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Lessons Learned on Resiliency and Uptake of Variable Energy Resources from Islanded Grids that support APEC Clean Energy Goals

APEC Energy Working Group

May 2023

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This report was prepared for APEC by Strategen Consulting. The report provides general information that is illustrative in nature only. It should not be interpreted as advocating for any specific solution or approach, nor relied upon as a basis for decision making. As the context and needs of individual customers, communities and energy systems are unique, specific advice should be sought from qualified experts to assess both the needs of, and most relevant solutions for, each individual case. Neither Strategen Consulting nor any of its employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, approaches, solutions or processes reported.

Executive Summary

Islanded power systems around the world are playing key roles in leading the transition to decarbonise electric power systems. They are also well positioned to realise the benefits and enhanced operational resilience given their typically remote locations and their historical reliance on diesel with its price volatility and supply chain risks.

At the same time, in contrast to GW-scale interconnected grids, islanded power systems face a unique set challenges to integrating higher amounts of Variable Renewable Energy (VRE), including:

- Technical considerations: Selection and deployment of generation technologies and their enabling technologies, particularly for system stability, frequency control and voltage management.
- Regulatory and policy considerations: Frameworks that allow for innovation and promote the necessary social license for change; and,
- Market and economic considerations: Innovative financing, subsidy and funding arrangements that are fit-for-purpose for supporting deep decarbonisation.

Intersecting each of these is strategy and planning, which must be undertaken in a rapidly changing, uncertain and unpredictable energy ecosystem.

This report is intended to be a resource for navigating these challenges in two ways:

1. By collating lessons learnt by existing high VRE islanded power systems in operation.

   The ten islanded grids listed below were selected to provide a diversity of insights given their varied generation mix, enabling technology choices, policy and regulatory environments and market and commercial dynamics:

   - Australia:
     - King Island, Tasmania,
     - Onslow, Western Australia
     - Lord Howe Island, New South Wales
   - United States:
     - Kaua’i Island, Hawaii
     - Kodiak Island, Alaska
     - Cordova, Alaska
     - Hawaii Island, Hawaii
   - Canada:
     - Old Crow, Yukon
   - Chile:
     - Isla Huapi, Los Lagos
   - Samoa:
     - Savai’I, Upolu and Manono Islands,

2. By identifying and summarising key insights captured in the diverse and voluminous global literature relevant to islanded power systems. This expansive scan was

undertaken to compliment and augment case study findings with insights from expert cross-cutting sources.

The findings derived from the amalgamation of detailed case studies and global literature review are provided in Part 1 of this report. This section is intended to be a traceable 'quick reference guide' for policymakers and other stakeholders seeking to advance the deployment of VRE in power systems across the APEC member economies. Part 2 details the experiences and lessons learned from specific islanded power systems that have integrated higher amounts of VRE.

The table below summarises several themes that emerged from this work that correlate strongly with successful uptake of VRE. It then provides some key recommendations for replicating this best practice in other power systems, including interconnected power systems.

	Recuring Themes relevant to successful uptake of VRE	Key Recommendations
Strategy and Planning	1. A focus on 'future-back' customer-oriented objectives	+ Establish and formalise longer-term objectives and embed in decision making processes as guardrails for 'present forward' technical design considerations, regulatory changes and any policy-driven initiatives required to achieve them. + Include recuring reporting requirements alongside the formalised strategy to ensure alignment with and measure progress against longer-term customer-orientated objectives.
	2. A holistic approach to strategy and planning activities	+ Strategy and planning processes and artefacts should seek to: o Integrate transparent and meaningful community engagement o Address expansion in complexity across technology, regulatory and market and policy domains while 'still on paper' o Elevate the role of the traditional 'demand-side' in meeting VRE and emissions targets, including energy efficiency measures

Technological Considerations	3. Comprehensive assessment of prospective VRE generation fleets	+ Beyond asset-specific technical specifications, selection of VRE generation technology should consider: o Complementarity with other generation sources with respect to coincident intermittence, seasonal variability and load profiles. o Scalability for potential load growth and diversification o Suitable siting and availability of land parcels, mindful of cultural sensitivities, and aesthetic and environmental impacts o Full range of available indigenous natural energy sources and comparative costs of exploitation o Level of local expertise required to operate and maintain o Impact on existing operating procedures and ability to facilitate orderly and incremental technology transition o Least-cost suite of technologies with respect to required balance-of-plant, system integration, enabling technologies, and necessary sizing of assets
	4. A complimentary suite of enabling technologies	+ A combination of enabling technologies is required to provide needed Essential System Services across different time-scales. For example, pairing a flywheel with batteries enables sub-second and second-to-minute frequency control respectively, with both technologies operating within their intended performance envelope. + A diverse mix of technologies is needed to reliably provide firming across shallow (< 4-hours); medium / intraday shifting (4 – 12-hours); and, deep / renewable energy drought (> 12-hours) timespans.
	5. Use of mature and proven technologies	+ Even as new and novel VRE and associated enabling technologies advance and proliferate, priority should be given to mature and proven technologies. This significantly reduces risks to reliable delivery of target outcomes, simplifies system operation, and decreases reliance on external expertise for troubleshooting and fault recovery.
	6. Inclusion and activation of demand-side resources	+ The traditional 'supply-side / demand-side' bifurcation is eroding as customers mass deploy Distributed Energy Resources, including rooftop solar, energy storage, and electric vehicles. Modern power system design should consider intelligence-based and data-centric approaches to activating these mostly privately-owned resources for mutual benefit. This will include creating the needed social license and facilitating equitable sharing of the value created by utilising those assets. Failure to activate and manage distributed resources may result in voltage-rise, reverse power-flows, and rapid variability in apparent load at high penetrations.
	7. Modularity and standardisation for ease of integration and deployment	+ Procure modular solutions to de-risk projects. Specifically, containerized solutions have several benefits, including ease of installation, reduced overall construction and commissioning time, ease of transportation, and durability. + Standardise sub-systems to simplify operation, maintenance, and augmentation. For example, interoperability standards are needed to enable the full value stack of Distributed Energy Resources (DER).

Regulatory and Policy Considerations	8. Community engagement and social license	+ Establish initiatives that encourage and welcome host community engagement and mechanisms to ensure engagement outputs meaningfully inform technical design and policy. Such processes should show genuine respect for local self-determination and, where appropriate, align with the principles of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP). Such initiatives could include: + Clearly outline benefits to the community to enhance social license, such as employment opportunities and achievement of decarbonisation objectives.
	9. Resiliency and risk mitigation	+ Integrate resilience by design principles at conception and throughout the project life-cycle, considering all plausible contingencies. Resilience by design may influence diversification and sizing of energy resources, redundancy provisions, emergency preparedness planning, risk assessment regimes, and stipulations around adequate stockpiling of equipment spares or other key supplies. Enhanced resiliency gives host communities greater confidence to pursue higher penetrations of VRE.
	10. Regulation that affords agility and flexibility	+ Regulation should be tailored to the unique needs and objectives of remote communities. Imposing regulatory frameworks developed for interconnected power systems can cause unnecessary bureaucratic inertia and friction. Fit-for-purpose regulations should include: o Flexibility in ownership models, including community ownership o Complimentary across levels of government o Mechanisms for private sector incentivisation, such as relaxed reliability standards, tax offsets, and exemptions from other duties
Market and Economic Considerations	11. Innovative capital raising	+ Developers should consider the full range of debt financing and funding options (or combinations thereof) now available to VRE integration projects, such as: o Project financing – securing capital based on specific project assets and revenues, rather than the balance sheet of the project sponsor o Climate-dedicated financing backed by both government pledges toward decarbonising developing economies and private sources encouraged by corporate environmental, social and governance goals o Participation in compliance and voluntary carbon markets o Sale of Renewable Energy Certificates o Co-located and symbiotic large industrial or mining companies o Partnerships with research bodies and associated funding entities o Export Credit Agencies (ECAs), Development Finance Institutions, and Public International Finance Providers

	12. Collaborative procurement and contract management	+ Collaborate with solution providers at an early stage and agree on a tightly defined scope for VRE integration projects such that project costing is well understood prior to commencement. This approach often allows for fixed-price contracting, de-risking projects and reassuring financiers. + Pursue fit-for-purpose and innovative Power Purchase Agreements (PPA) such as those structured as a 'contract for service'. These types of PPAs remunerate providers for provision of generation assets that meet specified performance criteria, including for Essential System Services.
	13. Targeted and value-aligned incentive programs for customers	+ In parallel to deploying technology solutions to integrate and activate DER, consideration should be given to targeted incentives programs for customer-sited DER. Examples of such schemes include variable time-of-export feed-in tariffs, static night-time feed-in tariffs, discounted or subsidised solar PV and battery systems, home energy audits, managed Electric Vehicle (EV) charging and vehicle-to-grid export schemes.

As an immediate and actionable 'next step', it is also recommended that APEC member economies consider convening a multi-day in-person workshop to facilitate collaboration on key challenges to high VRE power systems. Broadly, the workshop agenda should seek to add additional granularity to the challenges faced; prioritise challenges with respect to both solution feasibility and anticipated impact of remediation; and finally, leverage the collective experience of policymakers and technical practitioners in meeting those challenges.

This project directly supports APEC's goals to double the share of renewables in the APEC energy mix, including in power generation, from 2010 levels, by 2030 and decrease energy intensity by 45 percent by 2035. This final report is prepared under the EWG's 2019–2023 Strategic Plan stated goal to enhance energy resiliency and energy access and advance clean energy through improvements in electric power systems. The key beneficiaries for this project are energy policy makers across APEC, especially in developing economies. Other beneficiaries include program managers, evaluators, non-government organizations, academics, students, and associated stakeholders involved in local, regional, and disaster response activities.

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Acronyms, Abbreviations & Definitions

ADB	Asian Development Bank
AEMC	Australian Energy Market Commission
AES	Applied Energy Services
AGC	Automatic Generation Control
APEC	Asia-Pacific Economic Cooperation
ARENA	Australian Renewable Energy Agency
AUD	Australian Dollar
BESS	Battery Energy Storage System
BTM	Behind-the-meter
CAPEX	Capital Expenditure
CBRE	Community-Based Renewable Energy
CEC	Cordova Electric Cooperative
CGS	Customer grid-supply
COBS	Commercial Buyback Scheme
DC	Direct Current
DEBS	Distributed Energy Buyback Scheme
DER	Distributed Energy Resource
DERMS	Distributed Energy Resource Management Systems
DHEEE	Department of Hydraulic, Energy and Environmental Engineering
DPV	Distributed Photovoltaic
ECM	Energy Conservation Measures
EDRP	Emergency Demand Response Program
EPC	Electric Power Corporation
ESS	Essential System Services
EV	Electric Vehicle
FAT	Factory Acceptance Testing
FTM	Front-of-the-Meter
GHG	Greenhouse Gas
HCEI	Hawaii Clean Energy Initiative
HECO	Hawaiian Electric Company
HELCO	Hawaii Electric Light Company
HMI	Human-Machine Interface
HPUC	Hawaii Public Utilities Commission
HREP	Hybrid Renewable Energy Project
ICT	Information and Communications Technology
IDRPP	Integrated Demand Response Portfolio Plan
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IEEFA	Institute for Energy Economics and Financial Analysis

IOREC	International Off-Grid Renewable Energy Conference & Exhibition
IoT	Internet-of-Things
IP	Internet Protocol
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
KE	Kaua'i Electric
KEA	Kodiak Electric Association
KIREIP	King Island Renewable Integration Project
KIUC	Kaua'i Island Utility Cooperative
LCOE	Levelised Cost of Electricity
LED	Light-emitting Diode
LHIB	Lord Howe Island Board
LMI	Low-and-Moderate-Income
MECO	Maui Electric Company
MGC	Micro Grid Controller
MPPT	Maximum Power Point Tracking
NEI	Northern Energy Innovation
NRC	Natural Resources Canada
NRECA	National Rural Electric Cooperative Association
NREL	National Renewable Energy Laboratory
NT	Northern Territory
OPEX	Operational Expenditure
PGV	Puna Geothermal Venture
PPA	Power Purchase Agreement
PSEP	Power Sector Expansion Project
PUC	Public Utilities Commission
PV	Photovoltaic
RE	Renewable Energy
RFP	Request for Proposal
RPS	Renewable Portfolio Standards
SAESA	Sociedad Austral de Electricidad S.A.
SCADA	Supervisory Control and Data Acquisition
SEIAPI	Sustainable Energy Industry Association of the Pacific Islands
SESP	Samoa Energy Sector Plan
UBC	University of British Columbia
UNDRIP	UN Declaration on the Rights of Indigenous Peoples
UNIDO	UN Industrial Development Organisation
US	United States
USA	United States of America
VAR	Volt-Amps Reactive
VGFN	Vuntut Gwitchin First Nation
VGG	Vuntut Gwitchin Government

VRB	Vanadium Redox Flow Battery
VRE	Variable Renewable Energy
WA	Western Australia

Part 1

Key lessons relevant to APEC economies in the development and operation of high-renewable islanded grids

1.1 Overview

This report is broken into two parts. Part 1 is an amalgamation of an expansive scan of the global literature relevant to the broad range of issues contributing to or hindering the uptake of Variable Renewable Energy (VRE) in islanded power systems, together with a distillation of the key takeaways from the case studies explored in Part 2. As it is intended to function as a springboard for further exploration of the issues at hand, it also provides a list of the most relevant sources for each topic addressed. Part 2 provides a detailed account of transferable lessons learnt in deploying and enabling VRE across ten specific and diverse case studies based on published information and interviews with power system operators, vendors and policy makers.

Note that a glossary of key terms is provided in Appendix E. This includes terms that may be unfamiliar to industry outsiders or non-technical audiences.

1.2 The importance of high-renewable islanded grids in the global energy transition

Electric power systems are experiencing a once-in-a-century scale of change as global efforts to decarbonise accelerate. This presents a level of new opportunities and challenges not seen since the dawn of electrification in the late 1800’s.

Remote and islanded power systems are playing a unique role in this transformational context. Internationally, and across the twenty-one Asia-Pacific Economic Cooperation (APEC) member economies, they are providing the context for demonstrating how low carbon power systems may be achieved as conventional generation is replaced. As such, they may be considered ‘trailblazers’ for power system transformation, offering early insights into the future operational challenges faced by GW-scale power systems as they undergo deep decarbonisation.

There are several reasons that islanded grids provide such valuable ‘windows’ on the emerging future of power systems throughout the APEC region as follows.

- Firstly, due to their typically remote locations, islanded power systems exhibit favourable economics for renewable sources of electricity. Connection to gas supply or electricity transmission is commonly cost prohibitive, which also elevates exposure to volatile imported fuel prices and supply chain risks. In addition, the declining costs of Variable Renewable Energy (VRE) and enabling technologies are reinforcing the increasingly favourable economic case.
- Secondly, islanded power systems provide a significant opportunity for decarbonisation. Globally, there are almost 2,000 small islands with populations of between 10 and 100,000 people, which annually consume approximately 50,000 GWh. A large portion of these islands are currently powered by carbon intensive diesel generation, and approximately half are located in or around the Pacific Ocean.

- Thirdly, islanded and remote grids are also well placed to pursue more ambitious transformation due to their comparatively small scale providing a level of agility that is less incumbered by regulatory process and bureaucratic inertia.
- Finally, many islanded grids – especially true islands, experience firsthand the effects of climate-change such as more extreme weather and rising sea levels. This can provide further motivation to demonstrate global leadership while also bolstering the resilience and self-sufficiency of their own power system.

1.3 Benefits and Drivers of resilient high-renewables islanded power systems

Modern electric power systems are technical, economic and societal systems that are critical to the day-to-day activities of households, commercial enterprises, and the community as a whole. Islanded power systems servicing remote and isolated communities often must provide these over-arching functions in the context of harsh climates, proportionally more natural disasters, and limited access to on-site expertise for restoration following outages.

Given this critical role and the unique challenges faced by islanded power systems, it is important to comprehend the range of objectives that different customers and policy makers expect their systems to achieve. This is particularly necessary and helpful for thinking about the type of power system that a community will need into the future.

To that end, six key objectives are identified below as a baseline for successful implementations of high-VRE islanded power systems. Separate to the case studies and literary review that form the basis of this report, these six major objectives have been distilled from a parallel study of almost 40 relevant primary sources from around the world. While they are not proposed as either exhaustive or equally relevant in every location, they do reveal the wide diversity of things we expect power systems to achieve. Importantly, it is also acknowledged that trade-off decisions are required where achieving one objective comes at the expense of another.

Secure and Resilient - Reduced reliance on a single resource

While considered an essential service that must be both safe and highly dependable now for many decades, electricity systems today are becoming even more critical. This is driven by an ever-expanding societal dependence on digital communications and the global efforts to decarbonise by boosting renewable electricity sources. As the role of electricity systems continues to expand, so does the need for increasing levels of dependability. And in today’s interconnected world, the growing role of cyber-security in system dependability is assuming a new level of importance.

Sustainable - Reduction in emissions

Customers and policy makers increasingly expect power systems to actively transition toward a greater reliance on renewable energy-based electricity generation. While still a minority, a proportion of customers are willing to pay a modest premium for more sustainable forms of grid-supplied electricity. A more sizable and growing proportion of customers have or will invest in their own on-site renewable energy resources in the form of rooftop solar photovoltaics (PV). This achieves their most reported objective of reducing annual electricity costs while also allowing them to feel they have contributed to a more sustainable power system.

Affordable - Reducing dependence on volatile oil prices and reducing operational costs

Affordability is a key concern of customers and their representatives. Many factors contribute to affordability, including efficient investment in infrastructure and the full utilisation of existing resources. Fuel costs, the effectiveness of competition and the degree to which new solutions including automation, demand-side flexibility and cost-reflective tariffs are successfully deployed all have a bearing on affordability.

Adaptable - Larger range of available resources to meet energy needs

Power systems are likely to change more over the next ten years than they have for much of the last century. They must increasingly accommodate a diverse range of new and emerging technologies, business models, regulatory and pricing mechanisms while maintaining the security and stability of the system. In a context of transformative change, most of which simply cannot be fully anticipated, pursuing ‘least regret’ pathways and extensible design is required in an uncertain environment. The resulting adaptability and scalability of solutions will be key for ensuring resilience to all plausible futures and reducing stranded investment risks.

Equitable - Electrification of islanded areas with no existing power supply

Ensuring equitable outcomes in a rapidly changing power system is another key priority for customers and consumer advocates. The costs and benefits of a modernised power system should be distributed fairly across all consumers. Importantly, those who lack the opportunity to invest in new energy technologies such as rooftop solar PV should not disproportionately bear the costs of operating and maintaining the power system. Further, as new energy services and technologies proliferate, it is important that diverse customers are provided accessible information on the range of options most suitable to their circumstances.

Empowering - Use of local energy resources and creation of local jobs

Today, customers in every sector and industry have an expanding range of competing and customised solutions open to them – and the electricity sector is no different. In this context, new energy solutions and technologies must be developed to deliver the specific value and outcomes that different customer types are looking for. For some, this may involve enhanced options for using their on-site solar PV and energy storage to provide system services in exchange for a share of the value created. For others, it may involve access to options such as community solar, participation in demand response and/or access to a community battery. In all cases, it will involve empowering customers with the solutions most suited to their needs that also support wider power system efficiencies.

1.4 Summary of key lessons learnt from high-renewable islanded grids

The following section provides a summary of the lessons learnt by the islanded grids together with key outputs from an expansive study of relevant cross-cutting reports relevant to islanded grids, organised by four key domains: strategy and planning, technology considerations, regulatory and policy and markets and economics considerations. It is intended to provide a 'quick reference guide' for readers, with further granularity provided for specific lessons learnt available in the Part 2.

1.4.1 Strategy & Planning

Key Recommendations

- + Establish and formalise longer-term objectives and embed in decision making processes as guardrails for 'present forward' technical design considerations, regulatory changes and any policy-driven initiatives required to achieve them.
- + Include recuring reporting requirements alongside the formalised strategy to ensure alignment with and measure progress against longer-term customer-orientated objectives.

1.4.1.1 Key considerations

Decarbonising already complex legacy islanded power systems necessarily involves navigating significant additional complexity. Addressing this expansion of complexity while 'still on paper' is critical to the successful and cost-effective evolution of legacy systems to high VRE islanded systems. Islanded grids that have prioritised strategy formulation and planning activities identify potential challenges earlier, develop more targeted solutions, and avoid scope creep. Where strategy and planning activities are integrated with transparent and meaningful community engagement, islanded grids experience greater levels of community acceptance.

1.4.1.2 Strategic considerations

Strategy formulation for islanded grids should combine both 'future back' and 'present forward' approaches. A 'future back' perspective considers the goals and objectives of the islanded system from the perspective of end-users and policy makers (as outlined above) across relevant levels of government. Making longer-term objectives explicit provides guardrails for 'present forward' technical design considerations, regulatory changes and any policy-driven initiatives required to achieve them. Some islanded grids have also included recuring reporting requirements alongside their formalised strategy to ensure alignment with and to measure progress against longer term objectives.

Case Studies:

- + Kaua'i Island, Hawaii, USA
- + Kodiak Island, Alaska, USA
- + Hawaii Island, Hawaii, USA

Key Sources:

- + Hitting the Target – KIUC 2021 Annual Report, KIUC
- + Report to the 2019 Legislature on Hawaii's Renewable Portfolio Standards – State of Hawaii PUC
- + 2021 Annual Report, Kodiak Electric Association

- Strategic Plan Update 2023-2033, KIUC

1.4.1.3 Holistic system planning and design

With both the erosion of the traditional ‘supply-side / demand-side’ bifurcation and the increasing levels of volatility introduced by variable resources, a significantly more holistic approach to system planning and design will be required to ensure reliable operation of islanded power systems at least cost. Proportionally, islanded power systems often have significant amounts of distributed customer resources such as Distributed Photovoltaics (DPV), either by design or independent customer agency. System planning and design must enable centralised assets and distribution systems – together with deep demand-side flexibility – to function in a more holistic and dynamically independent manner than previously required. This may require new modelling capabilities and tools, extensive technical, financial, and institutional planning studies, new and expanded approaches to real-time data acquisition and operational decision making, and system modifications.

Case Studies:

- Onslow, Western Australia, Australia
- Kodiak Island, Alaska, USA (L2)
- Kaua’i Island, Hawaii, USA (L2)
- Old Crow, Yukon, Canada (L1)

Key Sources:

- Transforming Small-Island Power Systems - Technical Planning Studies for the Integration of Variable Renewables, IRENA, Pg 46
- Blueprint on how to conduct feasibility studies on off-grid and edge-of-grid power systems, IEA
- Microgrid Conceptual Design Guidebook 2022, Sandina
- Hybrid and Battery Energy Storage Systems - Review and Recommendations for Pacific Island Projects, ADB, Pg 9
- Grid Impact Study for Old Crow Solar Project, Yukon Research Centre
- KIUC 2021 Annual Service Reliability Report, KIUC

1.4.1.4 Consideration of Behind-the-Meter (BTM) DPV self-consumption, energy use and efficiency measures

Understandably, formalised strategy and planning processes are primarily focused on ensuring the resource adequacy of islanded power systems. However, consideration should also be given to opportunities to optimise energy practices in residential, commercial, and other premises. This may include providing subsidies or other incentives for energy efficiency measures, such as installing insulation and upgrading appliances, lighting, heating and cooling systems to use more energy efficient technologies. It may also involve home energy audits, and assistance to optimise energy use practices and maximise self-consumption of BTM generation, reducing the overall demand on the system. An islanded power systems in this study set a goal of 30% of their renewable energy target being achieved through efficiency measures alone.

Case Studies:

- Onslow, Western Australia, Australia
- Kaua’i Island, Hawaii, USA (L4)
- Hawaii Island, Hawaii, USA (L3)

Key Sources:

- Identifying Cost-Effective Residential Energy Efficiency Opportunities for the Kauai Island Utility Cooperative, NREL
- Kaua’i Island Utility Cooperative Member Services – KIUC
- Energy Performance Contracting, Hawaii State Energy Office
- For Home, Horizon Power

1.4.1.5 Technology selection

Separate to asset or class specific performance criteria, strategy formulation and planning

activities should consider providing high-level guidance on technology choices for islanded grids. This may include:

- Selecting mature, proven and robust technologies. In several cases, selecting emerging technologies has caused significant challenges for islanded power systems.
- Assessing the broader suite of technologies chosen for complementarity with existing or other elements of the system. For example, a variety of different energy storage technologies is generally needed to provide needed essential system services.
- Interoperability and ease of integration with existing facilities and sub-systems.
- Suitability to climate and weather. Many islanded power systems reside in harsh environments.
- Construction and commissioning requirements. Islanded power systems are well suited to containerised or otherwise pre-configured and tested solutions due to their smaller scale. There is also often a limited local construction workforce with relevant experience.
- Geographical constraints. For example, there may be an insufficient amount of useable land for utility scale deployments of wind and solar. Islanded grids often service communities with difficult and inaccessible terrain.
- Community acceptance. Some technologies may not gain social license from their host communities due to cultural significance of available land parcels or aesthetic preferences.

Case Studies:	Key Sources:
+ King Island, Tasmania, Australia (L1, L2) + Cordova, Alaska, USA (L2) + Kaua'i Island, Hawaii, USA (L1)	+ Hybrid and Battery Energy Storage Systems - Review and Recommendations for Pacific Island Projects, ADB, Pg 32-33 + Transforming Small-Island Power Systems - Technical Planning Studies for the Integration of Variable Renewables, IRENA, Pg 41-42 + Cordova's Microgrid Integrates Battery Storage with Hydropower, Cordova Electric Cooperative + The Role of Low-Load Diesel in Improved Renewable Hosting Capacity within Isolated Power Systems, University of Tasmania

1.4.2 Technological Considerations

Key Recommendations

- Beyond asset-specific technical specifications, selection of VRE generation technology should consider:
  - Complementarity with other generation sources with respect to coincident intermittence, seasonal variability and load profiles.

  - Scalability for potential load growth and diversification
  - Suitable siting and availability of land parcels, mindful of cultural sensitivities, and aesthetic and environmental impacts
  - Full range of available indigenous natural energy sources and comparative costs of exploitation
  - Level of local expertise required to operate and maintain
  - Impact on existing operating procedures and ability to facilitate orderly and incremental technology transition
- Least-cost suite of technologies with respect to required balance-of-plant, system integration, enabling technologies, and necessary sizing of assets

- A combination of enabling technologies is required to provide needed Essential System Services across different time-scales. For example, pairing a flywheel with batteries enables sub-second and second-to-minute frequency control respectively, with both technologies operating within their intended performance envelope.

- A diverse mix of technologies is needed to reliably provide firming across shallow (< 4-hours); medium / intraday shifting (4 – 12-hours); and, deep / renewable energy drought (> 12-hours) timespans.

- Even as new and novel VRE and associated enabling technologies advance and proliferate, priority should be given to mature and proven technologies. This significantly reduces risks to reliable delivery of target outcomes, simplifies system operation, and decreases reliance on external expertise for troubleshooting and fault recovery.

- The traditional 'supply-side / demand-side' bifurcation is eroding as customers mass deploy Distributed Energy Resources, including rooftop solar, energy storage, and electric vehicles. Modern power system design should consider intelligence-based and data-centric approaches to activating these mostly privately-owned resources for mutual benefit. This will include creating the needed social license and facilitating equitable sharing of the value created by utilising those assets. Failure to activate and manage distributed resources may result in voltage-rise, reverse power-flows, and rapid variability in apparent load at high penetrations.

- Procure modular solutions to de-risk projects. Specifically, containerized solutions have several benefits, including ease of installation, reduced overall construction and commissioning time, ease of transportation, and durability.

- Standardise sub-systems to simplify operation, maintenance, and augmentation. For example, interoperability standards are needed to enable the full value stack of Distributed Energy Resources (DER).

1.4.2.1 Renewable generation resources –

Key considerations

Selection of VRE generation technologies is highly dependent on the indigenous natural resources of the host community. Detailed assessments of those resources is a key first step. In many cases, a suite of VRE generation will be required to economically maximise available resources, reduce coincident intermittence, and ensure reliability.

Utility-scale solar generation

Many islanded power systems install utility-scale solar due to low capital costs, low operation and maintenance costs, ease of installation and long operating life (around 25 to 30 years). Due to the weather-induced intermittency and high output variability of solar PV generation (up to -/+ 70% in a time frames of 2 to 10 minutes many times per day), most power systems firm solar PV storage with energy storage, which can also provide necessary essential system services to maintain secure supply. With or without storage, utility scale solar PV can provide Reactive Power control, frequency and voltage control, and fast ramping.

Dual axis or single axis tracking technology is less common at the scale of typical islanded power systems. It also introduces additional complexity, maintenance requirements and often necessitates external specialist expertise to attend and repair in the event of a failure.

Seasonal variability in output must be considered when installing at high latitudes. Such locations may also require larger parcels of land or bespoke panel arrangements to optimise output. Where feasible, geographical dispersion of solar PV installations can help to reduce coincident variability from cloud cover and contingency requirements for unplanned disconnections.

Case Studies:

- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia
- Kaua’i Island, Hawaii, USA
- Old Crow, Yukon, Canada
- Savai’I, Upolu and Manono Islands, Samoa
- Hawaii Island, Hawaii, USA

Key Sources:

- Grid Integration Requirements for Variable Renewable Energy, World bank, Pg 3-8
- Best Practices for High Penetration PV in Insular Power Systems, IEA, Pg 18

Utility-scale wind generation

Wind turbines are often well suited to islanded power systems, particularly true islands, due to their smaller footprint compared with solar PV, low maintenance requirements, low operational costs, modularity and scalability and high nameplate capacity per unit. As with other types of VRE, wind power introduces intermittency and is therefore often paired with energy storage for firming and essential system services. Wind generation can contribute to essential system services, including voltage management, frequency regulation and inertial response. However, not all types of wind turbines can provide all services and differ in the extent to which they can provide these services.

Off-shore wind is not yet widely adopted by islanded power systems, though may in time become a cost-competitive alternative and avoid challenges around siting, land rights and accessibility issues.

Case Studies:
- King Island, Tasmania, Australia
- Kodiak Island, Alaska, USA
- Hawaii Island, Hawaii, USA
- Savai'I, Upolu and Manono Islands, Samoa

Key Sources:
- Grid Integration Requirements for Variable Renewable Energy, World Bank, Pg 15-20
- Renewable Power Generation Costs in 2021, IRENA, Pg 60-62

Figure 1 - Wind Farm - Kodiak Island, Alaska [1]

Hydro generation

Where the topography and water resources allow, hydropower can play a foundational role in both generation and storage of energy in islanded power systems. The cost of hydropower varies depending on the needed configuration to harness natural or run-of-river water flows, but in many cases is the lowest cost source of renewable energy.

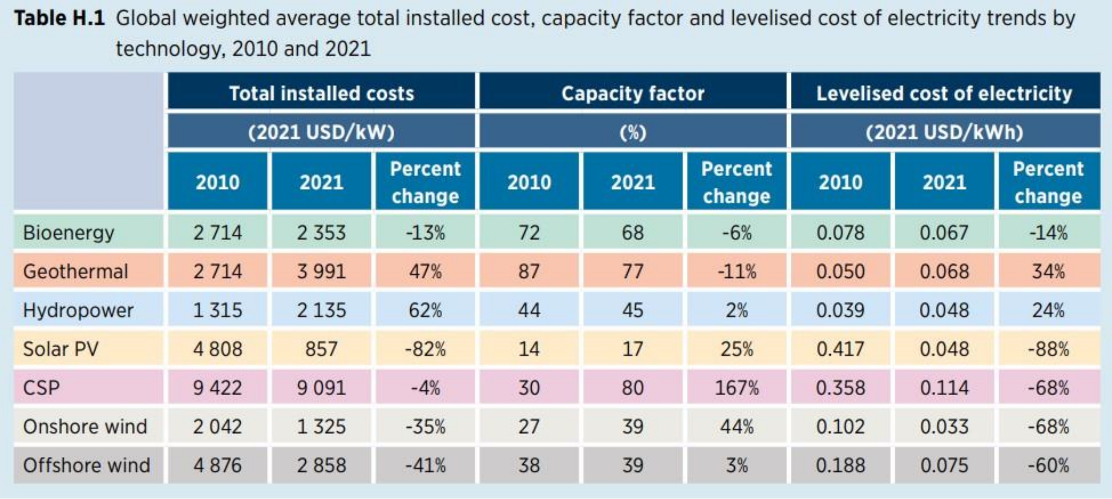


Table H.1 Global weighted average total installed cost, capacity factor and levelised cost of electricity trends by technology, 2010 and 2021

	Total installed costs (2021 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2021 USD/kWh)		
	2010	2021	Percent change	2010	2021	Percent change	2010	2021	Percent change
Bioenergy	2 714	2 353	-13%	72	68	-6%	0.078	0.067	-14%
Geothermal	2 714	3 991	47%	87	77	-11%	0.050	0.068	34%
Hydropower	1 315	2 135	62%	44	45	2%	0.039	0.048	24%
Solar PV	4 808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9 422	9 091	-4%	30	80	167%	0.358	0.114	-68%
Onshore wind	2 042	1 325	-35%	27	39	44%	0.102	0.033	-68%
Offshore wind	4 876	2 858	-41%	38	39	3%	0.188	0.075	-60%

Figure 2 - Global weighted total installed costs, capacity factor [2]

Reservoir type hydropower is a significant source of flexibility for islanded power systems due to its ability to store large amounts of energy for long duration, depending on the size of the reservoir. This combined with the ability to provide essential system services, such as frequency response, black start capability and spinning reserves, enables better integration of other VRE, which in turn reduces or eliminates the need for fossil-fuelled backup generation. Run-of-river type hydropower can also provide essential system services by controlling water flow with fast-acting deflectors.

Hydropower can also be integrated with water supply services, such as irrigation schemes, municipal water supply, drought management, and flood control.

Case Studies:

- Kaua'i Island, Hawaii, USA
- Kodiak Island, Alaska, USA
- Cordova, Alaska, USA (L1)
- Hawaii Island, Hawaii, USA
- Savai'I, Upolu and Manono Islands, Samoa

Key Sources:

- Renewable Power Generation Costs in 2021, IRENA, Pg 140-141
- Cordova's Microgrid Integrates Battery Storage with Hydropower, Cordova Electric Cooperative

Distributed solar generation

Figure 3 - Distributed Residential Solar - Onslow, Western Australia [160]

Distributed solar features prominently in many islanded power systems. Most commonly, this has come about due to customer-led take-up, or through policy-led incentive schemes. In either case, the vast majority of distributed solar is privately owned and BTM. Many islanded power systems have begun to experience the effects of high penetrations of distributed solar, including voltage-rise, reverse power-flows, and rapid variability in apparent load. These trends are likely to escalate where distributed solar systems are unmanaged and static limits are applied on exports to the distribution network. Some islanded grids have successfully implemented, or are intending to implement, more sophisticated mechanisms for operationally coordinating populations of distributed solar systems. This approach typically involves implementing Distributed Energy Resource Management Systems (DERMs) that communicate with inverters or intermediary communication devices, to issue setpoints for DPV systems based on current and predicted network state. These systems can operate over Internet Protocol (IP) based networks using widely adopted interoperability standards such as IEEE2030.5, reducing the need to deploy additional communication infrastructure. They also enable coordinated provision of essential system services. Coordinating privately owned assets in this way requires social license and equitable sharing of the value created by utilising those assets.

Apparent demand volatility due to the operational behavior of distributed solar can make it appear less conventional generation is needed than must be available to back up non-firm distributed solar.

Case Studies:

- Onslow, Western Australia, Australia
- Kaua'i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA

Key Sources:

- Hybrid Power Systems (PV and Fuelled Generator) System Design and Installation Guidelines, SEIAPI
- Off Grid PV Power Systems - System Design Guidelines, SEIAPI

+ Isla Huapi, Chile, South America (L1) + Savai'I, Upolu and Manono Islands, Samoa (L3)	+ Grid Connected PV Systems with Battery Energy Storage Systems Design Guidelines, SEIAPI + Best Practice for High Penetration PV in Insular Power Systems. IEA, Pg 58-59 + Case Study: Equitable Access to Energy And Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights, Pg 10-11

1.4.2.2 Other generation resources

Key considerations

Legacy hydrocarbon generation can play a role in transitioning islanded power systems to high VRE systems. They can provide needed redundancy to power system operators as they gain experience with new dispatch strategies and new sources of essential system services.

Diesel generation (incl. low load)

Many islanded power systems retain diesel generators for their flexibility, high ramping capabilities, short start-up/shutdown times, and as a backstop measure to ensure secure and reliable supply. Some islanded power systems have made significant advances in optimising their generation and storage fleet and dispatch regimes to ensure diesel generators are only called upon as a last resort.

Low load diesel generators are a key cost-effective enabler of higher levels of VRE, as they can run with as low as 10% loading compared to 30% for some conventional diesel generators, enabling reduced curtailment of renewable energy. Diesel generators can also support an orderly transition of islanded power systems to Battery Energy Storage Systems (BESS), as load matching and essential system services can be incrementally migrated to BESS as operational experience increases. Pairing diesel generators with solar PV requires more advanced control schemes to match supply to demand given weather induced volatility.

Case Studies:	Key Sources:
+ King Island, Tasmania, Australia (L3) + Diesel generation is operated as either main power production or as back-up in all islanded case studies, other than Isla Huapi	+ Hybrid Power Systems (PV and Fuelled Generator) System Design and Installation Guidelines, SEIAPI + Case Studies from Integrating Renewables into the Grid, SEIAPI. Pg 14 + Transforming Small-Island Power Systems - Technical Planning Studies for the Integration of Variable Renewables, IRENA, Pg 35-37 + The Role of Low-Load Diesel in Improved Renewable Hosting Capacity within Isolated Power Systems, University of Tasmania + Economics of Renewable Energy Integration and Energy Storage via Low Load Diesel Application, University of Tasmania

Gas generation (incl. low load)

Gas generation is rare in islanded power systems. It is generally confined to those remote locations where gas extraction activities occur, and therefore have existing infrastructure and reserves for power generation. To maximise the use of renewable generation sources, gas-fired power stations can be designed to use several smaller gas turbines, rather than fewer large turbines. This allows operators to bring gas-units online only as needed and avoids the limitation of minimum loading that could curtail renewable energy if larger turbines were used.

1.4.2.3 Buffering, firming and services

Key considerations

As islanded power systems transition to a decarbonised future with very high proportions of centralised and decentralised VRE, they experience growing levels of volatility. This is particularly impactful to electricity systems as, unlike most other supply chains, they have historically not needed and therefore not incorporated 'buffering' mechanisms to manage significant volatility. Weather dependent renewables also require firming, such that energy can be dispatched when needed, not just when weather conditions are favourable. Finally, as islanded power systems increase their share of Inverter Based Resources (IBRs), new sources of Essential System Services (ESS) are needed to replace those previously furnished by the synchronous generation.

A potentially 'game changing' development in the power sector is the advent of increasingly cost-competitive energy storage. All of the above requirements can be provided by centralised or decentralised energy storage.

In practice, a range of energy storage types will be required to support reliable operation across different functional time horizons, including:

+ Shallow / ESS (< 4-hours);
+ Medium / Intraday shifting (4 – 12-hours); and,
+ Deep / RE drought (> 12-hours).

The range of technologies that can provide these services include batteries (of various chemistries), flywheels, compressed air, pumped water storage, hydrogen, thermal energy, and others.

Case Studies:

+ Every case study in this report utilises some form of energy storage

Key Sources:

+ Best Practice for High Penetration PV in Insular Power Systems, IEA, Pg 20-22
+ The Point At Which Energy Storage is Required for Integrating Renewables in Remote Power Systems, Yukon Research Centre

Figure 4 - Utility-scale solar and energy storage - Onslow, Western Australia [3]

Loss of rotational inertia and increasing challenges in managing frequency

Historically, synchronous generators with spinning mass have provided the first-line of defence against frequency excursions due to their inherent inertial properties, allowing time for other resources to re-balance the system. As islanded power systems increase their reliance on intermittent weather-dependent renewable generation and withdraw synchronous generators, they become increasingly vulnerable to reduced levels of inertia. Sudden changes in generation or load from, for example, cloud cover or wind loss, can cause system frequency to rapidly rise or fall, potentially resulting in system-wide blackouts if not arrested.

Several different approaches have been adopted by islanded power systems to address this challenge, including:

+ Supplementing or replacing legacy fossil-fuelled synchronous generators with other renewable forms of synchronous generation that provide inertia in the same way, such as renewably derived fuels like bio-diesel and hydro-generation, and less commonly concentrated solar and geo-thermal.
+ Deploying inverter-based technologies capable of Fast Frequency Response. These inverters use electronic sensors to detect and respond changes in frequency within sub-second time windows, reducing overall inertia requirements. These assets may be centralised or distributed.
+ Installing flywheels, capacitor banks or dump loads to dampen sudden additions of supply or demand.

Case Studies:

+ King Island, Tasmania, Australia (L2)
+ Onslow, Western Australia, Australia
+ Kodiak Island, Alaska, USA
+ Cordova, Alaska, USA

Key Sources:

+ Microgrids with Energy Storage: Benefits, Challenges of Two Microgrid Case Studies, NRECA, Pg 7-11
+ Hybrid and Battery Energy Storage Systems - Review and Recommendations for Pacific Island Projects, ADB, Pg 32-33
+ Best Practice for High Penetration PV in Insular Power Systems, IEA, Pg 20-22

Reduction of spinning reserves to cover faults or sudden demand fluctuations

Protection regimes rely on sudden inflows of current, several multiples above that required for maximum load demand to trip circuit breakers and de-energise network segments that have experienced a fault. Traditional synchronous generators are capable of providing 5-6 times the nominal current rating for a short time. Typical unmodified Inverter-Based Resources (IBR) are limited to about 1.5 times normal ratings.

Islanded power systems can address this shortcoming by modifying system protection schemes or supplementing IBRs with alternative sources of fault current. On the former, modified inverters and early-stage intelligence-based solutions that perform complex computations based on sensor data from multiple locations on the network to detect faults and disconnect parts of the network have been employed. A more common approach is to utilise spinning mass in synchronous condensers, flywheels, hydro-generators, and similar to provide needed fault current in the same way as synchronous generators.

Figure 5 - Power Creek Hydro Electric Facility - Cordova, Alaska [161]

Case Studies:
- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia
- Kodiak Island, Alaska, USA
- Cordova, Alaska, USA

Key Sources:
- Hybrid and Battery Energy Storage Systems - Review and Recommendations for Pacific Island Projects, ADB, Pg 32-33
- Best Practice for High Penetration PV in Insular Power Systems, IEA, Pg 20-22
- Understanding Power Systems Protection in the Clean Energy Future, NREL

Battery storage

Battery technology continues to mature and expand the suite of functions it can reliably perform. Today’s battery systems can offset peak loads, provide primary frequency response, fast frequency response, voltage regulation, and perform grid-forming functions. Given that islanded grids, by their nature, have low inertia and low grid strength, battery systems will increasingly play a key role in ensuring secure and reliable power supply. Even with the rapid decline in capital costs, battery systems are still a significant cost contribution to islanded grids. Therefore, in-depth studies for the specific configuration of islanded systems is required to optimise sizing for least cost. Such a study may conclude that complimentary technologies, such as dump-resistors or flywheels, may decrease Levelised Cost of Electricity (LCOE) costs by increasing the operational life of the battery system.

Case Studies:
- Old Crow, Yukon, Canada (L2)
- Kodiak Island, Alaska, USA (L1)
- All case studies have a form of battery energy storage

Key Sources:
- Off Grid PV Power Systems - System Design Guidelines, SEIAPI
- Hybrid Power Systems (PV and Fuelled Generator) System Design and Installation Guidelines, SEIAPI
- Grid Connected PV Systems with Battery Energy Storage Systems Design Guidelines, SEIAPI

- Hybrid and Battery Energy Storage Systems - Review and Recommendations for Pacific Island Projects, ADB, Pg 8
- Grid Impact Study for Old Crow Solar Project, Yukon Research Centre Pg 83-85

Flywheels

Flywheels have proven to be a highly effective addition to islanded power systems. When paired with VRE, flywheels respond to sudden shortfalls in generation or a rapid rise in load with inertia support to maintain system frequency. Flywheels often compliment BESS by providing sub-second frequency support, allowing the BESS to respond to second to minute frequency changes, which can increase the operational life of the battery. Flywheels can also be mechanically coupled to diesel generators via a clutch system, providing a backstop measure for system security. Flywheels are extremely fast to charge, with high round trip efficiency; use abundant recyclable raw materials; have very low degradation and therefore high cycle life, and have an expected service life in excess of 30 years. Of benefit to many islanded grids is their ability to withstand a wide range of operating temperatures and low requirements for operation and maintenance. They are limited in their ability to operate at maximum power output, generally only providing 10 to 20 seconds at their nameplate rating, further highlighting their complementarity with batteries.

Figure 6 - Flywheel - King Island, Tasmania [162]

Case Studies:

- King Island, Tasmania, Australia (L2)
- Kodiak Island, Alaska, USA (L1)

Key Sources:

- Microgrids with Energy Storage: Benefits, Challenges of Two Microgrid Case Studies, NRECA, Pg 7-11
- Comparison and Influence of Flywheels Energy Storage System Control Schemes in the Frequency Regulation of Isolated Power Systems, DHEEE

Synchronous Condensers

In larger mainland power systems, synchronous condensers have reliably and cost-effectively provided rotational inertia and spinning reserve. However, they have not been deployed by any of the islanded power systems surveyed for this study. Generally, flywheels are preferred as they are more suited to smaller power systems. In cases where existing synchronous generators can be repurposed to operate as synchronous condensers or be added to a new or existing prime-mover or turbine via a clutch they could potentially compete on cost with alternate sources of essential system services. Synchronous condensers consume small amounts of electricity when in operation, modestly increasing operational costs for an islanded power system.

1.4.2.4 Control systems

Key considerations

Control systems are a critical enabler of high VRE islanded power systems. More advanced islanded power systems design and implement control systems with:

- Autonomous, semi-autonomous or remote operation. Due to smaller populations, communities with islanded power systems typically have limited technical expertise for trouble-shooting faults or restoring supply available locally, meaning external personnel may be required to attend, delaying restoration of power. Inclusion of remote diagnostics and configuration may also reduce the risks of extended outages.
- Redundancy. Related to the above, control systems reliably execute dispatch regimes and include pre-determined redundancy mechanisms for all known contingency events and plausible scenarios, such as Renewable Energy (RE) droughts, loss of communications network, or faults with generation assets.
- Scalable and expandable. Provision is be made for integration of additional resources as needed through modular and interoperable design.

System architecture

Architecture refers to the structural relationships and interfaces between different elements of the power system. As the control systems of islanded power systems become more complex with many more participating resources and greater variability, consideration of structural issues can help avoid coordination issues and simplify operation. Structural issues include:

- Tier/Layer Bypassing: The creation of information flows or coordination signals that 'leapfrog' a vertical Tier/Layer of the power system operational hierarchy.
- Coordination Gapping: An element of the power system does not receive an explicit flow of coordination signals from any higher Tier/Layer of the system and therefore operates in isolation.
- Hidden Coupling: Two or more control entities with partial views of system state issue simultaneous but conflicting coordination signals to a component of the power system.
- Latency Cascading: Creation of compounding latencies in information flows due to the serial routing of data through various systems and processes.
- Cybersecurity Structural Vulnerabilities: Ill-informed and often unnecessary structural choices result in communication and routings that create non-cyber vulnerabilities to system penetration.

Case Studies:

- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia
- Kodiak Island, Alaska, USA
- Cordova, Alaska, USA

Key Sources:

- Modern Distribution Grid – Decision Guide, Vol. 3, US DOE, Pg 27-43
- Operational Coordination across Bulk Power, Distribution and Customer Systems, PNNL, Pg 5-7

Multi-resource coordination

Advanced operational coordination of BTM and Front-of-the-meter (FTM) energy resources can support higher penetrations of renewable generation in islanded power systems. Integrating ‘both ends’ of the power system can enable optimised, and therefore more efficient and economic, dispatch of resources for generation, buffering, flexibility and provision of essential system services. Where previously unmanaged distributed resources are coordinated, additional feeder hosting capacity can be made available as system operators can effectively manage variability and minimum demand issues.

A data-centric approach is key to more advanced operational coordination. New data streams, datasets and data sources such as sensors deployed throughout the network are often required. This increases the criticality of Information and Communications Technology (ICT) infrastructure for low-latency data acquisition, transport, analysis and automated decision and control.

Case Studies:

- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia (L1)
- Kaua’i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA
- All case studies required some form of multi-resource coordination, with the four case studies above coordinating both FTM and BTM resources

Key Sources:

- Horizon Power: A Case Study on Integrating Customer DER, PXiSE, Pg 1-2
- Software-Defined Power Grids: A Survey on Opportunities and Taxonomy for Microgrids, IEEE

The role of Supervisory Control and Data Acquisition (SCADA)

Traditional industrial SCADA systems are designed such that human operators can monitor systems and intervene as necessary from central control rooms. They generally run on single-purpose communications networks that are not readily scalable, are often difficult to manage, and their associated data not easily shared. In addition, they often require back-end integration with other systems, which tend to be more brittle overall. In islanded power systems, SCADA systems must support autonomous decision making and operation and remote monitoring and diagnostics. This requires that they integrate with other management systems (such as Distributed Energy Resource Management Systems, Outage Management Systems and Geographic Information Systems).

Case Studies:

- Onslow, Western Australia, Australia (L1)
- Lord Howe Island, New South Wales, Australia (L1)
- Savai’I, Upolu and Manono Islands, Samoa (L2)

Key Sources:

- The Software-Defined Power Grid: How software and sensors are bringing century-old grid technology into the modern age, Patrick T. Lee
- Case Studies from Integrating Renewables into the Grid, SEIAPI, Pg 26
- Lord Howe Island Renewable Energy Project System Design Report, Lord Howe Island Board, Pg 8-9

1.4.2.5 Protection systems

Fault protection options

- Traditional synchronous generators intrinsically provide inertia to support stable frequency, and fault current - the ability to inject large amounts of current during faults, triggering protection devices to disconnect network segments that have experienced a fault. As discussed earlier, inverters that connect renewable resources to the power system are unable to provide the required fault current to engage protection devices. As inverter-based resources (IBRs) continue to be installed and traditional generation resources retired, alternative solutions to providing fault current are required. Possible solutions include for islanded power systems include:

- Inclusion of synchronous condensers, flywheels, hydropower or other forms of energy storage with rotating mass capable of providing fault current.
- Employ alternate protection schemes that detect faults computationally based on several dispersed sensors, and that therefore do not require large fault currents

Case Studies:

- King Island, Tasmania, Australia
- Kodiak Island, Alaska, USA

Key Sources:

- Transforming Small-Island Power Systems - Technical Planning Studies for the Integration of Variable Renewables, IRENA, Pg 28
- Best Practice for High Penetration PV in Insular Power Systems, IEA, Pg 23-24
- Understanding Power Systems Protection in the Clean Energy Future, NREL

1.4.2.6 Deployment considerations

Containerised solutions for remote deployment

Containerised systems allow for offsite assembly, pre-configuration, and testing. This has several benefits, including:

- Ease of installation. Minimal civil or other preparatory work on site. Reduced dependence on costly specialist expertise to attend site for commissioning and testing.
- Reduced overall construction and commissioning time. Assembling equipment in purpose-built facilities reduces time to completion.
- Ease of transportation. Multi-modal container transport infrastructure is well established and ubiquitous. Later removal or repositioning is straight forward.
- Durability. Containers are structurally strong and provide protection against harsh environments.

Figure 7 - Containerised BESS - Cordova, Alaska [163]

Case Studies:

- Kodiak Island, Alaska, USA (L1)
- Cordova, Alaska, USA (L1)

Key Sources:

- Replacing Diesel in an Alaskan Community: Cordova's New Battery Energy Storage System (5.7.20), Clean Energy Group / Clean Energy States Alliance
- SETuP Knowledge Sharing - Daly River Lessons Learned, PowerWater, Pg, 19-23

1.4.3 Policy and Regulatory Environments

Key Recommendations

- Establish initiatives that encourage and welcome host community engagement and mechanisms to ensure engagement outputs meaningfully inform technical design and policy. Such processes should show genuine respect for local self-determination and, where appropriate, align with the principles of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP). Such initiatives could include:
- Clearly outline benefits to the community to enhance social license, such as employment opportunities and achievement of decarbonisation objectives.
- Integrate resilience by design principles at conception and throughout the project life-cycle, considering all plausible contingencies. Resilience by design may influence diversification and sizing of energy resources, redundancy provisions, emergency preparedness planning, risk assessment regimes, and stipulations around adequate stockpiling of equipment spares or other key supplies. Enhanced resiliency gives host communities greater confidence to pursue higher penetrations of VRE.
- Regulation should be tailored to the unique needs and objectives of remote communities. Imposing regulatory frameworks developed for interconnected power systems can cause unnecessary bureaucratic inertia and friction. Fit-for-purpose regulations should include:
  - Flexibility in ownership models, including community ownership
  - Complimentary across levels of government
- Mechanisms for private sector incentivisation, such as relaxed reliability standards, tax offsets, and exemptions from other duties.

1.4.3.1 Policy Settings

Customer and societal objectives as foundational

Modern power systems are techno-economic systems that have a profound societal role. Communities with islanded power systems acknowledge this even more acutely. A ‘bottom up’ customer-centred approach to accelerating VRE take up can in the long run lead to enhanced outcomes. This starts with hearing from and understanding the objectives of customers and their advocates. Policy mechanisms can then align accordingly, which in turn informs implementation. Importantly, customer objectives will necessarily require a process of societal prioritisation and trade-off decisions as achieving one objective may come at the cost of another.

Case Studies:
- Old Crow, Yukon, Canada (L3)
- Kodiak Island, Alaska, USA
- Cordova Island, Alaska, USA
- Isla Huapi, Chile, South America (L3)

Key Sources:
- Project Ownership Models for Remote Renewable Energy Development in Partnership with Indigenous Communities, UBC Sustainability Scholars, Pg 9
- Powered by Nature: The Old Crow Solar Project, Arctic Council

- Case Study: Equitable Access to Energy And Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights

Explicit future-oriented objectives and goals

Related to the above, to align customer and policy objectives with solution implementation, an explicit, documented, future-oriented set of consensus goals and objectives is needed. This assists with feasibility assessments, encourages accountability, provides benchmarks for evaluation, and provides guardrails for decision makers. This may include goals around staged system-wide renewable energy targets over a set period, energy efficiency metrics, energy justice or other development related goals, or customer take-up of distributed assets. Some jurisdictions have enshrined such goals in legislation, enabling better enforcement, and providing stability and permanence.

Case Studies:
- Kaua'i Island, Hawaii, USA (L3)
- Hawaii Island, Hawaii, USA
- Savai'I, Upolu, and Manono Islands, Samoa

Key Sources:
- Guidelines to Develop Energy Resiliency in APEC Off-Grid Areas, APEC, Pg 12-17
- Report to the 2019 Legislature on Hawaii's Renewable Portfolio Standards, State of Hawaii PUC
- Hitting the Target KIUC 2021 Annual Report, KIUC

Knowledge sharing and diffusion of expertise

Ensuring lessons learnt and expertise gained is transferred between islanded power system projects is key to the uptake of VRE. Regulated utilities are, by design, heavily focussed on their respective service territories, which can be an impediment to knowledge sharing. To counteract this, policy makers have, in some jurisdictions, allowed regulated utilities to establish unregulated commercial subsidiaries. These subsidiaries can partner with other entities to deploy solutions developed in their own service territory into other regions and internationally with knowledge and expertise dispersed as a by-product. Another successful policy setting for knowledge sharing is contractually coupling funding to the delivery of knowledge sharing reports and other artifacts.

Case Studies:
- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia
- Old Crow, Yukon, Canada (L1)

Key Sources:
- Old Crow Solar Energy Project: Integrating renewable energy sources in Canada's North, UArctic
- Hydro Tasmania – Success Stories, Hydro Tasmania
- Powerful thoughts are powering our world Annual Report 2021/22, Horizon Power, Pg 21

Community engagement and social license

There is a strong correlation between the success of VRE integration projects and the level of trust built across all stakeholders, including electricity consumers, operators, funding entities, local and broader government representatives, and the general public. Establishing initiatives that encourage community engagement and meaningfully inform policy is a key part of building trust. Such initiatives often include consideration of:

- Provision of comprehensive yet concise and readily understandable information across a variety of mediums, such as websites, public gatherings, and printed materials.

- Respect for local self-determination and, where appropriate, alignment with the principles of the UN Declaration on the Rights of Indigenous Peoples (UNDRIP).
- Engagement on culturally significant matters of importance to communities
- Opportunities for end users to express concerns and have questions answered

Social license can also be consolidated by outlining key benefits to the community, such as employment opportunities, and achievement of decarbonisation objectives.

Case Studies:

- Lord Howe Island, New South Wales, Australia
- Old Crow, Yukon, Canada (L3)
- Kodiak Island, Alaska, USA
- Cordova Island, Alaska, USA
- Isla Huapi, Chile, South America (L3)

Key Sources:

- Project Ownership Models for Remote Renewable Energy Development in Partnership with Indigenous Communities, UBC Sustainability Scholars, Pg 9
- Clean Energy Mini-Grid Policy Development Guide, UNIDO, Pg 47
- Powered by Nature: The Old Crow Solar Project, Arctic Council
- Case Study: Equitable Access to Energy and Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights

Resiliency and risk mitigation

Islanded power systems pursuing higher VRE up-take face unique risks when compared with interconnected grids. Most notably, they typically reside in remote areas that are subject to extreme weather events. Other risks include new unforeseen block or stochastic loads that have a material impact on resource adequacy or introduce physics-based challenges to the system, or VRE projects that face insurmountable technical challenges and terminate prior to providing services to the system. Policy makers should consider all plausible contingencies in policy frameworks. This may include consideration of appropriate diversification and sizing of energy resources, redundancy planning, emergency preparedness, up to date risk assessments, and adequate stockpiling of equipment spares or other key supplies. Addressing resiliency will give greater confidence to communities and other stakeholders to pursue higher penetrations of VRE.

Case Studies:

- Onslow, Western Australia, Australia
- Kaua'i Island, Hawaii, USA
- Kodiak Island, Alaska, USA
- Savai'I, Upolu and Manono Islands, Samoa (L1)

Key Sources:

- Clean Energy Mini-Grid Policy Development Guide, UNIDO, Pg 47
- Cracking the distributed energy management challenge for Australia's largest regional utility, SwitchDin
- KIUC 2018 Annual Service Reliability Report, KIUC

Private sector incentivisation

Attracting private investment can be challenging for islanded power systems given their scale. A compelling proposition requires an overall package of risk and return that is attractive enough for private companies to deploy capital. Policy makers can encourage private sector participation with relaxed regulatory requirements, tax offsets, or exemptions on other duties. Another approach is portfolio licenses, such that developers or investors are competitively awarded contracts to service a bundle of islanded power systems, increasing economies of scale. This also reduces the bureaucratic and administrative overheads of issuing tenders for each islanded power system individually.

Case Studies:

- Kaua'i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA (L4)
- Isla Huapi, Chile, South America

Key Sources:

- Clean Energy Mini-Grid Policy Development Guide, UNIDO, Pg 16

- Off-grid renewable energy solutions and their role in the energy nexus, IRENA, Pg 11
- Competitive Bidding for System Resources, Hawaiian Electric
- Case Study: Equitable Access to Energy And Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights, Pg 10

1.4.3.2 Regulatory Environment

Ownership models

Regulated flexibility in ownership models for islanded power systems can indirectly encourage uptake of VRE. Some models adopted by islanded power systems include:

- Utility ownership
- Split asset ownership – for example, where government owns the distribution network and generation assets are privately owned
- Private ownership – most often with government assistance
- Community ownership – through a cooperative or similar entity

Community ownership is a common model of islanded power systems. This model often aligns with the 'identity' of remote and electrically islanded communities, who see themselves as unique and distinct from grid-connected communities. Financial ownership has also been seen to translate to high levels social license and support for integration of VRE along with increased organisational agility.

Case Studies:

- Kaua'i Island, Hawaii, USA
- Kodiak Island, Alaska, USA (L3, L4)
- Cordova, Alaska, USA (L3)
- Old Crow, Yukon, Canada (L5)
- Isla Huapi, Chile, South America (L4)

Key Sources:

- Project Ownership Models for Remote Renewable Energy Development in Partnership with Indigenous Communities, UBC Sustainability Scholars
- Clean Energy Mini-Grid Policy Development Guide, UNIDO, Pg 15-17
- Lesson Learned from Cordova – Connecting America's most advanced grid modernisation project with the world, University of Alaska Fairbanks
- Strategic Plan Updated 2016-2030, KIUC
- Case Study: Equitable Access to Energy And Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights, Pg 17

Complimentary regulation across levels of government

In many jurisdictions, multiple levels of government intersect with the operation and uptake of VRE in islanded power systems. In addition, utilities and other statutory bodies may also impose requirements on islanded power systems. Navigating this bureaucratic complexity can exhaust the resources of small local communities. Ensuring alignment and complementarity of government and other bodies is key to empowering remote communities.

Case Studies:

- Kaua'i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA
- Old Crow, Yukon, Canada (L6)
- Isla Huapi, Chile, South America

Key Sources:

- Renewable energy investments in Old Crow, Yukon Government
- Case Study: Equitable Access to Energy And Indigenous Participation in Chile's Energy Policy, The Danish Institute for Human Rights, Pg 9-10

Regulation tailored to unique needs and objectives of remote communities

Islanded power systems are, in some instances, subject to the same regulations and requirements of larger interconnected power systems within their jurisdiction. Given the unique needs of islanded power systems, tailored regulation cognisant of distinct use cases, and allowance for bespoke solutions and innovation is an important consideration for regulators.

Case Studies:

- King Island, Tasmania, Australia
- Onslow, Western Australia, Australia
- Lord Howe Island, New South Wales, Australia
- Old Crow, Yukon, Canada

Key Sources:

- Yukon's Independent Power Production Policy, Government of Yukon
- New rules allow distributors to roll out stand-alone power systems in the NEM, AEMC

Standards for ease of integration and deployment

Policy makers must balance the benefits of standardisation against the costs to upgrade legacy configurations of power systems, while not constraining innovation by narrowing technology choices. Standards can reduce long run costs but require upfront expense to implement.

Standards are particularly relevant to leveraging the full value stack of Distributed Energy Resources (DER). Interoperability is key to activating populations of inverters to provide energy services. Some interoperability standards such as IEEE2030.5 are well established and supported by nearly all off-the-shelf inverters. Standardisation of installation and commissioning codes and procedures can also benefit islanded grids by increasing compliance of participating distributed resources and simplifying .

Case Studies:

- Onslow, Western Australia, Australia (L3)
- Lord Howe Island, New South Wales, Australia (L4)
- Kaua'i Island, Hawaii, USA

Key Sources:

- Manuals, standards & metering, Horizon Power
- Lord Howe Island Renewable Energy Project Lessons Learnt Report: System Hardening, Lord Howe Island Board
- KIUC Service Installation Manual , KIUC

1.4.4 Markets and Economics

Key Recommendations

- Developers should consider the full range of debt financing and funding options (or combinations thereof) now available to VRE integration projects, such as:
    - Project financing – securing capital based on specific project assets and revenues, rather than the balance sheet of the project sponsor
    - Climate-dedicated financing backed by both government pledges toward decarbonising developing economies and private sources encouraged by corporate environmental, social and governance goals
    - Participation in compliance and voluntary carbon markets
    - Sale of Renewable Energy Certificates
    - Co-located and symbiotic large industrial or mining companies
    - Partnerships with research bodies and associated funding entities
    - Export Credit Agencies (ECAs), Development Finance Institutions, and Public International Finance Providers
- Collaborate with solution providers at an early stage and agree on a tightly defined scope for VRE integration projects such that project costing is well understood prior to commencement. This approach often allows for fixed-price contracting, de-risking projects and reassuring financiers.
- Pursue fit-for-purpose and innovative Power Purchase Agreements (PPA) such as those structured as a ‘contract for service’. These types of PPAs remunerate providers for provision of generation assets that meet specified performance criteria, including for Essential System Services.
- In parallel to deploying technology solutions to integrate and activate DER, consideration should be given to targeted incentives programs for customer-sited DER. Examples of such schemes include variable time-of-export feed-in tariffs, static night-time feed-in tariffs, discounted or subsidised solar PV and battery systems, home energy audits, managed Electric Vehicle (EV) charging and vehicle-to-grid export schemes.

Procurement and contract management

Islanded power systems have had procurement successes where proponents and solution providers engage collaboratively at an early stage to and agree on a tightly defined scope for VRE integration projects. This approach is conducive to fixed sum contractual arrangements, which brings greater certainty to project costs. For generation assets, competitive bidding processes have been used effectively, including through innovative Power Purchase Agreements (PPA) arrangements structured as a ‘contract for service’. These types of PPAs remunerate providers for provision of generation assets that meet specified performance criteria, including for essential system services.

Similarly, procuring energy via competitive capacity auction programs is increasingly common and helps to de-risk project economics.

Case Studies:

- Lord Howe Island, New South Wales, Australia (L5)
- Kaua'i Island, Hawaii, USA (L5)
- Hawaii Island, Hawaii, USA (L4)
- Old Crow, Yukon, Canada (L6)
- Savai'I, Upolu and Manono Islands, Samoa

Key Sources:

- Now Is the Time Early Fossil Fuel Displacement in South and Southeast Asia, IEEFA
- Unshackled: Hawai'i's Innovative New Power Purchase Agreements for Hybrid Solar Photovoltaic and Energy Storage Projects, Nicholas W. Miller
- Community-Based Renewable Energy (CBRE) for Low-and Moderate-Income (LMI) RFPs, Hawaiian Electric

Targeted and value-aligned incentive programs for customers

Incentives that activate customer sited DER can rapidly increase the proportion of VRE on an islanded grid. However, such incentives must be targeted such that they do not exacerbate system instability risks due to insufficient minimum demand. Examples of innovative DER enablement programs include variable time-of-export feed-in tariffs, static night-time feed-in tariffs, discounted or subsidised solar PV and battery systems, home energy audits, managed Electric Vehicle (EV) charging and vehicle-to-grid export schemes. Many of these programs require that customer DER can be managed by the system operator.

Incentivising electrification of commercial and industrial loads with sufficient flexibility to participate in demand response programs can indirectly increase VRE take-up by increasing minimum demand.

Case Studies:

- King Island, Tasmania, Australia (L5)
- Cordova, Alaska, USA (L4)
- Onslow, Western Australia, Australia
- Kaua'i Island, Hawaii, USA (L4)
- Hawaii Island, Hawaii, USA (L5)

Key Sources:

- For Homes, Horizon Power
- Distributed Energy Buyback Scheme, Horizon Power
- Energy Wise, KIUC
- Other Resources and Emerging Technologies, Hawaiian Electric
- Electricity-Sector Opportunity in the Philippines The Case for Wind- and Solar-Powered Small Island Grids, IEEFA, Pg 8-11
- Mini Grids in the Money, Rocky Mountain Institute, Pg 8

Falling LCOE of VRE generation

The steep decline in LCOE from renewable generation sources is having a significant impact on the economics of prospective VRE integration projects. IRENA's analysis, shown in Figure 8, indicates that, globally, LCOE of both un-firmed utility-scale scale solar PV and onshore wind are now below that of fossil fuel generation. While this would not translate directly to islanded power systems due to limited scale, remote locations and bespoke operation, it does demonstrate the pace at which VRE costs are falling.

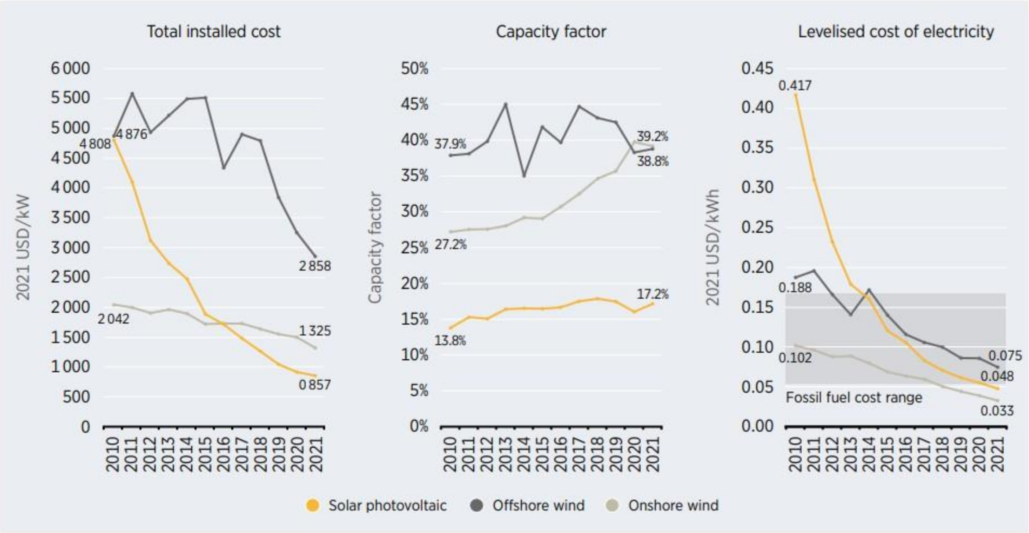


Figure 8 - Global weighted average total installed costs, capacity factors and LCOE of newly commissioned utility-scale solar PV, onshore and offshore wind, 2010-2021 [2]

LCOE from other VRE generation sources are also declining. Figure 9, also produced by IRENA, shows how their costs have fallen over the same period.

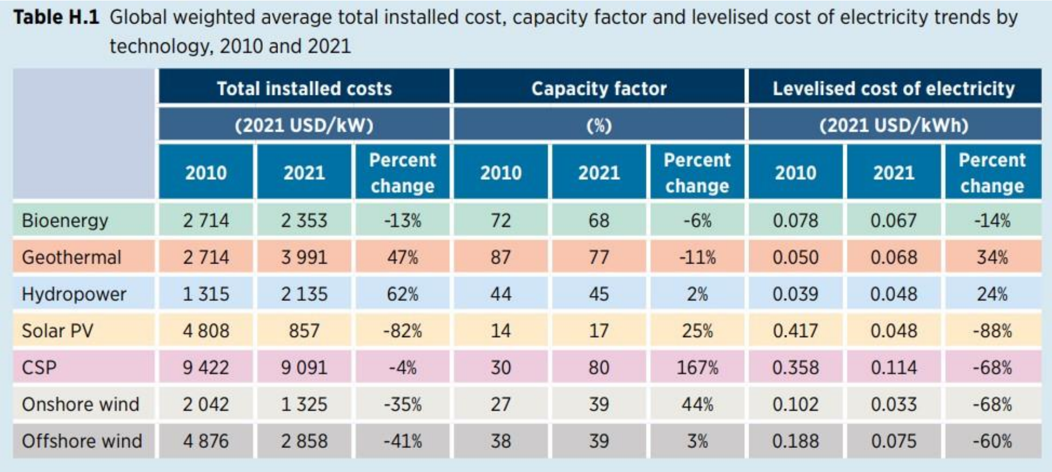


Table H.1 Global weighted average total installed cost, capacity factor and levelised cost of electricity trends by technology, 2010 and 2021

	Total installed costs			Capacity factor			Levelised cost of electricity		
	(2021 USD/kW)			(%)			(2021 USD/kWh)		
	2010	2021	Percent change	2010	2021	Percent change	2010	2021	Percent change
Bioenergy	2 714	2 353	-13%	72	68	-6%	0.078	0.067	-14%
Geothermal	2 714	3 991	47%	87	77	-11%	0.050	0.068	34%
Hydropower	1 315	2 135	62%	44	45	2%	0.039	0.048	24%
Solar PV	4 808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9 422	9 091	-4%	30	80	167%	0.358	0.114	-68%
Onshore wind	2 042	1 325	-35%	27	39	44%	0.102	0.033	-68%
Offshore wind	4 876	2 858	-41%	38	39	3%	0.188	0.075	-60%

Figure 9 - Global weighted total installed costs, capacity factor and levelised cost of electricity trends by technology, 2010 and 2021 [2]

In the United States, NREL's LCOE (Figure 10) analysis shows that in recent years distributed DPV costs have decreased at a faster rate than utility-scale PV, indicating that cost advantages of centralised scale verses distributed modularity and simplicity are narrowing. It is expected that this trend would be even more pronounced in islanded power systems, where utility-scale VRE typically cannot achieve significant scale, and faces additional challenges compared with interconnected grids. This highlights the potential of distributed approaches to VRE uptake.

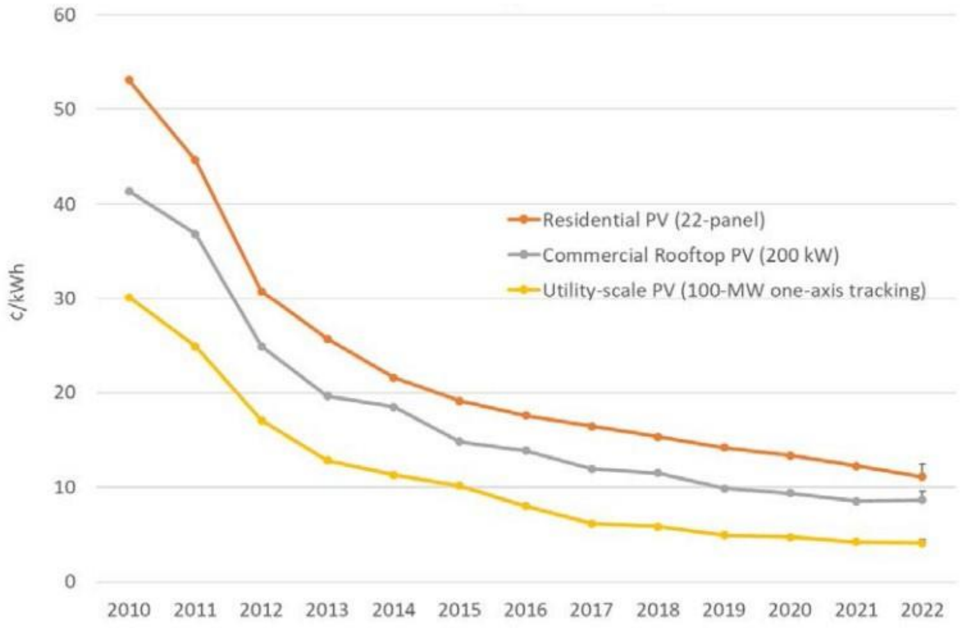


Figure 10 - Modelled solar PV LCOE in the U.S. [4]

Case Studies:

- Onslow, Western Australia, Australia (L5)
- Kaua'i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA
- Isla Huapi, Chile, South America

Key Sources:

- Now Is the Time Early Fossil Fuel Displacement in South and Southeast Asia, IEEFA, Pg 2
- Microgrids in the Money, Rocky Mountain Institute
- Renewables Are a More Affordable, Reliable and Resilient Solution for Small Islands and Isolated Power Grids, IEEFA
- U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022, NREL
- Renewable Power Generation Costs in 2021, IRENA

Pricing & Tariffs

Comparing currency adjusted residential rates across islanded power systems is challenging, given that customer-facing retailers/providers have varied billing practices and apply different combinations and tiers of volumetric pricing, demand charges and fixed fees. In addition, application of government backed subsidies is often opaque. Figure 11 provides volumetric rates of the islanded grids surveyed. As expected, it can be observed that larger islanded power systems with higher population density and commercial and industrial customers with large loads achieve lower tariffs, and/or lower subsidies.

Location	Residential Rates ($USD/kWh)	Subsidy Applied	System Size (MW)	Generation Sources
King Island	0.20	Yes	9.42	Solar, wind, DPV, diesel
Onslow	0.21	Yes	3	Solar, DPV, gas

Kaua'i Island	0.33	No	259.2	Solar, DPV, hydro, biomass, diesel
Kodiak	0.16	Yes	75	Hydro, wind, diesel
Cordova	0.38	Yes	18.3	Hydro, diesel
Old Crow	0.09 + Demand Charge	Yes	4.4	Solar, diesel
Isla Huapi	N/A	Yes	N/A	Standalone DPV
Samoa	0.28	No	78.51	Wind, solar, hydro, diesel
Lord Howe Island	0.19	Yes	2.84	Solar, diesel
Hawaii Island	0.43	No	525.6	Solar, DPV, wind, hydro, biomass, geothermal, natural gas, diesel

Figure 11 - Volumetric electricity pricing for islanded power systems assessed.

Tariff setting under subsidy schemes must balance affordability with an appropriate level of consumer cost pressure to avoid excessive discretionary use of electricity, which can increase the overall funding requirements of the subsidies. For this reason, many islanded power systems have a tiered rate structure, where usage over a threshold amount incurs higher rates.

Case Studies:

- Kaua'i Island, Hawaii, USA
- Hawaii Island, Hawaii, USA
- Savai'I, Upolu and Manono Islands, Samoa (L5)

Key Sources:

- Annual Report July 2019 – June 2020, EPC, Pg 4-5
- Mini Grids for Half a Billion People, World Bank, Pg 235

Access to affordable, long-term financing

VRE projects require significant amounts of capital, more so than thermal projects, but have very low ongoing operating costs once established. To fund projects, proponents must have access to capital markets either locally or abroad. In both cases, this can be challenging: the cost of international debt financing increases significantly for jurisdictions with lower sovereign credit ratings, and smaller economies often have limited sources of domestic capital. A third and increasingly compelling option is climate-dedicated financing, which is attracting significant interest and capital contributions from public sources through government pledges toward decarbonising developing economies; and private sources encouraged by corporate environmental, social and governance goals.

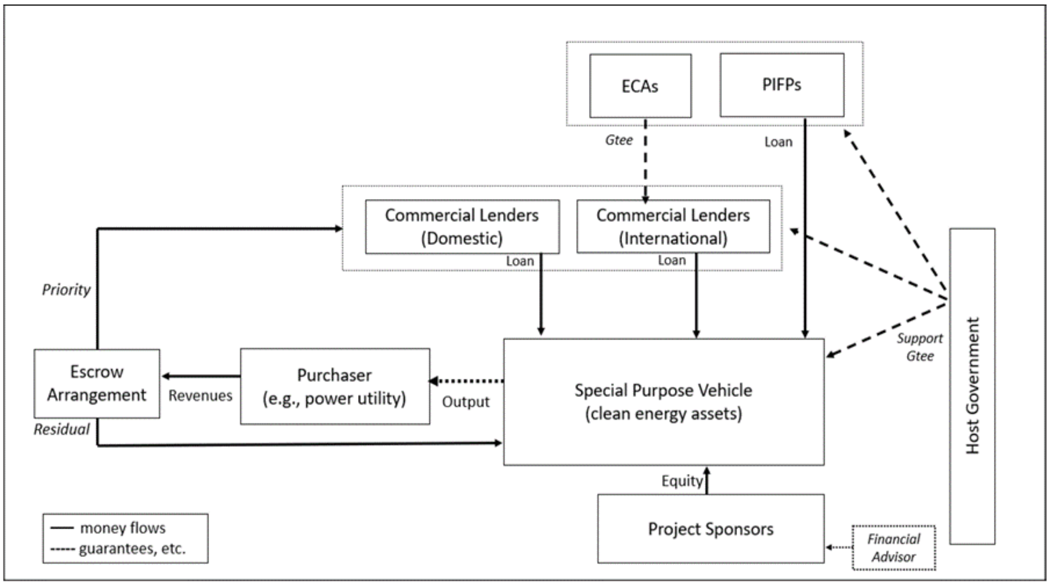


Figure 12 - Example Project Financing Arrangement [5]

Project financing is another viable alternative option for capital constrained economies. This approach attracts capital on the basis of specific project assets and revenues, rather than the corporate balance sheet of the project sponsor. While more complicated, it enhances proponents' ability to manage cash flow and service debt to the satisfaction of lenders.

Case Studies:

- Onslow, Western Australia, Australia
- Kodiak Island, Alaska, USA
- Cordova, Alaska, USA
- Hawaii Island, Hawaii, USA
- Old Crow, Yukon, Canada

Key Sources:

- Mini Grids in the Money, Rocky Mountain Institute, Pg 31-32
- Sandia participates in Cordova Energy Storage project, Sandia National Laboratories
- How Project Finance Can Advance the Clean Energy Transition in Developing Economies, The Oxford Institute for Energy Studies, Pg 10

Other sources of capital

Islanded power systems have in some instances been able to supplement traditional debt financing with other sources of capital. Many islanded power systems serve communities that support the operations of co-located large industrial or mining companies. These entities often have large balance sheets with the capacity to contribute considerable capital to VRE integration projects in-kind or through financial instruments. Further, their boards and executives are often inclined to do so as the success of their operations are tightly coupled to the success of their host communities. Another potential source of funding is carbon markets such as those pursuant to Article 6 of the Paris Agreement. Similarly, qualification to sell renewable energy certificates may enhance financial viability of a project. Other possible avenues for supplementary capital include partnerships with research bodies and associated funding entities, Export Credit Agencies (ECAs), Development Finance Institutions, and Public International Finance Providers. In many cases, these parties will play a role in a broader project financing scheme or other multi-party capital raising arrangement.

Case Studies:

- King Island, Tasmania, Australia
- Cordova, Alaska, USA
- Isla Huapi, Chile, South America

Key Sources:

- King Island Renewable Energy Integration Project, ARENA
- Lord Howe Island Hybrid Renewable Energy System, ARENA
- Operating in the Green - Clay Coplin CEO Cordova Electric Cooperative - CHARGE Energy Branding 2018, CHARGE Energy Branding Conference

Part 2

Key Insights and Lessons Learnt from Selected Case Studies

2.1 Background

Part 1 of this report provided a holistic, cross-cutting treatment of challenges and related solutions for islanded power systems, many of which have application to interconnected grids. Part 1 has been informed in large part by the findings of Part 2, along with a study of the voluminous global literature.

Part 2 of this report catalogues the real-world experience of specific islanded power systems relevant to the development and operation of high-VRE islanded grids in APEC member economies.

The following methodology has been applied to identify and select case studies for inclusion in this report.

Expansive Scan

An expansive scan of APEC member economy islanded grids identified 40 case studies of relevance to this study. Data collection was undertaken as the basis for shortlisting the highest potential case studies for this project.

Shortlisting of Potential Case Studies

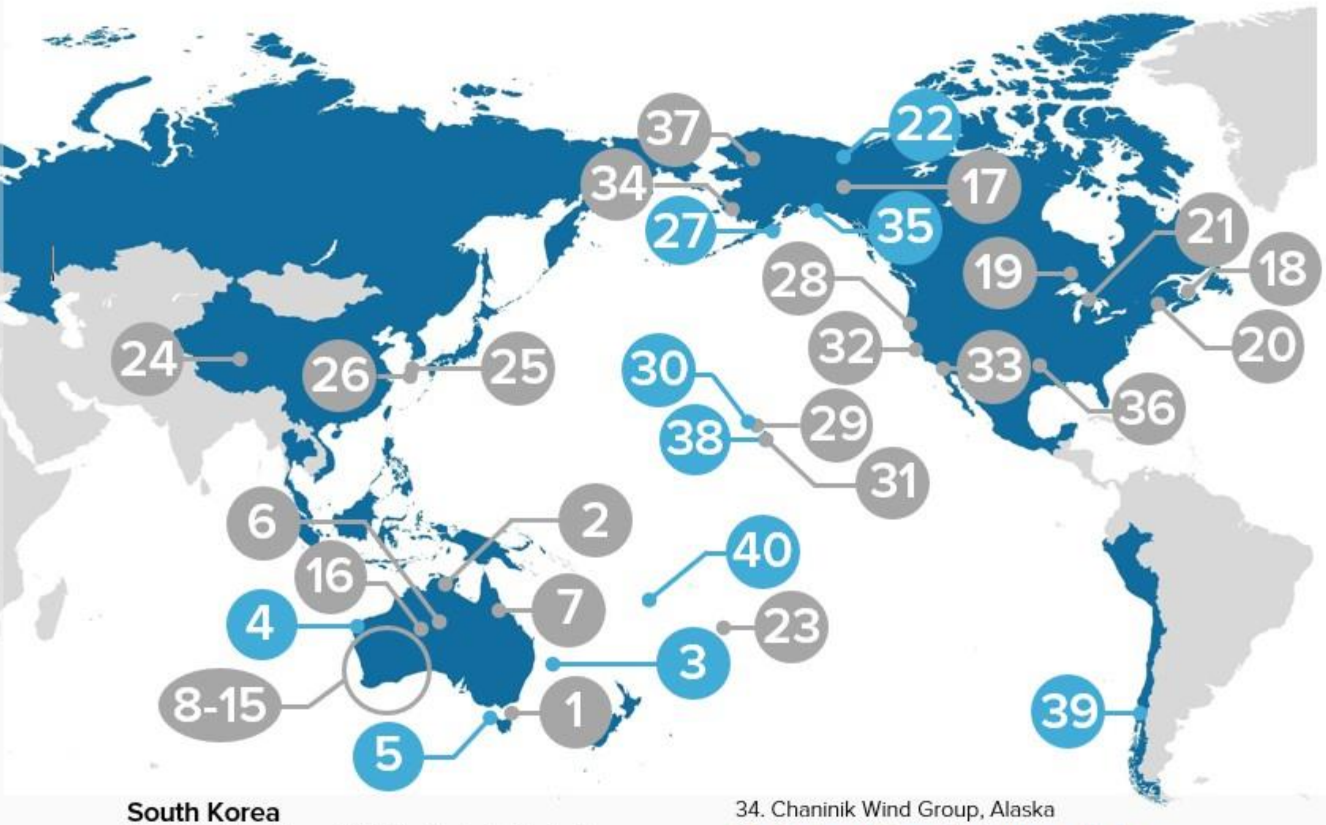
From the wide range of islanded grids surveyed in the detailed scan, the highest potential case studies were shortlisted by applying the following criteria:

- Relevance to APEC's Clean Energy Goals;
- VRE being confirmed as a significant proportion of the generation fleet serving the islanded grid;
- Confirmation of the grid being islanded (i.e. no other grid connection);
- Availability of relevant contacts and documented lessons-learned across technology, regulatory and market and commercial domains;
- Diversity of regulatory and ownership types;
- Number and diversity of customer connections served; and,
- Range of load types served and use of demand-side flexibility.

From this shortlist, a suite of case studies was identified representing a range of generation and enabling technologies, ownership models, system operation approaches and regulatory environments. For each identified case study, the available literature was interrogated for lessons learned, including industry, academic, vendor, and operator source materials. Supplementing this research, the project team interviewed several of the operators or proponents of the islanded grids and distilled their insights into the case study summaries.

Australia

1. Flinders Island Renewable Energy Hub, Flinders Island, Tasmania
2. Jabiru Hybrid Renewable Project, Jabiru, Northern Territory
3. Lord Howe Island Renewable Energy Project, Lord Howe Island
4. Onslow DER Project, Onslow, WA
5. King Island Renewable Energy Integra Project, King Island, Tasmania
6. NT Solar Energy Transformation Program (SETuP), Northern Territory
7. Daintree Microgrid, Daintree Rainforest, Queensland
8. Cooper Pedy Hybrid Renewable Project, Cooper Pedy, South Australia
9. Rottnest Island Water and Renewable Energy Nexus, Rottnest Island, Western Australia
10. Esperance Power Project, Esperance, Western Australia
11. Denham Hydrogen Demonstration Plant, Denham, Western Australia
12. Agnew Renewable Energy Microgrid, Agnew, Leinster, Western Australia
13. Kalbarri Microgrid, Kalbarri, WA
14. Clean Energy Innovation Hub, Jandakot, Perth, WA
15. Carnarvon DER Trials, Carnarvon, WA
16. Yulara Solar Project, Yulara, NT



Canada

17. Yukon Integrated System, Yukon
18. Prince Edward Island

19. Gull Bay Project, Gull Bay, Ontario
20. Lac-Megantic Microgrid, Lac-Megatnic, Quebec
21. Sault Smart Grid, Sault Ste Marie

22. Old Crow, Yukon

New Zealand

23. Cook Islands Renewable Energy Sector Project, Cook Islands

China

24. Shuanghu Microgrid Project, Shuanghu

South Korea

25. Jeju Island Smart Grid Testbed, Jeju Island
26. Gapa Island Microgrids for Electricity Self-Sufficiency, Gapa Island

USA

27. Kodiak Island Microgrid, Kodiak, Alaska
28. Redwood Coast Airport Microgrid, Redwood Coast, San Francisco

29. Mililani Solar, O'ahu, Hawaii
30. Kaua'i Island, Hawaii
31. Coconut Island DC Microgrid, Coconut Island, Hawaii

32. Valencia Gardens Energy Storage Project, Valencia Gardens, San Francisco
33. Marine Corps Air Station Miramar Microgrid, San Diego
34. Chaninik Wind Group, Alaska
35. Cordova Microgrid, Cordova, Alaska
36. The Oncor System Operating Services Facility, Oncor, Lancaster, Texas
37. Shungnak Community Solar Project, Shungnak, Alaska
38. Hawaii Island, Hawaii

Chile

39. Isla Huapi Electrification Project, Island Huapi

Samoa

40. Samoa

Figure 13 – The locations islanded grids identified in expansive scan (refer to Appendix D for detailed information)

Selected Case Studies

The locations of the ten shortlisted example islanded grids examined in this Summary Report are shown on the map below. They include the following:

Figure 14 – The ten case studies analysed

2.1.1 Key lessons relevant to APEC economies from selected case studies

The following section documents contextual information and key lessons that have emerged from detailed analysis of the shortlisted islanded grids.

King Island, Tasmania, Australia

Background and Overview

Operator	Hydro Tasmania
Population	1,800
Nearest Grid	110km
Installed Capacity	9.42MW
Max Demand	2.5MW
Annual RE Volume	65%

King Island is located in Tasmania, approximately 400km north-west of the state's capital, Hobart. The island's primary economic activity include agriculture, silviculture, fishing and a developing tourism sector. Being a remote island community, King Island is not connected to either mainland Tasmania or mainland Australia for its electricity supply. Until the late 1990s, electricity was generated solely by diesel generation supplied by the 6 MW power station, serving 12 GWh of annual customer demand, with peak instantaneous demand of 2.5 MW **[6].** Since then, the island's power system has evolved progressively, and now functions as an important case study for managing a system with high renewable penetration throughout Australia and around the world.

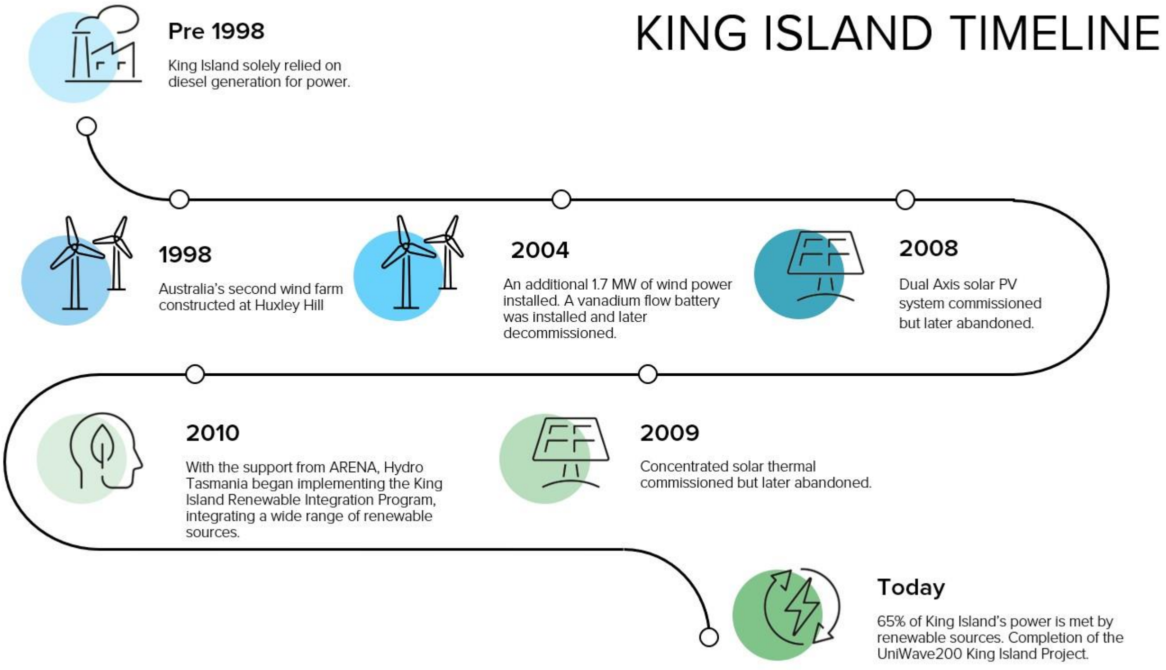
King Island was one of the world's earliest high renewable penetration islanded grids **[7]**. Hydro Tasmania, the entity responsible for the supply of electricity on King Island, was an early adopter of utility-scale wind power, commissioning the second wind farm in Australia, Huxley Hill, in 1998. As a result, diesel consumption was reduced by one fifth. In 2004, an additional 1.7MW of wind power was installed, bringing total wind generation to 2.4MW, and meeting 30% of the islands annual load. To support this level of renewable penetration, a 200kw/800kWh vanadium flow battery was installed in the same year but later decommissioned due to poor performance.

Figure 15 - King Island Huxley Hill Wind Farm [164]

Undeterred, Hydro Tasmania embarked on further attempts to integrate renewable technologies, including a dual axis solar PV system commissioned in 2008, and concentrated solar thermal in 2009, both of which faced challenges and later abandoned. In 2010, with assistance from the Australian Renewable Energy Agency (ARENA), Hydro Tasmania began implementing other enabling technologies for higher levels of renewable penetration under the King Island Renewable Integration Program (KIREIP). This included a dynamic resistor, use of biodiesel in diesel generators, two 12 tonne flywheels mechanically coupled with a low load diesel generator to function as a diesel uninterruptible power supply, an advanced lead acid battery energy storage system (BESS), and demand-side management supported by centrally orchestrated smart meters and smart switches. Through the integration of these technologies into a sophisticated and autonomous control system, KIREIP enabled the King Island power system extended continuous periods of zero-diesel or 100% renewable energy penetration.

Today, the King Island power system provides stable and reliable power around the clock. On average, the system operates at 100% renewable penetration ('diesel-off') for 20% of the year **[8]**. Enabling technologies allow for 65% of annual demand by volume to be met my renewable energy. Diesel usage for generation has reduced by 45% - from 4.5 million litres to 2.6 million litres per annum, reducing costs and exposure to fuel price rises significantly **[9]**. Innovation on the island, with the UniWave200 King Island Project, which produces electricity through a turbine by mimicking naturally occurring blow holes, recently completing a 12-month trial **[10]**. King Island's hybrid power system has also provided a template for other isolated systems, including Flinder's Island in Tasmania, Coober Pedy, in remote South Australia and Rottnest Island in Western Australia **[11]**.

History



KING ISLAND TIMELINE

Pre 1998
King Island solely relied on diesel generation for power.

1998
Australia's second wind farm constructed at Huxley Hill

2004
An additional 1.7 MW of wind power installed. A vanadium flow battery was installed and later decommissioned.

2008
Dual Axis solar PV system commissioned but later abandoned.

2009
Concentrated solar thermal commissioned but later abandoned.

2010
With the support from ARENA, Hydro Tasmania began implementing the King Island Renewable Integration Program, integrating a wide range of renewable sources.

Today
65% of King Island's power is met by renewable sources. Completion of the UniWave200 King Island Project.

Technological Considerations

Lesson 1: A focus on more mature, lower-complexity technologies significantly reduces risks to the reliable delivery of targeted outcomes in remote locations

Figure 16 - Vanadium Redox Flow Battery Electrolyte Containment Vessels [117]

Over the years, Hydro Tasmania has pursued several different emerging VRE technologies. In many cases, while the technical capability promised much on paper, in reality, those capabilities were not realised. For example, in 2003-2004, a 200 kW/800 kWh Vanadium Redox Flow Battery (VRB) was installed to enhance system flexibility and support higher amounts of renewables. At the time it was the first commercial installation of a VRB in Australia.

The VRB was expected to have a long service life and tolerate high cycle rates and depths of charge. In practice, commissioning and operation of the technology was challenging partly due to the lack of internal or external operational experience. The VRB encountered cell stack failures, inverter failures and finally, a breach in one of the electrolyte containment vessels which ultimately led to its decommissioning.

Figure 17 - Hydraulic Dual axis Tracking Solar Installation [117]

Similarly, with the intention of diversifying the King Island generation fleet, Hydro Tasmania installed 100 kW of solar PV mounted on six dual-axis hydraulic tracking structures in 2008. The hydraulic tracking system promised 40% higher yields than conventional static installations but repeat failures of the hydraulic mechanism and the high costs of remediation resulted in their decommissioning.

A consistent theme contributing the failures described was overly complex mechanical or electrical systems. Compounding the problems was the remoteness of the installation, requiring expertise to attend the Island, causing delays and friction in finding and advancing solutions.

Lesson 2: A combination of integrated firming technologies are typically required to support high penetrations of VRE.

After an extensive process of learning, the King Island power system has settled on a suite of complimentary enabling technologies that respond dynamically to maintain system stability while maximising wind generation. As an example, **Figure 18** demonstrates how the dynamic resistor, BESS and flywheel coordinated their response to variability in wind power generation. From t = 10 to 20 seconds, as wind generation spikes, the dynamic resistor responds by introducing a commensurate amount of load. From t = 20 to 30 seconds, as the wind generation sharply decreases, the dynamic resistor withdraws its load at the same time as the flywheel provides inertia support to maintain system frequency. Shortly after, the battery responds to cover the generation shortfall, dynamically adjusting its rate of discharge to align with the inverse profile of wind generation. In this instance, the battery had sufficient reserves to respond to wind generation variability and diesel-off operation was sustained. Were that not the case, a 1MVA diesel generator capable of fast st2s3dqwxz1art would be coupled with the flywheel via mechanical clutch to support system stability.

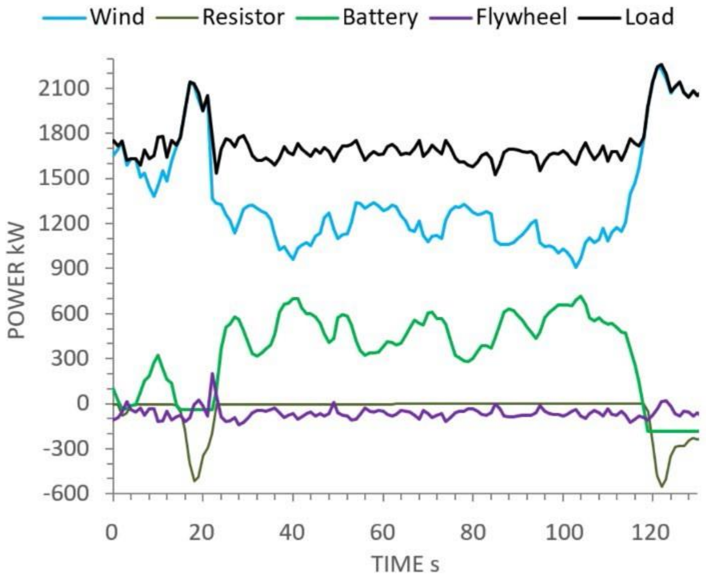


Figure 18 - Response of Enabling Technologies to Rapid Decrease in Wind Generation [165]

With this arrangement, diesel generation can be introduced at short notice and only when necessary. It functions as a backstop for generation shortfalls, allowing the programmed dispatch strategy to preference renewable wind generation without fear of system instability. Conversely, the dynamic resistor provides fast and accurate response to generation oversupply and enables fast frequency raise reserve. It also allows wind generation to operate unconstrained, improving inertia and capacity firming via dispatch or withdrawal of load in a fraction of a second, as required to smooth wind generation.

Lesson 3: Low-load diesel generators can support increased penetrations of renewable generation and the transition to BESS systems

One historical challenge for Islanded grids is the restriction of conventional diesel generators to operate at a floor of circa 30% loading, requiring dispatch strategies to spill renewable generation to accommodate this restriction. King Island operates a low-load diesel generator unit warranted to run at 10% loading, permitting acceptance of additional renewable generation. Further, the King Island is configured such that the low-load unit is the first diesel unit brought online and the last taken off further optimising the system for additional renewable generation. Operating diesel generators at low load does increase fuel consumption per kWh, however, the increased renewable generation it enables provides a net positive reduction in fuel use.

One challenge that low-load diesel must overcome is the risk of reverse power acceptance, given the reduced ability to regulate increases in renewable energy generation. In King Island's case, the dynamic resistor provides responsive load to prevent this occurrence.

While costs for utility-grade BESS for energy shifting and provision of ESS have reduced considerably, many capital constrained islanded grids are still unable to integrate them into their power systems. Low-load diesel provides a lower cost option to increase hosting capacity for renewables. Existing diesel generators may be modified to enable operation at low-load at low cost. Beyond capital costs, low-load diesel does not require additional training of personnel and most often integrates with existing well-established operational routines, further reducing costs, increasing operator acceptance and minimising disruption to system operation.

At the same time, low-load diesel can play a role as a transitionary technology in preparation for BESS solutions in the future. Operating low-load diesel enables a smaller capacity modular BESS to be introduced without immediately being critical to secure system operation. Transitioning in this way allows for operational coordination and dispatch strategies to be refined, and operator experience gained, providing a foundation for BESS expansion at a later date. King Island runs its low-load diesel unit in combination with an advanced lead-acid battery system.

Policy and Regulatory Enablers

Lesson 4: Utility-owned unregulated commercial subsidiaries can enable innovation and commercialisation of expertise

Hydro Tasmania is the regulated utility responsible for the secure and reliable supply of electricity to residents and businesses on King Island. While the need to regulate activities of utilities is not disputed, it does limit the extent to which such utilities are able and incentivised to share learnings and expertise beyond their service territory.

In developing the innovative King Island power system, Hydro Tasmania collaborated with their commercial consulting subsidiary Entura. In doing so, Entura was well positioned to take the lessons learned and apply them to other islanded grids undertaking similar ventures.

At the conclusion of the King Island Renewable Energy Integration Project (KIREIP), Entura developed a commercial offering replicating, modularising and containerising components of the King Island power station. The product, called Hybrid Energy Hub, was marketed on the basis of the success of King Island, strengthening its credibility. Entura went on to deploy their Hybrid Energy Hub solution on the nearby Flinders Island in Tasmania, the remote community of Cooper Pedy in South Australia, and later on Rottnest Island in Western Australia.

Figure 19 - Entura's Hybrid Energy Hub installation on Flinders Island [12]

Market and Commercial Enablers

Lesson 5: Initial government co-funding is often critical to support the scale of organisational learning required to build the necessary expertise

The King Island experience of increasing VRE is of limited commercial relevance given the high cost and complexity of the approach. A significant enabler of the project's success was the financial assistance of the government grant-making body, the Australian Renewable Energy Agency (ARENA), which contributed AUD $5.95m of the $17.69m project as part of their broader Advancing Renewables Program initiative. Under this program, funding recipients must agree to enter into an agreement with ARENA to publicly share knowledge and information about, and resulting from, the project undertaken. As such, the government investment has had broad benefit beyond the shores of King Island.

Onslow, Western Australia, Australia

Background and Overview	
Operator	Horizon Power
Population	850
Nearest Grid	35km
Installed Capacity	12.5MW
Max Demand	Not Available
Annual RE Volume	50%

Onslow is a small and remote coastal town in the Pilbara region of Western Australia, 1,386km north of Perth. Many of the residents work in the nearby gas extraction and processing facilities, tourism or fishing industries. The town falls within the service territory of the vertically integrated utility Horizon Power.

Prior to 2016, the islanded grid servicing Onslow was experiencing power quality and stability issues and risks of outages as the amount of uncontrolled solar PV hosted on the grid exceeded nominal technical limits by a factor of three [13]. Other islanded grids operated by Horizon were also experiencing solar PV saturation. A transferable solution to removing hosting capacity limits that enabled and realised greater participation and value from DERs was needed across its entire service area [14]. To address this challenge, Horizon Power announced the Onslow Power Project in 2016. Stage one of the project included a 7 MW gas-fired power station capable of turning down its output as renewable energy increases, along with a new transmission line, zone substation and distribution network extension. Stage 2 included the installation of a 1 MW utility-operated solar farm, and coupled with a 1 MWh lead-acid battery. On the demand-side, it piloted the orchestration of customer owned DER in such a way as to increase the penetration of renewable energy and maintain the stability of the system.

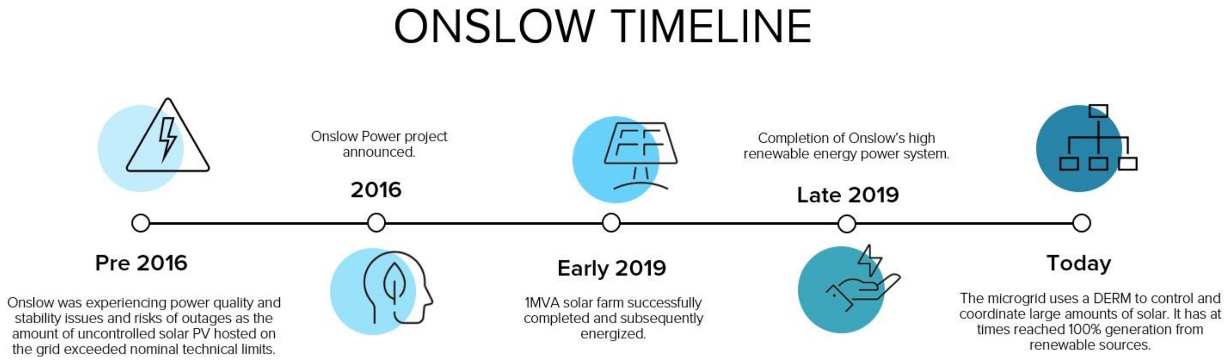
Figure 20 - Onslow Solar Farm [166]

A central feature of Horizon's efforts was to implement a Distributed Energy Resource Management System (DERMs) built using an implementation of the international 'smart grid' standard (IEEE 2030.5).

This approach enabled customer owned DERs to be monitored and to receive commands for feed-in management, demand management, reactive power management and battery management at individual sites. Enrolled customer solar PV and batteries are orchestrated by the DERMs based on sophisticated analytics that consumes data from advanced metering infrastructure, historical load profiles, distributed battery charge levels, and weather, and algorithmically applies multi-objective optimization, balancing key objectives of reliability, economics, and maximising renewable generation.

Homeowners and businesses were provided incentives to purchase solar PV and batteries which could be remotely managed. Horizon's engagement with the community resulted in 260 customers enrolling in the program, aggregating to 2.1 MW of distributed generation capacity and 500 kWh of distributed battery storage. Altogether, the microgrid has reduced in the order of 55,000 GJ of natural gas consumption and 3,000 metric tons of CO^2 annually [13].

History



Pre 2016
Onslow was experiencing power quality and stability issues and risks of outages as the amount of uncontrolled solar PV hosted on the grid exceeded nominal technical limits.

2016
Onslow Power project announced.

Early 2019
1MVA solar farm successfully completed and subsequently energized.

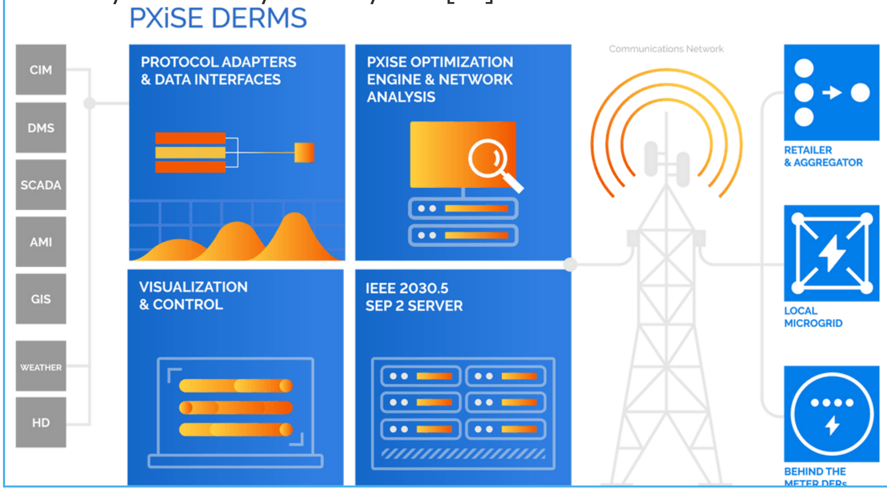
Late 2019
Completion of Onslow's high renewable energy power system.

Today
The microgrid uses a DERM to control and coordinate large amounts of solar. It has at times reached 100% generation from renewable sources.

Technological Considerations

Lesson 1: Advanced operational coordination of customer energy resources can support higher penetrations of renewable generation

The Onslow power system was limited in the volume of additional renewables it could host due to instability issues caused by already high penetrations of distributed PV (DPV) and the potential of stability and power quality issues. Horizon Power, the responsible utility, sought to increase hosting capacity threefold for customer-owned renewable DPV, whilst also maintaining and improving the reliability and stability of the system [15].



The Onslow DER Project was one of the first instances of a 'business as usual' approach to utility management of Distributed Energy Resources (DER) in Australia, the alternative approach being costly network augmentation. It involved a collaboration with vendors PXiSE and SwitchDin to design and implement a DER Management System (DERMS) using the newly launched IEEE2030.5 protocol. The grid would be the first of its kind to launch the protocol.

The project uses edge-devices (known as Droplets) developed by SwitchDin as secure gateway devices compliant with the protocol for 'smart grid' standard inverter control. The Droplets act as both communication gateways between the DERMS server and hardware, and energy managers to allow incorporation of customer-owned solar and batteries whilst maximising value to customers. Weather data is also incorporated into the DERMS to proactively protect the network from power quality and reliability issues caused by reverse power flow and intermittency of solar generation.

The DERMS coordinates and optimises the utility and customer-owned DER assets in tandem with the centralised gas-fired generator to provide essential grid services such as load balancing and frequency and voltage control. It decides which loads must operate at which times to optimise solar usage whilst providing grid stability [16]. The DERMS allows for a system to smooth intermittency due to the variable nature of rooftop solar, as well as prevent excess reverse power flows from disturbing the rest of the network. Without the DERMS for coordination of BTM sources, the Onslow microgrid would continue to see capacity limitations for rooftop solar installations and higher customer system curtailment rates. DERMS allows for a system to smooth intermittency due to the variable nature of rooftop solar, as well as prevent excess reverse power flows from disturbing the rest of the network. Internet-of-Things (IoT)-DER edge control is still an emergent technology, meaning it is not plug and play yet. The system requires a lot of fine tuning and co-design with the utility is required to allow the DERMS to operate securely under all plausible system conditions.

Figure 21 - PXiSE DERMS layers and functionality [13]

Lesson 2: Extensive collaboration with technology vendors and customers is critical to holistically integrating DPV and DER

The project provided a valuable example of partnering with vendors that have direct, demonstrated experience, as well as a shared approach to development and operation. A functional DERMS is technically complex and time consuming. Development of use cases in conjunction with sufficient time for development and testing allows for improved performance and visibility of isolated grids with high BTM uptake.

The project also demonstrated that extensive customer involvement is a key enabler for projects leveraging customer-owned DER to maximise renewable generation. Transparency and effective communication around the benefits of such a system, and an emphasis on customer agency were critical. Collaborative engagement was used to understand customer expectations ahead of setting project goals, as well as timely communication on the need and amount of generation management to bring community benefits such as increasing customer connections and solar benefits.

"A high DER energy system for the future needs to be open, secure and reliable. It is our responsibility as an operator to meet the needs of our customers. This includes their aspirations for cleaner energy, in a way that is safe, reliable and efficient. As Onslow is showing, we could quite possibly achieve this with the help of using some customer owned assets such as rooftop solar, batteries and major appliances." [15]

Ultimately, one of the goals of upgrading network infrastructure and technologies is to bring greater system security and reliability to its customers. Involving customers in the implementation process allows the utility to understand and meet the requirements of the customers they are serving.

Policy and Regulatory Enablers

Lesson 3: A comprehensive set of publicly available documentation, standards, and connection policy requirements is key for enhancing collaboration and integration

Horizon Power has an extensive public library of its metering and standards for its networks. These manuals apply to contractors, installers or anyone who is working on the Horizon Power networks to ensure power remains reliable and safe in the community. These manuals include the design, construction and installation of renewable sources into the networks, as well as metering requirements for any of these connections.

Horizon Power has set an ambitious emission reduction target of 80% by 2030. On top of this, they have set a zero refusals objective, enabling all customers to connect to rooftop solar by 2025.

Figure 22 - Onslow residential customers with solar installations [167]

Extensive and detailed documentation (as well as application) of manuals, standards and policies allows for greater clarity into design requirements and goals for all participating parties. These documents should be set up to increase renewable uptake and ensure ease of integration of renewable sources into an existing or emerging network without compromising security or reliability of the network.

Market and Commercial Enablers

Lesson 4: Large corporate customers can be a funding source for increasing the renewable energy component of an islanded grid

Petro-chemical multinational Chevron operates the Wheatstone Liquefied Natural Gas (LNG) facility 12 km west of Onslow. Many of the 850 residents of Onslow are employed by Chevron to support its operations. Chevron was therefore motivated to make a significant financial contribution to the Onslow DER Project, strengthening the business case for Horizon Power to proceed with the initiative. Like Onslow, many islanded grids exist to support major remote industries, who often have significant resources at their disposal together with a strong executive mandate to support the communities that support them and cultivate their social license to operate. Partnering with large corporations could in many instances provide the needed resourcing to make prospective renewable energy projects feasible.

Lesson 5: Targeted incentives for compliant and grid-integrated DPV and DER can enhance renewables uptake while mitigating negative grid impacts

The Onslow network is a unique case, in which around 80% of its customers live in rental properties. This brings challenges to incentivise homeowners to make large investments in solar installations. Through the Renewable Energy Pilot, Horizon Power offered homeowners discounted solar PV and battery systems. Eventually, over 50% of properties had solar installations.

Horizon Power also has a Distributed Energy Buyback Scheme (DEBS) for residential customers with energy systems up to 5 kW and a Commercial Buyback Scheme (COBS) for commercial systems greater than 5 kW. These schemes allow customers to be paid a certain rate depending on the time of day they export energy into the network (higher rates during peak periods). These programs also allow for vehicle-to-grid export of power.

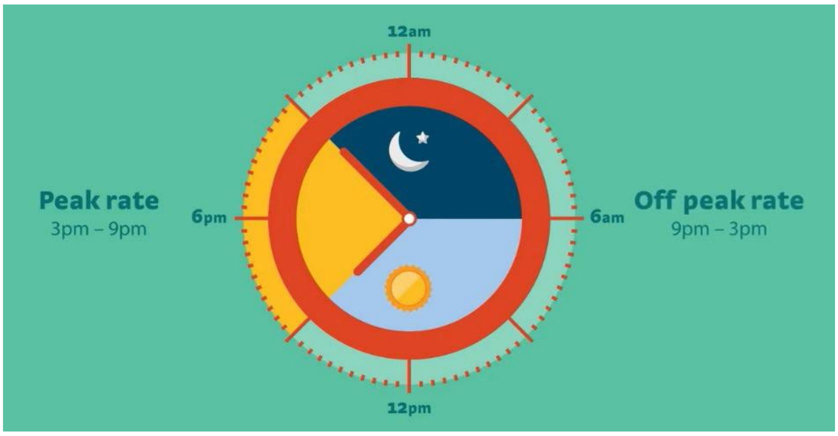


Figure 23 - Peak and off-peak rates for buyback schemes [168]

These rebate schemes aid customers in special circumstances to ensure equitable availability of system services. The buyback schemes incentivise customers to use electricity during off-peak periods (when the sun is shining) whilst exporting excess power during peak periods. This reduces the variance from the average load and reduces the need for peaking services. Onslow DER Project provides the basis for a transferable model for DER management for networks in similar situations.

Lord Howe Island, New South Wales, Australia

Background and Overview

Operator	LHIB
Population	347
Nearest Grid	600km
Installed Capacity	2.84MW
Max Demand	489kW
Annual RE Volume	69%

Lord Howe island is located off the east cost of the Australian mainland directly east of Port Macquarie. The island has been listed as a UNESCO World Heritage site since 1982 in recognition of the island's natural beauty and biodiversity. Nearly 50% of the residents on the island work in the tourism industry with a large portion of the island's economy relying on the tourists that come each year. Like many other island communities, Lord Howe relies on diesel fuel imports for its power generation. Transport risk at sea and volatile fuel prices have led the island to integrate larger shares of VRE. The Lord Howe Island Board (LHIB), a statutory authority charged with the control, management and care of the island, contracted Photo Energy to design and build a PV system on the island. The island now enjoys around 69% renewable energy penetration with greatly increased fuel savings.

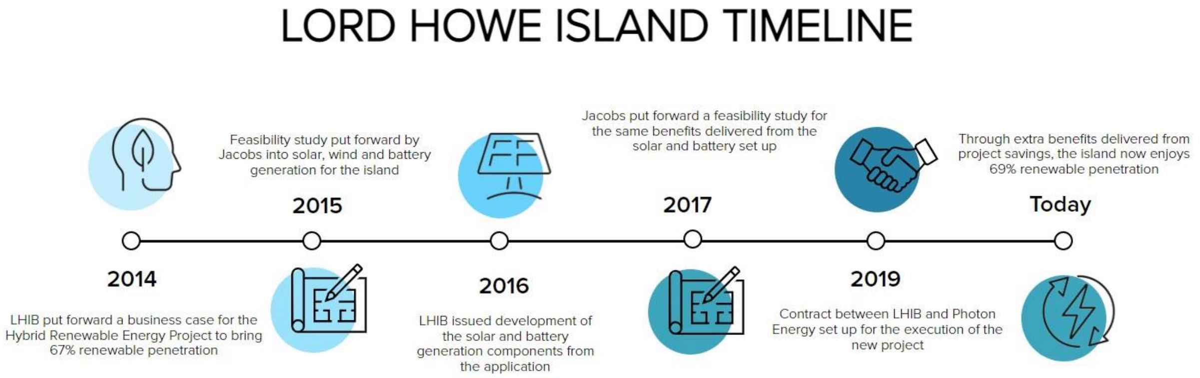
Figure 24 - Lord Howe Island solar farm [169]

The LHIB has a long history of reducing the island's reliance on diesel fuel imports for electricity. Feasibility studies began as early as 2011, with a business case put forward by LHIB for the Lord Howe Island Hybrid Renewable Energy Project in 2014. At the end of 2015, Jacobs completed a feasibility study into a combination of solar, wind and battery technology to provide 67% renewable penetration [17]. However, the wind turbine component could not be delivered, and the development proposal never achieved approval. In

2016 LHIB issued development consent for the solar and battery component of the project. In 2017 Jacobs put forward another feasibility study which saw the same benefits being delivered from a reconfigured and resized PV and battery storage system. With consent issued, the model was able to be put forward to tender and a final contract was awarded to Photon Energy in 2019 for the execution of the Hybrid Renewable Energy Project (HREP) under an Engineer, Procure and Construct (EPC) Contract.

The island's power system now consists of a 1.3MW Solar PV plant and a 1MW/3.7MWh BESS integrated with the existing diesel generation system. The diesel generation system consists of three 300kW Detroit Series 60 generating units supplying a total combined generating power of 840kW. The system utilises a new Micro Grid Controller (MGC) and a SCADA system to provide monitoring and supplementary control.

History



Technological Considerations

Lesson 1: Use of advanced control systems to coordinate high penetrations of renewable sources with diesel generators

Overarching control is required to coordinate multiple sources of generation (diesel, solar and BESS). The Tesla MGC communicates and manages the generating entities through the use of the Tesla Powerpack inverters, SMA solar string inverters and diesel generator controllers [18]. The existing diesel generator's control system was not compatible with the Tesla MGC and a new Woodward EasYgen 3200XT generator controller was installed to provide effective connection.

The BESS is the primary grid forming entity in the system; it provides the reference voltage and frequency for the other generating units to synchronise with. This provides greater security for the system, as it has two main mechanisms to control the output of the other generating units. The main control mechanism is through wide-area communications network using the MGC. In the event that connectivity is lost between the MGC and inverters, the BESS can adjust the level of generation by changing system frequency and subsequently manage the output of the diesel generators and PV plant by means of pre-loaded power-frequency droop settings [18].

The system also utilises a SCADA-Human Machine Interface (HMI) and Remote Monitoring performance management tool to provide operator viewing on web and smart phone apps. It provides automated performance reporting, real-time and remote monitoring and performance monitoring of the system to greatly increase ease of operation and maintenance tasks.

Figure 25 - Tesla battery storage system on the island [169]

Lesson 2: Advanced data collection and modern software applications for accurate modelling and testing

Extensive data collection was required to determine feasibility of proposed configurations along with modelling and testing of the final system. Photon Energy used 2011 load and future meteorological data to develop a PVsyst model of the solar farm. HOMER, the power system modelling software, was used to model expected outcomes by combining battery and diesel generation data over an annual period to determine the feasibility of a 67% renewable share.

To test the performance of the renewable project, the PVsyst model is updated with actual measured meteorological data and imported into the HOMER model which is also updated with actual load data over the same period. The model then predicts the target renewable fraction and manual calculations are conducted on the raw measured data to determine actual system performance. The system passes the performance test if the calculated renewable energy fraction is equal to or greater than the predicted fraction. This method provides an equitable means to protect LHIB and Photon Energy from variable weather and minimum load conditions [18].

Policy and Regulatory Enablers

Lesson 3: Agility in the decision making is required to navigate community concerns and achieve project outcomes

HREP has gone through many modifications in its feasibility, design and implementation phases to arrive at where it is today. In 2016 an initial application was put forward by Jacobs based on the design of a solar, battery and wind project. However, due to the aesthetics of wind turbines on a UNESCO world heritage island, the proposal did not receive consent. Instead, consent was given for the use of just the solar PV and battery storage. This required proponents to pivot to alternative solutions, which required additional system and financial modelling to prove the viability of the Solar and BESS proposal.

Originally, this second iteration of the design utilised two separate solar farms located at different locations on the island. However, through in-depth dialogue with relevant stakeholders, the layout was modified and relocated to one site rather than two separate sites to preserve natural areas for grazing, and reduce the need for high voltage reticulation, long lengths of excavation and long runs of cable. The third design iteration created savings in the project that were procured for additional solar panels and increased battery storage.

Lesson 4: Adherence to both technical standards and land use requirements requires flexibility

The project faced a key issue with the fencing off of sensitive equipment on the solar PV farm. The area of land the solar farm is located on is situated in close proximity to a section of woodland in which Flesh Footed Shearwaters breed. The close proximity to the breeding ground requires the Project Technical Specifications and the Conditions of Consent to specify that any fence constructed by the project must not contain any barbed wire and provide clearance of at least 150mm at the base to avoid injury to fauna as breeding parents migrate to and from the woodland. However, the same Technical Specifications also require adherence to the AS5033: Installation and safety requirements for PV arrays. Under this standard, installations with DC voltages exceeding 600V require construction of a lockable barrier effective at restricting access to the facility and does not permit a 150mm gab that could allow unauthorized access.

This contradiction required the project team to re-evaluate the use of a typical perimeter fence and rely on alternative solutions. Under clause 3.1 of the AS5033 standards:

"If in accessible areas, the associated protection and isolated devices shall also be fully enclosed and not accessible without the use of a tool" AS5044 clause 3.1.

This allowed the project team to develop and design a series of access barriers to prevent intentional or unintentional access to high-risk elements without a tool. This included the installation of a cable tray, fixing a padlock to the BESS inverter to lock it in the 'on' position and fitting the distribution board with an outer shell to protect sensitive equipment.

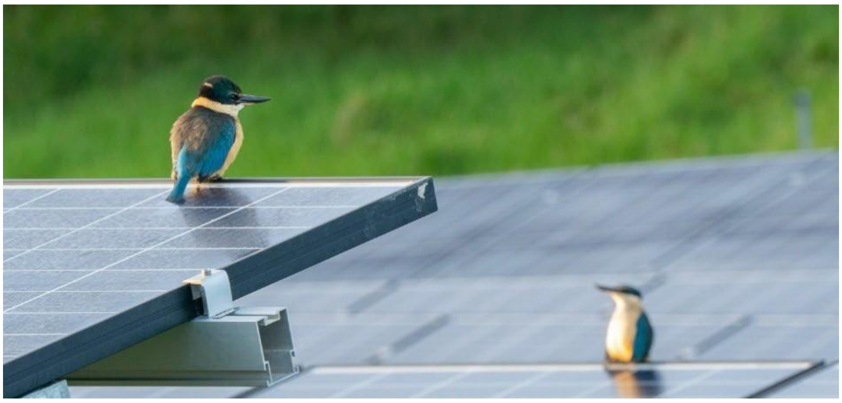


Figure 26 - Native birds on the solar arrays [170]

The final access restrictions do not include a perimeter fence, which increases the risk of damage, thought this was considered an acceptable trade-off decision given the priorities of competing objectives .

Market and Commercial Enablers

Lesson 5: Fixed sum contracts provide opportunities for savings and added value in other project areas

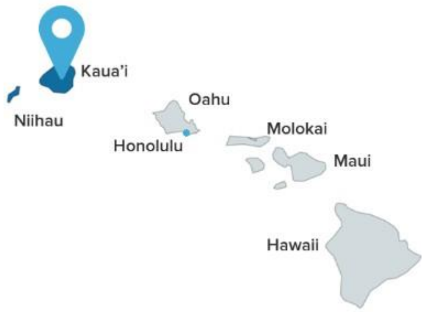
From the beginning, the Lord Howe Island Board VRE integration project was executed under a fixed sum contract with Photon Energy. The contractual arrangement included provisions to adjust the budget envelope for slippage in delivery timelines and scope expansion of the project. The delivery team was also able to consider design improvements and optimisations that created savings for the project under the same contract. Any savings were redirected to deliver more infrastructure such as expanding the solar generation and battery storage, and the provision of public amenities such as toilets and a storage shed.

Strong relationship between consultants and contractors were key to the success of fixed sum contractual arrangements. This was vital for the team’s ability to conduct honest and open conversations into the risks and costs associated with delivering beneficial opportunities to the project.

Kaua’i Island, Hawaii, United States

Background and Overview

Operator	KIUC
Population	73,300
Nearest Grid	3,900km
Installed Capacity	259.2MW
Max Demand	75.17MW
Annual RE Volume	69.5%



Kaua’i Island is one of Hawaii’s six main islands located around 3,900 km west of San Francisco. Kaua’i Island, also known as the ‘Garden Island’ is one of the more scenic islands with many popular tourist destinations. It has a large tourism industry with many of its residents working in tourism, retail or in government. The adoption of higher initial priced renewable energy facilities has brought about more stable electricity prices for consumers (from $0.43/kWh in 2011 to $0.33/kWh in 2022).

Since 2002, much has changed for the island of Kaua’i. Kaua’i Island Utility Cooperative (KIUC) purchased Kaua’i electric (KE) from Citizens Utilities. Prior to the sale, KE had relied heavily for decades on imported diesel fuel for its generators. This reliance increased as sugar plantations on the island shut down and KE no longer had access to renewable power supplied by the plantations via the burning of bagasse. After the sale to KIUC oil prices rose significantly, the board realised that member bills could increase to unacceptable levels. In conjunction with growing concerns about carbon emissions, KIUC embarked on one of the most ambitious shifts to renewable energy sources anywhere in the American electric utility industry. Renewables have increased from 6% of sales in 2007, to 37% in 2016 [19]. The island had originally set aggressive targets to source 70% of its energy using renewables by 2030 in its 2016 Strategic Plan, but has achieved this goal in 2021, nine years ahead of schedule. The new draft Strategic Plan (as of September 2022) establishes a 100% renewable target by 2033 [20].

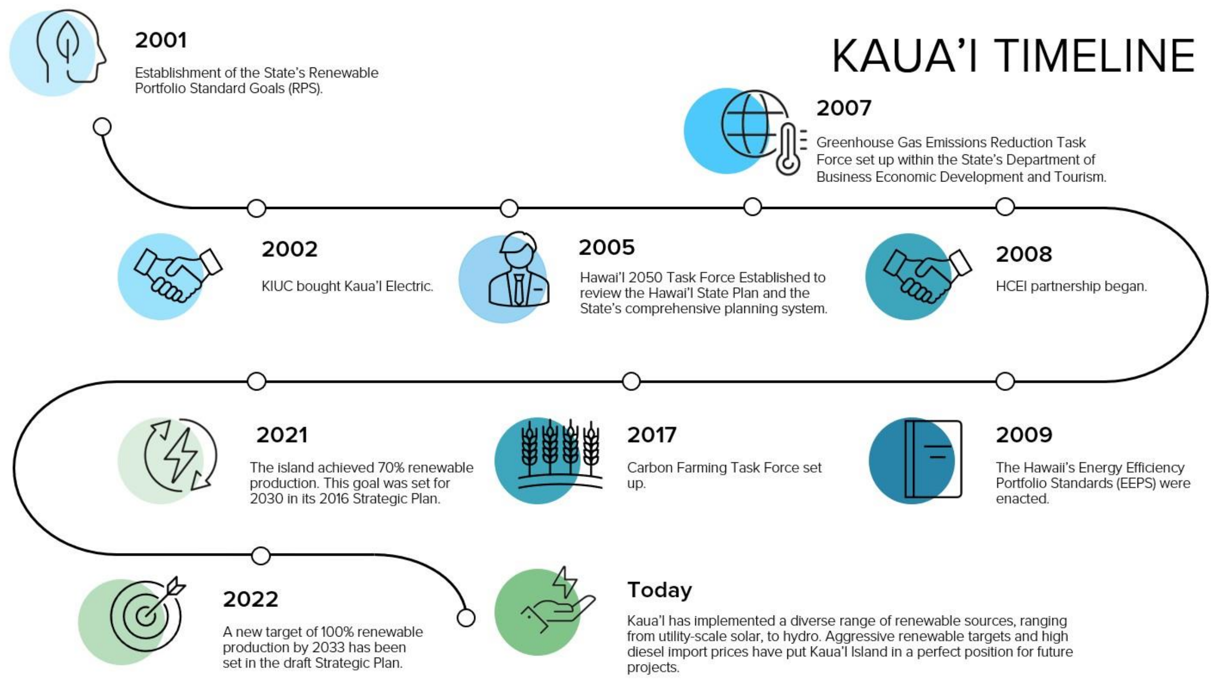
Figure 27 - Kaua'i Island Solar Farm [171]

In 2008, Hawaii and the United States Department of Energy established a long-term partnership with the purpose of transforming the way in which renewable energy and energy efficiency resources are planned and developed in Hawaii. This partnership, referred to as the Hawaii Clean Energy Initiative (HCEI), set a goal for Hawaii to meet 70% of its energy needs by 2030 through clean energy, with 30% coming from energy efficiency measures, and 40% coming from renewable sources [21]. Since then, HCEI has enacted over 80 laws between 2008 and 2017, with amended renewable portfolio standards (RPS) of 100% by 2045 and reducing electricity consumption by 4,300 gigawatt-hours by the year 2030 [22].

At the end of 2012, more than 1,200 Kaua'i Island households had rooftop solar generation, this number has now risen to 4,300 in 2022. Over the years, KIUC has collaborated with many private sector members and investors for the construction of renewable energy projects. From 2014 to 2017, KIUC signed a PPA with Gay & Robinson for the purchase of electricity generated from a hydroelectric facility, one with AES Distributed Energy for a new solar and battery facility in Lawai and another with AES Distributed energy for a new solar and battery facility at the Pacific Missile Range Facility. The same year they also paired with Tesla for the SolarCity solar and storage project [23]. Since then, Kaua'i has implemented 21 MW of residential solar, 118.9 MW of Utility-scale solar, 17.3 MW of hydro, 6.7 MW of Biomass, 47 MW of BESS and 110.5 MW of fossil generation to power its network for an average of 69.5% annual renewable penetration [24].

Kaua'i island's large and diverse supply of indigenous renewable energy resources paired with Hawaii's aggressive approach to policy and regulatory enablement for renewable energy and a willing utility cooperative has created an ideal environment for rapid renewable energy uptake.

History



KAUA'I TIMELINE

2001 Establishment of the State's Renewable Portfolio Standard Goals (RPS).

2002 KIUC bought Kaua'I Electric.

2005 Hawai'I 2050 Task Force Established to review the Hawai'I State Plan and the State's comprehensive planning system.

2007 Greenhouse Gas Emissions Reduction Task Force set up within the State's Department of Business Economic Development and Tourism.

2008 HCEI partnership began.

2009 The Hawaii's Energy Efficiency Portfolio Standards (EEPS) were enacted.

2017 Carbon Farming Task Force set up.

2021 The island achieved 70% renewable production. This goal was set for 2030 in its 2016 Strategic Plan.

2022 A new target of 100% renewable production by 2033 has been set in the draft Strategic Plan.

Today Kaua'I has implemented a diverse range of renewable sources, ranging from utility-scale solar, to hydro. Aggressive renewable targets and high diesel import prices have put Kaua'I Island in a perfect position for future projects.

Technological Considerations

Lesson 1: Leveraging a diverse portfolio of indigenous renewable resources may be required to meet system needs and maximise community acceptance

Kaua'i Island has an abundance of local renewable energy resources. However, the availability of sites for VRE facility construction that are not subject to environmental, community or cultural concerns is limited. Achieving higher renewable shares is dependent on community acceptance of VRE fleet expansion project plans.

As a result, the Kaua'i Island Utility Cooperative (KIUC) looked to incorporate a diversity of indigenous renewable energy resources that were acceptable to the local community. On the supply-side, KIUC utilises solar, hydro, and biomass, supplemented by both non-firm and firm renewable power purchase agreements and company-owned fossil fuelled generation as required. On the demand-side, active customer-owned solar and demand-side management, such as hot water, provide additional flexibility to the system.

KIUC is also exploring ways to convert legacy diesel generation to propane or renewable-based fuels as a low capital cost option to further decarbonise that doesn't require any additional land parcels.

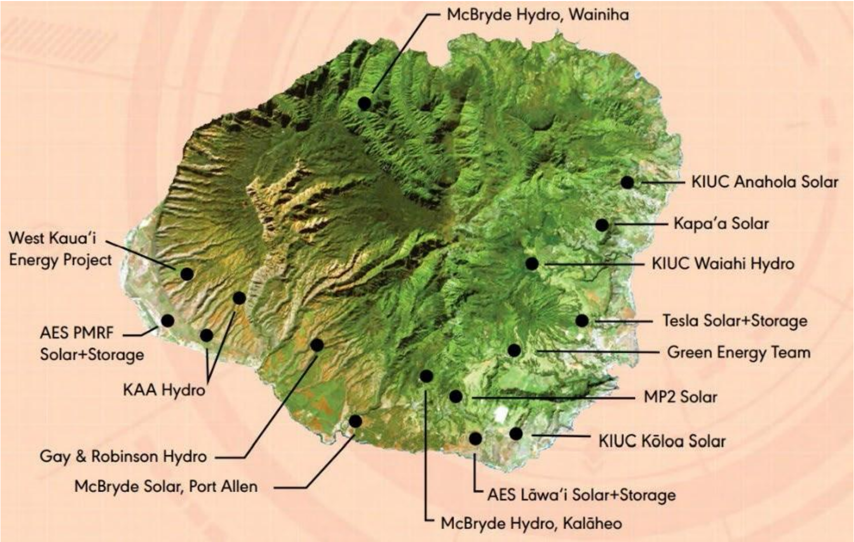


Figure 28 - Kaua'i Island current active renewable generation locations [172]

Lesson 2: The early stages of the transition to high-renewable islanded grids will often involve significant technical challenges and system modifications

KIUC's high penetration of VRE lead to the island experiencing major reliability events, including several major system-wide blackouts during high renewable penetration periods driving grid instability. In both 2017 and 2018, reliability events occurred around noon where there was only one conventional dispatchable unit online. The power station tripped on reverse power due to grid fluctuations causing the entire system to blackout. In both cases the fault was fixed in just over an hour [25]. In April 2021 at around noon, the grid was running on 100% renewable energy when the system began experiencing severe frequency swings. Attempts were made to stabilise the issue but were unsuccessful and a system wide black out occurred for around 1 hour.

Following on from this event, modifications have been made to the BESS frequency droop settings, BESS site control system communications and AGC tuning [26]. Synchronous condensers have also been demonstrated as being cost-effective approaches to maintain grid stability as increased renewable shares displace conventional synchronous generators. The generator provides essential grid services such as inertia, voltage support and fault current to keep the grid stable during high renewable periods [27].

Policy and Regulatory Enablers

Lesson 3: The establishment of explicit government goals, policies and requirements is a key driver of accelerating the transition to renewable energy

In 2001, the State of Hawaii enacted legislation which requires each electric utility to establish Renewable Portfolio Standards (RPS). An RPS sets a mandate of the percentage of electricity that must be generated from renewable energy resources by the end of the identified benchmark years. The RPS policy mechanism was initially created by Act 272, which states:

"It is the intent of the legislature to recognize the economic, environmental, and fuel diversity benefits of renewable energy resources and to encourage the establishment of a market for renewable energy in Hawaii using the State's renewable energy resources and to encourage the further development of those resources.... Accordingly, the legislature finds that it should establish goals for electric utilities to guide them in incorporating renewable resources into their resource portfolios to reduce the use of imported oil." [21]

RPS targets have evolved through several legislative amendments that have followed Hawaii's energy policy developments. State law requires that the Commission periodically review every five years, starting in 2013, whether an RPS remains effective and achievable.

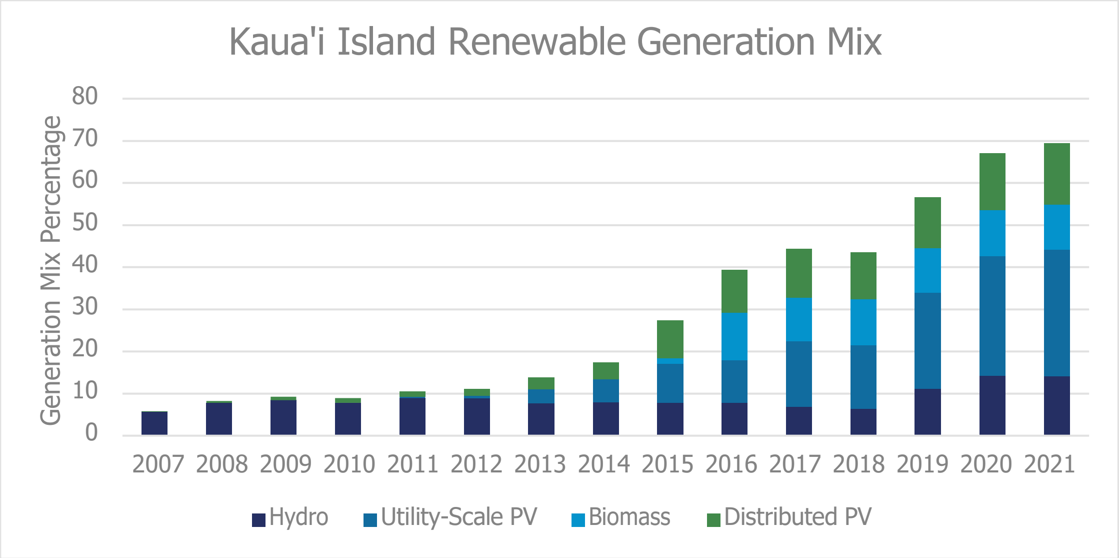


Figure 29 - Kaua'i renewable energy generation mix per year

Kaua'i Island has continuously exceeded its RPS goals with the quickest rise in renewable shares out of any of Hawaii's islands, setting an example for the rest of America, and the world. Achieving these RPS requirements and providing reliable and affordable electric services all require careful planning and optimisation of a viable portfolio of resources in a utility system. Collaboration of many stakeholders, including the utilities and the Commission is required to provide the necessary analysis, planning and regulatory guidance to best meet shared energy objectives [21].

Market and Commercial Enablers

Lesson 4: Utility enablement programs can help enhance overall system efficiency and increase the uptake and grid-integration of customer-owned DPV and DER

KIUC has initiated a range of 'member services' to enable greater customer ownership of, and participation in a high VRE power system. The programs cover a range of members, including residential and commercial customers both in special circumstances that require assistance and for incentivising uptake of renewable technologies such as rooftop solar or EVs. Some of these services include:

Appliance Replacement Rebate

This residential program is designed to encourage customers to discard older, less efficient appliances and replace them with new, energy-efficient models. This rebate is a set lump sum payment (usually around $50) to the customer who is replacing their appliance.

Commercial Programs

Commercial customers may qualify for programs to install cost-effective energy-saving technologies. The Commercial Retrofit Program range from 50% to 100% coverage to promote energy saving measures by delaying some of the initial costs that may otherwise prohibit or postpone implementation of energy saving technology. The Commercial New Construction program allows the cost of planned new construction to be covered for energy efficient measures. The Commercial Equipment Replacement program covers equipment that has failed or reached the end of its life. KIUC will cover 80% of the incremental cost difference between the standard and high efficiency replacement equipment.

Electric Vehicle Programs

KIUC has initiated a number of EV programs to incentivise the uptake of EVs and accompanying technologies. KauaiEV is a grassroots organisation that is dedicated to accelerating the adoption of EVs. They have publicly available information on charging station locations and cost comparisons between EVs and conventional vehicles for the Kaua'i area. Drive Electric Hawaii also provides educational resources for customers considering owning an electric vehicle.

Home Assessment

This program allows members to apply for a Home Assessment Learning Experience (HALE). During the visit, an energy specialist collects appliance and demographic information to establish if high consumption is justified and if not, document the conditions that are causing unnecessary high consumption. Direct installation of low-cost energy saving devices such as LEDs, Smart Plugs and Smart Power boards may also be offered. Smart Hub education is also offered as a platform to make payments, view bills and manage accounts. During 2017, the number of members using Smart Hub doubled from 3,211 to 7,352 users.

Rooftop Solar

Before a customer can install a solar system, the Hawaii Public Utilities Commission requires all customers to submit an interconnection request application to KIUC for review. This ensures that the PV system can be safely and reliably connected to the utility grid without severe side effects. It also ensures the member understands the rules of the interconnection agreement.

Education Resources

The 'Together We Save' program provides a collection of educational resources that are publicly available for customers. These resources help customers gain a better understanding of how they are using their electricity, and how they can save money through energy efficiency measures, appliances and other small saving techniques.

Water Heating Programs

Customers are able to apply for a $1,500 rebate or a zero-interest loan to replace their existing electric water heater with a solar water heater or replace an existing non-function solar water heater. They can also apply for a $500 rebate to replace an existing water heater with an Energy Star heat pump water heater.

Lesson 5: PPA innovation is a key component of a commercial ecosystem in which renewable energy investments are supported and future-ready

The State of Hawaii introduced a fundamentally altered PPA structure that departs from traditional energy-based (MWh) PPAs. In smaller isolated systems, dispatching fossil-fuel plant for essential reliability services or to stabilise VRE output often leads to curtailment of renewable energy generation due to minimum loading requirements. Traditional VRE PPAs are typically long-term agreements with average contractual spans of 20 years with energy (MWh) delivered paid at a negotiated rate. The risk associated with uncertainties in projected future weather and equipment performance and availability is taken into consideration through this process. Traditional PPAs have deficiencies when VRE becomes a major contributor to the energy mix.

Figure 30 - Tesla 13 MW solar farm and storage on Kaua'i island [173]

The regulator in Hawaii acknowledged the need for new contractual provisions for PPAs, including as they relate to curtailment and evergreen terms. Under traditional 'seniority curtailment' provisions, newer and more efficient generation assets that come under newer PPA agreements are curtailed first. Preferencing existing PPAs in this way discourages Independent Power Producers from deploying VRE and signing new PPAs. So called evergreen provisions mandate that upon the expiration of the initial term, the PPA is automatically renewed without change. Under these arrangements, customers are not able to benefit from technology improvements or innovation, and the utility is incumbered by contracts that lack flexibility [28]. Other islands have attempted to resolve these issues with a variety of incremental PPA contractual mechanisms, though managing complications with allocating risk has proven difficult [29].

The new PPA contractual provisions are structured as a 'contract for service'. Revenue is based on providing capital equipment with specified performance characteristics, coupled with demonstrated proof that the equipment is able to provide specific service functions when called upon. The generation sources are obligated to be capable of providing a variety of frequency and voltage control and support service and dispatch responses. With this structure, the developer knows its CAPEX and has accurate estimates of OPEX required to meet its contractual obligations. The developer is obligated (and policed) to ensure that it constructs a generation facility that meets all of the specifications provided by the utility and that it maintains the facility to provide contracted services for the duration of the agreement [29].

This arrangement allows the isolated grid to adapt and change, become more efficient and cleaner. It enables the facility to be used differently throughout its life for the benefit of the ratepayers. Innovation by the utility is rewarded as they have the ability to use the resource differently as circumstances and requirements change.

Kodiak Island, Alaska, United States

Background and Overview		
Operator	EA	
Population	12,800	
Nearest Grid	270km	
Installed Capacity	75MW	
Max Demand	27.8MW	
Annual RE Volume	99.7%	

Kodiak Island, situated just 50km off the Alaskan Coast, is Alaska's largest island and second largest in the United States (covering an area of around 9,300 square km). Most of Kodiak Island is categorised as uplands where the east coast exceeds 1,500 meters with heavy forestation. With no grid connection to mainland Alaska, the island has been utilising hydro resources since 1984. The utility operator, Kodiak Electric Association (KEA), set a vision statement in 2007 which drove the addition of multiple wind farms, a third hydro turbine and several energy storage systems, enabling the community to achieve an average annual renewable penetration of 99.7%. Kodiak's economy relies heavily on the relatively electricity-intense fishing industry and is the US's third largest fishing port. Stable electricity rates resulting from the new renewable system have led to an expansion in the fishing industry, creating more jobs and tax revenue for the local government [30].

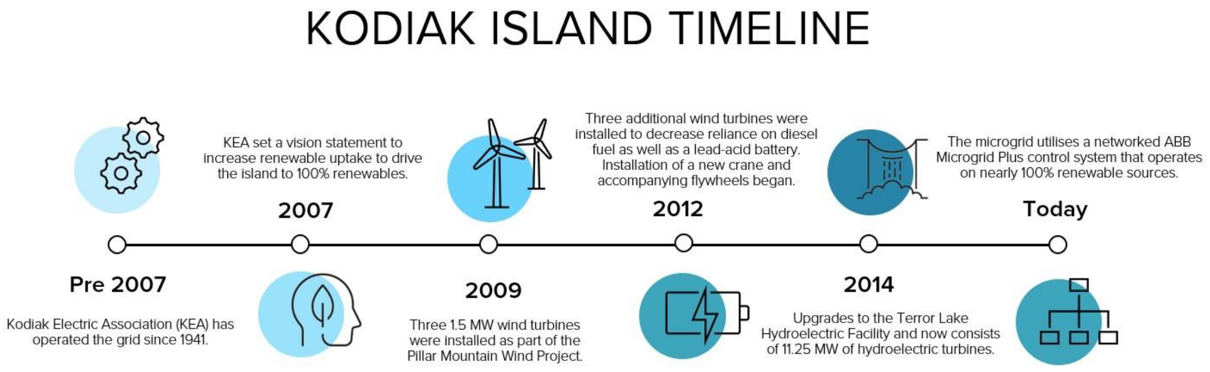
KEA has operated the island's electric grid since 1941. Given the need to upgrade port infrastructure and move away from costly diesel generation, the integration of new renewable sources and storage technologies have been key enablers to bring the island to nearly 100% renewable generation. In 2009, three 1.5 MW wind turbines were installed as part of the Pillar Mountain Wind Project, with three additional 1.5 MW turbines planned for installation in 2012 to decrease reliance on diesel fuel (estimated to save 76,000 litres per year). The existing power network would not be able to provide sufficient frequency response services for the additional 4.5 MW of wind power. Xtreme Power delivered a 3 MW/750 kWh advanced lead-acid battery to provide second-to-minute frequency response. The system responds to on average 285 frequency events each day to enable full use of the new 4.5 MW wind power [31].

Figure 31 - Kodiak Island Wind Farm [174]

In 2012, the City of Kodiak planned to install a 2 MW electric crane to replace the older diesel-powered crane. The new crane would create destabilising power fluctuations and undesirable battery cycling. Therefore, two 1 MW ABB PowerStore flywheels (2 MW total) were installed to effectively integrate the crane load into the grid as well as provide frequency and voltage regulation. The flywheel also reduces stresses and increases the cycle life of the BESS by responding to microsecond frequency changes, allowing the BESS to respond to longer second to minute frequency changes. Terror Lake Hydroelectric Facility is the largest form of energy storage deployed on the island, generating around 124,400 MWh of electricity annually whilst also providing long-term storage of excess wind energy. It consists of three 11.25 MW hydroelectric turbines, with the most recent of which was installed in 2014. The system is also able to respond to over-frequency disturbances caused by high penetration of wind energy through an internal governor system that can rapidly limit hydro power output [32]. The Kodiak Island grid utilises the networked ABB MGC600 Decentralised Microgrid Control system to manage power flows, which consists of distributed control modules that are coordinated on a peer-to-peer basis, allowing communication among resources [32].

What once was a community that had its electricity rates controlled by diesel prices, is now a thriving community with steady and declining rates. No major reliability events have been caused by the integration of high renewable shares. Instead, the renewable energy projects have brought greater reliability and resiliency to the isolated grid. Diesel generators once generated around 40% of the island's electricity, but now they remain mostly idle, only being required for emergency backup power.

History



KODIAK ISLAND TIMELINE

Pre 2007
Kodiak Electric Association (KEA) has operated the grid since 1941.

2007
KEA set a vision statement to increase renewable uptake to drive the island to 100% renewables.

2009
Three 1.5 MW wind turbines were installed as part of the Pillar Mountain Wind Project.

2012
Three additional wind turbines were installed to decrease reliance on diesel fuel as well as a lead-acid battery. Installation of a new crane and accompanying flywheels began.

2014
Upgrades to the Terror Lake Hydroelectric Facility and now consists of 11.25 MW of hydroelectric turbines.

Today
The microgrid utilises a networked ABB Microgrid Plus control system that operates on nearly 100% renewable sources.

Technological Considerations

Lesson 1: A combination of different firming technologies may be required across timescales from sub-second to minutes

Kodiak Island provides an example of the importance of selecting the most appropriate energy storage technology to meet the requirements of its operating context. Originally, when the cost of energy storage was high, energy storage was primarily used in islanded grids to support intermittent renewable power with grid services. However, with decreases in capital costs, energy shifting, and peak shaving applications have become more prevalent.

At the time, KEA had limited examples to draw upon on managing grid frequency and voltage issues inherent to VRE. The BESS was originally designed for energy storage and to support second-to-minute services. However, it instead was largely used to respond to microsecond frequency fluctuations. This caused significant unwanted stress on the battery, which inevitably reduced its projected lifetime. In hindsight, identifying both the current and future operating context and technical requirements for the system was needed to determine the most appropriate mix of technologies for energy storage and frequency regulation. KEA later approached ABB to install a flywheel to support the existing BESS [32].

Off-site, ABB constructed and tested a containerised flywheel system to be installed into the Kodiak network. Having a containerised system enabled ease of transport and installation, as well as reduced associated construction and maintenance costs. The container also reduces the effects of the cold, wet and windy weather seen in the Kodiak area on the equipment.

Installation of the flywheel achieved two main benefits for the power system. Firstly, it enabled the effective integration of an electric crane for the fishing industry, avoiding current overload due to stochastic load and operation. The crane replaced an existing diesel crane, reducing reliance on costly and volatile diesel imports. Secondly, the flywheel provides backup power, energy storage, and voltage or frequency regulation, depending on the selected mode of operation.

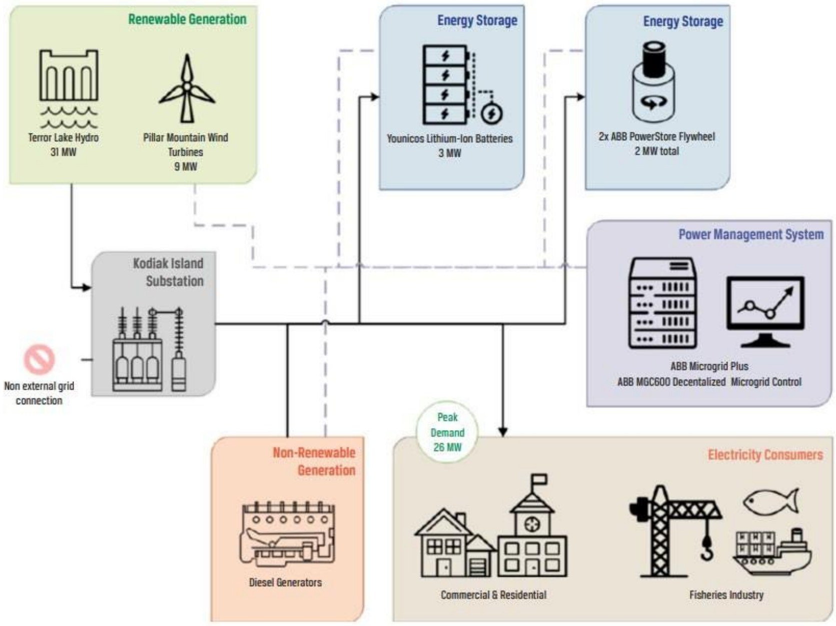


Figure 32 - Schematic of Kodiak Island System (2020) [32]

Operation in frequency regulation mode allows the BESS to operate as originally designed. Rather than respond to microsecond frequency fluctuations, the BESS responds to second-to-minute disturbances, which increases its operating lifetime [32]. Operation in voltage regulation mode stabilises the large injections and consumptions of the crane but ignores the frequency requirements of the grid. The flywheel used is very robust to high frequency responses with high frequency charge/discharge cycles but is limited to about a 16 second maximum power discharge period [33].

Kodiak Island represents a unique case of integrating different forms of energy storage technologies that require coordination to meet a variety of technical challenges and provide grid services. Effective coordination of the BESS and flywheel allows the BESS to provide storage and second-to-minute services, whilst the flywheel provides microsecond frequency response and backup power services. Trust and communication with KEA's respective vendors was vital to ensure proficient planning, testing and construction of these enabling technologies.

Dependent on the system, different battery and energy storage technologies should be considered and tested to provide required system services. The lowering costs and increase in technological capabilities of batteries has increased the variety of applications within a network to enable greater share of renewable sources.

Lesson 2: Staged phases of construction and testing provide opportunities for smoother integration of VRE

KEA embarked on deploying 9 MW of wind power over two distinct construction stages. This staged approach resulted in additional expense and time to completion. However, it also provided the opportunity for inter-stage detailed testing and collection of modelling data to ensure effective installation of the new wind turbines and battery system without disruption to supply due to frequency and voltage excursions.

For example, prior to the addition of the wind turbines, the hydro plant played a significant role in managing frequency. Following stage one of construction, it was found to be unsuitable for doing so with increased penetrations of VRE given the slow response of its analogue governor system. Following the installation of the first tranche of wind turbines, three phase motors with capacitor banks were installed with the capability of providing fast frequency response. A new digital governor system also provided sufficient frequency management for further increasing VRE [33].

After the completion of the first stage of the wind power project, it was discovered that the network required a BESS to provide grid services. The BESS insured that the frequency of the 9MW of wind could be controlled without having major effects on reliability in the event of sudden wind drops or rises.

Figure 33 - Kodiak Island Pillar Mountain wind turbines (9 MW) [1]

Policy and Regulatory Enablers

Lesson 3: Localised regulation can increase organisational agility and the social license to accelerate the deployment of renewable energy

Under the provisions of state law, in 2004 the members (customers) of KEA voted in favour of withdrawing from the oversight of the Regulatory Commission of Alaska, the state agency that regulates public utilities and cooperatives. A model of local regulation superseded state-based regulatory mechanisms.

Localising regulation benefited the uptake of VRE in two significant ways. Firstly, it gave members a greater degree of agency and ownership of the cooperative which resulted in increased social license for KEA projects and initiatives. Secondly, it provided additional organisational agility to KEA in pursing their ambitions to displace diesel generation with renewables. KEA's management has been cited as describing the shift to local regulation as the most important strategic milestone in the construction of its VRE generation fleet [34].

Market and Commercial Enablers

Lesson 4: Member-owned utility cooperatives provide one potential governance model for islanded grids pursuing deep decarbonisation

KEA is a member-owned utility cooperative overseen by a board of nine community representatives. Structuring the organisation in this way ensures the voice of the community is heard and informs the decisions of the utility, which in Kodiak's case, has increased social license and accelerated VRE take-up. In contrast to other ownership and governance models, this approach moderates the profit motive of the utility, while not eliminating it altogether such that inefficiencies arise. The 'shareholders' of the utility are, in Kodiak's case, local residents who as members are the recipients of any profits generated.

Cordova, Alaska, United States

Background and Overview	
Operator	CEA
Population	2,500
Nearest Grid	240km
Installed Capacity	18.3MW
Max Demand	6.5MW
Annual RE Volume	78%

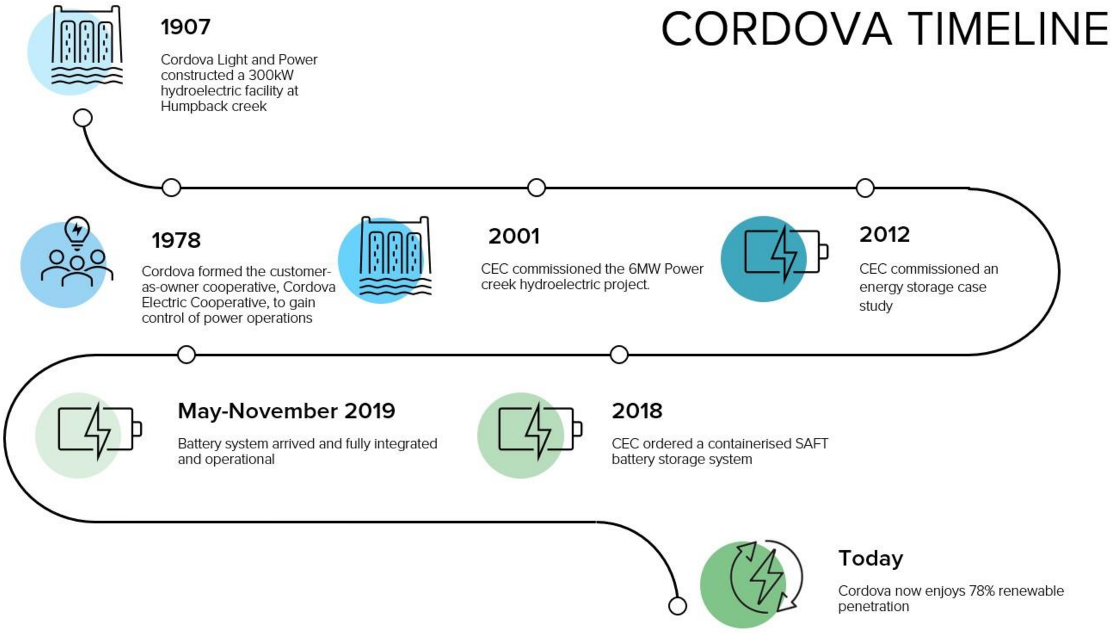
Cordova is located on the south-central coast of Alaska along the Gulf of Alaska, 240km southeast of Anchorage, the most populated city in Alaska. The town's residents largely work in the fishing industry. The town is famous for its copper river salmon and is home to the 11th largest seafood port in the US in 2017. The fisheries economy approaches around USD$100million annually. Cordova draws the majority of its power from a 6MW run-of-river hydro facility and a smaller 1.5MW hydro facility. The town uses around 10.8MW of diesel backup and they have recently installed a 1MW BESS. Cordova has a very rainy and cold climate situated on the northern limit of the coastal boreal rain forest. Over the past seven years alone, Cordova has experienced four earthquakes with magnitudes over 7.0, a large volcanic eruption, tsunami warnings and evacuations, superstorms with winds exceeding 160km/hr and massive snowstorms leading to avalanches [35]. All these events have threatened the run-of-river hydro facilities with some shutdowns occurring. The entire distribution system is run underground to protect the critical infrastructure during powerful storms. Cordova has no road connections or grid connections to the rest of Alaska and must generate all its own power.

Cordova has been operating hydroelectric facilities for over a century. In 1907, Cordova Light and Power built the Humpback creek hydroelectric project to provide 300kW of power to Cordova. Due to the variability of hydropower, the local utility shifted power production to conventional diesel generation in the 1940's. By the 1970's the diesel generators were reaching the end of their operating life with faults causing rolling blackouts for the community. In 1978 the community of Cordova formed the electric cooperative, Cordova Electric Cooperative (CEC), to takeover power production for the town. This customer-as-owner model prioritises community values over utility profits and responsibility for grid operation and maintenance falls on the community. In 1999, a relaying and load shedding program was implemented which reduced outages to under 2-3 hours per customer per year. In 2001 the utility commissioned the Power creek hydroelectric project adding 6MW of hydro to the electricity system for a total of 7.5MW of hydro. Cordova also sold renewable energy certificates procuring around $40,000 per year, which has funded heating in the local school, conversion of all community lighting to LED and automation of hydro plant lights for further fuel savings.

Figure 34 - Cordova fishing port [175]

Cordova's seasonal load profile is highly variable, with a substantial difference in maximum demand and minimum demand through the year. Primarily this is due to fish-processing plants ramping up during the spring as hundreds of workers arrive. CEC must transition from hydro-only operation to hydro-diesel generation to maintain system operation during this time. This greatly affects system costs as hydropower costs are around US$0.06/kWh whilst diesel can be as high as US$0.6/kWh. When hydro reserves drop a diesel genset starts up. Due to the genset's minimum operating output, hydro power must be spilled. In hydro-only mode, operators control grid frequency by adjusting fast-acting deflectors at Power Creek [36]. In 2012 CEC recognized the benefits of energy storage and partnered with ACEP to produce a case study. In 2018 CEC ordered a containerised power converter and battery storage system produced by SAFT and ABB. The containerised system arrived in May 2019 and was fully integrated and automated by November 2019. The battery system provides frequency regulation in place of diesel, works as an emergency supply, is load following to make hydro dispatchable, and provides preheating of dormant diesel gensets. The town now has around 78% of energy being generated from renewable sources with $150,000 of annual savings created by the BESS.

History



CORDOVA TIMELINE

1907

Cordova Light and Power constructed a 300kW hydroelectric facility at Humpback creek

1978

Cordova formed the customer-as-owner cooperative, Cordova Electric Cooperative, to gain control of power operations

2001

CEC commissioned the 6MW Power creek hydroelectric project.

2012

CEC commissioned an energy storage case study

2018

CEC ordered a containerised SAFT battery storage system

May-November 2019

Battery system arrived and fully integrated and operational

Today

Cordova now enjoys 78% renewable penetration

Technological Considerations

Lesson 1: Reduction of hydro power load shedding through the use of a BESS

Cordova Electric Cooperative (CEC) covers the base load of Cordova with the 6MW hydro Power Creek facility. The power system operates in either hydro-only operation or hydro-diesel operation with the support of two 1MW diesel gensets during summer (June to August) peak periods and winter (December to February) when the rivers freeze. In hydro-only mode, the grid operators control grid frequency by adjusting the angle of fast-acting deflectors at the Power Creek facility [36]. These allow part of the water stream to divert away from the turbines to module power output. This acts as a spinning reserve seen in a conventional grid with around 500kW of capacity diverted to support sudden load increases. Also, when demand increases and hydro reserves drop, a 1MW diesel genset starts up. The genset has a minimum output of 400kW which increases the amount of hydro that must be spilled. During this period up to 1MW of water capacity is spilled for periods of a couple of hours to several days [36]. The hydro facilities at Cordova are run-of-river facilities, which means that there is no water storage and power is produced when the river flows, as compared to traditional hydro where water is stored before being released. This effectively means that any water spilled is energy lost, essentially curtailing the renewable source. Before the installation of the BESS, around 3 to 4 GWh of hydro was spilled per year.

Figure 35 - Power Creek Hydro Facility [159]

CEC turned to SaFT to develop a Li-ion-based ESS to reduce reliance on diesel and reduce the amount of water that was spilled. A containerised solution was chosen as the optimum solution with an ABB power converter and battery located in the central substation of the Cordova grid. As the BESS state of charge drops below 30%, the genset will operate at its minimum output to supply demand and charge the battery. Once the state of charge reaches 70%, if the load remains, the battery will discharge and supply the load. If the load increases, the diesel will take over frequency control and charge the BESS if there is spare capacity [36].

Lesson 2: Optimisation of proven renewable technology for the operating condition it is in

Figure 36 - Cordova SAFT Lithium-ion Battery Storage System [176]

Selection of the optimum battery technology for Cordova was a key step in its VRE integration pathway. Initially, modelling and testing were conducted by Sandia National Laboratories and the Alaska Centre for Energy and Power [36]. Alternate solutions were explored, including ultra-capacitors, synchronous condensers, pump storage and fly-wheel technology as deployed on Kodiak Island. The BESS was chosen as a proven technology seen in other commercial applications. Existing deployments of the technology in harsh Alaskan environments provided assurance the battery could operate in such conditions long periods of times. In addition, the long track record and responsiveness during the tender process that both Saft and ABB provided gave CEC the confidence that they would have both the financial and technical experience to deliver long-term benefits for the community of Cordova.

The system has high-speed grid controls and a modular containerised and shippable package that can be easily installed on a plug and play basis. Optimising the size of the battery for the operating conditions required balancing the need to minimise full charge-discharge cycles needed to increase battery lifetime, and the the additional costs of larger battery systems. Another important factor was the recycling and replacement of the battery. For Cordova, full battery replacement would represent around 60% of the initial purchase price. Further, annual maintenance and factory warranties can be rather costly for remote areas such as Cordova [36].

Overall, based on the modelling conducted and taking into consideration the cost of hardware, design and integration and other costs, CEC estimated annual costs of around US$170,000 for the BESS. The fuel savings calculated from the BESS are in the region of 130,000 litres annually. Overall, annual operating savings are around $150,000 annually through the implementation of the BESS.

Policy and Regulatory Enablers

Lesson 3: Customer owned cooperative governance models can drive efficiency

Figure 37 - Cordova, Alaska, United States [177]

In 1978 the community of Cordova formed the electric cooperative, Cordova Electric Cooperative (CEC), to takeover power production for the town. The utility owners in 1981 voted to deregulate to then have pioneering freedom to accelerate the energy transition for Cordova. The customers are now responsible for the operation and maintenance of the power system directly incentivizing a more resilient, reliable and renewable system. CEC created a strategic plan to upgrade diesel and hydro generation as well as harden community's distribution system. From the start of 2018, over 18 months CEC invested around $3M dollars to maintain and upgrade the system with a focus on efficiency and security measures. This also included implementation of a new preventative maintenance program and a federally certified online training program. The outputs of this were $500,000 - $750,000 dollars in savings annually through 5-10% efficiency gains in the diesel plants and 10-15% output gains in the hydro facilities [37].

Through the development of strong projects and good management practices the cooperative has managed to keep debt under 2% for many years and grow its equity from 37% to 57% in seven years. It has allowed CEC over the past few years to return investments in the system back to the cooperative members and owners [37].

Market and Commercial Enablers

Lesson 4: Multi-party project funding models can provide needed capital for VRE integration projects

Cordova received capital funding from a range of different entities to construct both the Power Creek hydropower facility and the BESS project. CEC acquired $24 million of capital for the Power Creek hydropower facility through a multi-party funding arrangement. This funding arrangement was set up by Cobank, the cooperative bank of rural America, to ensure energy security and cost stability was achieved.

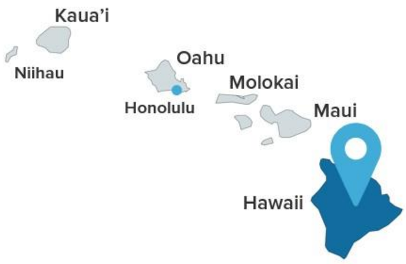
For the battery storage project, CEC partnered with the Department of Energy, the US National Laboratories and others to model the BESS and assist with installation. This also multiple sources of capital for the project. SANDIA National Laboratories and Pacific Northwest National Laboratories provided funding as part of research and modelling for the project, contributing $500,000 and $325,000 respectively, with CEC contributing $1,025,000 of the upfront costs.

Lesson 5: Renewable energy certificates as an additional revenue stream

Cordova Electric Cooperative began a green power program, legal advisors determined that they would not be able to get it certified under a renewable energy program. However, through the Green-E organisation and Low Impact Hydro Institute, they were able to get an exception. Cordova now sells renewable energy certificates on voluntary markets in the U.S, creating $40,000 in revenue per year. This revenue has gone to heating the local school, conversion of 100% of community lightning to LED (20% per year for 5 years) and automation of hydro plant lighting for further fuel savings [38].

Hawaii Island, Hawaii, United States

Background and Overview	
Operator	HELCO
Population	200,000
Nearest Grid	3,900km
Installed Capacity	525.6MW
Max Demand	TBC
Annual RE Volume	60%



The island of Hawaii is the largest island in the state of Hawaii. The island is a popular tourist destination with vastly varying geological features and environments from snow-capped mountains to jet-black sandy beaches. The 200,000 residents mainly work in tourism, hotels and public schools on the island, with these being the largest economic drivers for Hawaii. Each of the six main islands of the Hawaiian state has its own independent electrical grid and utility operating them. Maui Electric Company (MECO) serves the islands of Maui, Lanai, and Molokai, Hawaii Electric Light Company (HELCO) serves the island of Hawaii, and Hawaiian Electric Company (HECO) serves the island of Oahu. MECO and HELCO are subsidiaries of HECO, which is owned by the publicly-traded, investor-owned company, Hawaiian Electric Industries and collectively referred to as Hawaiian Electric Companies [39]. The Hawaii Public Utilities Commission (HPUC) regulates Hawaii's electrical utilities including the review and approval of renewable energy projects.

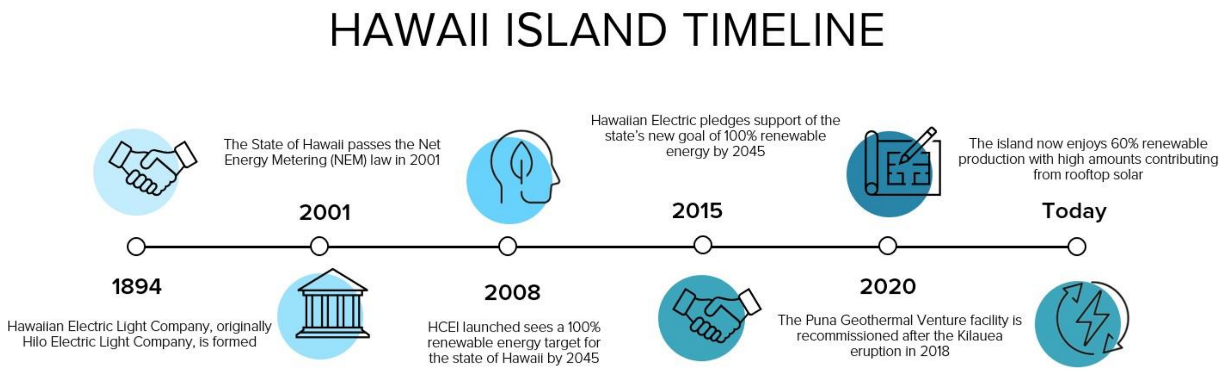
Like many other islands, Hawaii has a heavy dependence on volatile fossil fuel imports, an energy intensive transportation sector, greatly varying annual demand due to tourism and vulnerability to climate change impacts. This has led HELCO and HPUC to leverage the wide range of available renewable resources on the island through aggressive policies and programs to accelerate the transition to clean energy, reduce costs, and lessen dependence on fossil fuels [40]. Additionally, clean energy in Hawaii is creating jobs at twelve times the rate of the rest of the U.S. economy, creating a unique opportunity for Hawaii to increase economic prosperity [41]. Discussed in more detail in the Kaua'i case study, the Hawaii Clean Energy Initiative (HCEI), launched in 2008 by the State of Hawaii and the U.S. Department of Energy, sees a 100% renewable energy target for the state of Hawaii by 2045.

Figure 38 - Hawi Renewable Wind Farm [178]

Hawaii island uses a large mix of renewable energy resources to provide reliable and secure power to the island. Due to a wide range of utility programs incentivizing customer, grid connected systems and high solar penetration, distributed PV has the highest contribution to renewable energy on the island with a capacity of 116MW and around 19% of total production.

The 38MW geothermal plant was a high contributor to the renewable energy mix, but in 2018 the plant was decommissioned due to volcanic activity. This greatly dropped the renewable share of the island from 56.6% in 2017 to 34.7% in 2019. However, it was later recommissioned in 2020 and the island now enjoys around 60% renewable energy production. Wind is also another large contributor with only 34.4MW capacity but contributed around 15% to total energy production in 2021. Hawaii also has around 60MW of utility scale solar, 21.5MW of Biomass, 19.3MW of hydro, 60MW of biofuel, 152MWh of battery storage and 177.5MW of fossil fuel generation, all contributing to the reliable power on the island.

History



HAWAII ISLAND TIMELINE

1894
Hawaiian Electric Light Company, originally Hilo Electric Light Company, is formed

2001
The State of Hawaii passes the Net Energy Metering (NEM) law in 2001

2008
HCEI launched sees a 100% renewable energy target for the state of Hawaii by 2045

2015
Hawaiian Electric pledges support of the state's new goal of 100% renewable energy by 2045

2020
The Puna Geothermal Venture facility is recommissioned after the Kilauea eruption in 2018

Today
The island now enjoys 60% renewable production with high amounts contributing from rooftop solar

Technological Considerations

Lesson 1: Geothermal generation has the potential to provide baseload power similar to traditional synchronous generation whilst also providing renewable and dispatchable power

The Puna Geothermal Venture (PGV) facility owned and operated by Ormat Technologies is a 38MW geothermal plant that has greatly increased the renewable share on Hawaii island. The plant began operation in 1993 at 25MW and was later expanded in 2011 to 38MW contributing 31% of total energy production. It became the world's first integrated combined cycle power plant capable of providing both baseload power (similar to traditional diesel generation) and dispatchable power to support integration of other variable and intermittent renewable resources [39]. The plant operates by extracting steam and hot fluids from production reservoirs deep below the earth's surface and converts the steam into energy. The closed loop system allows the steam to be reused and maximises efficiencies. In May 2018, the Kilauea eruption caused the plant to go out of operation, greatly reducing the renewable share for Hawaii.

As of November 2020, PGV was back online. A new PPA was set in March 2022 by Hawaiian Electric, under this new PPA one of the conditions was that PGV needs to perform an environmental review before doing any construction. Under the agreement, PGV decommissioned twelve older generating units with three new generating units. This required less rotating equipment, less emissions and the ability to produce 8 more MW with the same amount of geothermal resource input [42].

Geothermal plants have the ability to be a firm and cost-competitive source of baseload renewable energy whilst providing dispatchable power to increase integration of variable renewable resources. If designed and regulated correctly, geothermal energy offers environmental benefits with minimal emissions and manufactured wastes. However, without proper regulation and operation, the opposite can occur. Geothermal electricity pricing is comparable with energy produced from other sources, with PGV selling power to HELCO at around $0.1190/kWh on-peak and $0.1206/kWh off-peak for the first 25MW of firm capacity [39].

Figure 39 - Geothermal plant after volcanic eruption [179]

Policy and Regulatory Enablers

Lesson 2: DER programs incentivise customers to install private PV systems providing extra financial benefits to the customer whilst maintaining safe and reliable power

Hawaii has a range of DER programs available for its customers depending on their energy needs. These programs are used to incentivise private PV uptake and provide economic benefits for the customers. Large supplies of uncontrolled PV power leads to instabilities in the power system and in some cases, blackouts. HELCO has placed limits on PV installations and export limits of these systems to maintain safe and reliable power on the island, whilst still increasing the uptake of cost effective PV installations for customers to participate in the renewable energy transition.

The island originally had a Net Energy Metering (NEM) program which saw 61,000 applicants connecting metered PV systems (100kWh or less) to the grid. Under this program the customers would be rewarded for exporting more electricity than they use by being charged a minimum bill. The completion of this program saw the NEM Plus program arising, allowing NEM customers to connect more solar. These new systems are not allowed to export to the grid and are solely used to reduce the energy demand of the customer, especially if they are planning on renovating or increasing electricity use. Similar to the NEM programs are the Customer grid-supply (CGS) and CGS plus programs which allowed customers to install PV systems with the ability to export to the grid whilst the utility managed power output through installed equipment.

The utility also had the Smart Export program which allowed customers to install PV with battery systems. Under the program the customer is compensated for exporting power during night periods, but is not during the daytime, incentivizing them to charge the battery during the day and discharge the battery during peak periods. HELCO has many more customer specific programs that have contributed to the aggressive uptake of individual systems and continue to contribute to the goal of 100% renewable energy by 2045 [39].

Figure 40 - Hawaii Rooftop Solar [43]

Market and Commercial Enablers

Lesson 3: Energy performance contracts provides a guarantee on future energy savings that can offset initial project costs

Energy performance contracts (EPC) are an innovative approach to implementing energy and water efficiency projects in Hawaii by guaranteeing energy savings to pay the upfront costs of projects. Under the agreement between a facility manager and a private energy services company, the future operational cost savings are used to pay for the entire cost of a building's energy efficiency retrofits. Energy conservation measures (ECM) are installed, which include PV installations, which guarantee the savings, with the energy services company paying the shortfall. Hawaii in 2017 had around half-billion-dollars in investment in EPC with around double this in estimated savings over the life of the contracts [44].

Lesson 4: Extensive RFP and competitive bidding processes for supply of electricity to the utility to reach the island's high renewable goals

In 2006 the Public Utilities Commission adopted the 'Competitive Bidding Framework' to establish a competitive process for acquiring new energy generation resources. HELCO is required to follow the framework for new generation projects greater than 2.72MW. Under this framework, an RFP process is put forward to procure new projects that will provide the necessary grid needs of the island and its customers. Part of this and alongside other RFPs, are the Community-Based Renewable Energy (CBRE) for Low-and Moderate-Income (LMI) RFPs that allow participating subscribers without privately-owned rooftop solar to benefit from electricity generated by a renewable energy facility located in their utility service area [45]. Independent power producers are subject to the framework, with all projects going through a process of RFP development through to project selection.

Lesson 5: Demand Response programs provide opportunities for customers and utilities to coordinate BTM resources for a reliable, resilient and flexible power system

In 2014 Hawaiian Electric submitted an Integrated Demand Response Portfolio Plan (IDRPP), proposing to implement a range of DR programs to reduce energy supply costs, increase the effective use of renewable energy, increase system reliability and enhance customer choice [46]. The increase in operation flexibility supports the integration of additional renewable resource and assist in addressing a changing energy demand profile. In 2018 the PUC approved the proposed tariff structure for the grid services that will serve as the basis for the portfolio of DR programs. In 2021 the PUC approved a new program called the Emergency Demand Response Program (EDRP), allowing battery storage to dispatch electricity between 6 and 8 pm from participating residential and commercial customers. Hawaiian Electric (the utility) and the Public Utility Commission (regulating entity) have gone through several loops of program propositions and approvals to keep the DR programs relevant and effective at aiding the challenge of increasing renewable energy shares.

Old Crow, Yukon, Canada

Background and Overview	
Operator	VGG
Population	300
Nearest Grid	160km
Installed Capacity	4.4MW
Max Demand	587kW
Annual RE Volume	24%

The small rural community of Old Crow, home of the Vuntut Gwitchin First Nation (VGFN), is located in Yukon, 130km north of the Arctic Circle, 800km north of the territory's capital, Whitehorse. The town is home to around 280 permanent residents with around 20 transient residents (professionals). Due to its extreme remoteness, the community is not accessible by road and has no interconnection with other power systems. Old Crow has been reliant on regular deliveries of diesel transported by air for local electricity generation, resulting in some of the highest electricity costs in Canada.

Environmental concerns, economics and traditional VGFN values have contributed to a strong social license to reduce dependence on diesel for power. In 2008, the Vuntut Gwitchin Government began exploring alternative energy solutions for the community. In 2016, the detailed design of Sree Vyah (the Old Crow Solar Project) commenced following the completion of a feasibility study. The feasibility study stated the project would be, "a challenging but feasible opportunity" [47]. In 2018, Yukon University completed a grid impact study, which identified the optimum system component sizing for stable and reliable power. The study analysed various configurations of solar PV and batteries and their ability to provide sufficient grid services and reduce energy curtailment, while also being economically viable.

During the same year, an Electricity Purchase Agreement was set up between ATCO Electric Yukon, the local utility, and the Vuntut Gwitchin First Nation. The VGFN owns the solar generation assets whilst ATCO owns the battery energy storage system and microgrid controller. Under the 25-year agreement, ATCO Electric Yukon will purchase electricity generated from the solar array at a rate similar to the cost of diesel generation. This relationship is made possible under the Yukon's Independent Power Production Policy and provides stable profits of around $410,000 per year for the community to invest in other projects. An Operating Committee was also established, comprised of VGFN and ATCO representatives to ensure solar generation is optimized without compromising power quality and safety [47].

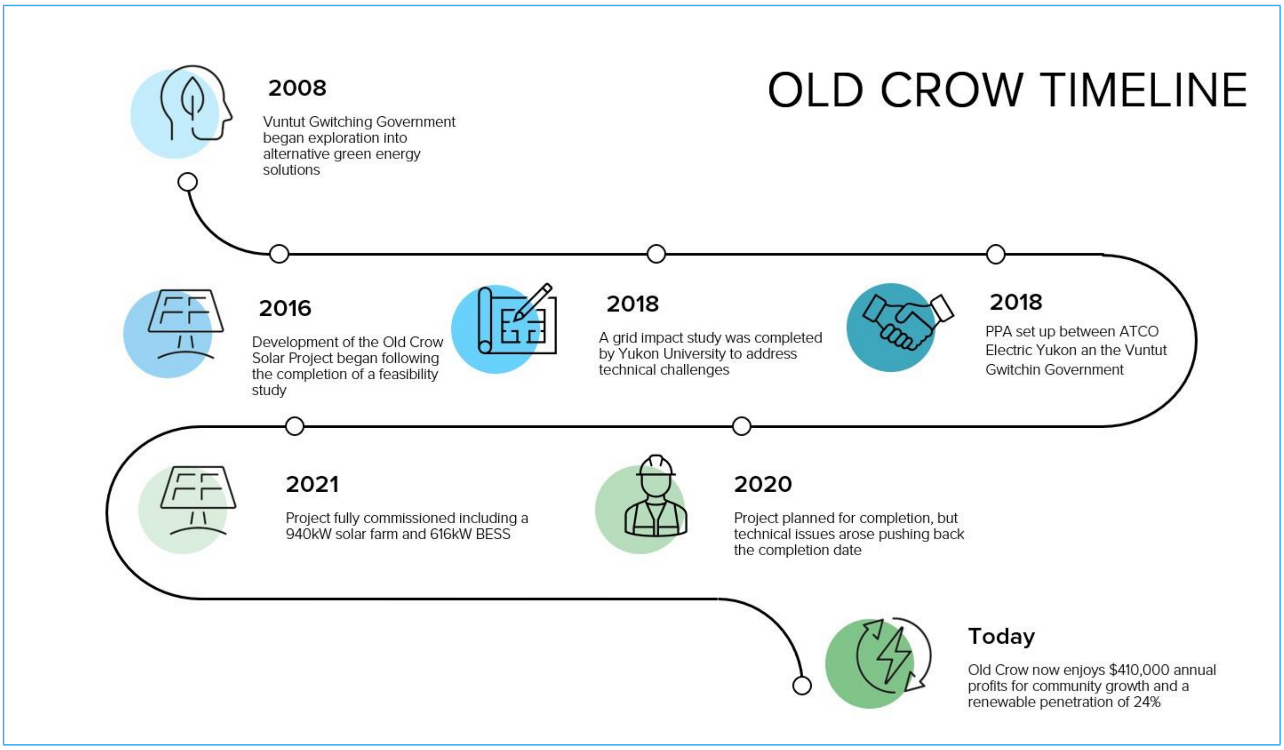
The project was planned to be operational in 2020, however, due to the pandemic and limited access to technical and trained personnel, final commissioning was delayed. As Dana Tizya-Tramm, chief of the Vuntut Gwitchin First Nation stated:

“Because of the pandemic, we were not able to do a full launch of the project in 2020 as we had hoped. We don’t have technical expertise within our community, and we’re relying on technical consultants from outside the country.” [48]

Figure 41 - Vuntut Gwitching Community of Old Crow, Canada [49]

Construction of the solar system was eventually completed around April of 2021 with limited power flowing to the local grid. Construction of the BESS was completed by July 2021 and commissioning was completed by August 2021 [47]. The complete system has been operating at its full capacity since June 2022. The new system consists of a 940kW solar array system with an accompanying 616kW/612kWh BESS. The project provides 650 MWh of electricity per year to the grid. In summer months (June to August), due to its location, Old Crow experiences 24-hour daylight as the sun circles above the horizon for a full 360 degrees. This creates an angle of incidents much lower than the average solar project. The system therefore utilizes a unique east-west solar PV module design rather than a typical south-facing design in order to maximise energy capture. Due to the remote location, the design of the system also incorporates local materials or those that are easily transportable by air.

History



OLD CROW TIMELINE

2008

Vuntut Gwitching Government began exploration into alternative green energy solutions

2016

Development of the Old Crow Solar Project began following the completion of a feasibility study

2018

A grid impact study was completed by Yukon University to address technical challenges

2018

PPA set up between ATCO Electric Yukon an the Vuntut Gwitchin Government

2020

Project planned for completion, but technical issues arose pushing back the completion date

2021

Project fully commissioned including a 940kW solar farm and 616kW BESS

Today

Old Crow now enjoys $410,000 annual profits for community growth and a renewable penetration of 24%

Technological Considerations

Lesson 1: Standardised design methodologies can simplify implementation of high-renewables grids

The Northern Energy Innovation (NEI) team, a research program part of the Yukon University, strives to help remote communities in northern Canada to operate isolated power systems in severe weather conditions with greater renewable uptake [50]. The NEI team is developing a grid impact study tool to streamline the process of modelling and evaluating how much renewable energy a grid can safely integrate without affecting stability and reliability [51]. The intent of the tool is to provide a standardized design methodology for use by utilities implementing high renewables isolated systems. In 2018, Old Crow was chosen as the first community to be modelled and developed using the grid impact study tool. This study covered the technical feasibility of varying solar and battery arrangements as well as the impact of each configuration on the grid. The study focused on energy balance, protection coordination and large-disturbance stability and did not consider regulatory requirements or cost-benefit assessment, which were evaluated subsequently to determine the optimum system based on the combined technical and economic considerations.

Figure 42 - Old Crow Utility-scale Solar PV system [180]

The tool uses IEEE Std. 2030.2-2015 as a basis, which covers the recommended procedures and methods for connecting energy storage to electric power infrastructure and the varying system simulation models that should be performed. The Old Crow study focused on two main scenarios, a smaller 260kW solar PV system and a 450kW solar system with a 400kWh BESS. Use of the tool identified that a smaller solar PV system had less impact on protection coordination, and that the capacity of the plant would be limited without the addition of a BESS, as much of the solar PV generation would be spilled to maintain stable operation. Finally, the study revealed that increasing the battery size increased the lifespan of it (by reducing discharge depth) as well as increasing the length of time the system operates in diesel-off mode.

Lesson 2: BESS systems provide flexibility and buffering to isolated high-renewables grids

Isolated power systems with high penetrations of weather dependent solar PV need to manage significant supply-side variability. According to ATCO Electric Yukon (the utility responsible for Old Crow), a diesel generator can take anywhere between 60 and 90 seconds to come online, far too long to provide the necessary flexibility and buffering required for stable operation during solar energy fluctuations. The BESS provides stability to the system by injecting or receiving sudden variations in energy on a microsecond basis. In addition, the Old Crow power system utilises a BESS to reduce the curtailment of solar energy during high solar penetration periods by diverting excess energy to charge the battery and to reduce use of diesel generation during low solar penetration periods as the stored energy in the battery can be discharged for up to one hour before power from the diesel generators is required.

Policy and Regulatory Enablers

Lesson 3: Importance of community engagement, acceptance and training for the effectiveness of the project

Throughout the project, the Vuntut Gwitchin Government (VGG) held numerous public information sessions for the community. Particular attention was given to hearing from diverse voices, from respected elders through to the youth as future custodians of the power system. Concerns were raised regarding the proposed siting and design of the solar farm as it would have encroached on a culturally significant berry patch. A compromise in technical design was agreed to, which provided the necessary social license for the project to proceed with community support. No fencing was installed around the solar arrays allowing the community and fauna access to the site. The solution allowed the project to leverage the sunniest spot in the community whilst minimising disturbances to the berry bushes As Dana Tizya-Tramm, chief of the Vuntut Gwitchin First Nation stated:

Figure 43 - Residential housing in Old Crow, Canada [181]

“Our elders are picking berries in an ancient natural energy system beside a new modern technological energy system,”

Lesson 4: Upskilling locals can reduce maintenance costs by reliance on external technical expertise

Figure 44 - Entrance to Old Crow, Canada [182]

One of the major challenges faced by the project was access to adequate technical expertise within the community. In the beginning, the project necessarily relied on external technical consultants, which severely impacted progress during the pandemic when travel restrictions applied. The project was planned for completion by 2020 but had to be delayed due to insufficient expertise. However, the Northern Energy Innovation team returned to Old Crow with Solvest, a Canadian based solar company, to provide training to community members to maintain and operate the new solar energy system. This upfront investment is expected to reduce dependence on outside help and therefore reduce the cost of operating and maintaining the power system.

Lesson 5: Community ownership with local utility operation provides benefits to the community

Prior to 2015, Yukon had no off-grid independent power production (IPP) policy. As a result, isolated communities faced limited autonomy in meeting their own energy needs and were subject to the high-costs for provision of electricity from their responsible utilities, with high risk for local utilities and IPPs to invest in community renewable energy projects. The Yukon government prepared legislation to allow the VGG to receive a return on investment from the project. In October 2015 the Yukon Government adopted the IPP policy which provided:

"opportunities for non-utility entities to generate new power that can assist the utilities in meeting the demand for affordable, reliable, flexible and clean electrical energy" [52].

Set in 2018, the new 25-year Electricity Purchase Agreement (EPA) between the Vuntut Gwitchin Government and ATCO Electric Yukon allows the community to enjoy greater benefits with around $410,000 going to the community annually. Under the EPA, ATCO purchased the capital assets, including the BESS, microgrid controller and solar farm. ATCO also operates the microgrid controller to ensure the system operates efficiently, maximizing diesel-off periods whilst providing safe and reliable power. The VGG is responsible for the maintenance of the PV plant. Through this agreement the VGG will sell ATCO Electric Yukon energy generated by the solar farm at a price representing avoided diesel fuel costs and maintenance and capital costs savings (around USD$0.65/kWh). This will generate stable, long-term income for the community over the project life and contribute significantly to community sustainability. Many ownership models can be observed in Canada, however a general partnership between the indigenous community and utility allows the community to be in the driver's seat for energy planning whilst utilising the expertise and funding of energy developers.

Market and Commercial Enablers

Lesson 6: Complementary roles between federal, provincial, and territorial levels of governance

The federal government is responsible for economy-wide policies and initiatives. As part of this, Natural Resources Canada (NRC) was formed as the lead federal department for energy policy. It has been mandated to lead Canada's efforts to achieve 100% net-zero electricity by 2035. NRC works with indigenous rural communities to decarbonise their electricity systems. In 2018 NRC launched the Clean Energy for Rural and Remote Communities program providing $220 million over 8 years to reduce reliance on diesel in rural and remote communities. This program brought $2.45 million in funding for the Old Crow Solar Project alongside another $6 million through other federal government programs. New programs have been established since then such as the Wah-ila-toos hub which received a budget of $300 million until 2027 to advance clean energy for indigenous, rural and remote communities across Canada. The provincial and territorial levels of government are responsible for planning and regulating their respective energy resources and utilities. This includes the rates that utilities charge their customers.

Isla Huapi, Chile, South America

Background and Overview		
Operator	Community	
Population	300	
Nearest Grid	10km	
Installed Capacity	417kW	
Max Demand	TBC	
Annual RE Volume	TBC	

Isla Huapi is an island located in the south-eastern part of Chile in the middle of Lake Ranco in the commune of Futrono, Los Rios region. The island is home to around 300 residents accounting for 145 households. There are two communities on the island, both springing from the Mapuche Huilliche community. The island's residents are mainly farmers who support themselves through the sale of their agricultural products and the islands tourism industry. The Mapuche people populated the island as they fled from war. Throughout their history, the Mapuche people have been suppressed and manipulated by Chilean state authorities most notably through land loss and displacement in the nineteenth and twentieth century [53]. In many cases rural Mapuche communities have wrestled with authorities over self-determination, recognition and the restitution of ancestral territories. For the case of Isla Huapi, residents demand governmental and municipal funding on material development in their community. The community is eager to participate in government development initiatives aimed at economic enhancement and infrastructural development such as water and electricity. Through partnerships with the Ministry of Energy in coordination with the Municipality of Futrono and the local community, Huapi Island has become the first 'solar island' without generation backup in Chile, with more than 150 families receiving permanent electricity supply through household PV installations. The island has no outside grid connections and interconnections between households on the island are sparce. Most households are self-sustaining with only their PV system available for power whilst others rely on small diesel generators.

Between 2004 and 2007 the local government worked on a rural electrification project which saw diesel generation electrifying the island. In 2014 the community came forward that they were against the diesel microgrid and sought for a more renewable alternative. During the same year the local government requested the Ministry of Energy for a new PV technology project for the community [53].

Figure 45 - Barge connecting Isla Huapi to mainland [54]

In 2010 a family from Isla Huapi researched and installed an individual PV system for their household. The system provided great benefits and so the community approached the authorities to adopt this solution across the entire island. Between 2014 and 2016, the Ministry of Energy partnered with the Municipality of Futrono to establish a dialogue with the community about the feasibility of this solution. This project was implemented alongside the development of the 2050 Chile Energy Policy which was adopted in 2016. The policy set an ambitious goal to transition to 70% renewable generation by 2050. The project also followed the guidelines for the development of rural electrification initiatives set out in the policy. In 2017, the project was drawn up by the Ministry of Energy at the request of the Municipality of Futrono [53].

Between July 2017 and March 2018 equipment installation took place across the island. Continuous community participation in the project decision-making process was fulfilled through regular meetings. These meetings were convened by the electrification committee who acted as representatives for the community to voice the ideals and requirements of the community to the leading entities. The project was fully completed and operational in March 2018 which saw 151 individual PV arrays installed at local households, four churches and the ruca ('house' in Mapudungún, a traditional Mapuche building for community use) [53]. Each system consists of 8 PV panels of 345kWp each, totalling 2.76kWp per home, with a 25kWh OPzV-type battery bank, 2kVA inverter and regulator with MPPT [55]. There are plans to install 114 additional PV systems during the second phase of the project.

Equitable access to energy has had a positive effect on the enjoyment of several internationally recognized human rights by the community. These include but are not limited to:

a) The rights to food and health through access to food refrigeration leading to better hygiene and food preservation

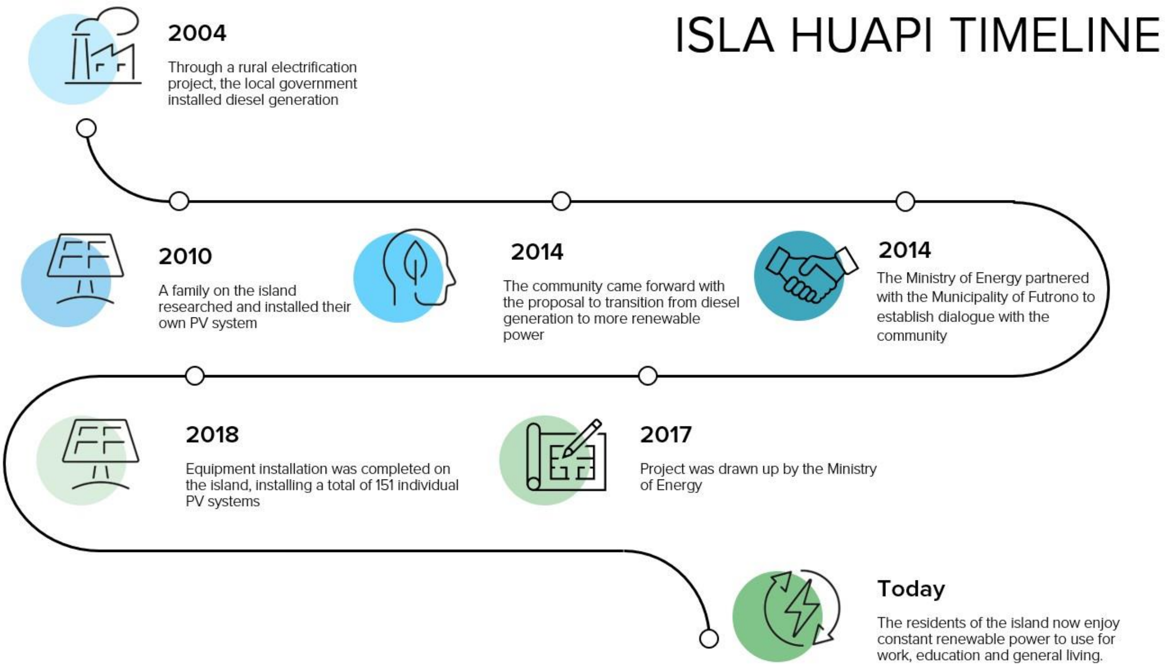
b) The right to education through electric lighting to allow children and teenagers to complete school asks after school hours

c) The right to work through internet and electricity access within work areas to complete certain tasks

d) The right to access to information through access to telephones, televisions, radios and internet connections

e) The right to a healthy environment as the community no longer relies on diesel for power

History



ISLA HUAPI TIMELINE

2004
Through a rural electrification project, the local government installed diesel generation

2010
A family on the island researched and installed their own PV system

2014
The community came forward with the proposal to transition from diesel generation to more renewable power

2014
The Ministry of Energy partnered with the Municipality of Futrono to establish dialogue with the community

2017
Project was drawn up by the Ministry of Energy

2018
Equipment installation was completed on the island, installing a total of 151 individual PV systems

Today
The residents of the island now enjoy constant renewable power to use for work, education and general living.

Technological Considerations

Lesson 1: Ease of installation and operation of individual PV systems for communities in remote areas

This project brought electricity access for many of the residents on the island. The island has no centralised generation or a distribution grid. Each household has to produce its own power, with it being common in isolated areas of Chile without power to use small diesel generators at each household (no more than 3kVA). There is no obligation to report these connections to the authorities, making it difficult to track the number, cost and consumption of these systems. Since 2012, the residents of Isla Huapi identified the importance of renewable sources to provide power to their community. The solution realised was a one-size-fits-all approach, electrifying each household with a standard PV arrangement.
This allowed for ease of installation across all households, whilst also allowing the systems to be easy to maintain when ownership was transferred over to the community. These systems come with a 2kVA off-grid inverter with charger function, allowing connection to an external diesel generator if more electricity is required. The solar panels come with MPPT to allow maximum production. The energy is then stored in the battery systems to allow the residents to use the power during the night.

Policy and Regulatory Enablers

Lesson 2: Value of equitable access to clean and secure energy

The 151 individual PV systems have enabled the families of Isla Huapi to enjoy the benefits of reliable and accessible electricity. Each household now has enough power for lightning, television, refrigeration. Washing machines and other less impactful needs such as telephone and tablet charging and internet access [53]. The use of these appliances and technologies greatly increases the quality of life for families on the island. The island has even seen an increase in population of around 100 people since the installation of the PV systems. The ministry is currently working alongside the community to install PV arrays for the new households under construction on the island. Financing for the addition of these new systems has just begun.

The project has aided in the eradication of poverty, more specifically the eradication of energy poverty. It has also had a positive effect on the enjoyment of the right to work. This was especially prevalent during the construction phase which saw SAESA training and hiring local residents to conduct some of the work on the island. This increased the overall skill level of the community and increased their likelihood of finding work. Alongside this training the authorities and the company provided training and talks to the community on the project and effective use of equipment. There was on average one training session a month during the life cycle of the project with a total of 20 training sessions organized.

Figure 46 – Aerial view of Isla Huapi [54]

Lesson 3: Participation and dialogue between community, utility and state

Figure 47 - Members from the Ministry of Energy and Isla Huapi residents [183]

Through the successful implementation of a single PV installation, in 2017 the electrification project was proposed by the Ministry of Energy at the request of the Municipality of Futrono, who was in charge of the bidding process [53]. The community expressed a great desire to install PV systems as sustainable renewable energy at each household. More than 20 companies expressed interest in the project and after many visits to the island 8 concrete bids were established. The electricity distribution company, Sociedad Austral de Electricidad S.A. (SAESA), won the bid with Wireless Energy who had experience with previous PV projects.

The project was characterized by a high-level participation and ownership by the community with guidance and regulation from the leading entities. The top-level and start-up of the project involved coordination and leadership from the Ministry of Energy with the Municipality of Futrono. At the central level there was collaboration between the Ministry of Energy and the Ministry of Social Development as well as the community who had to approve the project. At the local level the Municipality of Futrono, who was the administrative entity responsible for Isla Huapi, participated in technical development and processes with the assistance of the Ministry of Energy.

Coordination at this level posed several challenges, with some concerns about the effect of the project on the surrounding environment and the costs associated with the project. However, through a high level of participation and ownership by the community and the commitment to the project from all participating entities, it was possible to implement flexible and accepted solutions. As one community member stated:

'I wondered how this is all going to work and how much is going to come out but, over time, through the conversations I realised that everything was going to work out well. I am very satisfied with the project' [53]

Another issue that arose was during the beginning of the project, the Ministry of Energy, contractor, resident engineer, municipality, on-field advisor and the local community were all receiving different requirements and information on the project. New families who wanted to participate in the project communicated with on-field advisors, whilst others spoke directly to the mayor's office, and some spoke with the installation workers. This created conflict within the community as families wished to be a part of the project, but due to budget restrictions, they were unable to join. The Ministry of Energy solved this issue by coordinating all stakeholders involved to enable the interests of all stakeholders to be clarified and coordinated to come to a solution.

Lesson 4: Committee as a community-based management model

Figure 48 - Community meeting on Isla Huapi [53]

To establish greater coordination and communication between the community, the Municipality of Futrono, the Ministry of Energy and SAESA, a committee was created to represent the people of Isla Huapi. The committee was established as a mandatory part of the project which started off with around 20 members and now has around 40, all of which are residents of the island, with an even gender split. The committee began at the start of the project and has closely followed all stages of development, from proposal and installation and now to operation and maintenance. SAESA's warranty expired in 2019 and has now placed the committee in charge of equipment maintenance and any other technical expertise required. With the assistance of the training sessions and support from SAESA, the committee has been able to effectively maintain the induvial systems.

Market and Commercial Enablers

Lesson 5: Fixed monthly fees provide equitable access to electricity for all

Through an initial grant of US$100k provided by the Ministry of Energy, the electric distribution company SAESA, was able to install the PV systems as well as train the community in the operation and maintenance of the systems. During the transition period in 2019 from SAESA operation and maintenance to committee operation and maintenance, the committee communicated with the community and established a fixed monthly to be paid by each household with a PV system (currently 3.6 USD) [53]. A fixed fee was chosen instead of payment by consumption as it was determined to be an equitable and predictable payment for everyone. This did bring about some conflict as the community had questions about the value of the payment, and why they need to pay even when the sun does not shine. The committee spoke with the community and came to a resolution through an understanding of a need for available funds during emergencies and for operation and maintenance. The community now sees value in the payments and greatly appreciates the benefits the systems have brought to their community.

Savai’I, Upolu and Manono Islands, Samoa

Background and Overview		
Operator	EPC	
Population	197,000	
Nearest Grid	4,400km	
Installed Capacity	78.51MW	
Max Demand	33MW	
Annual RE Volume	38%	

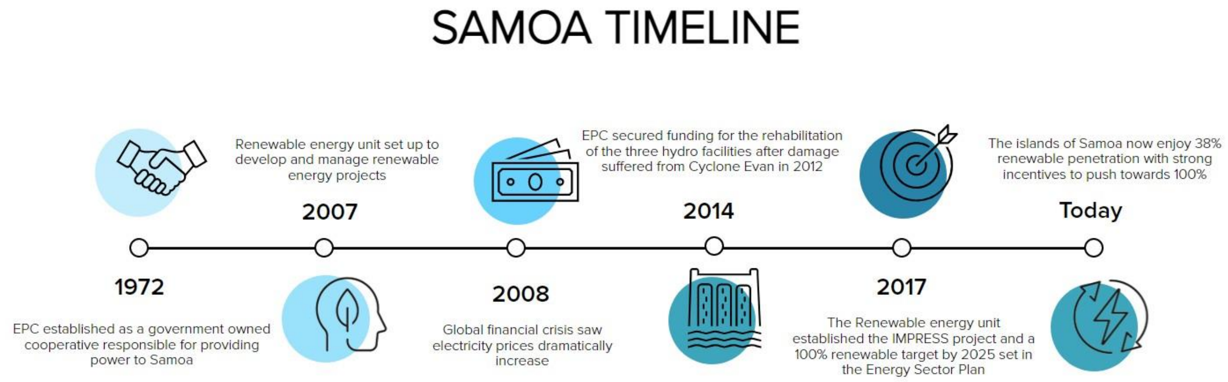
Samoa is located in the Pacific Ocean between Fiji and French Polynesia and consists of four islands. Most of the population reside on the two main islands, Savai’I and Upolu, followed by the smaller islands, Manono and Apolima, situated in between the two main islands. Economic growth is driven by major exports of fresh fish, coconut oil, taro and nonu juice with many of its residents working in tourism, agriculture and fisheries. Electric Power Corporation (EPC) is an autonomous government owned corporative that has been responsible for providing electricity on the four islands since its establishment in 1972. EPC began by supplying electricity exclusively to the capital of Samoa, Apia, but now provides power to around 98% of the population. Each of the islands have their own grid network, with Upolu providing power to Manono via an underwater cable. Majority of the power is generated from a total of 39.5MW of diesel, 30.7MW on Upolu and 8.8MW on Savai’i. Hydro generation then contributes roughly 24% to the generation mix with 15.46MW of capacity, 15.26MW on Upolu and 0.2MW on Savai’i. Next is a mix of IPP and EPC owned solar farms totalling around 15MW of capacity, 0.55MW of wind energy, 0.75MW of biomass and two BESS totalling 8MW/13.6MWh of capacity. The islands now enjoy a total of around 38% renewable penetration.

Like many other islands in the pacific region, Samoa is vulnerable to volatile fuel prices due to its large reliance on imported diesel for power generation. This was highlighted during the 2008 global financial crisis which saw electricity prices on the island dramatically increasing. The Government responded to this by taking initiatives to shift to more renewable energy. A commitment to achieve 100% renewable energy generation by 2025 was set under the Samoa Energy Sector Plan (SESP). In 2007 a renewable energy unit was set up to manage and develop projects associated with renewable energy technologies. From 2008 to 2016, the unit was responsible for the Samoa Power Sector Expansion Project (PSEP) which saw implementation of various improvements to the power system, including a new Supervisory Control and Data Acquisition (SCADA) system. Additionally, in 2017 the renewable energy unit established the Improving the Performance and Reliability of RE Power System in Samoa (IMPRESS) project to improve utilisation of indigenous renewable energy sources.

Figure 49 - Faga-loa Bay, Samoa [184]

Samoa is regularly subject to cyclones, earthquakes, droughts, and flooding causing damage to infrastructure and reducing generation capacity. One major event was Cyclone Evan in 2012, which damaged three hydro-generation facilities and the transmission network infrastructure. In 2014, EPC secured funding for the Renewable Energy Development and Power Sector Rehabilitation Project which saw repairs for the three damaged hydro facilities as well as construction of three new hydro power stations.

History



SAMOA TIMELINE

1972
EPC established as a government owned cooperative responsible for providing power to Samoa

2007
Renewable energy unit set up to develop and manage renewable energy projects

2008
Global financial crisis saw electricity prices dramatically increase

2014
EPC secured funding for the rehabilitation of the three hydro facilities after damage suffered from Cyclone Evan in 2012

2017
The Renewable energy unit established the IMPRESS project and a 100% renewable target by 2025 set in the Energy Sector Plan

Today
The islands of Samoa now enjoy 38% renewable penetration with strong incentives to push towards 100%

Technological Considerations

Lesson 1: Providing energy security in harsh weather conditions and in a volatile power system with high renewable uptake

As stated above, Samoa is subject to heavy rainfall, cyclones, earthquakes, flooding and droughts. Paired with the unpredictable, intermittent and variable nature of solar, wind and hydro, the grids in Samoa can be very unstable, unreliable and insecure. In response to this, in 2018 EPC installed two BESS systems (2MW/ 3.3MWh and 6MW/ 10.2MWh) and a micro-grid controller under the PSEP on the island of Upolu. Funded by the ADB, government of Japan through JICA, Australian Government and government of Samoa, the systems now provide better stability for the grid and increased efficiency at which electricity is stored and released to customers [56]. The systems also gives EPC the option to run diesel generators at a lower capacity and standby mode whilst providing the flexibility required to use solar during the day and hydropower during peak times. Originally, a higher capacity of diesel generation was required in order to provide reliable power to cover the variability of solar generation on the island.

EPC has a risk management strategy in place including a service continuity and response plan to reduce risk and consequence of natural disasters on the operation of grid infrastructure. The plans ensure continuity in electricity supply before, during and after a natural disaster whilst bringing safety to staff and protection of important assets. There is also a recovery plan safeguarding all of EPC’s sensitive data and hardware in the event of a natural disaster or man-made incident [56].

Lesson 2: Utilisation of SCADA to coordinate and automate multiple renewable sources with traditional diesel generation

Three SCADA systems have been constructed on the islands of Samoa. One at the Fiaga Power Station on Upolu, Salelologa Power Station on Savai’I and at the Fulugsou Substation in Apia. The SCADA systems provide generation assets with the capability to operate autonomously and communicate to a third-party system to provide 24/7 monitoring and control of all generation on the main islands of Upolu and Savai’i. The systems improve the operating efficiency, reduce unplanned outages, and provide early detection and restoration of outages. The successful implementation of the systems required major communication upgrades including 30km of multi-core fibre optic cable, installation of high-capacity radio links, construction of radio towers and UHF radio links to remote hydro facilities. These upgrades allowed for more accurate data to be combined with historical data to better forecast power generation requirements, optimise allocations of renewable power on an hour-by-hour basis and improve preventative maintenance regimes [56].

Lesson 3: Small-scale PV and Battery systems bring continuous and reliable power to small islands

Figure 50 - Solar array on Apolima [185]

Residents on the smallest island, Apolima, originally received power from 100% diesel generation. They received around 4 to 5 hours of electricity a day due to the high cost of operating the diesel generators on the island. In 2007, EPC launched a mini-grid project on the island comprising of a 13.5kW PV system with a BESS. The system provides 100% renewable energy to all 100 residents on the island and was designed to be oversized to meet the expected increasing demand of the residents [57]. However, this was achieved by arranging an agreement with the residents to not use high-power electric devices (such as kettles and cookers) during cloudy periods and only use energy efficient devices. The system also takes advantage of stacked inverters rather than a single inverter for scalability of the system looking into the future.

Policy and Regulatory Enablers

Lesson 4: Policy and project formation requires strong enforcement and accountability to achieve high renewable penetration

The Samoan Government has had heavy involvement in the transition of the island's energy generation to renewables. This began with the Samoa Energy Sector Plan (SESP) vision enacted in 2012-2016 which saw ‘improved quality of life for all”. This was later updated to “sustainable and affordable energy for all” for 2017-2022 and has been later modified to achieve 100% renewable generation by 2025. These policies have enabled nearly 100% electrification on the island with balanced energy costs set forward by the EPC.

However, the government originally set a policy to have 100% of energy generated from renewable sources by 2017. Due to limited uptake of this plan, this goal was not able to be achieved and the plan had to be set back.

The renewable share on the island has been slowly declining, with a renewable share of 38% in 2020 when previously they had a renewable share of 42% in 2018, even though 31GWh of new renewable generation has been added since 2015.

Another key issue is that even though the Samoan Government's Ministry of Commerce, Industry and Labour has a key monitoring role for electrical equipment such as refrigerators, there is currently no regulatory system in place for renewable energy equipment [56]. As a result of this, there have been issues with faulty equipment from a non-standardised company. EPC in response to this have become more attentive in monitoring equipment to ensure they are properly tested and meet the relevant standards. This also includes adhering to Australia's Clean Energy Council approved inverters and modules list. As part of this, EPC has also requested the Samoan Government to be more aggressive in their electronic equipment monitoring.

Market and Commercial Enablers

Lesson 5: Changing PPA and tariff structures to bring fair and cost-reduced renewable energy to its customers

Since 2010, Samoa has promoted private sector investment in its renewable energy sector and currently has five Independent Power Producers (IPPs) systems installed. This includes three IPPs who introduced PV systems to Samoa. The main issue with the IPP PV systems is that PV generation costs are around 12% higher than the avoided diesel generation costs [56]. This is due to the capital-intensive nature of PV infrastructure and significant market risk causing the IPPs to have significant return on capital which increases the feed-in tariff paid by EPC to the IPPs. Under the contract, this price needs to be paid to the IPPs even if they are generating more than Samoa's demand. Also, before the battery systems were installed, EPC required the diesel generators to operate at a higher capacity in order to cover for the variability of the IPP PV generation, further contributing to generation costs. However, EPC still remains committed to achieve the Government's renewable energy targets and long-term sustainable and low-cost generation for customers. This requires restructuring of new PPA's to share the risk and rewards across all involved parties and ensure the cost of generation remains affordable and sustainable. EPC has set up a Memorandum of Understanding with Grid Market to develop a new procurement methodology to assist EPC in producing a robust strategic plan for future projects.

In 2019, EPC transitioned to a new tariff structure for its large industrial customers, with a significant proportion of the fixed costs of providing electricity to such customers now recovered by fixed charges [58]. EPC discovered that with the lower diesel prices, large consumers could run their diesel generators rather than purchase electricity from EPC to reduce their costs but increase non-renewable generation use. This resulted in cost-shifting the recovery of debt and operation costs onto smaller consumers. The fixed charge recovers a large proportion of the costs that would have been recovered from the variable debt and usage charges [56]. The 100 largest customers of EPC pay a fixed charge and a discounted variable rate, which are determined such that they will pay the same bill charged by the standard variable rate applying to all other customers. The average electricity prices for all customers in 2020 was AU$0.40/kWh, a 26% reduction from the electricity price in 2015.

Part 3

Appendices

Appendix A – Technical System Characteristics of Selected Case Studies

	King Island	**Onslow**	**Kaua'i Island**	**Kodiak Island**	**Cordova**	**Old Crow**	**Isla Huapi**	**Samoa**	**Lord Howe Island**	**Hawaii Island**
Nameplate Capacity	9.42 MW	3 MW	259.2 MW	75 MW	18.3MW	4.4 MW	416kW	78.51 MW	2.84 MW	525.6 MW
Maximum Demand	2.5 MW	-	75.17 MW	27.8 MW	6.5 MW	587 kW		33 MW	489 kW	
Annual Generation	12 GWh	-	435 GWh	145.6 GWh	26.8 GWh			173.6 GWh	2 GWh	1043 GWh
VRE Penetration	65%	50%	69.5%	99.7%	78%	24%	100%	38%	69%	60%
Centralised Wind	2.45 MW	-	-	9 MW				0.55 MW		31 MW
Centralised Solar	Solar 0.47 MW	Utility Solar Farm 1 MW	Solar 118.9 MW	N/A		940 kW		15 MW	1 MW	60 MW
Distributed PV	-	Residential Solar 1.34 MW Commercial/Industrial Solar 0.64 MW	Residential Solar 21 MW	-			416kW			116MW
Other	Wave Generator 0.2 MW [59]	-	Hydro 17.3 MW Biomass 6.7 MW Fossil 110.5 MW	Hydro 31 MW Back Up Diesel 31 MW	Hydro 7.5 MW Diesel 10.8 MW	Diesel 2.8 MW		Hydro 15.46 MW Diesel 39.5 MW	Diesel 0.84 MW	Hydro 16.6 MW Biomass 21.5 MW Geothermal 38 MW Fossil 242.5 MW
Storage	BESS 3 MW/1.5 MWh	Utility Power Station BESS 500 kWh Utility Network BESS 1 MWh	BESS 47 MW/ 222 MWh	Lithium-Ion BESS 3 MW	BESS 1 MW/1 MWh	BESS 616 kW/612 kWh		BESS 8 MW/13.6 MWh	BESS 1 MW/3.7 MWh	BESS 152 MWh
BTM Resources	-	Residential ESS 190 kWh Commercial/Industrial Smoothing Storage 361 kWh	-	-			Residential ESS 3.78MWh			
Other	Flywheel 2 MVA Dynamic Resistor 1.5 MW	-	-	Flywheel 2 MW						

Appendix B – Regulatory and Policy Arrangements for Selected Cast Studies

	Responsible Utility	Competition Enablers/ Requirements	Integration of VRE	Government Program/ Policies	Utility Programs/Policies
King Island	Regulated utility in collaboration with unregulated commercial subsidiary				
Onslow	Vertically integrated regulated utility		Horizon Power Manuals, Standards & Metering [60]		Concession and rebate schemes for customers in special circumstances.
Kaua'i Island	Community-owned utility	Hawaii State Planning Act – 226-6/226-10	Renewable Portfolio Standards DHHL's Energy Policy	Hawaii Clean Energy Initiative Energy Efficiency Portfolio Standards Hawaii 2050 Sustainability Plan	Concession and rebate schemes for customers in special circumstances or to incentivise renewable and efficient technology uptake.
Kodiak Island	Community-owned utility	Kodiak Electric Association Bylaws			Kodiak Electric Association Bylaws
Cordova	Community-owned utility	Cordova Electric Cooperative Bylaws			Cordova Electric Cooperative Bylaws
Old Crow	Regulated local utility alongside local government				
Isla Huapi	Community-owned committee			Chile Energy Policy, sets a target of 70% renewable penetration by 2050 for Chile	
Samoa	Regulated local utility			Energy Sector Plan - target of 100% renewable penetration by 2025 for Samoa. Clean Energy Initiative	Renewable Energy Unit Samoa Power Sector Expansion Project IMPRESS Project National Renewable Energy Project
Lord Howe Island	State Statutory authority		Solar Energy Systems – Checklist for Streamlined DAs	LHI Electricity Supply – Service and Installation Rules	LHIB Guarantee of Service Policy

Hawaii Island	Regulated local utility	Hawaii State Planning Act – 226-6/226-10	Renewable Portfolio Standards	Hawaii Clean Energy Initiative Energy Efficiency Portfolio Standards	Solar schemes and programs to incentivise uptake of rooftop solar. Integrated Demand Response Portfolio Plan implementing a range of DR programs

Appendix C – Market Structure and Features of Selected Case Studies

	Commercial Arrangements	Funding, CAPEX and OPEX	Electricity Rates
King Island	Electricity provision is subsidised by the Tasmanian Government via a Community Service Obligation [7].	King Island Renewable Energy Integration Project, one phase of several in the build-out of the King Island system had total project costs of U$17.7M with $6M coming from ARENA. $11.98 [7]M CAPEX per MW Installed	AUS$0.26/kWh
Onslow	One of the first instances of a 'business as usual' approach to utility management of DER assets in Australia, using an end to end DER management system [15]. Distributed Energy Buyback Scheme and Commercial Buyback Scheme to incentivise energy exports from customers to the grid	Part funded by Petro-chemical multinational Chevron given dependence on Onslow community for workforce and social license.	AUS$0.30/kWh
Kaua'i Island	New Renewable Dispatchable Generation PPA model to address renewable energy curtailment. KIUC has signed PPAs with several generation facilities for the purchase of renewable sources to serve the customers of Kaua'i. Any individual, company, joint venture, etc is eligible for membership to KIUC for the purchase of electricity.	Partnering with various generation and operation companies (such as AES, Gay & Robinson and McBryde) to construct and operate renewable plants.	US$0.43/kWh [2011] US$0.33/kWh [2022]
Kodiak Island	The Board of Directors is made up of 9 individuals who operate the network. Each network member must purchase electricity from KEA as soon as it is available.	$16M through Alaska Energy Authority, $39.6M through clean renewable energy bonds, KEA contributed $3.5M and Matson and City of Kodiak contributed $0.4M each	US$0.177/kWh [2000] US$0.162/kWh [2022]
Cordova	The Board of Directors is made up of 7 individuals who operate the network. Each network member must purchase electricity from CEC as soon as it is available.	Battery Project: $1,025,000 (CEC), $500,00 (SANDIA), $325,000 (PNNL) $24mil for Power Creek Hydro Project Upfront costs of USD$2mil with USD$171,644 per year.	US$0.375/kWh
Old Crow	Under a 25 year PPA, the VGFN owns the solar generation assets whilst ATCO owns the BESS and microgrid controller to operate the grid at lowest cost for the customers.	$500,000 investment from the Government of Yukon $8.5 million funding from the Government of Canada	

Isla Huapi	Community selected committee operates and determines fixed monthly prices to be paid by each user with a solar array.	Funding from Ministry of Energy of USD$100k in partnership with the Municipality of Futrono	AU$5.28/month
Samoa	Different tariff structure for large industrial users to incentivise renewable generation rather than cheaper self-owned diesel generation to balance operation costs across all customers.		US$0.28/kWh
Lord Howe Island	There are two tariff classifications covering all customers on a domestic or commercial basis with no off-peak hot water tariff.	$4.5mil grant from ARENA and a $5.9mil loan from the NSW Government (paid back via diesel fuel savings) with the balance of funds contributed by the LHIB	
Hawaii Island	Energy Performance Contracts to subsidise upfront costs and an extensive competitive bidding framework to procure new energy projects	Shareholders provide upfront funding for capital improvement projects whilst the PUC determines reasonable return on equity.	US$0.43/kWh

Appendix D – Expansive Scan of 40 Case Studies Explored

Details of Islanded Grid		Operating Context *(Customers served, load types, reason for being islanded, etc)*	System Specifications *(Generation types, capacity ratings, integrated storage, etc)*	Key Learnings *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	Assessment of relevance to APEC's Clean Energy Goals
Australia					
01: Flinders Island Renewable Energy Hub					
Location	Flinders Island, Tasmania	*Background:* The islanded grid was originally served entirely by diesel fuel supplied by the 3 MW power station. The project was built on Hydro Tasmania's successful King Island Renewable Energy Integration Project. [1] *Project Costs:* Total project costs of $13.4 mil with $5.5mil of this funded by ARENA. The current energy tariff is $0.26/kWh.	*Resource Types:* - Wind Turbine (900 kW) - Solar Array (200 kW) - BESS (750 kW/ 300 kWh) - Flywheel (850 kVA) - Dynamic Resistor (1.5 MW) - Diesel generator (3 MW)	Challenges overcome during the project included the ability to integrate the renewable energy, both solar and wind, while maintaining power quality and system security. As the renewable contribution increases, so does the need to carefully manage the wider power system (including diesel generators, feeders and auxiliary systems) to effectively integrate the variable renewable energy sources without putting the power supply at risk.	The project has aided in displacing diesel fuel usage by 60%. A key objective was to develop scalable and modularised designs for 'readily deployable enabling technologies' such as batteries, flywheels and resistors, enabling significant commissioning activities to be carried out in factories, which would reduce time on site.
Operator	Hydro Tasmania				
Nameplate Capacity	7.2 MW				
Max/Min Demand	1.3 MW (max)				
VRE Penetration	60%				
Load Type/s	Residential/Commercial				
02: Jabiru Hybrid Renewable Project					
Location:	Jabiru, Northern Territory	*Background:* Jabiru, which is seen as the gateway to Kakadu National Park and the West Arnhem Region, had been supplied by diesel generators from the nearby – and now shuttered – Ranger uranium mine operated by Energy Resources Australia. With the mine closed and the diesel generators decomissioned, the NT Labor government sought the opportunity to shift the town to at least 50 per cent renewable supply, awarding EDL the tender for the job in early 2021.[2] *Project Costs:* The project is part of the Commonwealth and Northern Territory Governments pledge of $351mil of funding for infrastructure projects	*Resource Types:* - Solar Farm (3.9 MW) - BESS (3 MW / 5 MWh) - Back up Diesel generator (4.5 MW)[3]	The Jabiru project is part of the Territory Labor government's $135.5 million dollar commitment to the Future of Jabiru and Kakadu package, and is the first project to be completed as part of the transition to a tourism and services hub. Environmental approval was achieved through extensive research and feasibility studies.[4]	During the day, the town will run 100% on solar energy. On average, the Jabiru power station will supply more than 50% renewable energy to the town over the course of the year, which puts the remote town in line with the NT government's target of 50% renewables by 2030.
Operator	EDL				
Nameplate Capacity	11.4 MW				
Max/Min Demand					
VRE Penetration	50%				
Load Type/s	Residential				
03: Lord Howe Island Renewable Energy Project					
Location	Lord Howe Island[5]	*Background:* A small island with a population of 305 using a microgrid to provide reliable power to the general public and surrounding necessities. *Project Costs:* Total project capital costs of $11.8mil with $4.5mil of it funded by ARENA.	*Resource Types:* - Solar PV array (1MW) - Diesel Generator (840kW) - BESS (1MW/ 3.7MWh) - Tesla Microgrid Controller	Lord Howe Island is a UNESCO world heritage listed island which makes it difficult to achieve development approval.	The Hybrid Renewable Energy Project (HREP) was undertaken to: 1. Achieve 67% renewable capacity from the solar PV and BESS 2. Improve the island's self-sufficiency 3. Removal reliance on imported diesel fuel 4. Protect the Island's World Heritage and tourism 5. Seek lowest long-term cost
Operator	Lord Howe Island Board (LHIB)				
Nameplate Capacity	2.84 MW				
Max/Min Demand	489kW				
VRE Penetration	69%				
Load Type/s	Residential/Commercial				

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[1] 2018-10 Hydro Tas - Flinders Island Hybrid Energy Hub
[2] 2022-02 One Step Off the Grid - Territory town runs on 100% solar during day with new hybrid microgrid
[3] 2021-00 EDL - Jabiru Hybrid Renewable Project
[4] 2021-03 Department of the Chief Minister and Cabinet - Environmental Approvals Jabiru Power Station

Details of Islanded Grid		**Operating Context** ***(Customers served, load types, reason for being islanded, etc)***	**System Specifications** ***(Generation types, capacity ratings, integrated storage, etc)***	**Key Learnings** ***(Cost recovery, pricing, market mechanisms, consumer protections, etc)***	**Assessment of relevance to APEC's Clean Energy Goals**
04: Onslow DER Project					
Location	Onslow, WA	*Background:* Design and installation both reflected the extreme conditions experienced at the site, including extreme heat, cyclonic conditions and a corrosive environment.[6] *Customer Base:* 850 residents	*Resource Types:*[7] - 1,341 kW of residential solar PV (261 systems) - 640 kW of commercial and industrial solar PV (8 systems) - 190 kWh of residential energy storage (19 systems) - 361 kWh of commercial and industrial smoothing storage (8 systems) - 1 MW of utility solar farm - 500 kWh of utility power station BESS - 1 MWh of utility network BESS	Australia's first implementation of the international 'smart grid' standard (IEEE 2030.5). This approach allows them to monitor and securely issue control commands to DERs for feed-in management, demand management, reactive power management and battery management for individual sites.[8]	On completion the Onslow DER Project will be one of Australia's largest distributed energy resources (DER) microgrids with a very high level of renewable energy penetration.
Operator	Horizon Power, PXiSe Energy Solutions and SwitchDin				
Nameplate Capacity	3 MW				
Max/Min Demand					
VRE Penetration	50%				
Load Type/s	Residential/Commercial				
05: King Island Renewable Energy Integration Project					
Location	King Island, Tasmania	*Background:* Being a remote island community, King Island is not connected to either mainland Tasmania or mainland Australia for its electricity supply. Electricity on the island was traditionally generated entirely from diesel fuel supplied by the 6 MW power station, serving 12 GWh of annual customer demand, peaking at 2.5 MW.[9] *Customer Base:* 1,800 Residential and Commercial with peak demand of 2,500 kW. *Project Costs:* Total project costs of $17.7mil with $6mil of this funded by ARENA. The current energy tariff is $0.26/kWh.	*Resource Types:* - Wind Generation (2.45MW) - Solar PV (470kW) - BESS (3 MW/ 1.5MWh) - Flywheel (2 x 1MVA) - Dynamic Resistor (1.5MW) - Aggregated customer demand response system - Hybrid control system	Volunteers installed smart meters within homes to monitor loads including hot water and local PV. These loads can act as a VPP to aid the grid when necessary.	At its time, a world leading hybrid power system that provides 65% of its energy from renewables. It is an innovative idea that has aided as a good example of renewable integration into isolated grids.
Operator	Hydro Tasmania				
Nameplate Capacity	9.42 MW				
Max/Min Demand	2.5 MW (max)				
VRE Penetration	65%				
Load Type/s	Residential/Commercial				
06: NT Solar Energy Transformation Program (SETuP)					
Location	Northern Territory	*Background:* There are 72 indigenous remote communities spread throughout the NT that largely rely on diesel generators for power. This is due to their extreme distances from transmission networks. For example, to power Kaltukatjara, 60,000 litres of diesel fuel is transported every eight weeks from Darwin, over more than 2,000 km of highways and dirt tracks.[10] *Project Costs:* Total project costs of $59mil funded by ARENA.	The project provided in total 10MW of solar PV with medium to high penetration to 26 remote communities during the initiatives' life cycle. 9 MW of the installations was designed to achieve 15% diesel fuel displacement. A 1MW high penetration system was installed at Daly River achieving 50% diesel fuel displacement.	The primary financial metric is the value of the avoided diesel fuel burn. The aim of the project is to manage and minimise operating expenditure.	The aim of the project was to displace diesel fuel usage within remote communities and foster understanding within the community of the importance of renewable energy.
Operator	ARENA				
Nameplate Capacity	10 MW				
Max/Min Demand	Varies based on community				
VRE Penetration	15-50%				
Load Type/s	Residential				

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[6] 2021-06 CPS National – Onslow – Design, Supply, Install and Commission 1MW Solar PV System

[7] 2019-11 Horizon Power – Onslow DERMS

[8] 2019-00 SwitchDin – Onslow - Cracking the distributed energy management challenge for Australia's largest regional utility

[9] 2014-00 Hydro Tasmania – King Island Renewable Energy Integration Project

[10] 2014-00 ARENA – NT Solar Energy Transformation Program

Details of Islanded Grid		**Operating Context** *(Customers served, load types, reason for being islanded, etc)*	**System Specifications** *(Generation types, capacity ratings, integrated storage, etc)*	**Key Learnings** *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	**Assessment of relevance to APEC's Clean Energy Goals**
07: Daintree Microgrid[11]					
Location	Daintree Rainforest, Queensland	*Background:* The Daintree area faces many geographical issues which 'boxes' it in from the rest of Queensland, making it difficult to transport important infrastructure and connect the area to the rest of the NEM. The area also is heavily forested, making it hard to implement solar due to low sunlight penetration. *Customer base:* 640 residents and 550 overnight visitors with peak demand of 3.2MW. *Project Costs:* Current cost of electricity is $0.45/kWh for residents within the area. Varying capital costs of $15 to $70mil with ongoing costs of $1.3 to $3.6 mil depending on supply option chosen.	*Grid Assessments:* Assessments of different microgrid structures have been explored and evaluated by the Queensland Government, whilst the Federal Government has already funded a microgrid project.[12]	*Customer Involvement:* • Establishing a mechanism to allow customers to benefit from sharing their excess solar production (similar to a FIT scheme) and implement residential and business tariffs • obtaining stakeholder support and agreement on the key principles for engineering solutions, tariff structures, subsidies and schemes, ownership, regulation and governance	Daintree is proposing a pathway to 100% renewable energy.
Operator	Sunverge				
Nameplate Capacity	10.6 MW				
Max/Min Demand	3.2MW (max)				
VRE Penetration	100%				
Load Type/s	Residential/Commercial				
08: Cooper Pedy Hybrid Renewable Project					
Location	Cooper Pedy, South Australia	*Background:* Cooper Pedy is an isolated opal mining town. In 2013, EDL began investigating the potential to integrate renewable energy into the existing power station to reduce diesel consumption in Coober Pedy.[13] *Customers Base:* Average demand of 1.4MW and peaks of 3.1MW in 2011. *Project Costs:* Total project costs of $39mil with $18.4mil of this from ARENA funding	*Resource Types:* • Solar (1MW) • Wind (4MW) • Total (9.3MW) • BESS (1MW/ 500kWh) • Diesel Generator (3.9MW) • Flywheel (1.7Mv) • Dynamic Resistor (3MW)[14]	Implementation of the hybrid system proved to reduce occurrence of unplanned outages and duration of these outages. Thus, providing further energy security.	The Cooper Pedy Microgrid is able to run for long periods of time on 100% renewables. It paves the way for future projects which learn from the mistakes of this project.
Operator	EDL				
Nameplate Capacity	9.3 MW				
Max/Min Demand	3.1 MW (max)				
VRE Penetration	75%				
Load Type/s	Residential/Commercial				
09: Rottnest Island Water and Renewable Energy Nexus					
Location	Rottnest Island, Western Australia	*Background:* Due to Rottnest Island's high visitation with over 500,000 visitors annually, a range of educational resources, including a digital energy dashboard, physical signage and a phone App, were developed to increase the knowledge of school groups and the general public in sustainable energy.[15] *Project Costs:* Total project costs of $6.1mil with $3.8mil of this funded by ARENA.	*Resource Types:* • Diesel Generation (1.54 MW) • Solar Generation (600 kW) • Wind generation (600 kW) • Dynamic Resistor (500 kW) • Hybrid power system controller	Remote data performance management tools provide operator viewing via web and smart phone apps. Automated performance reporting, allowing real-time and remote monitoring and performance monitoring of the power system. Main driver of the project was to displace diesel with renewable generation.	The project proved that the storing surplus renewable energy, by converting it to desalinated water and storing in tanks is a cost-effective approach to increase the utilisation of renewable energy.
Operator	Hydro Tasmania				
Nameplate Capacity	3.2 MW				
Max/Min Demand	1.1 MW (max)				
VRE Penetration	45%				
Load Type/s	Residential/ Commercial				
10: Esperance Power Project					
Location	Esperance, Western Australia	*Background:*	*Resource Types:*[16] • Gas (22 MW) • Wind (9 MW)	Local goods and services were used wherever possible in the delivery of this project. Projected annual savings to the State Government of $10m.[17]	The 20-year-old power station has now been replaced, cutting carbon emissions by almost 50%.
Operator	Horizon Power & Pacific Energy				

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[11] 2020-00 Sunverge – Powering Daintree
[12] 2019-09 KPMG – Daintree Electricity Supply Study
[13] 2019-06 EDL - Cooper Pedy Hybrid Renewable Project
[14] 2019-06 Renew Economy - Coober Pedy powered by 100 per cent renewables – most of the time
[15] 2018-10 Hydro Tas - Rottnest Island water renewable energy nexus
[16] 2020-00 Pacific Energy - Esperance Power Station
[17] 2021-00 Horizon Power - Esperance Power Project Facts Sheet

Details of Islanded Grid		**Operating Context** ***(Customers served, load types, reason for being islanded, etc)***	**System Specifications** ***(Generation types, capacity ratings, integrated storage, etc)***	**Key Learnings** ***(Cost recovery, pricing, market mechanisms, consumer protections, etc)***	**Assessment of relevance to APEC's Clean Energy Goals**
Nameplate Capacity	39 MW	Opportunities are being explored to facilitate community involvement in 50% of the solar farm into the future. The Synergy-owned Nine Mile and Ten Mile wind farms reached end of design life in 2014.	- Solar (4 MW) - BESS (4 MW)		
Max/Min Demand					
VRE Penetration	50%				
Load Type/s	Residential/Commercial				
11: Denham Hydrogen Demonstration Plant					
Location	Denham, Western Australia	*Background:* This will be Australia's first renewable hydrogen demonstration plant in a remote power system. The hydrogen plant equipment will be located at the existing power station site.[18] *Project Costs:* Project Costs and Electric Rates: Total project costs of $8.9mil with $2.57mil of this funded by ARENA.	*Resource Types:* - Solar Farm (704 kW) - Electrolyser, Hydrogen Compression and Storage (348 kW) - Fuel Cell (100 kW) The project will provide 526 MWh of dispatchable renewable electricity per year, enough to power 100 homes.	ARENA has funded $2.6 mil and the Western Australian Government's Recovery Plan has funded $5.7 mil to Horizon Power to build the renewable hydrogen demonstration.[19]	The hybrid solar and hydrogen power system will test the technical capability of hydrogen as a dispatchable power source in remote microgrids, in anticipation of the technology becoming cost competitive in the future and is a step towards Horizon Power meeting its target of no new diesel generation systems from 2025.
Operator	Horizon Power				
Nameplate Capacity	1.14 MW				
Max/Min Demand					
VRE Penetration	Unknown (planned for 100%)				
Load Type/s	Residential				
12: Agnew Renewable Microgrid					
Location	Agnew, Leinster, Western Australia	*Background:* This is a unique microgrid project that looks at powering a gold mine through a hybrid system. The gold mine uses complementary wind and solar for 54% of its annual electricity usage with a gas and diesel engine power station for the other 46%. [20] *Project Costs:* Total project costs of $111.6mil with $13.5mil of this funded by ARENA. .	*Resource Types:* - Wind Farm (18 MW) - Solar Farm (4 MW) - BESS (13 MW/ 4MWh) - Gas and diesel engine power station (21MW) *Annual Production:* - Wind (56,600 MWh) - Solar (6,886 MWh) - BESS (356 MWh) - Thermal (53,163 MWh)[21]	The cost of solar, wind and battery projects are on their own continuing to approach commercially competitive levels through economies of scale. The Project has demonstrated that investing in renewables is a change in risk profile for miners. Prepaying for energy (via the capital cost of building a renewable energy power generating facility) requires a significant, upfront investment, which tests the strength of the balance sheet and may not be feasible for small cap miners with smaller capitalisations.	This project is providing a blueprint for organisations to deploy similar off-grid energy solutions and demonstrate a pathway for commercialisation of low emissions technologies by de-risking the technical and commercial integration of high renewable energy fraction power solutions.
Operator	EDL				
Nameplate Capacity	55 MW				
Max/Min Demand	20 MW (max)				
VRE Penetration	54%				
Load Type/s	Industrial				
13: Kalbarri Microgrid					
Location	Kalbarri, Western Australia	*Background:* The Kalbarri microgrid is a small-scale power grid connected to the main electricity network to help meet peak demand and improve reliability of power supply to the town. The microgrid uses local generation and energy storage to provide a supply to the town when the network connection is interrupted. [22] *Customer Base:* 1,500 permanent residents with 100,000 annual visitors are served by the microgrid. *Project Costs:* $15mil investment by the State Government.	*Resource Types:* - Wind Farm (1.6 MW) - Roof-top Solar (1 MW) - BESS (2 MWh)	An automated text message alert system will be activated so that when power is interrupted and the microgrid is operating, a notification will be sent to mobile phones so residents can adjust their power usage.	The Kalbarri microgrid solution will be used as a blueprint for other regional areas and to help in the development of further renewable generation across the rural edges of the electricity network.
Operator	Western Power				
Nameplate Capacity	5 MW				
Max/Min Demand	3 MW (max)				
VRE Penetration	100% when off the grid				
Load Type/s	Residential/ Commercial				
14: Clean Energy Innovation Hub					

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[18] 2021-00 Horizon Power - Denham Hydrogen Demonstration Plant
[19] 2020-11 ARENA - Powering regional and remote Australia with renewable hydrogen
[20] 2022-03 Gold Fields - Gold Fields Agnew Gold Mine
[21] 2022-03 Gold Fields - Gold Fields Agnew Hybrid Microgrid Facts Sheet
[22] 2022-02 Western Power - Kalbarri Microgrid Facts Sheet

Details of Islanded Grid		Operating Context *(Customers served, load types, reason for being islanded, etc)*	System Specifications *(Generation types, capacity ratings, integrated storage, etc)*	Key Learnings *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	Assessment of relevance to APEC's Clean Energy Goals
Location	Perth, Western Australia	*Background:* ATCO Gas wanted to demonstrate the commercial viability of integrating hydrogen into microgrids, as well as the blending of hydrogen with natural gas for domestic use. Further excess power is used to produce renewable hydrogen which is stored on site. This can be used directly in a small hydrogen fuel cell or be blended with natural gas to run generators or appliances.[23]	*Resource Types:*[24] • Rooftop Solar (300 kW) • BESS (500 kWh) • Electrolyser (260 kW) • Gas generator (200 kW)	Produce a live virtual bill that details AGA's energy unbundled contract and drivers[25]: • Outline the real time impact on energy value streams, network value, capacity markets and environmental emissions; and Display site load profile and the energy market trading profiles to: • Encourage informed behaviours to turn off loads or turn on the generators • Interface with links from AEMO on total grid output.	ATCO's CEIH is an Australian-first, which integrates renewable hydrogen production and fuel cell technology with a renewable energy stand-alone-power-system in a "living lab" microgrid setup.
Operator	ATCO Gas Australia				
Nameplate Capacity	0.76 MW				
Max/Min Demand					
VRE Penetration	Unknown				
Load Type/s	Industrial				
15: Carnarvon DER Trials					
Location	Carnarvon, Western Australia	*Background:* The isolated town experienced a rapid uptake of solar PV in 2008-2011. As part of this, unique monitoring infrastructure was installed on a sampled distributed PV system. For the analysis period of 2017-2018, data collected was used to determine and review fluctuation and diversity factors currently used in Horizon Power's approach to determining PV hosting capacity on their networks. [26]	*Resource Types:* • Gas-fired Power Station (13 MW) • 121 customer connected solar systems (~700 kW) • Commercial solar farm (300 kW)	Monitoring infrastructure found varying cloud cover and inverter tripping events were the main causes for fluctuation in power ay 27% and 53% respectively. The study focused on the fluctuation due to cloud movement rather than providing solutions to the issue.	The Carnarvon DER trials aim to experientially understand how to manage DER in a microgrid environment, how DER orchestration can be used to remediate power quality issues and how a system operator can effectively exchange DER value with customers.
Operator	Horizon Power				
Nameplate Capacity	14 MW				
Max/Min Demand	585 kW (Max from solar)				
VRE Penetration	Unknown				
Load Type/s	Residential				
16: Yulara Solar Project					
Location	Yulara, Northern Territory	The study was conducted to highlight the effects of geographical dispersion on PV output variability within the Yulara region. It found that centralised PV systems reached fluctuation magnitudes of nearly 70% whilst dispersed systems only had 40%.[27] *Project Costs:* Total project costs of $6.9mil with $0.45mil funded by ARENA.	*Resource Types:* • PV (1.8 MW)	The largest array of Yulara's PV system can be curtailed to ensure stability of the grid and responds to signals from the central power station. The project also highlighted the importance of high-resolution data at 5-second intervals rather than 30-minute averages to capture true crucial underlying information.	The project uses geographical dispersion as one solution to provide secure, resilient and consistent power to the Yulara area.
Operator	Voyages Indigenous Tourism				
Nameplate Capacity	1.8 MW (Solar only)				
Max/Min Demand	1.5 MW (max)				
VRE Penetration	15%				
Load Type/s	Commercial				
Canada					
17: Yukon Integrated System					
Location	Yukon	*Background:* 78% of the residents of Yukon live in the city of Whitehorse and the rest live in or near Yukon's 17 towns. All but five of these communities are connected through an electrical transmission network, called the Yukon Integrated System. The YIS is not connected to the rest of North America.[28]	93% of Yukon's electricity is generated by four hydro pants with one wind turbine, the remaining 7% is generated by diesel and LNG. *Resource Types:*	The 2013 Micro-generation Policy and its resulting production incentive program provides the opportunity for residential and commercial electricity customers to generate electricity from renewable energy sources and sell surplus electricity to the grid.[29]	Policy incentives for uptake of renewables to further support the grid. Energy security through large use of hydro electricity and minimum use of diesel fuel.[32]
Operator	Yukon Energy Corporation				

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[23] 2021-09 International Microgrid Association - Microgrids The Way Forward (p.33)
[24] 2019-11 ATCO - Clean Energy Innovation Hub Lessons
[25] 2019-12 ATCO - Clean Energy Innovation Hub (p.7)
[26] 2020-03 Horizon Power - Carnarvon DER trials technical report
[27] 2018-12 ARENA - Yurala's Dispersed Design to Reduce System Variability
[28] 2018-00 Government of Yukon – Yukon's Energy Context
[29] 2022-00 Yukon - Apply for a rebate to install a renewable energy system for your home
[32] 2020-09 Government of Yukon – Our Clean Future

Details of Islanded Grid		**Operating Context** *(Customers served, load types, reason for being islanded, etc)*	**System Specifications** *(Generation types, capacity ratings, integrated storage, etc)*	**Key Learnings** *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	**Assessment of relevance to APEC's Clean Energy Goals**
Nameplate Capacity	156.6 MW	*Customer Base:* 38,000 *Project Costs:* In partnership with the government of Canada, around $500mil will be invested from 2020 to 2030 to implement 'Our Clean Future'.	- Hydro (92.1 MW) - Wind (0.65 MW) - Diesel (31.1 MW)	Nationwide IEEE standards for the specification of Microgrid Controllers.[30] Government of Yukon has made investments to install 14 EV fast chargers through a Natural resources Canada Initiative.[31]	
Max/Min Demand	104 MW (max)				
VRE Penetration	93%				
Load Type/s	Mixed				
18: Prince Edward Island Microgrid					
Location	Prince Edward Island, Canada	*Background:* Over the years several initiatives to transition to an electrified, low carbon sustainable community have been implemented by the need for grid reliability and resiliency. The key initiatives include[33]: - Solar Program[34] - Summerside Sunbank Project[35] - Slemon Park Microgrid Project[36] - 2020 Wind Farm[37] *Project Costs:* Current Residential rates of $0.16/kWh. Project costs of around $69mil for Summerside Sunbank Project	Each previously described project has brought new generation and storage types and capacity to the island: - Solar PV (10 Mw and 21 MW) - BESS (1.5 MWh and 20 MWh) - Wind Farm (73.56 MW)	Federal funding for the Slemon Park Microgrid Project is provided by Natural Resources Canada's Smart Grid Program, part of the Government of Canada's Investing in Canada Infrastructure Program: Green Infrastructure stream. The Solar Program provides up to 40% of the installed costs of home PV arrays, up to $10,000. The investor-owned integrated utility administers a net metering program for distributed generation up to 100kW.	In 2017 PEI Energy Corporation implemented an energy strategy to drive the island towards more local economic opportunities, lower greenhouse gas emissions and more cost efficiencies.[38] 99% of the island's energy generation comes from renewable sources, however, 60% of its demand comes from imports.[39]
Operator	PEI Energy Corporation				
Nameplate Capacity	376 MW				
Max/Min Demand	286 MW (max)				
VRE Penetration	40%				
Load Type/s	Mixed				
19: Gull Bay Project					
Location	Gull Bay, Ontario	*Background:* It was not economically viable to connect the community to the Ontario electrical grid. The town can reach extreme temperatures of -45ºC with a lack of accommodation for out-of-town workers. Large amount of pre-planning went into avoiding winter work. The planning and construction of the project had to be done in a way to respect traditional values.[40] *Customer Base:* 375 residents, 100 homes and 13 community buildings. *Project Costs:* Project costs of around $8-9mil.	The Solar PV and BESS will assist in reducing diesel fuel use by 30% (130,000 l per year). *Resource Types:* - Solar PV Array (365kW) - BESS (300kW/ 555kWh) - Hitachi Energy's MGC600 microgrid controller**Error! Bookmark not defined.**	Provincial and federal government provided additional funding to boost the project. Some members of the public feel uneasy about removing the use of diesel fuel as it has been a reliable source of power for generations. The project allows communities to become comfortable and aware of the benefits of renewable energy. Ontario has implemented pilots for residential consumers to test new pricing structures.[41]	The project aimed at introducing renewables to meet the energy requirements of remote communities without much disturbance whilst maximising the reduction in carbon emissions.
Operator	Ontario Power Generation				
Nameplate Capacity	0.65 MW				
Max/Min Demand	Unknown				
VRE Penetration	25%				
Load Type/s	Residential				

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[30] 2018-04 IEEE - 2030.7-2017 - IEEE Standard for the Specification of Microgrid Controllers
[31] 2022-02 Government of Canada - New EV Chargers Coming to The Yukon
[33] 2021-00 Natural Resources Canada - Smart Grid in Canada (p.34)
[34] 2022-06 Prince Edward Island - Solar Electric Rebate Program
[35] 2020-00 Summerside Sunbank - The Summerside Sunbank Project
[36] 2021-00 AMERESCO - AMERESCO AWARDED 10-MW SLEMON PARK MICROGRID PROJECT
[37] 2020-00 PEI Energy Corporation - 2020 Wind Farm
[38] 2017-03 Prince Edward Island - Provincial Energy Strategy
[39] 2018-08 University of Alberta - Prince Edward Island Energy Market Profile
[40] 2022-04 T&D World – Microgrid Helps Indigenous Canadians Use Less Diesel, Have More Energy Independence
[41] 2020-12 Ontario Energy Board - Regulated Price Plan Pilot Meta-Analysis

Details of Islanded Grid		**Operating Context** ***(Customers served, load types, reason for being islanded, etc)***	**System Specifications** ***(Generation types, capacity ratings, integrated storage, etc)***	**Key Learnings** ***(Cost recovery, pricing, market mechanisms, consumer protections, etc)***	**Assessment of relevance to APEC's Clean Energy Goals**
20: Lac-Megantic Microgrid					
Location	Lac-Megantic, Quebec	*Background:* Following the July 2013 rail disaster and the destruction of its downtown core, Lac-Megantic was given the opportunity to rebuild with a more renewable focus.[42] *Customer Base:* Approximately 30 buildings including a sport complex, fire station, city hall and a railway station.	*Resource Types:* - 2,200 Solar Panels (800 kW total) - BESS (700kWh) - Centralised control system - Buildings equipped with smart devices - Energy efficient measures - An EV charging station[43]	Energy efficiency programs that encourage people to stop wasting power and adopt energy-saving behaviours. Optimise peak-period management and reduce the associated costs by applying energy efficiency measures and tapping into auxiliary power sources and cut back on high-priced energy purchases.	The microgrid was designed in consultation with an engaged, forward-looking community that was willing to innovate and support sustainable development.
Operator	Hydro-Quebec				
Nameplate Capacity	0.8 MW				
Max/Min Demand	unknown				
VRE Penetration	99%				
Load Type/s	Residential/Commercial				
21: Sault Smart Grid					
Location	Sault Ste. Marie	*Background:* Sault Ste. Marie is in a good location for hydro power due to the neighbouring Ste. Mary's rapids.[44] *Customer Base:* PUC Distribution serves approximately 33,500 mostly residential and commercial electricity customers in the city. *Project Costs:* Around $1bil has been invested into energy for the Sault Ste. Marie region, this project accounts for $34mil.	*Resource Types:* - Wind Generation (272 MW) - Solar Generation (68MW) - Hydroelectric Generation (203MW) - BESS (7MW) - Cogeneration Facility (70MW)[45]	The project provides an enabling platform for renewable energy and expands customer opportunities to take advantage of enhanced energy services and solutions. Improved reliability will be realized through a reduction in the impact and duration of power outages	Sault Ste. Marie is focused on providing high quality, highly reliable, green power at a lower cost for businesses interested in locating at Sault Ste. Marie.
Operator	PUC				
Nameplate Capacity	620 MW				
Max/Min Demand					
VRE Penetration					
Load Type/s	Residential/Commercial				
22: Old Crow					
Location	Old Crow, Yukon	*Background:* Old Crow is 160km from the closest community and is not accessible by road with reliance on diesel being transported by air for power. This has resulted in some of the highest electricity costs in Canada. This incentivised the installation of solar panels to reduce reliance on diesel for power.	The solar panels are fixed design at a much lower angle than most panels due to the low angle of the sun at this location. *Resource Types:* - Solar Generation (940kW) - BESS (616kW/612kWh) - Diesel (2.8MW)	Community engagement, education and training of the local residents was an important aspect to the effective completion of the project. There was conflict of interest between some of the elders and the project plan, which was successfully resolved.	Focus on reducing costs for both the operator and its residents through renewable energy uptake has been a large focus for Old Crow, with great success installing the solar farm.
Operator	Vuntut Gwitchin Government				
Nameplate Capacity	4.4MW				
Max/Min Demand	587kW				
VRE Penetration	24%				
Load Type/s	Residential/Commercial				
New Zealand					
23: Cook Islands Renewable Energy Sector Project					
Location	Cook Islands	*Background:* Energy needs throughout the Cook Islands have been met by long-established distribution systems supplied by diesel-generated electricity on Rarotonga and the Pa Enua. The introduction of alternative energy sources has been minimal and	The project was completed in two phases each including subprojects on the islands of Atiu, Mitiaro, Mauke and Mangaaia (Phase 1), and Aituki (Phase 2).	The main economic driver and cost recovery mechanism is the savings in diesel fuel imports. This causes the reduction in household electricity prices.	Large shifts in government policy towards renewable energy re-confirms energy as a fundamental prerequisite to sustainable development. Large amounts of efforts have gone in from the government to move the islands towards 100% renewable.
Operator	Ministry of Finance and Economic Management and Asian Development Bank				

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[42] 2021-07 Hydro Quebec - The Lac-Mégantic microgrid: a window on the technologies of the future

[43] 2018-00 Hydro Quebec – Lac-Megantic Microgrid

[44] 2017-07 Wilson Center - Person, Place, and Policy

[45] 2021-05 Sault Ste. Marie - First-in-Canada Community Wide Smart Grid Project Advances in Sault Ste. Marie

Details of Islanded Grid		**Operating Context** *(Customers served, load types, reason for being islanded, etc)*	**System Specifications** *(Generation types, capacity ratings, integrated storage, etc)*	**Key Learnings** *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	**Assessment of relevance to APEC's Clean Energy Goals**
Nameplate Capacity	3 MW	isolated. The growth of the Cook Islands economy has been largely dependent upon fossil fuels as its energy source. [46] *Customer Base:* The islands have a total population of 17,500, with varying load types being provided from commercial to residential buildings. *Project Costs:* Total project capital costs of $26mil.	*Resource Types:* - Solar Generation (2MW) - BESS (1MW/ 9MWh)[47]		
Max/Min Demand	151 kW (max)				
VRE Penetration	95%				
Load Type/s	Residential/Commercial				
China					
24: Shuanghu Microgrid Project					
Location	Shuanghu	*Background:* Shuanghu County's extreme climate and elevation has frequently posed challenges to inverters and other solar components, operating in the region's frigid conditions.[48] *Customer Base:* 14,000 local residents	*Resource Types:* - Energy Storage Inverters (7 MW) - 5000 Smart Meters - Solar PV (13 MW) - BESS (23.5MWh)[49] - Energy Storage Inverters (7 MW)	The project was developed with Advanced Metering Infrastructure as the main technology. The key benefit of the technology used is to improve the process of managing supply, demand and data quality.	Sungrow is looking to provide reliable renewable energy to communities within harsh environments that would normally not be able to use such technologies.
Operator	Sungrow Power Supply				
Nameplate Capacity	20 MW				
Max/Min Demand	Unknown				
VRE Penetration	Unknown				
Load Type/s	Residential				
Korea					
25: Jeju Island Smart Grid Testbed					
Location	Jeju Island	*Background:* Jeju island is the largest island in Korea and a popular tourist destination. The sunny and windy conditions of the island made it a perfect test-site for wind and solar deployment. The project began in 2009 and the island continues to be a test site for smart grid technologies and to create new business models. *Customer Base:* Approximately 6,000 homes were served by the project with 168 companies participating in it.[50]	*Resource Types:* - Wind Farms (400 MW) - Rooftop solar (600 MW) - Smart Meters - Energy consumption info portal - Electric Vehicles	Several pricing mechanisms were tested including consumers having a choice of different electricity rates, with the ability to sell renewable energy back to the grid. There was also the feature to implement real-time pricing nationwide. Each consortium will perform in a competitive environment, and the government will provide persistent support to allow creation of new business models.[51]	The test system aims to demonstrate the management of next generation utility networks and how they can be supported by modern IT platforms and communications networks. At the time, the government had plans to produce 11% of all energy from renewables from its 2012 share of 2.1%. The island now has plans to be carbon neutral by 2030. [52]
Operator	Jeju Energy Corporation				
Nameplate Capacity	1879 MW				
Max/Min Demand	386/ 791 MW[53]				
VRE Penetration	16%				
Load Type/s	Mixed				
26: Gapa Island Microgrids for Electricity Self-Sufficiency					
Location	Gapa Island	*Background:* The island covers an area of 0.86 km2 and has a population of 300. Electricity is produced with three 150 kW diesel generators installed in 1992 and supplied to 196 customers through two distribution lines. The main loads are residential, commercial and desalination facilities. The	*Resource Types:* - Wind Turbine (0.5 MW) - Rooftop PV (174 kW) - BESS (3.85 MWh)	The government has enacted relevant legislation, laws and policies for the growth of microgrids within the Korean region. This includes but is not limited to: - Low Carbon Green Growth Basic Act - Green Building Support Act	The microgrid is able to run up to 7 days using only renewables with the potential to run for 25 days a month on average if the BESS was doubled. The model has been shared with Dubai Power Authority to be extended to five other islands nationwide.
Operator:	KEPCO				
Nameplate Capacity	1.2 MW				

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[46] 2018-04 Ministry of Finance and Economic Management - Cook Islands Renewable Energy Sector Project
[47] 2022-03 Hydro-Electric Corporation - Cook Islands Environmental and Social Monitoring Report
[48] 2021-08 power Technology - Shuanghu Microgrid Project, China
[49] 2016-12 Microgrid Knowledge - Sungrow Connects China's Largest Solar Plus Storage Microgrid Project
[50] 2012-09 GSMA - Korea Jeju Island Smart Grid Test-Bed
[51] 2011-08 Ministry of Knowledge Economy - JEJU Test Bed (p.12)
[52] 2021-07 UPI - Jeju, Korea's island paradise, also is a high-tech testbed
[53] 2013-10 Dong-Hee Yoon - A Study on Jeju Power System Considering Smart Grid Elements

Details of Islanded Grid		Operating Context *(Customers served, load types, reason for being islanded, etc)*	System Specifications *(Generation types, capacity ratings, integrated storage, etc)*	Key Learnings *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	Assessment of relevance to APEC's Clean Energy Goals
Max/Min Demand	230 kW[56]	annual average ocean temperature of the is 16 ℃, the average wind speed is 5.5 m/s, and the maximum wind speed is 13 m/sD[54]	- Diesel Generator (450 kW)[55]	- Expansion of Smart Grid new Service - Foundation of Smart Grid Expansion	
VRE Penetration	42%				
Load Type/s	Residential/Commercial				
United States of America					
27: Kodiak Island Microgrid					
Location	Kodiak, Alaska[57]	*Customer Base:* 15,000 *Barriers:* - Kodiak's remote location and climate funnels the decision-making process for facility construction - The microgrid was one of the first of its kind, KEA did not have many examples to look on.	*Resource Types:* - Terror Lake Hydroelectric Generation Station (31MW) - Wind Turbines (9MW) - Back Up Diesel Generators (31MW) - Lithium-Ion BESS (3MW/ 2MWh) - FESS (2MW)[58]	*Successes:* - Stable electricity rates have led to an expansion of the fishing industry, creating more jobs and tax revenue - Combination of a variety of storage systems allows for a more robust microgrid in its operation	In 2004 EKA set a target of 95% electricity from renewable sources by 2020. In 2014 it was able to achieve 99.7% of its average energy penetration from renewable resources.
Operator	Kodiak Electric Association				
Nameplate Capacity	75 MW				
Max/Min Demand	27.8 MW (max)				
VRE Penetration	99.7%				
Load Type/s	Mixed				
28: Redwood Coast Airport Microgrid					
Location	Redwood Coast, San Francisco	*Background:* It is a rural isolated community at the end of a transmission line. It is vulnerable to tsunamis, earthquakes, landslides, floods, wildfires and now PSPS events.[59]	First front-of-meter, multi-customer microgrid on PG&E's system. System works in either islanded or grid-connected modes depending on larger grid operation. *Resource Types:* - PV array DC-coupled (2.2MW) - BESS (2.2MW/ 8.8MWh) - Net-metered PV array (300kW)	- Provide resilience to critical community services in the face of climate change and natural disasters - First front-of-meter, multi-customer microgrid on PG&E's system.	Supporting vulnerable populations with a focus on project replication and demonstration of feasibility.
Operator	Redwood Coast Energy Authority				
Nameplate Capacity	4.7 MW				
Max/Min Demand	330 kW				
VRE Penetration	100% back up				
Load Type/s	Industrial/ Commercial				
29: Mililani Solar					
Location	O'ahu, Hawaii	Mililani Solar is the company's fourth solar power plant. It is also Hawaii's first utility-scale solar and battery storage plant.[60]	*Resource Types:* - BESS (156 MWh) - Solar Power Plant (39 MW)	Mililani provides grid reliability and energy security. The solar panels shift throughout the day to maximise sunlight and enable energy security throughout the night.	Aim of the project is to stabilise the cost of energy for customers through renewable energy means. This project currently only slightly reduces rates, but eight other projects are planned to be coming in 2023 and 2024. One of nine projects to move Hawaii towards 100% renewable energy by 2045.
Operator	Clearway Energy Group				
Nameplate Capacity	39 MW				
Max/Min Demand					
VRE Penetration	33%				
Load Type/s	Mixed				
30: Kaua'i Island Isolated System					
Location	Kaua'i Island, Hawaii				

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[56] 2016-07 Hankyoreh - One small island's dream of energy self-sufficiency
[54] 2020-09 Nautilus Institute - Microgrids for Electricity Generation in the Republic of Korea (p.11)
[55] 2017-03 KOREA - Gapado Goes Green
[57] 2015-11 RMI – Renewable Microgrid Profiles from Islands and Remote Communities (p.14)
[58] 2020-09 NRECA – Microgrids with Energy Storage: Benefits, Challenges of Two Microgrid Case Studies (p.7-11)
[59] 2020-09 SchatzCenter – Redwood Coast Airport Renewable Energy Microgrid
[60] 2022-08 Hawaiian Electric - Mililani I Solar now sending clean energy to O'ahu grid

Details of Islanded Grid		Operating Context *(Customers served, load types, reason for being islanded, etc)*	System Specifications *(Generation types, capacity ratings, integrated storage, etc)*	Key Learnings *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	Assessment of relevance to APEC's Clean Energy Goals
Operator	Kaua'i Island Utility Cooperative	*Background:* In 2008 KIUC set a goal to power 50% of the island with renewable energy. At the time, hydroelectric plants accounted for 8% of the island's electricity production. The rest was from imported oil. Hawaii's electricity prices are higher than nearly anywhere else in the US, paired with high sunshine penetration, this has given incentive to make the islands long time leaders in renewable energy adoption. The adoption of higher initial priced renewable energy facilities has brought about more stable electricity prices for consumers, with residential rates of $0.37/kWh.[61]	*Resource Types:* • Solar (118.9 MW) • Hydro (17.3 MW) • Biomass (6.7 MW) • BESS (47 MW/ 222 MWh) • Renewable Generation Capacity (142.2 MW) • Oil Fired Generation Capacity (117 MW)[62]	Because of the high percentage of renewables on KIUC's system, which are purchased largely through long-term power purchase agreements, KIUC achieved substantial rate stability in 2021 in the wake of skyrocketing oil prices. While KIUC's rates rose roughly 5% compared to 2020 rates, the rest of the state experienced rate increases approaching 30%.	In 2021 the island reached more than double the Hawai'i State Renewable Portfolio Standard requirement of 30% by 2021. Nine years ahead of KIUC's Strategic Goal of 70% by 2030.
Nameplate Capacity	259.2 MW				
Max/Min Demand	75.17 MW (max)				
VRE Penetration	69.5%				
Load Type/s	Mixed				
31: Coconut Island DC Microgrid					
Location	Coconut Island, Hawaii	*Background:* Coconut island is home to two Hawaii Institute of Marine Biology (HIMB) buildings. It is an ideal site for a renewable energy technology-based microgrid test bed that represents a remote location vulnerable to energy disruption yet serving mission critical power needs with a tropical coastal environment. [63]	A DC-powered e-car, e-boat and portable emergency power source using a novel swappable BESS have been deployed. They are powered primarily from a 6.2kW rooftop solar PV system couple with an 8kWh BESS.	Environmental compliance was required by the SSFM to permit HNEI in carrying out improvements to the microgrid testing system.	The project objective is to demonstrate and assess the reliability, resilience, and energy efficiency benefits of a DC microgrid serving two HIMB buildings. The system is intended to support critical building loads during grid supply interruptions and provide clean transportation options powered primarily by rooftop solar energy.
Operator	Hawaii Natural Energy Institute				
Nameplate Capacity	6 kW				
Max/Min Demand					
VRE Penetration	100% during grid supply interruptions				
Load Type/s	Residential/ Commercial				
32: Valencia Gardens Energy Storage (VGES) Project					
Location	Valencia Gardens, San Francisco	Sited at the Valencia Gardens Apartments (VGA), a low-income and senior housing facility with 260 units.[64]	*Resource Types:* • Solar (580 kW) • BESS (250kW/556kWh)	• Electricity savings due to reducing the need for new distribution and transmission grid infrastructure • Enhanced grid capabilities, reliability and resilience through renewable-driven backup power to critical loads during outages	The project is driving the small community towards a more resilient and renewable-focused grid.
Operator	Clean Coaltion				
Nameplate Capacity	830 kW				
Max/Min Demand	570 kW				
VRE Penetration	25%				
Load Type/s	Residential				
33: Marine Corps Air Station Miramar Microgrid					
Location	San Diego, USA	*Background:* The microgrid at the 23,000-acre air base, home to the 3rd Marine Aircraft Wing. The microgrid is part of the US military's effort to make sure its facilities have secure power supplies, partly through the use of microgrids.[65]	*Resource Types:* • Solar PV (1.3MW) • Diesel (4MW) • Natural Gas (3MW) • Landfill Gas (3.2MW)	The DERs are managed with a centralised digital control system, allowing the microgrid to communicate and interact with the main grid. The result is greater energy security for the military base should power supply from the main grid be disrupted. [66]	It is possible to manage the microgrid so efficiently that local energy sources produce as much energy as is consumed throughout the course of a year (net zero). This results in greater energy security for the military base should power supply from the main grid be disrupted.
Operator	Schneider Electric				
Nameplate Capacity	11.5 MW				
Max/Min Demand					
VRE Penetration	up to 21 days of 100%				
Load Type/s	Industrial				
34: Chaninik Wind Group Project					
Location	Chaninik Wind Group, Alaska	*Background:* In 2005 Chaninik Wind Group (CWG), a consortium of stand-alone utilities in south western Alaska, was formed to combat the high electricity and home heating prices	Each of the four CWG village's wind system consist of the following: • Wind Turbines (95kW) • Diesel Generators (250kW)	One method employed by CWG to increase the projects' scale was embracing beneficial electrification, designing wind systems with excess capacity diverted to electric thermal stoves installed in village homes. Even	CWG demonstrated one model for increasing renewable energy projects' economies of scale, which often constrain developments in rural Alaska.
Operator	Chaninik Wind Group				

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[61] 2022-03 Honolulu Civil Beat - Kauai Quit Using Oil To Produce Most Of Its Electricity Years Ago. That's Paying Off Now
[62] 2021-00 Kaua'i Island Utility Cooperative - KIUC 2021 Annual Report
[63] 2021-11 Hawaii Natural Energy Institute - Coconut Island DC Microgrid
[64] 2020-05 Clean Coalition – Valencia Gardens Energy Storage Project
[65] 2021-03 Microgrid Knowledge - Schneider Electric, Black & Veatch Finish Miramar Microgrid
[66] 2021-09 International Microgrid Association - Microgrids The Way Forward (p. 37)

Details of Islanded Grid		**Operating Context** *(Customers served, load types, reason for being islanded, etc)*	**System Specifications** *(Generation types, capacity ratings, integrated storage, etc)*	**Key Learnings** *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	**Assessment of relevance to APEC's Clean Energy Goals**
		in many rural communities not connected to Alaska's road system, especially through the high dependency on fossil fuels.[67] *Project Costs:* Original energy costs of \$0.65/kWh are now estimated at \$0.09 to \$0.12/kWh. Project costs of around \$2mil	• Residential Electric Thermal Storage Units • Smart metering system • Improvements to the diesel power plants[68]	residents without thermal stoves see positive economic benefits from these wind/diesel hybrid systems.	
Nameplate Capacity	1.38 MW				
Max/Min Demand	200 kW (average)				
VRE Penetration	30%				
Load Type/s	Mixed				
35: Cordova Microgrid					
Location	Cordova, Alaska	*Background:* The town of Cordova is prone to large seasonal demand changes. During the spring several hundred workers arrive and the electrical load ramps up. During this period there is more reliance on the diesel generators which causes wastage of around 1MW of power. The installation of a BESS assists in offsetting this wastage. [69] *Project Costs:* Diesel generation costs of \$0.60/kWh with hydropower costs of \$0.06/kWh. Upfront project costs of around \$2mil with annual operational costs of \$171,644.	CEC is able to meet 78% of its annual demand from the hydro plant, at times it is able to run solely on the hydro generator. *Resource Types:* • Hydro Generator (6MW) • Diesel Generators (2MW) • BESS (1MW/1MWh)	CEC put all the town's power lines underground to eliminate risk of outages during the winter months and natural disaster events.	Cordova is transitioning to 100% renewables with its use of hydro and a BESS. Initial costs and maintenance are estimated to be higher than without the BESS, however, this is not preventing the town from continuing with the project.
Operator	Cordova Electric Cooperative				
Nameplate Capacity	8 MW				
Max/Min Demand	6.5 MW				
VRE Penetration	78%				
Load Type/s	Mixed				
36: The Oncor System Operating Services Facility					
Location	Oncor, Lancaster, Texas	*Background:* The Oncor System Operating Services Facility experiencing power outages due to either local or main grid issues. It had nine existing energy sources including two solar PV arrays, a propane microturbine, five generators and batteries. To build in more resilience and stability, a microgrid was created. The idea was to use the existing infrastructure, operate all nine local power generation sources, and to optimise use of the DERs with a DERMS.[70]	The innovative system consists of four interconnected microgrids and utilizes nine different distributed generation sources, including two solar photovoltaic arrays, a microturbine, two energy storage units and four generators. *Resource Types:* • Diesel Generators (605 kW) • Microturbine (65 kW) • PV (106 kW) • BESS (200 kW/ 400 kWh) • Energy Storage (25kW/25kWh)[71]	During a loss-of-power event, a combination of S&C's advanced distribution automation equipment and Schneider Electric's Microgrid Controller (MGC) use high-speed communications and distributed grid intelligence to automatically detect a problem on the grid.[72]	Use of pre-existing systems with new and improved coordination to provide energy security and stability to the community. [73]
Operator	Schneider Electric				
Nameplate Capacity	1 MW				
Max/Min Demand					
VRE Penetration	100% during grid supply interruptions				
Load Type/s	Commercial				
37: Shungnak Community Solar Project					
Location	Shungnak, Alaska	*Background:* Shungnak village of about 300 individuals, is only accessible by air or by barge in the summer. Mostly everything such as fuel and food needed to sustain the village must be shipped in. This cost of transportation adds to the cost of living, especially when it comes to the electric bill. In 2019, a villager could expect to pay almost \$8.50 for a single gallon of gas. Temperatures in the area can drop to 40 below zero within the Northwest Arctic Borough area.[74]	*Resource Types:* • Diesel Generation (1.3 MW) • Solar Array (224 kW) • BESS (235 kW/ 383 kWh)	Savings of around 25,000 gallons of fuel and \$200,000 per year. Estimated reduction in fuel costs.	The project has provided energy security and cost reduction for a remote community. It has paved the way for other rural Alaskan communities to look upon when developing more within the area experiencing similar conditions.
Operator	Alaska Village Electric Cooperative				
Nameplate Capacity	1.5 MW				
Max/Min Demand	363 kW (max)[75]				
VRE Penetration	10%				
Load Type/s	Residential				

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[67] 2021-07 Nature Conservancy - Alaska's Renewable Energy Economy
[68] 2016-00 University of Alaska - Microgrid Market Analysis - Alaskan Expertise, Global Demand
[69] 2019-03 Cordova Electric Cooperative - Cordova's Microgrid Integrates Battery Storage With Hydropower
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Details of Islanded Grid		**Operating Context** *(Customers served, load types, reason for being islanded, etc)*	**System Specifications** *(Generation types, capacity ratings, integrated storage, etc)*	**Key Learnings** *(Cost recovery, pricing, market mechanisms, consumer protections, etc)*	**Assessment of relevance to APEC's Clean Energy Goals**
38: Hawaii Island					
Location	Hawaii, United States	*Background:* Hawaii island, like other physical islands, has a heavy reliance on fossil fuels for power, with extreme weather conditions and volatile loads throughout the year due to the large tourism industry seen on the island. This has led HELC to take up the aggressive goals set by the Hawaiian Government and Utility Commission. This includes several rooftop-solar programs to incentivise the uptake of rooftop solar on the island.	*Resource Types:* • Wind (34.4MW) • Centralised solar (60MW) • Distributed PV (116MW) • Hydro (19.3MW) • Biomass (21.5MW) • Geothermal (38MW) • Fossil (177.5MW) • BESS (152MWh)	The coordination between the state, utilities commission and the utility of Hawaii island has led to the uptake of the many renewable generation sources available on the island. This includes the recommissioning of the 38MW geothermal plant after its decommission in 2018 due to volcanic activity.	Aggressive policy setting and enactment has been a key factor for Hawaii's high renewable penetration, with a target of 100% by 2045.
Operator	Hawaii Electric Light Company				
Nameplate Capacity	525.6MW				
Max/Min Demand					
VRE Penetration	60%				
Load Type/s	Residential/Commercial				
Chile					
39: Isla Huapi Electrification Project					
Location	Island Huapi, Chile	*Background:* Approximately 300 people live on the island with 145 households. Since the 90's, electrification of the island was of a high concern. Previous approaches/ proposals provided either inconsistent power, or power in a non-renewable form (diesel generators). The community wanted a clean energy solution, which began from a single family researching and installing a PV system, which was later established by the Ministry of Energy to electrify all households with similar solutions.[76]	*Resource Types:* • 151 Individual household PV systems	The project aimed to bring electrification to the community through PV systems. This brought about equitable access and security of energy to the island.	The aim of the project was to electrify the community using renewable sources. The community required high involvement throughout the entire project. Community engagement was conducted to inform the community of the project's details, as well as to assure and communicate the reliability, safety and environmentally friendly nature of the PV systems.
Operator	Huapi Local Committee				
Nameplate Capacity	151 individual PV systems				
Max/Min Demand					
VRE Penetration					
Load Type/s	Residential/Commercial				
Samoa					
40: Samoa					
Location	Samoa	*Background:* Economic growth driven by exports of fresh fish, coconut oil, taro and nonu juice with many of its residents working in tourism, agriculture, and fisheries, EPC operates electricity for the four main islands of Samoa, each with their own grid network. Majority of power is generated from diesel and hydro, with IPP owned solar farms adding to the total generation.	*Resource Types:* • Wind (0.55MW) • Centralised Solar (15MW) • Hydro (15.46MW) • Diesel (39.5MW) • BESS (8MW/13.6MWh)	With a similar case to other physical islands where high fossil fuel prices govern the prices of energy, energy security and affordability have been a key priority for the island. Uptake of secure renewable sources that can withstand the harsh weather conditions on the island have been a high priority for EPC.	Samoa has implemented a range of small renewable projects that have helped guide it slowly towards a more renewable and less cost future. This includes giving power to some of the smaller islands through solar and battery storage projects.
Operator	Electric Power Corporation				
Nameplate Capacity	78.5MW				
Max/Min Demand	33MW				
VRE Penetration	38%				
Load Type/s	Residential/Commercial				

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[76] 2021-10 Danish Institute for Human Rights - Equitable Access to Energy and Indigenous Participation

Appendix E – Glossary of Key Terms

Key Terms	Definition
Behind the Meter (BTM)	Any technology located on the customer's side of the customer-network meter.
Black Start Capability	A capability that allows a generating unit, following its disconnection from the Power System, to be able to deliver electricity to either: a) its connection point; or b) a suitable point in the network from which supply can be made available to other generating units without taking supply from any part of the power system following disconnection.
Capacity Market	A market in which Energy Resources receive a payment for having capacity available, even if it is not used. An additional payment (spot price) is also made for actual amounts of electricity sold.
Demand-side Flexibility	The dynamic Orchestration of large volumes of Distributed Energy Resources (DER/CER) and Flexible Resources in a manner capable of supporting supply/Demand balance over timescales from days to milliseconds. Flexibility in a high-VRE / high-DER Power System is closely related to the topic of Operational Coordination.
Dispatch	Instructions issued by the Market/System Operator (MSO), Distribution System Operator (DSO) and/or Aggregator that either provide directives or targets for participating Energy Resources and Active DER/CER to alter their operating behaviour. This generally means ordering a (dispatchable) generation resource to produce a set amount of output power for a set period of time. The setpoint (power level) may be adjusted periodically either via a predetermined schedule or as the result of shorter-term factors such as to maintain system frequency and/or power balance. This can include setting ramp rates for ramp-capable resources and storing (withdrawing grid power) for bulk energy storage devices. Dispatch may adjust setpoints up or down in general. In addition to bulk generation, CER and ESS devices may also be dispatched. For resources that are not dispatchable (such as wind generation and solar PV) devices may under some circumstances be curtailed. While curtailment is usually considered as a separate topic, it fits into a larger view about dispatch for the grid. Which parties have the authority to Dispatch particular resources will largely depend on the System Architecture decisions made in each jurisdiction.
Dispatch Schedule	A dispatch schedule is a list of generator power generation settings as a function of time, in order of execution. A generation dispatch schedule may be determined day ahead or intra-day on an hourly basis, for example.
Distributed Energy	A diverse range of small to medium scale Energy Resources that are either connected directly to the Distribution System (known as DER) or located behind

Resources (DER/CER)	the meter at residential, commercial and industrial customer premises. In some jurisdictions, the latter may be referred to as Customer Energy Resources or CER. Active DER/CER are a multi-application resource capable of providing valuable Electric Products to the Power System. It includes the following types of technologies: • Distributed Generation (DG): including Distributed Photovoltaics (DPV) and Embedded Generators; • Energy Storage Systems (ESS): including small and medium-scale batteries; • Electric Vehicles (EV); • Smart Inverters; and, • Flexible Resources: including various loads that are responsive, such as air conditioning, electric hot water storage, water pumping, industrial loads and EV charging.
Distributed Generation	A generic term for all forms of electricity generation that are connected to the distribution network. It includes both fossil-fuel and renewable forms of generation.
Distributed Photovoltaic (DPV)	Includes both residential and commercial solar panel installations, typically located on consumers' rooftops.
Energy Storage (ES)	A means of storing electrical energy, either directly or indirectly and either at centralised locations or widely distributed across a Power System. The numerous types of Energy Storage can provide system services across different time horizons. These include: a) Shallow storage / Provision of Essential System Services (< 4-hours); b) Medium storage / Intraday shifting (4 – 12-hours); and, c) Deep storage / Renewable energy drought (> 12-hours). Direct forms of Energy Storage such as chemical batteries and power capacitors are those where energy enters the storage as electrical energy and is retrieved as electrical energy. Indirect forms of Energy Storage convert electric energy into thermal, rotational or potential energy and may include pumped hydro (pumping of water to elevated storage), the pre-heating or pre-chilling of bulk water or glycol and/or the pre-cooling of a building envelope.
Fast Frequency Response (FFR)	A very rapid response to re-balance megawatts on the Power System. May be automatic in response to frequency, or a centrally controlled response (that is, a control scheme to shed load).
Flexibility	The ability of the system to respond to expected and unexpected changes in the supply-demand position (such as changes in Variable Renewable Energy (VRE) generation output, generation failures, and variations in Demand) over all necessary timeframes, is another critical dimension of dispatchability. The flexibility of a resource is the extent to which its output can be adjusted or committed in or out of service. This includes:

	a) The speed of response to start up and shut down. b) The rate of ramping. c) Whether it can operate in the full range of capability, or has restrictions (such as a minimum generation requirement, or a limitation on the amount of bulk energy that can be produced).
Frequency	For alternating current electricity, the number of cycles occurring in each second. The term Hertz (Hz) corresponds to cycles per second.
Front of the Meter (FTM)	Any infrastructure located on the distribution network side of the customer meter (i.e. not behind a customer meter, or BTM). FTM infrastructure is still metered, but it is not part of a customer site.
Grid Formation	Grid formation refers to the ability of the Power System to set and maintain Frequency. If frequency can be thought of as the heartbeat of the power system, grid formation is like its pacemaker.
Hosting Capacity	The amount of DER/CER that can be accommodated within a distribution network, or a specific segment of the distribution network, without adversely affecting security, reliability and/or power quality.
Inertia	The ability of the Power System to resist changes in Frequency before cascading instability causes widespread blackouts. Inertia has traditionally been provided by Synchronous Generators, electric motors and other devices that are synchronised to the Frequency of the system.
Interconnector	A transmission line or group of transmission lines that connects transmission networks in adjacent regions. Can facilitate AC or DC power flow.
Intermittent	A description of a generating unit whose output is not readily predictable, including, without limitation, solar generators, wave turbine generators, wind turbine generators and hydro-generators without any material storage capability.
Inverter	An electrical device which uses semiconductors to transfer power between a DC source and an AC source or load.
Inverter-based Resources (IBR)	IBR include wind farms, solar PV generators, and batteries that export power to the grid. They do not have moving parts rotating in synchronism with the grid frequency, but instead are interfaced to the Power System via power electronic converters which electronically replicate grid frequency.
Load	A connection point or defined set of connection points at which electrical power is delivered to a person or to another network or the amount of electrical power delivered at a defined instant at a connection point, or aggregated over a defined set of connection points. The term also refers to devices at the end user's location drawing electrical energy from the network and converting it to some other useful form.
Microgrid	A group of interconnected loads, generation sources and diverse Distributed Energy Resources (DER/CER), within clearly defined electrical boundaries that is

	supported by its own internal management systems and presents to the wider power system as a single controllable entity. Microgrids function as a 'microcosm' of larger-scale Power Systems. They may connect and disconnect from the Power System, operating in both grid-connected or islanded mode. Alternatively, they may serve a geographically remote customer base, be entirely autonomous and have no interconnection with a larger Power System.
Orchestration	The coordination of dispatchable Energy Resources, including but not limited to Distributed Energy Resources (DER/CER), in a manner that moderates negative system impacts and may include facilitating the provision of Electric Products to the bulk power and/or local distribution system under a commercial arrangement.
Power System	A highly complex cyber-physical, transactional and societal System that, in the case of GW-scale Power Systems, exists to provide safe, reliable, and efficient electricity services to millions of customers.
Primary Frequency Response	Primary frequency response (PFR) is the first stage of frequency control in a Power System. It is the response of generating systems and loads to arrest and correct locally detected changes in Frequency by providing a proportionate change in their active power output or consumption. PFR is automatic; it is not driven by a centralised system of control and begins immediately after a frequency change beyond a specified level is detected.
Protection System	A system, which includes equipment, used to protect a Registered Participant's facilities from damage due to an electrical or mechanical fault or due to certain conditions of the Power System.
Ramp Rate	The rate of change of active power (expressed as MW/minute) required for Dispatch.
Reactive Power	The rate at which reactive energy is transferred. Reactive power is a necessary component of alternating current electricity which is separate from active power and is predominantly consumed in the creation of magnetic fields in motors and transformers and produced by plant such as: a) alternating current generators; b) capacitors, including the capacitive effect of parallel transmission wires; and synchronous condensers.
Reliability	The ability of the Power System to supply adequate power to satisfy consumer demand, allowing for credible generation and transmission network contingencies. The probability that a system will perform its intended functions without failure, within design parameters, under specific operating conditions, and for a specific period of time. In the utility industry, reliability is often expressed as system reliability indices, for example Customer Average Interruption Duration Index (CAIDI)

Resilience	Grid resilience is the ability to avoid or withstand grid stress events without suffering operational compromise or to adapt to and compensate for the strain so as to minimize functional or performance compromise via graceful degradation.
Resources Adequacy	Resource adequacy and capability relates to having a sufficient overall portfolio of energy resources to continuously achieve the real-time balancing of supply and Demand. Achieving this balance is an intricate optimisation, operationally in real time and over longer-term planning timescales, of available energy resources – a diverse mix of centralised generation and DER, demand response, and network capacity. It is the capability of the overall, aggregated portfolio of available energy resources which is important in the realtime balancing of supply and demand.
Spinning Reserve	An additional margin of generation capacity that is made available by increasing the power output of generators which are already generating electricity into the Power System.
Stability	The ability of a Power System to maintain a state of equilibrium during normal and abnormal conditions or disturbances.
Supervisory Control and Data Acquisition (SCADA)	A system of remote control and telemetry used to monitor and control the transmission system.
System Security	The physical stability of the Power System resulting from key technical parameters, such as Voltage and Frequency, being maintained within defined limits. The maintenance of Frequency, for example, requires electricity supply to be instantaneously balanced against customer Demand.
System Strength	The ability of the Power System to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance. System strength can be related to the available fault current at a specified location in the power system, with higher fault current indicating higher system strength with greater ability to maintain the voltage waveform. System strength is an umbrella term that refers to a suite of interrelated factors which together contribute to power system stability. It reflects the sensitivity of power system variables to disturbance, and indicates inherent local system robustness, with respect to properties other than inertia. System strength affects the stability and dynamics of generating systems' control systems, and the ability of the power system to both remain stable under normal conditions and return to steady-state conditions following a disturbance.
Value Stacking	The process of providing Electric Products to several vertical Tiers/Layers of the Power System (e.g. wholesale market, transmission, distribution system) for the purpose of maximising participant remuneration.
Variable Renewable Energy (VRE)	A generic term for highly intermittent forms of generation powered by renewable resources that are inherently variable, such as wind and solar energy.

	While some forms of Distributed Energy Resources (DER/CER) are considered VRE, the term is most commonly used to describe large, utility-scale applications of solar and wind generation. In the absence of Firming Resources, large volumes of VRE can impact the stability of the Power System and exacerbate periods of misalignment between Demand and Supply.
Voltage Management	Voltage control in the Power System acts to maintain voltages at different points in the network within acceptable ranges during normal operation, and to enable recovery to acceptable levels following a disturbance. Voltage control is managed through balancing the production or absorption of Reactive Power. Reactive power does not 'travel' far, meaning it is generally more effective to address reactive power imbalances locally, close to where it is required. Adequate reactive power reserves are maintained to ensure the security of the transmission system in the event of a credible contingency.
Volt-VAR Response	A response mode of an Inverter that smooths the network voltages by absorbing Reactive Power when voltage levels rise. Alternatively, when network voltages fall below 220V, the Volt-VAR mode causes the Inverter to generate Reactive Power to support the network voltage.
Volt-Watt Response	A response mode of an Inverter that reduces its power output when needed in order to avoid exceeding the voltage limits. If this mode is not enabled the Inverter may experience frequent nuisance tripping when the network is lightly loaded.

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