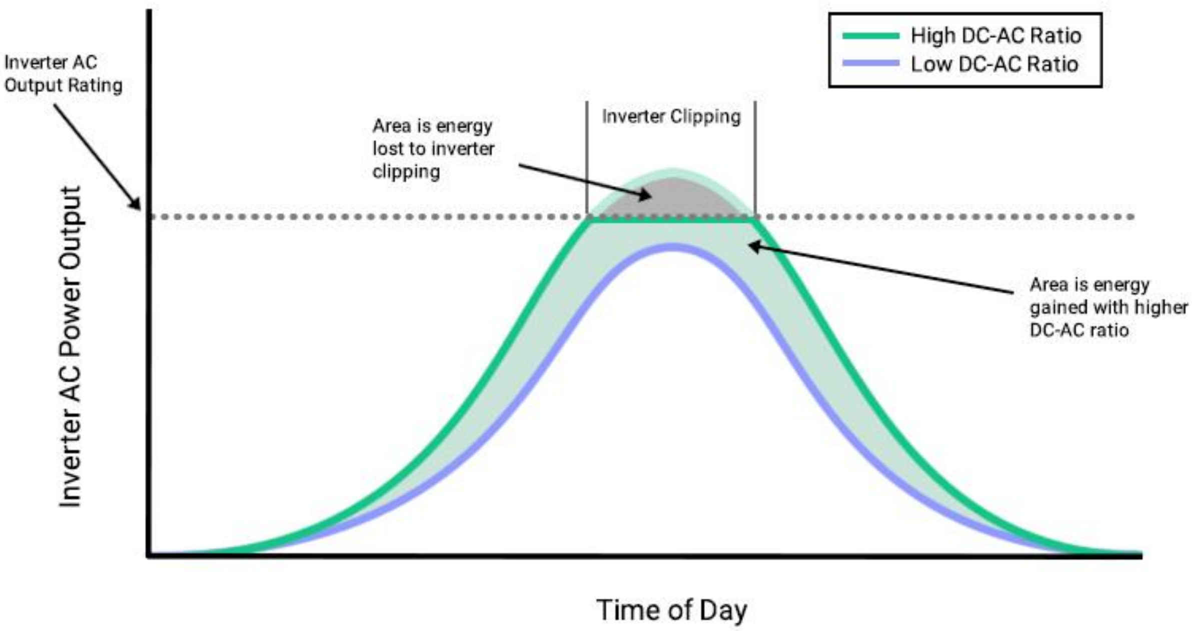
PV modules' DC rating is under standard test conditions which is 25°C, insolation 1,000 W/m^2 and 1.5 air mass. Installed on site and rooftops, PV modules can reach temperatures as high as 75°C and their temperature derating coefficient needs to be considered. This means that a 1 MW_{DC} PV array in the Pacific will average a peak daily output (on clear days) of around 0.8 to 0.9 MW_{DC} depending on type of PV module, actual solar insolation in the plane of the array, dust levels and any cooling from the wind.

When PV module costs were high and PV costs were a significant proportion of project cost, the design approach was to have no to very little PV generation spill. This meant that the inverter's AC sizing was chosen to match the PV array's maximum expected DC output, after temperature correction. These systems would likely have DC/AC ratios in the range of 1.0 to 1.2.

Now that PV module costs are relatively low, the trend has been to increasing DC/AC ratios. This results in partial PV generation clipping on some days but decreases the LCOE of annual generation. Performance modelling is used to maximise the return on investment by optimising the DC/AC ratio. This means that DC/AC ratios can now be in the range 1.2 to 1.5, depending on location and other factors.

The concept is illustrated in the following figure.

Figure 4: Daily output for PV systems with different DC/AC ratios, from Aurora Solar, 2018



Consider the graph above of energy production as a function of time of day. The blue line represents the design approach when PV costs were high wherein a typical bell curve of AC output power is peaking at noon just below the rating of the inverter indicated by the dashed line. Now that PV costs are relatively low, adding more panels to increase the size of the solar array increases the DC/AC ratio of the system allowing higher energy harvest throughout the day as shown by the green line. The area between the green and blue curves is the energy gained by increasing the DC/AC ratio. The optimal return on investment can be the design approach shown as the green line. In the middle of good solar days, the inverter manages the PV array's voltage and current, so that generation matches the maximum AC capacity of the inverter.

Capacity Factor

Capacity factor is defined as the annual generation (kWh AC) divided by the nameplate capacity output for the full year (8,760 hours x kW_{DC} rating of the PV array).

Capacity factors achieved in the Pacific will vary depending on numerous factors including annual insolation, DC/AC ratio, inverter efficiency, orientation, tilt, temperatures, dust, shading and grid outages. The capacity factor will also decrease over time due to PV module degradation.

For the Pacific, non-tracking PV capacity factors would typically be in the range 0.15 to 0.2. For the LCOE analysis, an average first year capacity factor of 0.18 has been used. This has been linearly degraded to 80% output in year 25, (capacity factor 0.144).

Batteries

Batteries can be designed and sized for a variety of functions, such as frequency control, ramp rate smoothing and/or grid-forming, overnight load supply. For example, a 1 MWh battery could be connected to a 0.2 MW_{AC} inverter or a 1 MW_{AC} inverter.

Definitional and data quality issues associated with batteries are discussed further in Section 3.1.

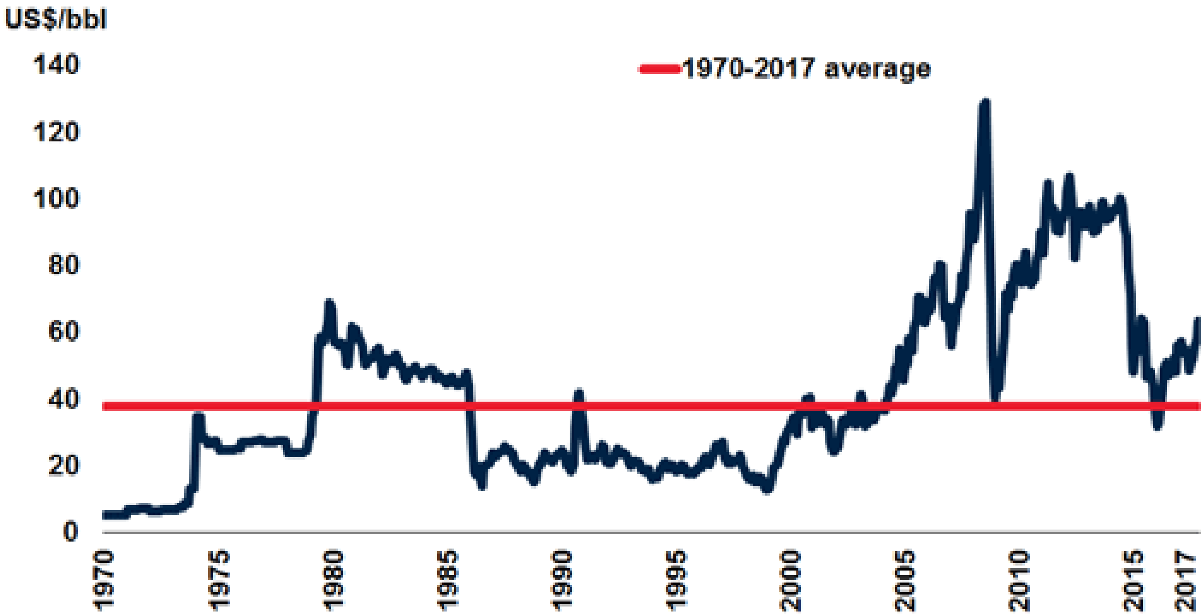
3. Capital Cost Analysis

This report focuses on capital costs (CAPEX) while the importance of operation and maintenance costs (OPEX) and the Levelised Cost of Electricity (LCOE) are acknowledged.

This is particularly so in the PV-battery-diesel mini-grid sector where there are examples of CAPEX being minimised in a manner that increases OPEX and LCOE. As the deployment of batteries is expected to increase in the Pacific region, the issue of assessing forecast lifecycle costs and battery life are likely to increase in importance. Also of importance is the disposal costs of solar PVs and batteries, which is becoming a growing concern in the Pacific. It is being investigated in a separate PRIF study on "Pacific Region Solid Waste Management and Recycling."

In addition, the cost of delivered diesel also varies by location and changes over time due to global markets. An indication of historical, real oil prices is shown below.

Figure 5: Real Oil Prices, from World Bank[2]



PICs are likely to be paying significantly more than the Singapore bulk diesel fuel price (about USD $0.65/litre in September 2018) due to the costs of delivery and the relatively small quantities of diesel purchased.

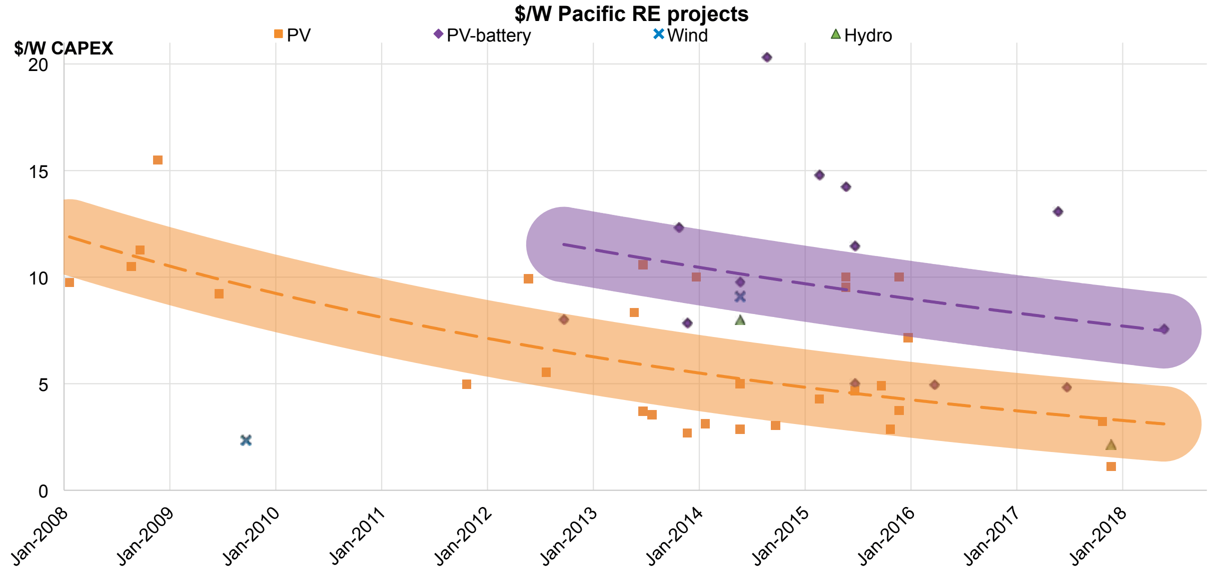
To provide an overview, the cost (USD / W) of 47 projects in the target project list in Annex A is summarised in Figure 6. The reasons why not all target projects are included, in order of frequency, are the following:

- inadequate information on category, capacity, budget or date,
- the inability to disaggregate significant costs from new transmission and distribution lines, e.g. desalination plants other infrastructure upgrades from the project budget,
- budget includes hydro refurbishments that were not able to be disaggregated, and
- multiple generation sources, e.g. a combined PV and wind project.

The analysis calculated W_{DC} for PV and W_{AC} for wind and hydro. The PV and PV-battery CAPEX trend lines are exponential best fit. There is insufficient data points to generate CAPEX trend lines for wind and hydro.

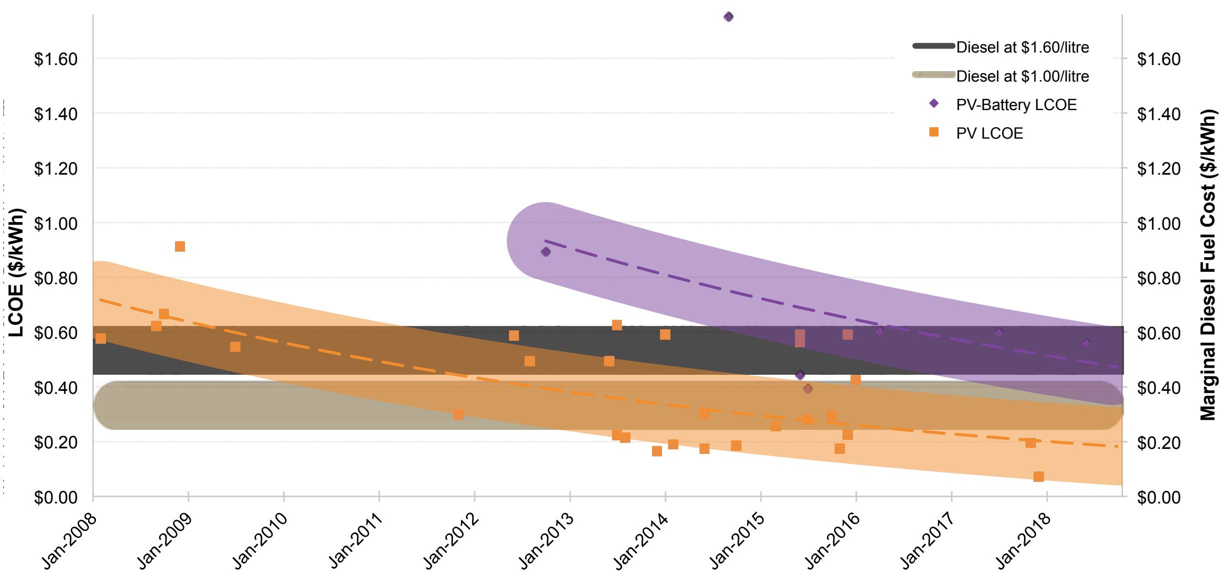
2 http://blogs.worldbank.org/developmenttalk/governance/what-triggered-oil-price-plunge-2014-2016-and-why-it-failed-deliver-economic-impetus-eight-charts

Figure 6: $/W capital costs of Pacific RE projects



To provide a comparison with the diesel fuel cost of generation, an estimate of the Levelised Cost of Electricity for PV projects is shown in Figure 7. Care is needed in drawing conclusions from this, as the average fuel efficiency of diesel generation in the Pacific varies widely.

Figure 7: Estimated $/kWh LCOE of Pacific PV projects and PV-battery projects compared to the marginal diesel fuel cost of generation



The PV LCOE estimates for this figure have been developed using an average PV capacity factor of 0.18 in year 1, degrading to 0.144 over 25 years, and a discount rate of 7%. The PV-battery LCOE estimates have assumed 65% of the PV output is delivered through the battery at 80% round trip efficiency with a battery life span of seven years. For six out of thirteen PV-battery systems, there was insufficient information on the battery details to estimate a LCOE.

The midpoint of the marginal diesel fuel cost bands illustrate only the fuel cost of generation for a diesel genset averaging 3 kWh/litre. As the actual fuel efficiency of diesel gensets can vary from 2 kWh/litre to more than 4 kWh/litre, depending on loading and other factors, the diesel trend lines are also shown as a band.

The trend lines in Figures 6 and 7 should be seen as indicative due to a variety of factors including:

- the potential for full project costs to not be captured where a project may have more than one funding source or contract,
- the potential for the budget to include additional costs that are beyond the renewable generation project build cost, for example Government and utility overheads, feasibility studies, owners engineering costs, approvals as well as other new infrastructure such as diesel powerhouse, gensets and power lines,
- scale and remoteness significantly affecting project costs as well as the cost differences for PV between rooftop, ground-mount concrete footings and pile-driven footings, and
- the costs from any new diesel gensets and range of costs from different battery sizing for PV-battery projects, (as usable battery sizing can vary from ~1 hour to 100 hours of full load depending on RE penetration and contribution as well as the function the battery is designed for).

The trend line for wind and hydro is not shown as there was insufficient data.

The large range of project costs highlight the challenges in developing cost forecast models for renewable generation projects in the Pacific. The Pacific region's specific challenges include:

- higher transport costs and limited shipping schedules,
- lack of local contracting capacity,
- small size of projects and markets resulting in poor economies of scale,
- high cost of locally sourced goods,
- low availability of locally sourced materials requiring importation of some construction materials, and
- contractors lacking familiarity with countries resulting in high risk premiums being added to bidding prices.

Due to the wide diversity between and within countries, a renewable generation project cost forecast model for the Pacific region has not been developed.

Any further work in this area would also need to consider other parameters that affect costs such as:

- instantaneous maximum RE penetration and forecast annual RE contribution,
- PV array DC/AC ratio and footing types,
- battery type, sizing, function and forecast life,
- network upgrades,
- new diesel gensets and control systems, and
- new transformers and buildings etc.

Care also needs to be taken in that lifecycle cost (c/kWh) is more important than CAPEX, as the highest CAPEX tender may have the lowest lifecycle cost due to the design optimising performance, minimising maintenance issues and achieving the longest battery life.

3.1 Other trend lines

Alternative trend lines for Figure 6 based on different timeframes and locations are provided below. Figure 8 shows the $/W capital costs of recent projects with available disaggregated data while Figure 9 shows Pacific RE projects implemented in the last 5 years.

Figure 8: $/W CAPEX trend lines for projects in 2012-18 with disaggregated data

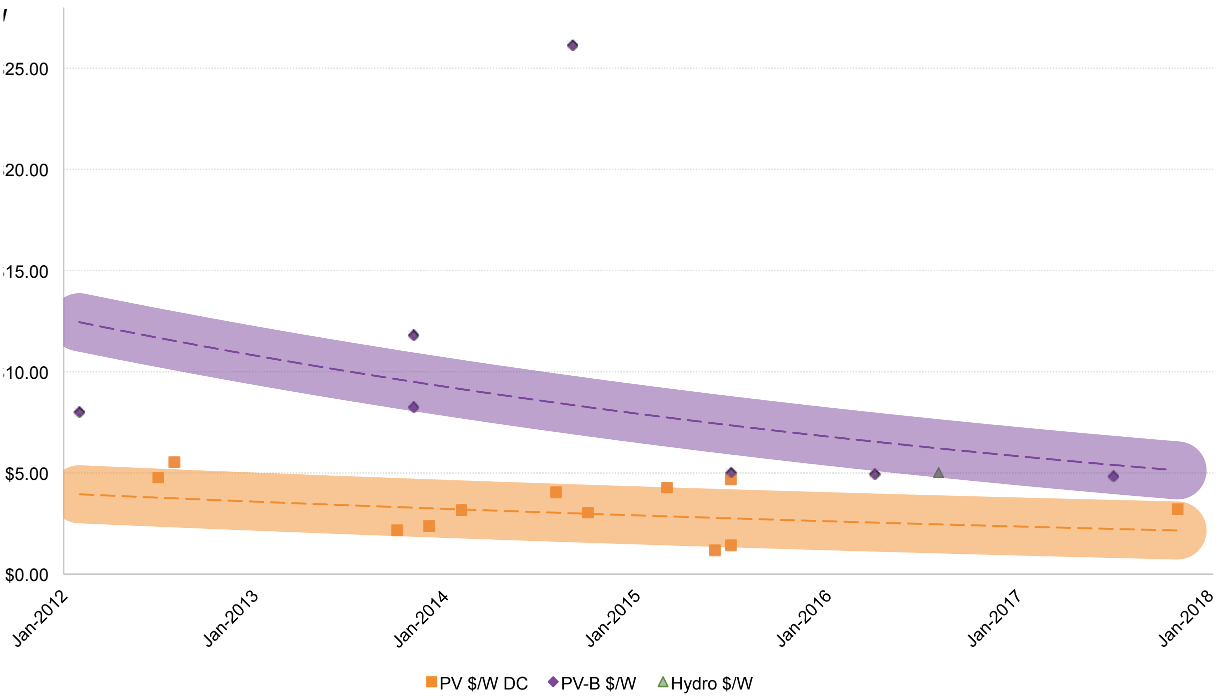
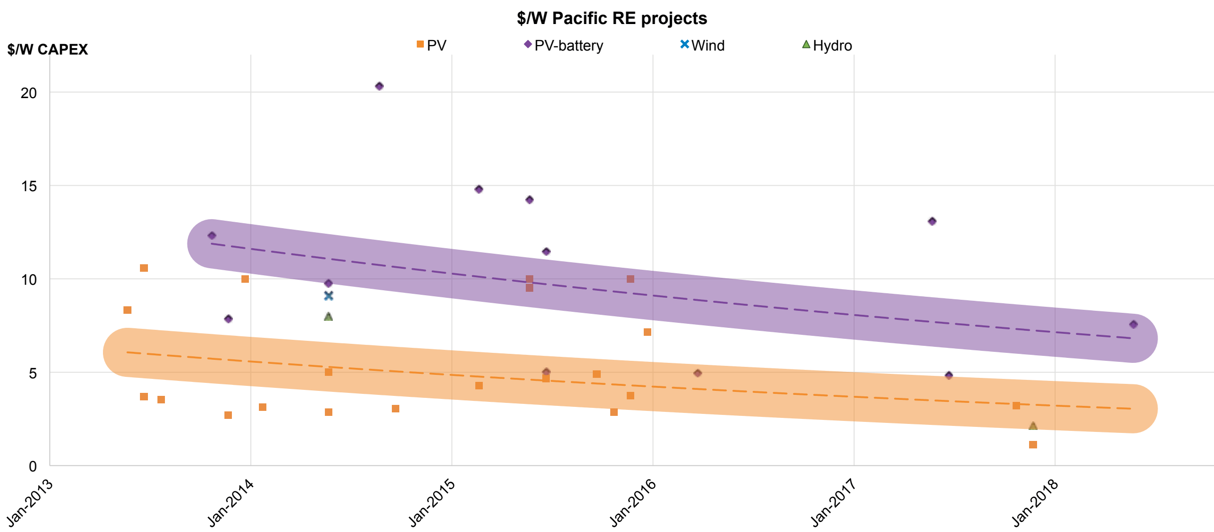
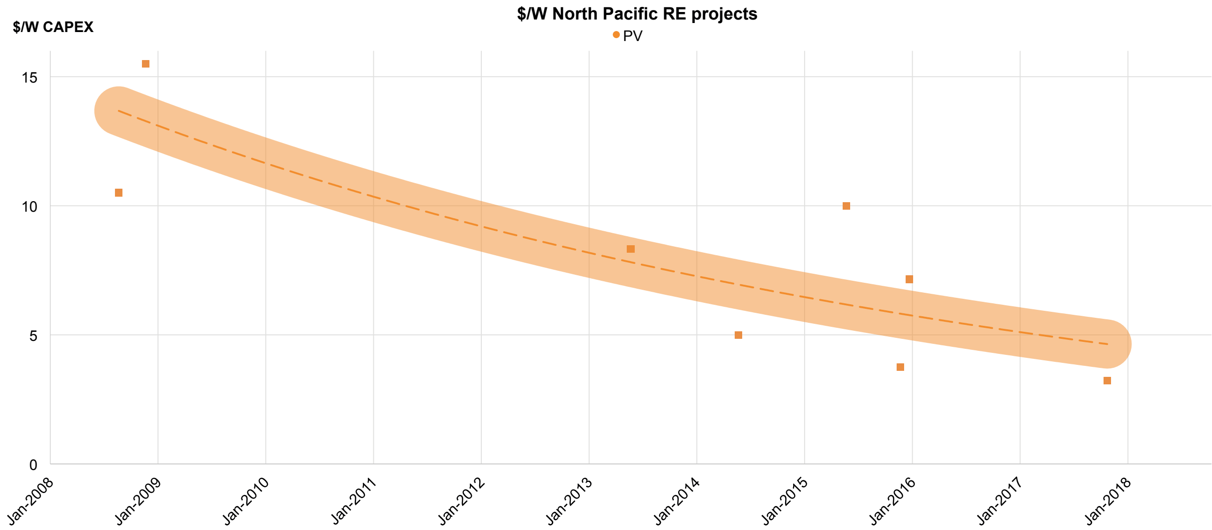


Figure 9: $/W CAPEX trend lines for RE projects in 2013-18



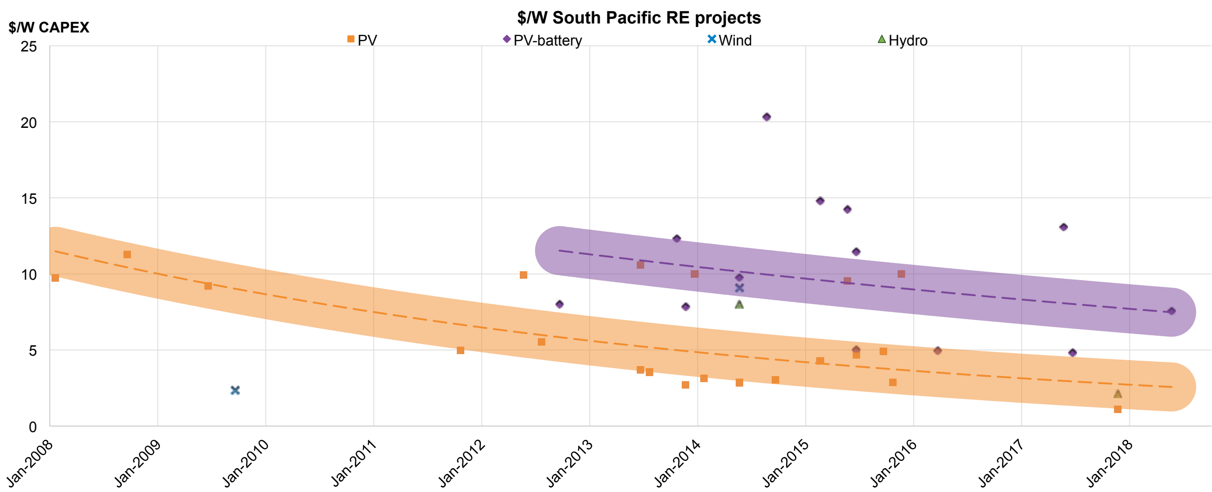
Given the geographical dispersion of Pacific island countries, the effect of project location is reflected in the following graphs considering the equator as the basis of grouping north and south countries.

Figure 10: Capex of projects north of the equator



The limited number of projects north of the equator makes the above trend line more indicative than others. However, the figures on this page do appear to indicate that PV projects in the North Pacific tend to have higher costs than those in the South Pacific.

Figure 11: Capex of projects south of the equator



3.2 Key trends

The key overall findings from the analysis include:

- The average, total installed cost of PV systems has fallen from around \$12/W in 2008 to \$3/W in 2018. Key factors affecting installed costs include scale, location, and footing type, (rooftop, concrete or piled) as well as the need for fencing, civil works and any requirements to bring in sand and repair/upgrade existing infrastructure.
- The average, total installed cost of PV-battery systems has fallen from around \$11/W in 2014 to \$5 to \$8/W in 2018. Key factors affecting costs are similar to PV only systems with the added factors of battery type plus inverters function and sizing, as well as any requirements for new control systems and buildings to house battery banks and inverters.

Analysis of the commercial in-confidence, cost breakdowns obtained for this report provides the following generalised insights for component and other costs:

- PV modules have fallen from around \$3/W_{DC} in 2012 to \$1/W_{DC} by the end of 2013 and now can be as low as approximately \$0.5/W_{DC}.
- PV frames, show less of a downwards cost trend, possibly because this category sometimes includes footing components, with prices in the range \$0.20 to \$0.85/W_{DC}.
- Grid-connected PV inverters have a range from around \$0.15 to \$0.40/W_{DC}, with inverters for PV-battery systems being 30% to 75% more expensive. A better parameter for inverters is \$/W_{AC} and this should be examined in any future work.
- Where listed separately, civil costs show a wide range over time (\$0.05 to \$0.61/W for PV systems and \$0.28 to \$0.90/W for PV-battery systems, with two outliers at \$3.52 and \$9.88/W) with no clear trends, indicating the site specific nature of preparing a site for a PV array and, if required, lifting ground levels, new battery and inverter building(s) plus the high costs of bringing in sand, aggregate, cement and earth moving equipment.
- Where listed separately, transport and insurance costs vary from \$0.09 to \$0.56/W (4% to 14% of total project costs) for PV systems and \$0.31 to \$3.19/W (6% to 15% of total project costs) for PV-battery systems. The wide range indicates the different logistical challenges of various locations in the Pacific, particularly outer islands.
- Large batteries and battery inverters varied from 22% of total project costs to 42% of total project costs. Small batteries varied from 14% of total project costs to 38% of total project costs.
- Batteries were costed between about \$200 to \$750/kWh in the tenders examined, with no clear time-based trend. This cost range may be misleading as:
  - some tenders were unclear in their methodology for specifying the capacity of the battery bank, its nominal or usable capacity or for what discharge rate[3] the kWh capacity was for,
  - some battery costs were given as total costs, while others were given as just the battery purchase cost and there were also costs that may be somewhere in between, for example battery cost includes racking and cables but not fuses and other protection, and
  - there are significant cost and battery life differences between the various battery types.

3 While C10 (discharge over 10 hours) is considered standard by some for assessing battery capacity, it is not always the most relevant depending on the design function and type of the battery. Usable capacity is a system design choice and effects the life of the battery which can have significant impacts on lifecycle costs (\$/kWh).

Table 2: The variety of battery types and characteristics make cost comparisons complex[4]

	Flooded Lead Acid	Gel Lead Acid	Lithium-ion	Zinc-bromine
Size litres/kWh	12 to 14	12 to 16	4 to 10	28
Approximate weight kg/kWh	35	25 to 35	7 to 10	24
Maintenance	High	Low-Medium	Low	Low
Cost	Low	Low-Medium	Medium-High	High
Roundtrip efficiency	80%	80%	90 to 95%	70 to 80%
Cycle life	1,200 at 50% DoD	1,800 at 50% DoD	3,000 at 90% DoD	3,650 at 100% DoD
Maximum Depth of Discharge	50%	50%	80% to 90%	100%
Relative capacity by discharge rate	100% at 20 hour rate	100% at 20 hour rate	100% at 20 hour rate	97% at 20 hour rate
	80% at 4 hour rate	80% at 4 hour rate	99% at 4 hour rate	100% at 4 hour rate
	60% at 1 hour rate	60% at 1 hour rate	92% at 1 hour rate	50% at 1 hour rate

- While it is widely reported that battery costs are decreasing over time, a significantly more important parameter for the Pacific is battery life, as a battery that fails after just a few years' operation is not optimal.

Due to the limited data obtained, the wide variety of cost breakdown methodologies and project costs, analysis of average % costs under each main component breakdown (e.g. PV modules/civil works/inverters/BOS etc) has not been undertaken for this report.

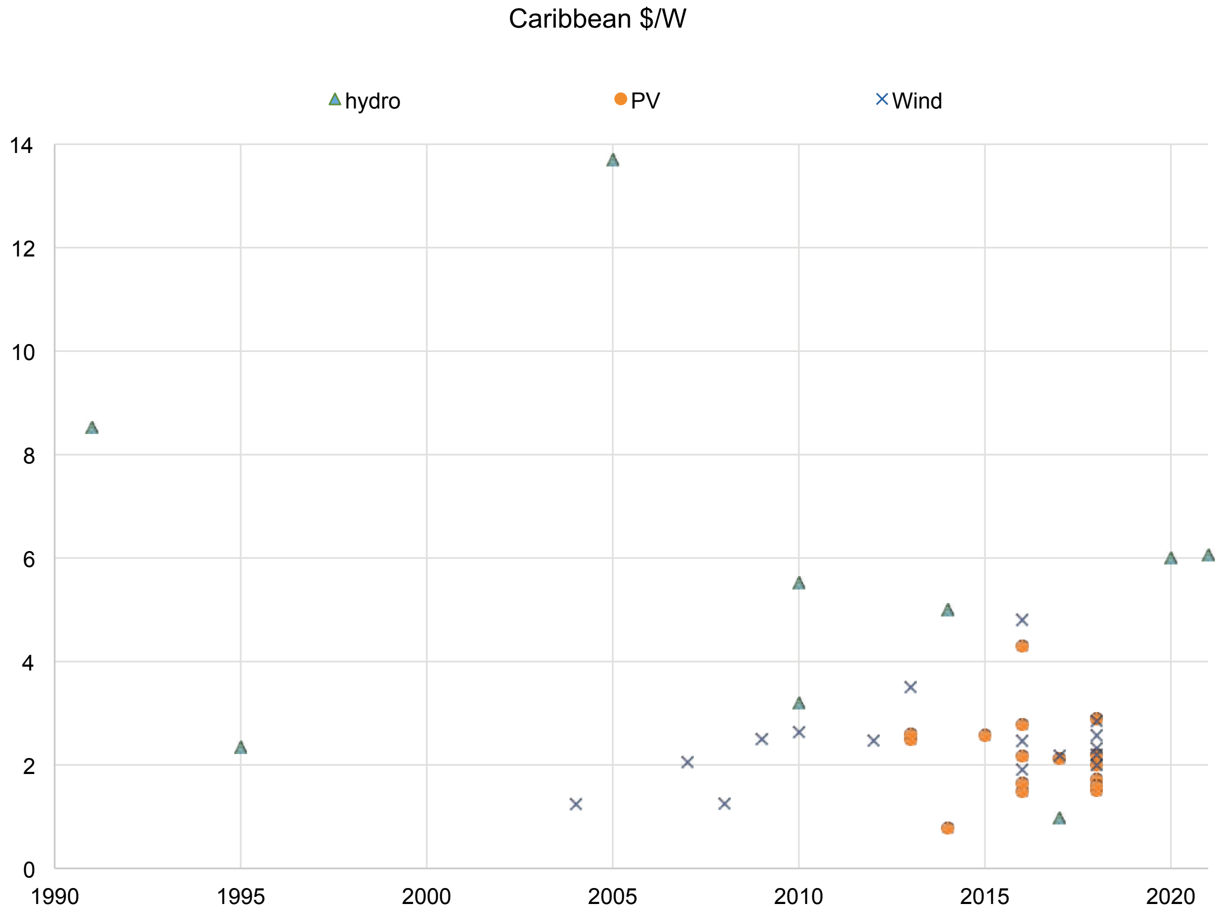
Developing a generic, project cost forecast model is not appropriate due to the wide range of renewable generation project costs and locations in the Pacific. If stakeholders require more accurate renewable generation project cost forecasts, they may need to engage expert advice after developing a detailed scope of work.

4 Illustrative, typical battery characteristics from various sources. Actual battery parameters depend on many factors (e.g. the category Lithium-ion has a range of types) and are provided in the battery product specifications sheet. The level of battery maintenance and temperature range also affect performance.

4. International Comparison

The data in Castalia's *Marketplace and the Index* Database[5] for Caribbean renewable generation projects was used to produce the following figure.

Figure 12: Caribbean renewable generation projects costs $/W, from Castalia data



This figure should be seen as illustrative only as:

- For the 268 projects in the spreadsheet only 146 have a CAPEX and it is unclear if this is a forecast figure, actual budget figure or an as constructed cost,
- For the 146 with a CAPEX only 41 have a 'Operation Date' with some dates being 2018 to 2021 indicating that the CAPEX is a forecast, and
- the PV figures haven't been split between rooftop, ground mount or diesel mini-grid potentially with batteries.

While the Caribbean is significantly less remote than the Pacific and has very different scale as well as economic bases, it is interesting to note that for 2018:

- grid-connected PV is forecast to cost between $1.51/W (5.9 MW Aruba) and $2.89/W, (19 MW Dominican Republic),
- wind generation is forecast to cost between $2.00/W$_{AC}$ (50 MW$_{AC}$ Dominican Republic) and $2.85/W$_{AC}$ (43.8 MW$_{AC}$ Dominican Republic),
- hydro generation costs show such a wide range that interpolating a cost for 2018 would be misleading.

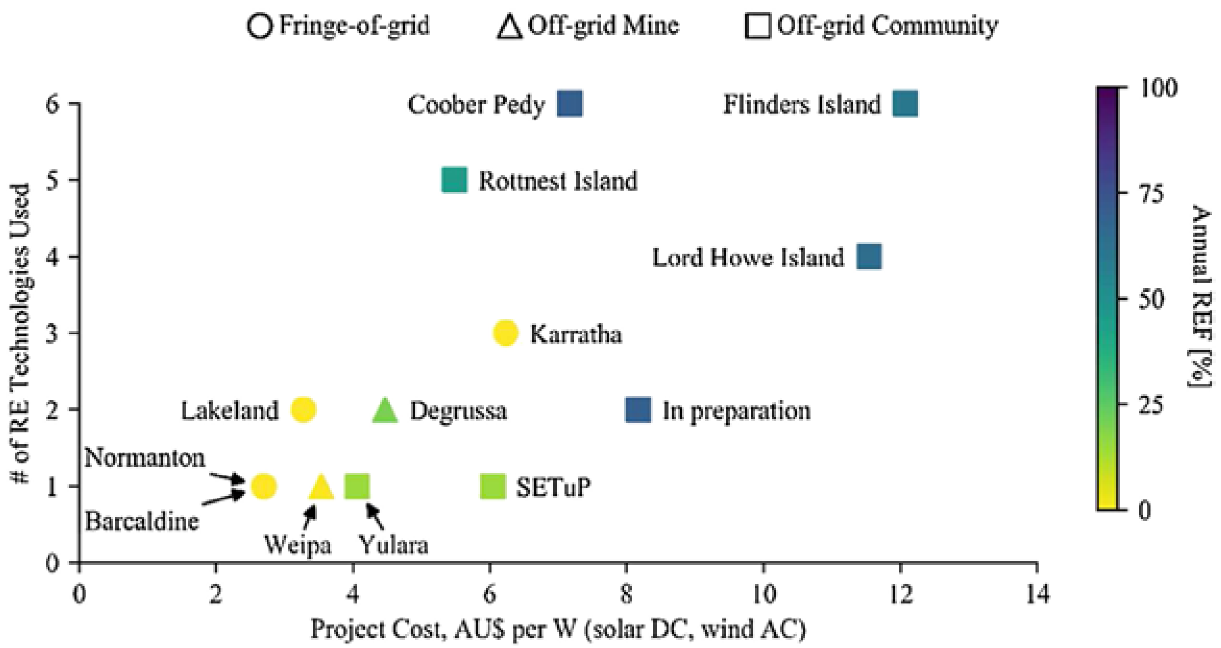
5 Available for download from: www.castalia-advisors.com/news_at_castalia.php&news_id=263

It is also interesting to note that while wind's CAPEX appears to have been increasing in the Caribbean, its lifecycle cost has been decreasing (see Figure 3) due to a trend towards higher capacity factors.

Costs in the Pacific are higher than in the Caribbean due to a variety of factors including scale and remoteness. Islands in the Caribbean also tend to have larger populations, local resources and larger economies.

Another interesting comparison is with remote sites in Australia. The following figure is from Ekistica's analysis of projects funded through the Regional Australia Renewables program.

Figure 13: Australian remote, renewable generation projects costs $/W (PV DC, Wind AC), from Ekistica paper



This figure shows costs in AUD. It illustrates that as the annual Renewable Energy Fraction (or annual renewable contribution) increases, the costs of integration with diesel gensets (e.g. batteries etc), significantly increase the $/W costs of the project.

5. Conclusions

This report has analysed the available capital cost data of large solar photovoltaic, wind and hydro generation projects built in the Pacific over the past decade.

While a significant data-set was found to be available for PV and PV-battery systems, there was insufficient data on wind and hydro generation capital costs to provide meaningful analysis.

The investigation found the average, total installed cost of PV systems has fallen from around USD $12/W in 2008 to $3/W in 2018. Key factors affecting installed costs include scale, location, and footing type (rooftop, concrete or piled), as well as the need for fencing, civil works and any requirements to bring in sand and repair/upgrade existing infrastructure.

For PV-battery systems, the system cost has fallen from around $11/W in 2014 to a range of $5 to $8/W in 2018. Key factors affecting costs are similar to PV-only systems with the added factors of battery type plus inverters function and sizing, as well as any requirements for new control systems and buildings to house battery banks and inverters.

It can be noted that the LCOE of PV is now significantly below the marginal diesel fuel cost of generation at both at $1/litre and $1.60/litre. Thus PV fuel-saving systems are economic in many Pacific locations, either as behind-the-meter rooftop systems or ground mount solar farms.

Once the capacity of PV fuel-saving systems reach the hosting capacity of the local grid and generators, further PV can be added with appropriate grid management, which typically involves energy storage. While Figure 7 in this report indicates that the LCOE of PV battery systems is now below the marginal diesel fuel cost of generation at $1.60/litre, it still has further to reduce to be below diesel at $1/litre.

However, it should be noted that this is general analysis and that PV-battery systems can be designed for anywhere between 30% and 100% solar contribution to annual load which has major effects on battery sizing and costs. Thus site specific analysis is required to optimise the economics of PV-battery systems and integration with existing infrastructure. The optimum solar contribution depends on numerous factors including generators' sizing, load forecast, diesel price path and battery price. This illustrates the importance of Government policies in assisting Pacific Island Countries making progress towards their renewable energy targets.

To improve future research in this area, the following could be considered:

- that tender specifications and contracts be changed so that cost breakdown data or percentages can be published,
- the development of a standard template to allow for consistent cost data collection and publication, and
- that any future work includes forecast and actual performance and OPEX, so that lifecycle costs can be analysed.

6. References

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2018 Pocket Statistical Summary, SPC, 2018.

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Grid-connected Photovoltaic Systems in the Pacific Island Region, GIZ-SPC, August 2013.

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Pacific Energy Update 2017, ADB, 2017.

Renewable Energy Island Index and Marketplace, Castalia presentation to the Caribbean Renewable Energy Forum, October 2017.

Identifying risks, costs and lessons from ARENA-funded off-grid renewable energy projects in regional Australia, Ekistica, 2017.

IRENA_PacificSIDS_Project Funding Dec2217.xls, project tracking spreadsheet provided by IRENA.

Aurora Solar, 2018

Pacific Energy Country Profiles, MFAT 2016

Annex A: Renewable Energy Projects List

An overview of the target project list follows.

Note: NI = no information found. Further notes provided at the end of the tables.

Cook Islands						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
NZ Aid solar	96.0			$340	NI, before Aug 2013	3 systems.
Solar PV Mini Grid - Mitiaro, Atiu, Mauke and Mangaia	1,364.0			$3,900	approved June 2014	Website says PEC Fund Grant $3,914,229.
Te Mana O Te Ra Solar Farm - Airport solar (Rarotonga Airport West)	960.0			$3,000	approved 2014, completed 2015	Switched on 15 Oct 2014, built by Infratec/ Solar City. Dec 2015 report on MFAT website says NZ funding was for 900 kW_p and NZD $3.5m.
Outer Islands Northern Group Solar	850.5			$17,281	tender 10 Dec 2013, USD convert rate 10 Dec 2013 completed 2015	$20.5m NZD six atolls (Manihiki, Rakahanga, Penrhyn, Pukapuka, Nassau, and Palmerston), 8 systems, opening ceremony for Penrhyn and Manihiki 19 May 2015, PowerSmart, Dec 2015 report on MFAT website says 6 mini-grids and NZD $19.5m and completed 2015, IRENA spreadsheet says NZD $25.554m before tax for 8 systems with 8,021 kWh of batteries.
Solar PV Projects - CI: RESP Mangaia, Mauke, Mitiaro, Aitutaki, Atiu and Rarotonga	3,000.0			$17,020	approved Nov 2014	Up to 6 PV projects includes battery plus network upgrades.
BESS - CI: RESP Battery (3 MW, 12 MWh) to facilitate 6 MW PV	potential 6,000			$12,000	approved 2016	Battery may be across 3 sites and PV 5 sites, includes networks and capacity building, weblink says $12m GCF grant is additional funding.
CI RESP: Additional funding				$13,710	approved 2016	This row and above two may be components of the one project.

FSM

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Kosrae 5 rooftops	52.3			$549	Sep-2008	PV 7.8, 11.7, 16.38, 4.68, 11.7 kWp roof and ground mount.
Grid Connect Solar Project - Chuuk, Kosrae, Pohnpei and Yap	800.0			$4,000	2014, approved June 2012	Up to 800 kW across four sites.
Pohnpei solar farm	600.0			$2,250	approved April 2015	Vergnet website has the 600 kWp Pohnlangas Solar Project, Madolenihmw municipality in Pohnpei and has contract signed Oct 2015, commissioned in March 2016 and launched 14 May 2016.
Kosrae State RE Project (not built yet)	500.0			$15,000	approved 2017	Includes 42.7km of new distribution lines.
Pohnpei State RE Project (not built yet)	9,000.0		5,500	$66,300	approved 2017	9 MW PV, 5.5 MW hydro, 5 MWh battery.
Yap RE Development	300.0	875		$9,040	approved 2013	0.3 MW PV, 0.875 MW wind, 2 diesel gensets, battery 1.5 MW for 5 mins.

Fiji

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Port Denarau	122.0			NI	Feb-2013	Sunnergise install 'in December'.
LaKaRo Solar PV systems	525.0			$5,000	2015	3 systems 153 kW Lakeba, 153 kW Rotuma and 225 kW Kadavu.

Kiribati

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Solar PV Grid Connect project, South Tarawa	400.0			$4,000	2015	Approved 2012, Bikenibeu.
Solar and Water Protection	500.0			$5,000	2015	Approved Jan 2014, built on aquifer, off-grid mentioned.
Kiribati Grid Connected Solar PV Project	548.0			$3,920	approved March 2013 cost and size from WB media release dated 23 Sept 2016	WB website also says 516 kW and $2.85m (no date). Installed at four sites in Tarawa: Kiribati Institute of Technology, Betio Sports Complex, Tungaru Hospital and King George V Secondary School.
Kiritimati Energy Sector Program	150.0			$7,550	to be completed in 2018	EU EDF10 / NZ, website calls it Solar Energy for Outer Islands $4.1m euro, SPC website says groundbreaking ceremony 23 March 2017 and energy project is 7m euro = $7.55 USD on 23 March 2017. Tender dated Nov 2017 is in euro and has the 151.2 kWp project costing more than $3/W.

Marshalls

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Majuro Hospital	205.0			$4,462	Feb-2012	Japanese Cool Earth program, budget likely to contain other infrastructure costs and upgrades.
Ebeye Solar	600.0			NI	outline design July 2017	Not in IRENA spreadsheet.
Solar Water Collection	600.0			$5,000	approved 2013	Water reservoir system, 'launched' August 2016.

Nauru

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Nauru College	39.0			$439	Oct-2008	REP-5.
Desalination and Solar Power Generation	131.0			$1,300	approved Dec 2011	NI on location, was part of PEC Fund for desalination, website says $4m but this includes Hitachi desal plant, Purchase Order for PV components supply was for 132.07 kWp and more than NZD $5/W dated 31 July 2012.
Masdar Solar	500.0			$5,000	2013	IRENA spreadsheet says 2013. Project was commissioned in May 2016.
Meneng PV Farm (not built yet)	1,000.0			NI	to be built in 2018	Includes some demo water collection, Infratec won tender, final size of PV array may be larger than 1 MWp.

Niue

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Niue 2 rooftops & ground mount	52.8			$487	Jul-2009	Roof 1.7 kW Niue Power Corp, 20 kW high school and ground mount timber frame 30.6 kWp (180 x 170W panels) at hospital, (totaling 52.3 kW though sentence says 52.8 kW) REP-5 funding. IRENA spreadsheet has this as 52.5 kW at Hospital and High School.
RE & EE for Niue - project focused on upgrading network	95.0			$3,360	approved 2008	NI on number of PV systems, photo is ground mount. This may be airport project. Majority of funds spent on upgrading network.
Solar System for Nuie Airport	89.3			NI	commissioned 1 May 2014	458 x Aleo 195 Wp PV modules with SMA STP10000TI-10 and SB3000 inverters.
Design, Manufacture and Installation of Solar Powered Grid Connected Generators and Battery Backed Power Stabiliser Project	202.4			NI	installed 2014	The PEC Fund will support the supply and installation of a 200 kW grid connected solar PV system with 200 kW battery bank to stabilize the grid. Concrete slab spans entire array. 880 Mitsubishi 230 Wp PV modules. Toshiba battery (200 kW, 157.3 kWh li-ion) disconnected soon after installation. Two 100 kW inverters replaced with 10 SMA 20000TLEE-10 inverters.
Solar PV	600			$3,400	2016	To install solar PV panels and battery storage to increase Niue RE generation from 13% to 40% by 2018. MFAT website has budget as NZD $5m and target by 2018. 2016 pdf on MFAT website has a project of 200 kW on northern feeder, 50 kW wind, 1.8 MWh battery to bring Niue to 13% RE. This project is BESS 750 kW, 3.15 MWh plus 600 kW PV. There's also some distributed PV, which may be a separate project.
Accelerating RE and EE	NI			$3,322	2017	Mainly institutional but may include some PV demonstrations.

Palau						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
Capital Complex Solar Carpark Shade	98.3			$1,523	Dec-2008	REP-5, car park shading, IRENA spreadsheet has 100 kW.
Airport Solar Carpark Shade	226.8			$6,956	Oct-2011	Cool Earth program, IRENA spreadsheet has 225 kW. Cost may include other infrastructure costs and upgrades.
Peleliu desal project	64.0			$4,000	2014	Cost includes RO desalination plant.
National Track and Field	150.0			NI	2014	IRENA's Palau Energy Roadmap (Feb 2017) has this as 'installed July 2014'.
Peleliu 100 kW + low load diesel and Angaur 100 kW + low load diesel	200.0			$5,000	2014	Cost also includes funding for 100 subsidised loans for 100 residential 1.7 kW PV systems.
IRENA spreadsheet has 6 JCM grant funded rows for 8 PV systems	1,089.9			NI	2012 to 2017	JCM acronym not explained, Ace Hardware, Ben Franklin Warehouse, Desekel, Surangel Supercenter, PMA Gym, SDA Elementary School, Commercial Project, Mindszenty High School.
IRENA spreadsheet has loans for 217 kW residential and 40.8 kW commercial	257.8			NI	2010 to 2017	NDBP acronym not explained, probably the National Development Bank of Palau, possibly numerous small systems.
Ministry of Health, Swimming Pool, Ministry of Education, Echang Gym, Koror Elemental School.	292.0			NI	various years 2008 to 2017	Across five sites, funded by Taiwan.

PNG						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
5 solar powered desal plants + maybe two spares	200.0			$4,000	2014	
Expand Access to affordable, reliable and clean energy	NI			NI	2015	Extending the grids and piloting renewable sources of generation and standalone mini-grid distribution.
Facilitating Renewable Energy & Energy Efficiency Applications for Greenhouse Gas Emission Reduction (FREAGER)	240.0			$3,141	June 2017 to May 2021	Total project $27m includes hydro mini-grids, PV mini-grids township EE and CB, website indicates $3,140,640 is budget administered by UNDP.
Town Electrification Program Tranche 1			6,000.0	$73,300	approved 2010	Construction of the 150 km of 66 kV transmission lines between Bialla and Kimbe in West New Britain province began in July 2016, and land acquisition for two run-of-river sites (Divune and Ramazon) is complete. Each hydropower plant will provide 3 MW of generation capacity.
Town Electrification Program Tranche 2			refurb 38 MW and new 3 MW	$60,900	approved 2017	Construct Ramazon run-of-river 3 MW including 5km pipeline, new road.
Port Moresby Power Grid Development			NI - refurb	$83,000	2017	Rehabilitate two existing hydroelectric plants - Rouna 1 and Sirinumu TOD; construct new Kilakila substation and 66kv transmission line; improve Moresby transmission and distribution infrastructure; and provide project management support and capacity building.

Samoa						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
RE Development and Power Sector Rehabilitation Project			refurb 4.69 MW and build 3.3 MW	$19,210	$18.21m approved 15 Nov 2013, extra $1m approved 18 Nov 2015	Project will support the Govt's policy to increase power generation from RE sources, rehabilitate damage to the power sector caused by cyclone, and increase the power sector resilience to future natural disasters. It will rehabilitate 3 small hydropower plants (SHPs) on Upolu and construct 3 new SHPs on Upolu and Savai'i. The project will also provide training to the Electric Power Corporation (EPC) on O&M of the SHPs for up to two years after plant commissioning.
Solar Power Development Project (out-of-scope as loan is for private procurement?)	1,800.0			$2,000	Approved Aug 2017	The project is to expand a 2.2 MW solar arm operated by Sun Pacific Energy Ltd (SPEL) by adding 1.8 MW of solar. The project will install up to 4 MW of solar power generation owned and operated by SPEL (IPP) and sell electricity to EPC.
Faleata Racecourse + Salelologa PV projects (Reid).	1,940.6			$5,231	Racecourse finished as 2.2 MW in Aug 2014 Salelologa 143.5 kW finished in Oct. Reid website says farm started feeding power to grid in Nov 2014.	Final cost may be NZD $7.5m which may include Gym's 240 kW.
Faleata Racecourse PV project (First Solar).	2,100.0			20 year PPA	First Solar say switched on 26 May 2016	First Solar racecourse PV is 1.4 MWAC. Solar for Samoa say project cost $6m.
Faeolo International Airport PV project (First Solar)	NI			PPA	first half of 2016	Airport PV is 2.1 MWAC, First Solar say in operation since first half of 2016. Maybe 3.1 MWDC.

Samoa						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
Samoa's 400 kW Solar PV project	546.0			$4,550	Apr-14	The project is to install 400 kWp solar system at Tanugamanono (Upolu), Vaitele (Upolu), Salelologa (Savai'i). Unclear why IRENA spreadsheet lists this as a 540 kW PV project. Media release lists it as 546 kW and has it spread over 3 sites. Tender was for over $3m not including 15% VAGST, higher reported cost may be due to contract requiring string inverters as opposed to tender's central inverters.
550 kW Cyclone Proof Wind Farm		550		$5,000	2014	Upolu 550 kW wind farm.
Hydropower project in Samoa			NI	$5,420	NI	Weblink has budget as 4,600,000 euro but no further info.
Power Sector Expansion Project			1,050	NI	Approved 2007	Project data sheet has 4 generation projects, NI on size, one appears to be the Alaoa Hydro Refurb to 1.05 MW for $1.5m, Upolu 23 MW diesel.

Solomon Islands

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Provincial RE Project			750	$6,000	approved 12 May 2014	Fiu River Hydropower plant put into operation by SIEA. Construction of a 750 kW hydropower plant
Solomon Islands mini-grids	492.8			$2,437	29 April 2016	Three PV-battery systems (Afio, Seghe, Taro). Date from cost summary. Total battery capacity 3.246 MWh.
Solar Power Development Project	2,000.0			$9,000	approved 21 Nov 2016	May be across 5 remote provinces and be total cost $15.2m.
Solar PV plant Honiara	1,000.0			$5,000	NI	Website says first 600 kW was funded by NZ MFAT.
Stimulating Progress towards Improved Rural Electrification in the Solomons (SPIRES)	NI			$18,340	resubmission date 21 Mar 2017	GEF contribution $2,639,726 with concept approved 1 Nov 2017.
Tina River Hydro			14,000	$30,000	concept clearance 24 May 2017	Website says $12m grant plus $18m loan, not built yet.

Tokelau

Project Name & details	PV kWp DC	Wind kW AC	Hydro kW AC	Cost USD $,000	Key Dates (if known)	Notes
Tokelau Renewable Energy Project	927.4			$7,427	Commissioned Oct 2012	3 atolls, 8 MWh of batteries, cost is converted from NZD $8,425 (Jan 2012) to USD (March 2018).

Tonga						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
Maama Mai Solar Farm	1,300.0			$6,468	site works start Nov 2011, commissioning completed Aug 2012	Meridian to provide support to TPL for 5 years, IRENA spreadsheet has this as 2012, 1 MW and $5.4m, TPL website says commissioned July 2012, 1 MW and NZD $7.9m. Dec 2015 report on MFAT website says Project Budget NZD $9.24m and ~1 MW_{AC}.
Mata ' o e La'a Solar Facility	1,000.0			$14,800	Mar-2015	Monocrystalline, 1 MW lithium ion capacitor bank.
Outer Island RE Project (43452-022)	1,320.0			$6,800	approved 27 June 2013	The Project will supply secure, environmentally sustainable energy to households, schools, and other public facilities, on the islands of 'Eua, Ha'apai, and Vava'u. ADB website says nine outer islands and 1.32 MW with additional $5m. Additional funding $1.44m ADF and EU $3.57m.
Vava'u 512 kW Solar PV System	512.0			$5,000	Nov-2013	PV system on the island of Vava'u with storage integrated into the system.

Tuvalu						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
Funafuti soccer stadium	42.1			$410	Feb-2008	Japan Govt plus E8, IRENA spreadsheets has $412,000.
Funafuti desal	65.5			$693	Jul-2013	PEC funded, IRENA spreadsheet has $4m which probably includes the desal plant.
Tuvalu RE Project	1,039.0			$12,806	2013 USD convert rate 5 Feb 2014	Includes the installation of 4 hybrid PV systems (Nanumea, Nanumanga, Niutao and Vaitupu) on outer islands and hybrid PV on selected buildings in Funafuti. IRENA spreadsheet has this as $13m and 5 PV systems, June 2015.
Solar 500 kW across three rooftops and three structures	500.0			$2,454	Oct-2015	PV on Funafuti (350 kW at TEC and 150 kW rooftop at PMH and Marine Shed).
Improving reliable access to modern energy services through solar PV systems for rural (outer islands) of Tuvalu	192.0			$2,201	2015	Nukulaelae, Nukufetau and Nui.
Tuvalu Energy Sector Development Project	925.0			$7,000	2018	Yet to start.

Vanuatu						
Project Name & details	**PV kWp DC**	**Wind kW AC**	**Hydro kW AC**	**Cost USD $,000**	**Key Dates (if known)**	**Notes**
Luganvile 3 rooftops	40.0			$148	Jul-2013	College de Santo, Sanma Province & Northern District Hospital.
Parliament and VMGD solar	767.2			$2,207	Contract signed Nov 2014	Four PV systems, one car park shade, two ground mount and one rooftop. Contract signed November 2014 and significantly varied April 2015.
UNELCO Wind farm		2,750		$6,440	IRENA spreadsheet has 'approved Oct 2009'	Website has EIB finance as 4.3m euro and cost as 5.72m euro and signature date as 20 Oct 2009. Vergnet website has this as commissioned Dec 2008.
Port Vila PV rooftop and ground mounted	500.0			$5,000	Jan-2014	Three new solar PV plants help increase the share of renewable energy in the energy mix in addition to providing shading for 112 parking spaces at the country's key civic areas.
Solar PV grid-connected	1,500.0			$4,300	2015	PRDR for SE4ALL website says tender in process Nov 2015, but no further updates.

Notes

1. A large amount of information on websites is undated, so determining key dates or the relevance of information is not always straightforward. For some dates, the reference website does not specify if the date is funding approval, tender closing, contract award, construction start or system commissioning or launch event.
2. Many projects have different costs and sizes depending on which website is being referenced. Some of this is rounding, eg a PV 98.3 kW_{DC} project being reported as 100 kW solar system. There's also issues with some projects in that the sizing and budget appears to change over the project cycle, eg approval, design, tender, construction and commissioning. For example, the World Bank website reports two different sizes for the Kiribati Grid Connected Solar PV Project.
3. The majority of information on websites regarding PV projects does not document if it is the DC rating of the PV array or the AC rating of the inverters that is being described. Ideally both numbers should clearly be reported, as falling PV prices have increased the trend to higher DC/AC ratios for PV systems. There's also extremely limited information reported on the type of PV module being used, eg monocrystalline, polycrystalline or thin-film. Battery power and capacity is frequently inadequately documented with limited information on type, discharge rate, nominal or usable capacity.
4. All costs have been converted to USD as at the most appropriate date identified. Where the date is given only as a year, the average conversion rate for that calendar year has been utilised.
5. Care needs to be taken in interpreting project costs as many projects include other items such as network upgrades and new network infrastructure, diesel gensets, powerhouse control systems, desalination plants, capacity building, training, spare parts and other components.

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