International Solar Alliance Expert Training Course: Session 42

Solar PV in Island Contexts: Key Considerations

In partnership with the Clean Energy Solutions Center (CESC)

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ISA INTERNATIONAL SOLAR ALLIANCE

CLEAN ENERGY SOLUTIONS CENTER

ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY

Overview of Training Course Modules

This Training is part of Module 7, and focuses on the issue of Off-Grid Solar

Eight Modules

Expert Content and Analysis

Up-to-date Market Insights

1. Policies for Distributed PV
2. Policies for Large-Scale PV
3. The Future of Solar Policy
4. Technical Integration of Solar
5. Market Integration
6. Socio-Economic Aspects
7. Off-grid Solar
8. Solar Heating & Cooling

Overview of the Presentation

1. Introduction: Learning Objective
2. Why Solar PV Technology Suits Islands
3. Island Power Generation Technology
4. Costs and Financing of Solar PV on Islands
5. Case Studies
6. Concluding Remarks
7. Further Reading
8. Knowledge Check: Multiple-Choice Questions

1. Introduction: Learning Objective

Learning Objectives (draft)

- Understand solar PV technologies and their application in island contexts
- Understand innovations emerging to improve grid integration, including demand response and storage
- Understand the cost-competitiveness landscape and market factors facing the solar industry in island regions
- Learn from case studies demonstrating the current state of play

2. Why Solar PV Technology Suits Islands

Solar PV Suitability for Islands

1. Insolation (sunlight) is abundantly available in most island regions

- Hydro and biomass resources typically have limited availability in island regions
- Virtually all SIDS have abundant solar power resources
- **Exception**: northern regions near the Arctic and in deep southern climates near the Antarctic,

- In such contexts, the need for clean, affordable and reliable power generation 365-days-per-year remains a major challenge.

Equatorial regions with large numbers of islands:

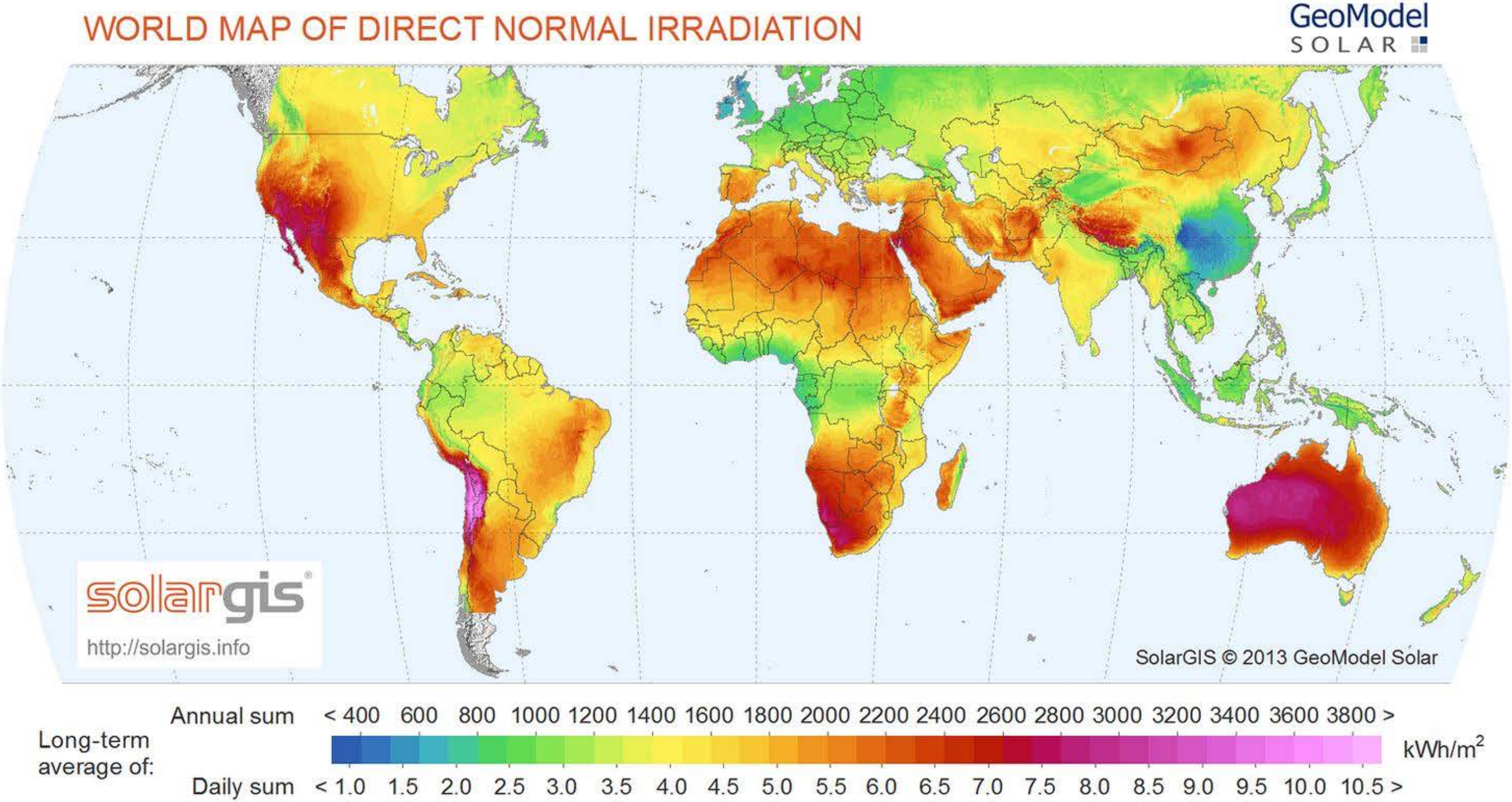
Caribbean

Source: https://www.worldatlas.com/r/w728-h425-c728x425/upload/22/7a/2f/untitled-design-337.jpg

Polynesia

Source: https://www.tripsavvy.com/thmb/4-svDEwm8WzoC_dzbhxFtZh-zIl=/870x0/filters:no_upscale():max_bytes(150000):strip_icc():format(webp)/Caribbean_general_map-56a38ec03df78cf7727df5b8.png

Solar PV Suitability for Islands

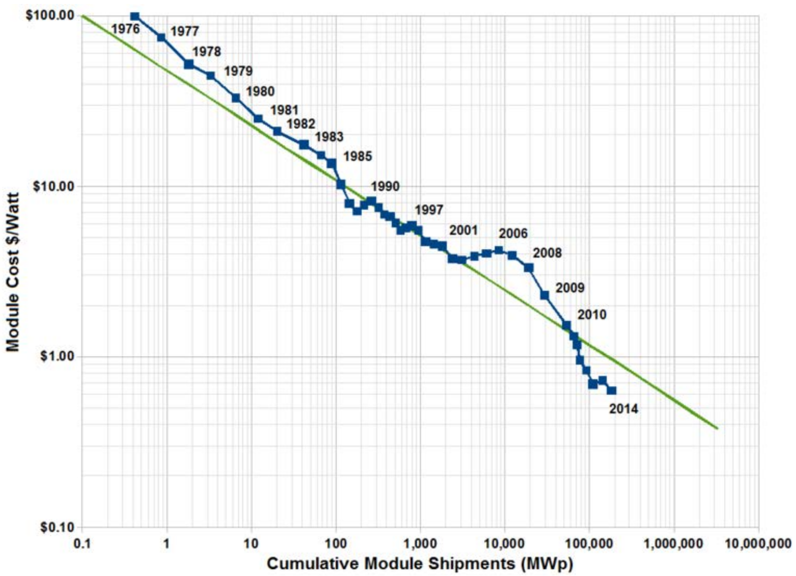


Solar PV Suitability for Islands

2. Solar PV systems continue to decline in cost and improve in both performance and efficiency

Solar PV has declined in cost by over 80% since 2010. Module prices have declined to between US$0.20–0.40 per Watt and continue to drop.

Fall in solar PV module price (Swanson's Law)



Source: http://www.itrpv.net/Reports/Downloads/2017/

Solar PV Suitability for Islands

3. Solar power projects require comparatively less skilled labour

This makes it easier for island and remote regions to keep their systems running.

Maintenance includes cleaning solar PV panels

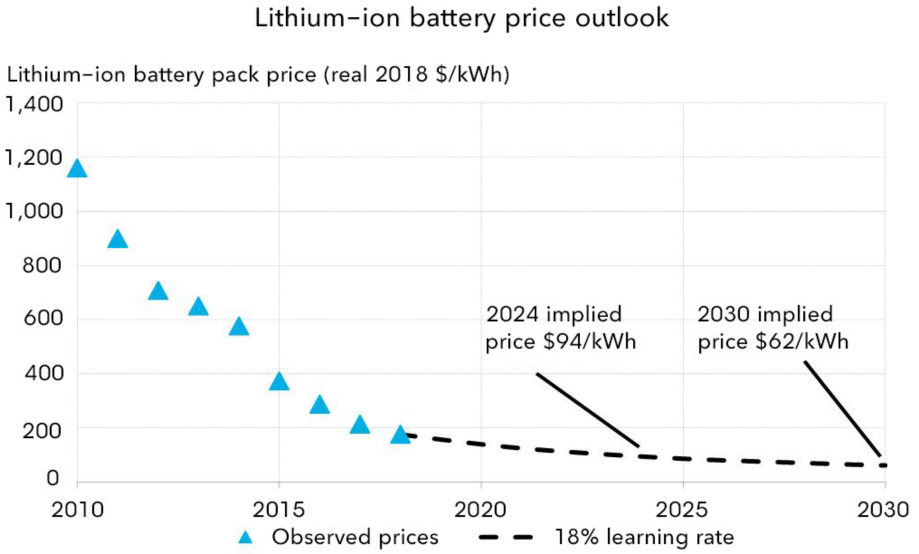
Source: https://l2classica.com/solar-panels-maintenance.html

Solar PV + Battery Storage

4. Solar PV in combination with battery storage is very cost-competitive, and battery costs are declining

The most important cost-competitiveness benchmark in the coming decades is likely to become **solar PV combined with storage**.

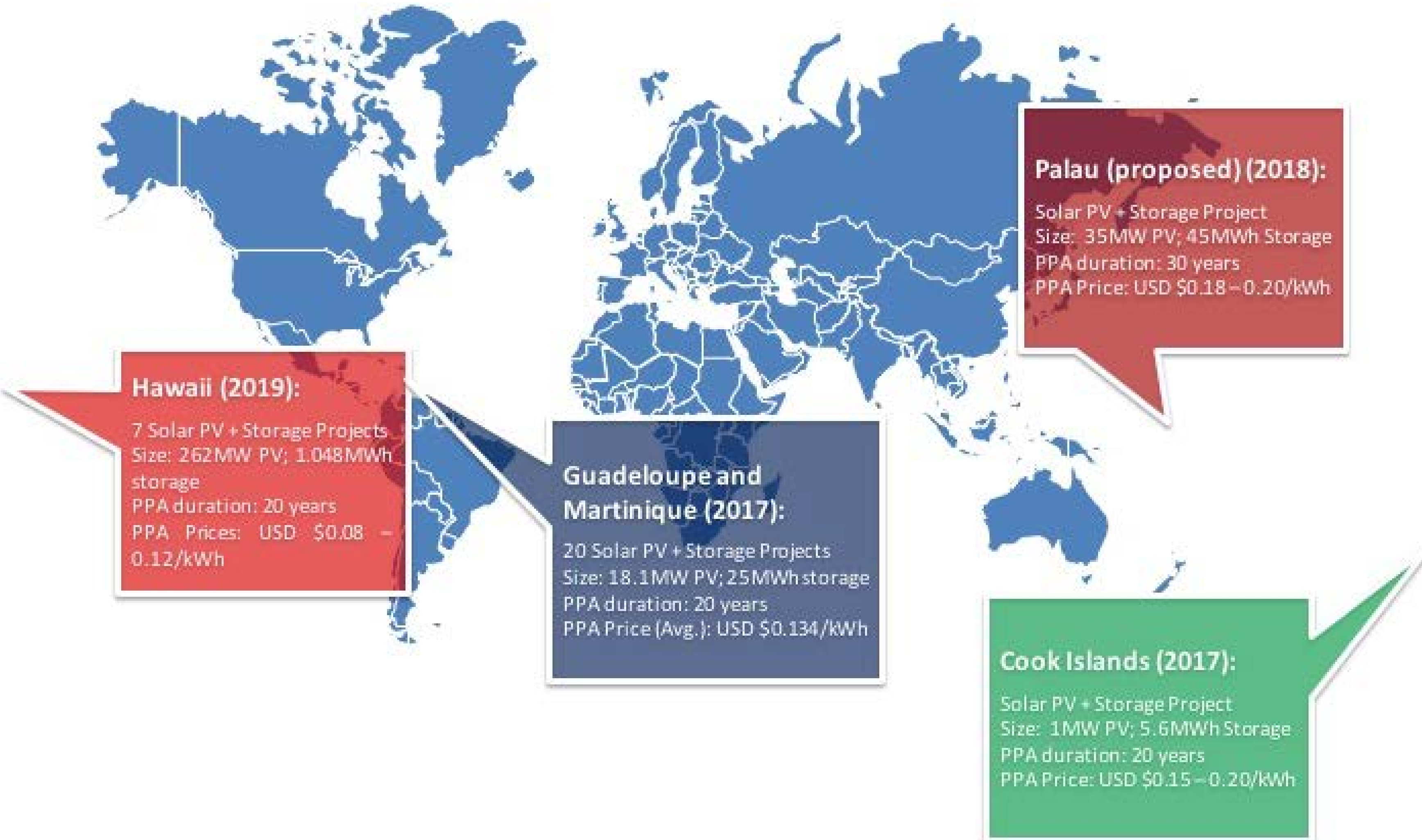
Solar PV + battery storage installations are emerging as the cheapest way of providing reliable, around-the-clock power supply to island regions.



Source: https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

Sources:
https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/;
https://about.bnef.com/blog/tumbling-costs-wind-solar-batteries-squeezing-fossil-fuels/

Solar PV + Battery Storage



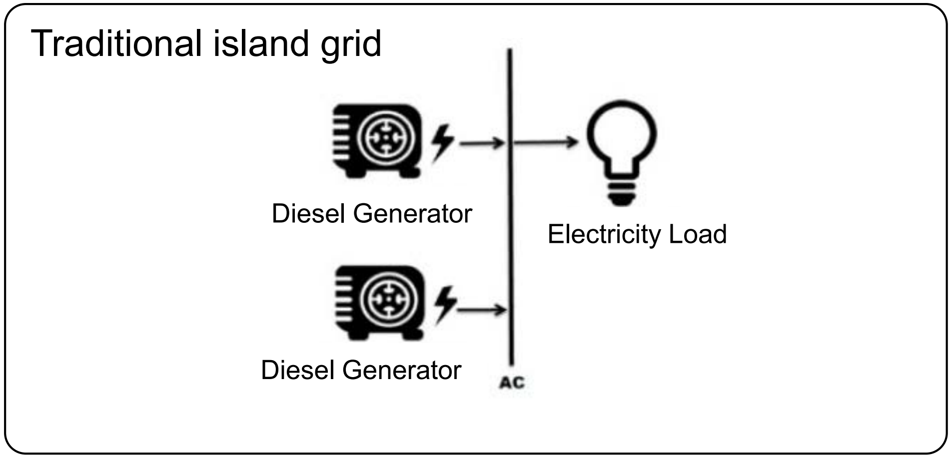
Source: E3 Analytics 2019

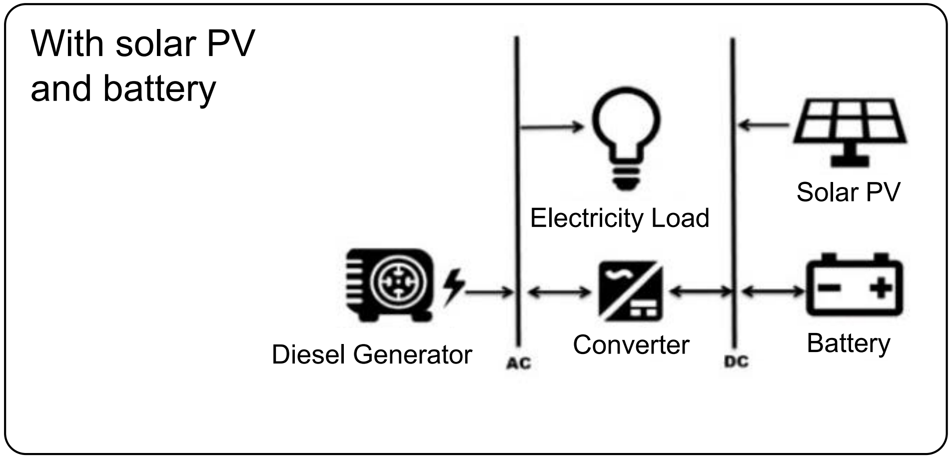
3. Island Power Generation Technology

Island Grid Technology

Diesel Generators vs Solar PV

- Many island grids around the world continue to be powered by diesel generators (see right)
- A different network setup using a hybrid system is shown on the right below.
- Diesel generators are able to provide power on short notice at all times of day, but they have a **high marginal fuel cost** compared to the almost-zero marginal cost of solar power.
- Many islands also have massively **over-dimensioned** diesel generators, with far more capacity than they need: this leads to lower-efficiency operation and higher wear-and-tear



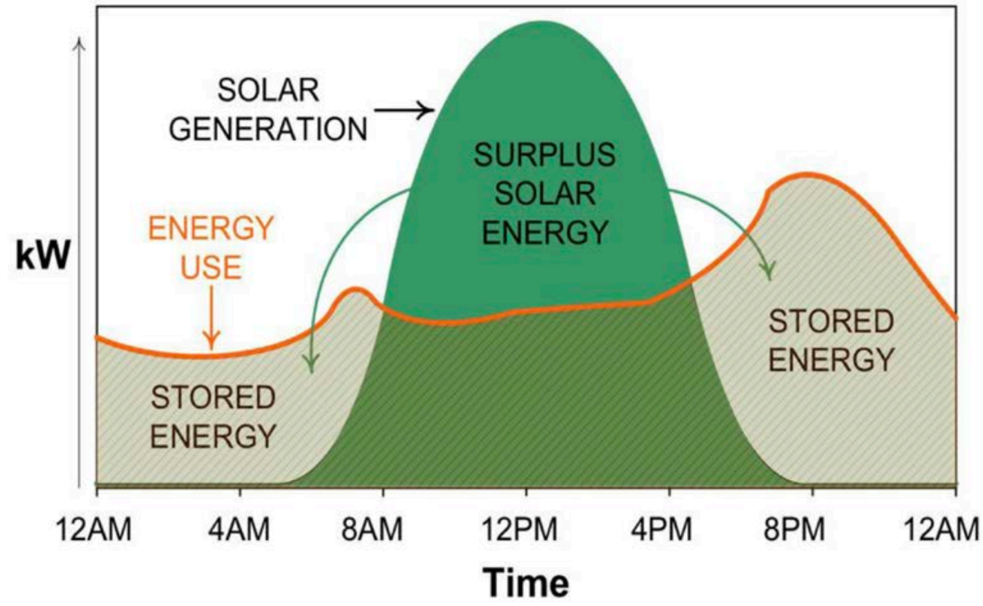


Source: http://www.aimspress.com/article/10.3934/GF.2019.2.139/fulltext.html

Solar PV + Battery Storage

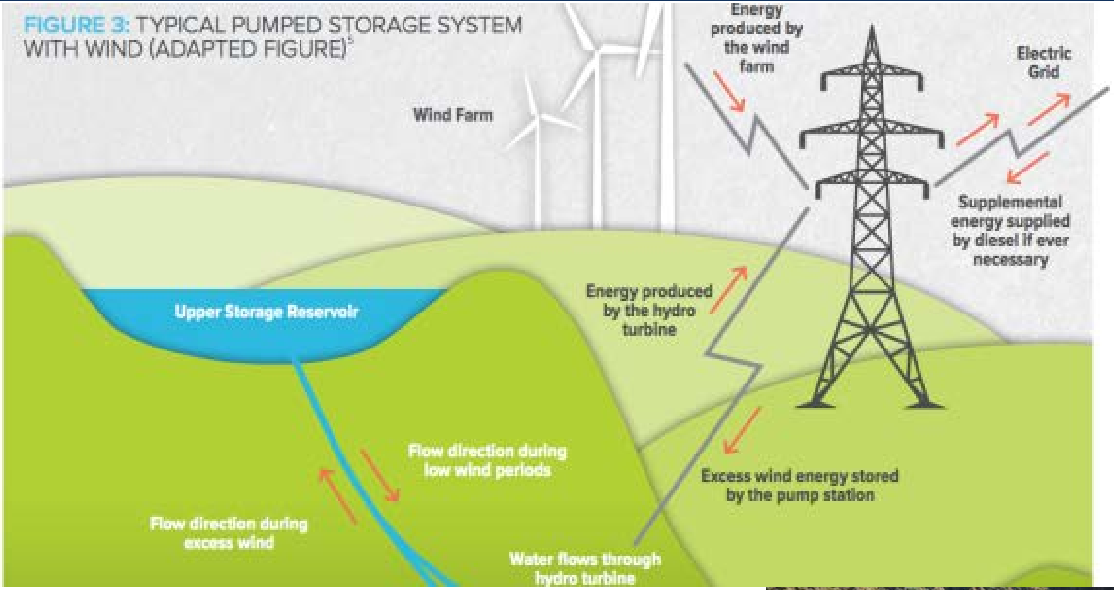
Balancing demand with generation

- Solar PV generates power according to the position of the sun in the sky and local weather factors.
- This means maximum power generation is usually around midday.
- This doesn't usually align with maximum demand, which usually experiences two peaks, one in the morning, one in the evening.
- To **balance generation with demand in island systems** (no electricity imports), energy storage technology is often required.
- Battery-based energy storage increasingly prefered, although pumped hydro storage is also viable where suitable conditions exist (e.g. El Hierro).



Source: https://www.newenglandsolarpower.com.au/plans.php

El Hierro Pumped Storage System

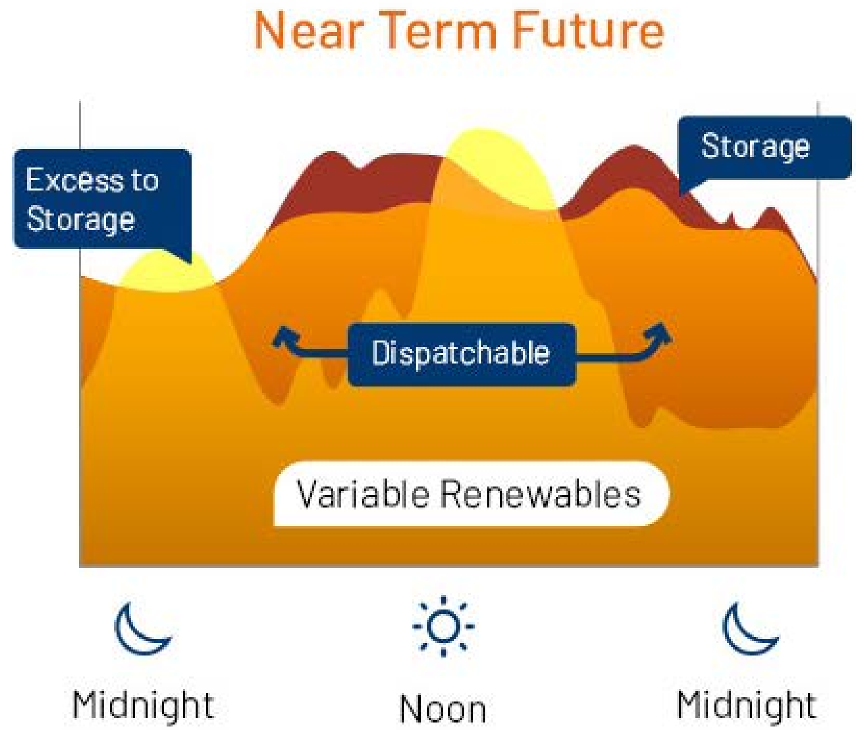


http://microgridprojects.com/microgrid/el-hierro-microgrid/

Such pumped storage systems can significantly ease the grid integration of variable solar power

Source: Enel

Storage becomes increasingly vital

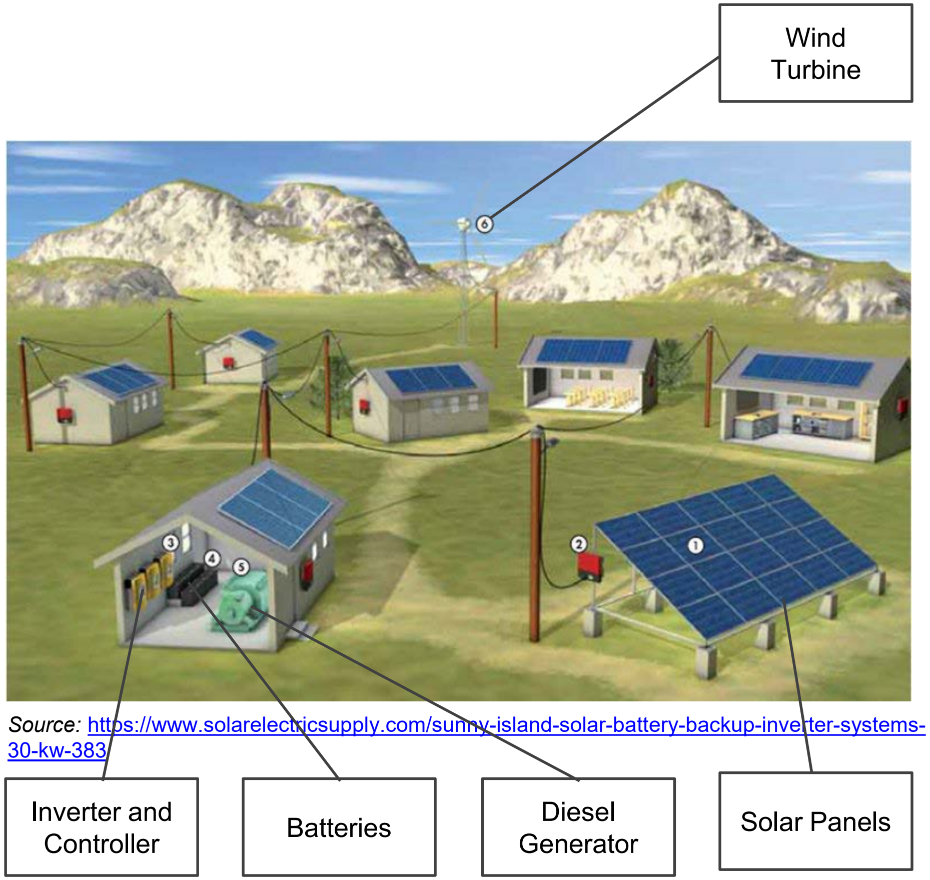


Source: https://www.ises.org/what-we-do/dispelling-myths

Solar PV + Battery Storage – Integration

Grid integration

- Combining traditional power generating assets, like diesel generators, with intermittent sources of power like solar PV and wind turbines can be complex.
- Integration of these sources of generation is achieved using a controller, an electronic device that measures demand and controls generation.
- An advanced controller is able to control input from a wide range of generating sources, and provide feedback to instruct them to deliver either more or less power.
- A major issue in SIDS remains how to mitigate (i.e. reduce) **curtailment**

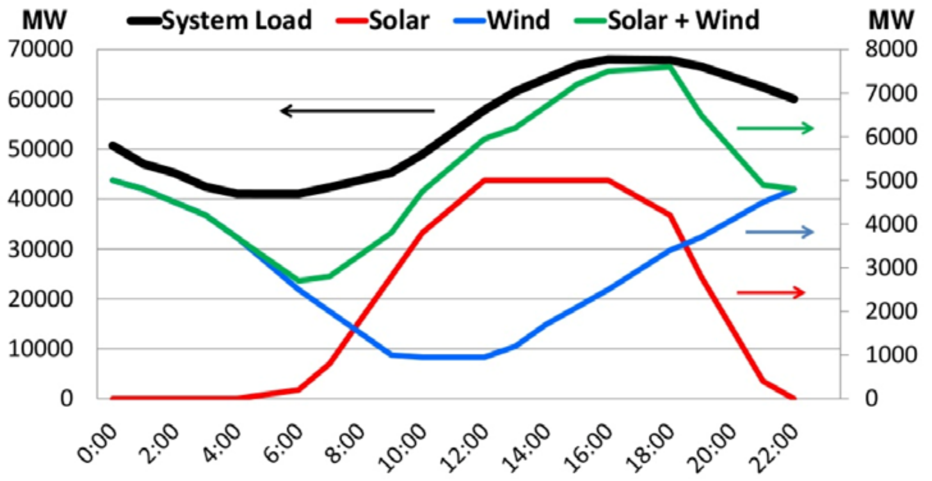


Source: https://www.solarelectricsupply.com/sunny-island-solar-battery-backup-inverter-systems-30-kw-383

Solar PV + Battery Storage – Integration

Solar PV + Wind can ease integration

- Wind power typically experiences low generation in the middle of the day, and high generation in the mornings and evenings.
- This pattern conveniently mirrors the profile of solar PV, which experiences the opposite peaks and lows.
- Wind and solar PV generation can be combined to create a generating profile that more closely matches typical demand.

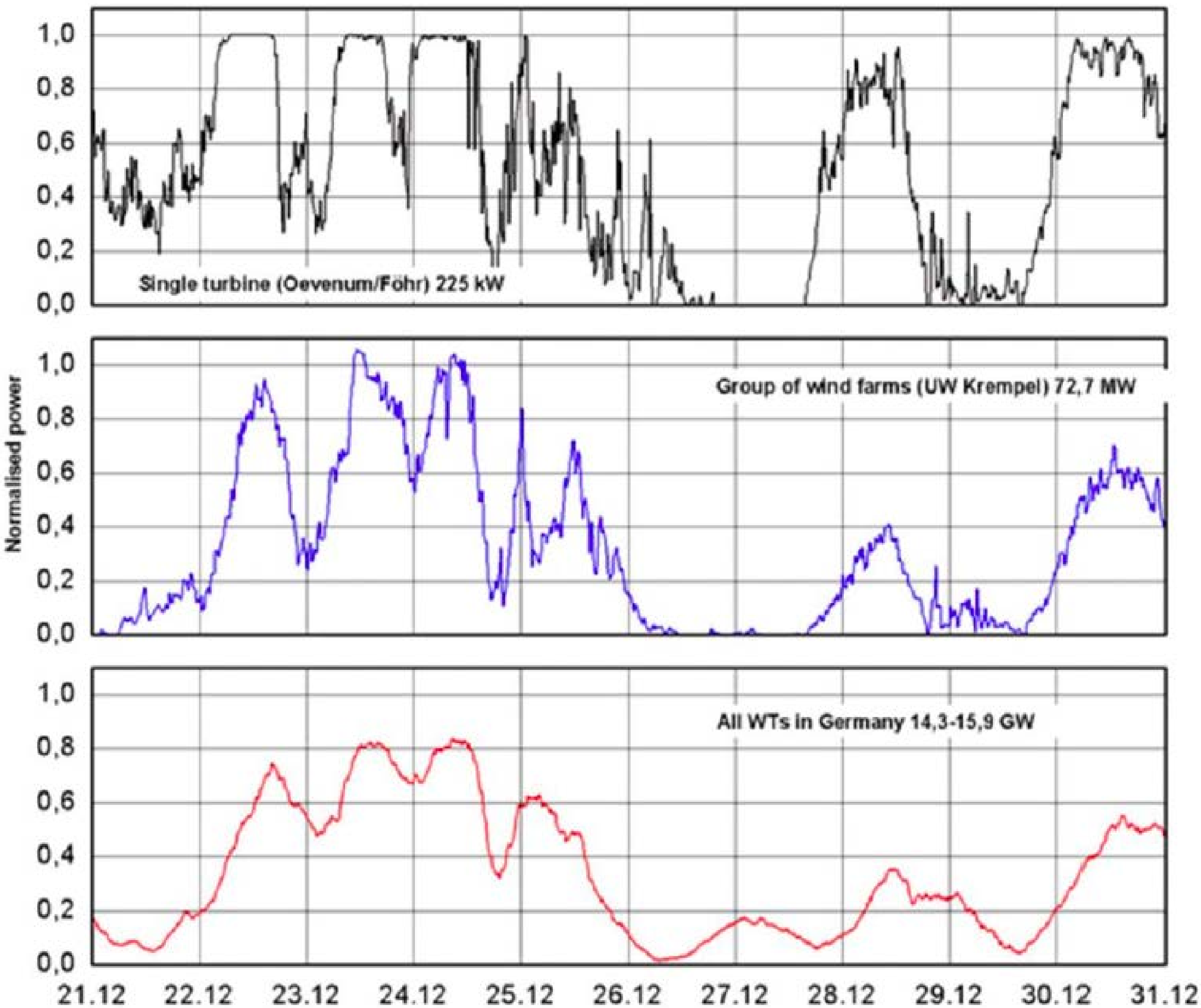


Source: https://www.slideshare.net/rborry/delivering-to-the-energy-marketplace-texas-harvests-wind-and-solar

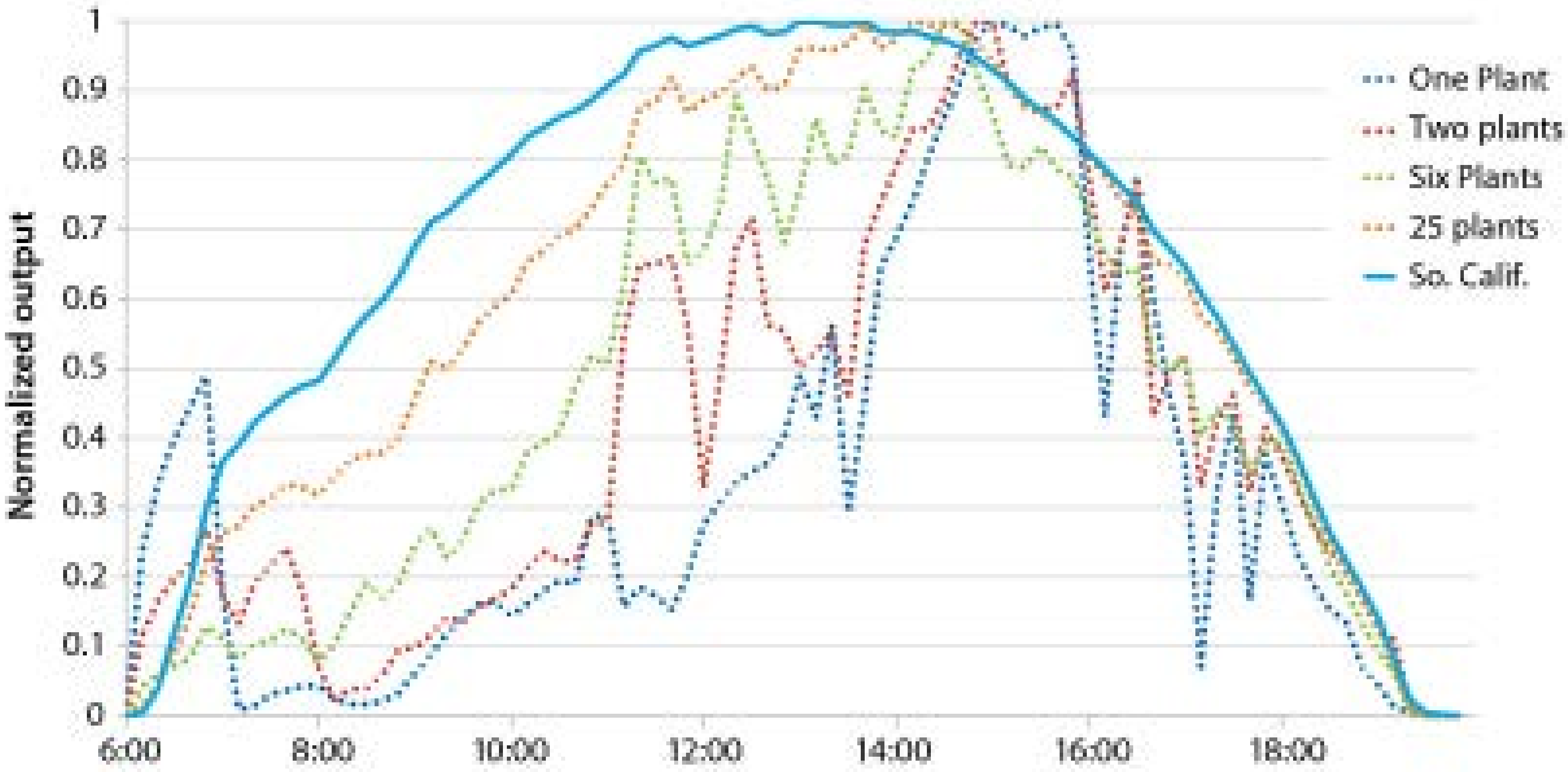
Renewable Energy Integration

Single wind turbine vs. thousands:

More VRE generation on the system leads to important “smoothing” effects and facilitates forecasting



Solar PV Integration

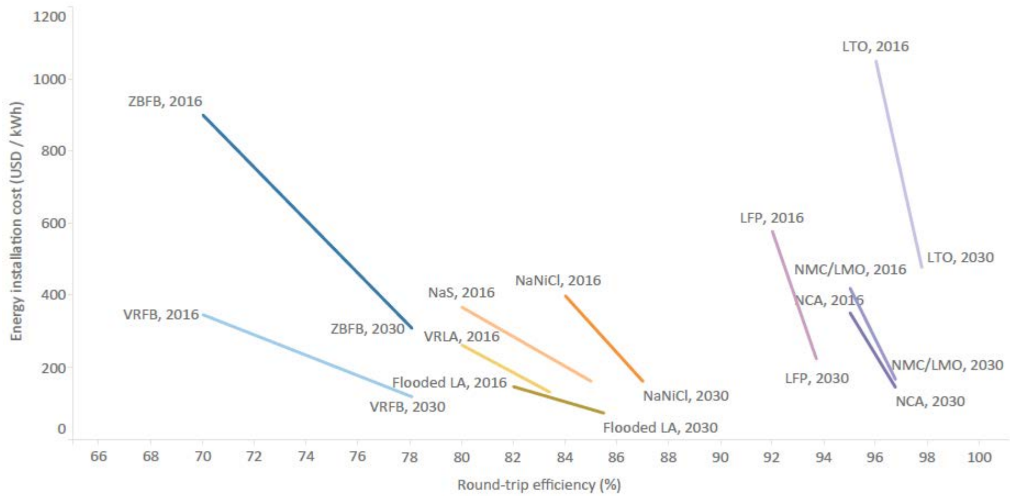


NREL 2013, http://www.nrel.gov/docs/fy13osti/60451.pdf

Decreasing Costs of Battery Technology

- According to recent forecasts, the costs of major battery technologies like Lithium-ion are projected to continue to decline steadily through to 2030.
- Lithium-Ion battery technology costs have declined by 79% since 2010.
- As these technologies become increasingly cost-competitive, it is conceivable that other generation technologies seeking to penetrate this rapidly growing market will struggle to gain a foothold.
- History shows a Li-Ion battery learning rate of around 18%. This means that every time total global Li-Ion battery capacity doubles, price per kWh is reduced by 18%.

- Li-ion battery prices now are around $176/kWh. Based on this, the price is expected to reach $94/kWh by 2024 and $62/kWh by 2030



Installed Cost of Different Battery Storage Types and Projected Cost Declines to 2030 (US$/kWh) on vertical y-axis; round-trip efficiency on the horizontal x-axis

Source: IRENA 2017, p.102

Sources:
https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/
and
https://about.bnef.com/blog/tumbling-costs-wind-solar-batteries-squeezing-fossil-fuels/
and
https://www.engie.com/en/journalists/press-releases/engie-bonds-of-which-green-bond

Curtailment

Curtailment

- Solar power is non-dispatchable, and weather-dependent
- When solar output exceeds load, or exceeds the ability of the network to deliver the electricity to customers, curtailment results
- Curtailment rates vary widely on islands
- In Cabo Verde, for instance, curtailment varies widely from 2% on the main island of Santiago up to 46% on the island of Sal (!!!)
- Curtailment can be limited either by using storage, by shifting electricity demand patterns through behavioural change, or by using demand response

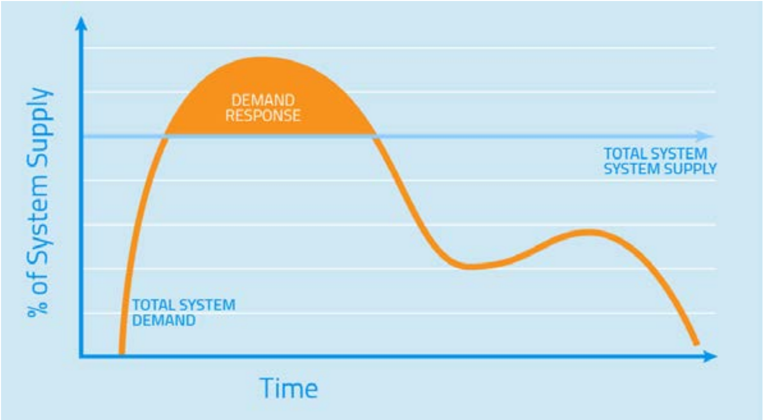
Cabo Verde

Source: https://www.islandstudies.ca/sites/default/files/ISJNordmanCapeVerdeRenewableEnergy.pdf

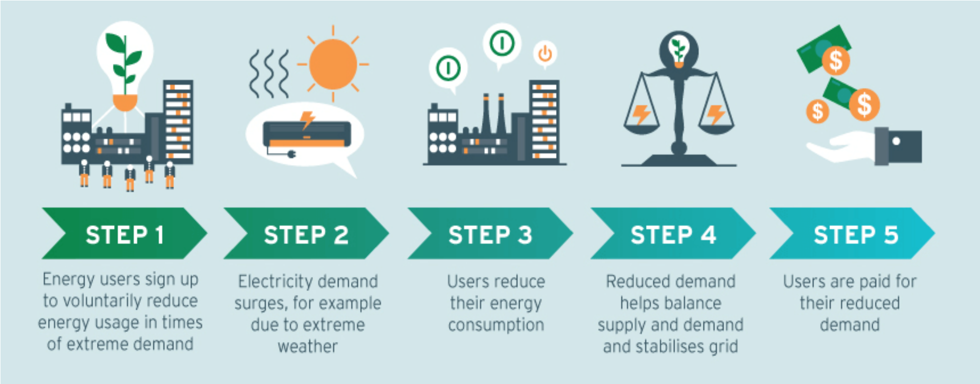
Demand Response

Controlling Demand

- The principle of demand response is that instead of the controller (mentioned in the previous slide) controlling only generating assets, it also controls demand.
- This is achieved by setting up relationships with major power users – residential blocks, industrial units, commercial buildings.
- When generation is not sufficient to meet demand, such power users are instructed not to request power at that time, or participating appliances are automatically switched off.
- Demand response is increasingly utilised as part of solar PV integration on grids of various sizes



Source: http://encorp.com/demand-response/



Source: https://www.leadingedgeenergy.com.au/blog/demand-response-nsw/ http://encorp.com/demand-response/

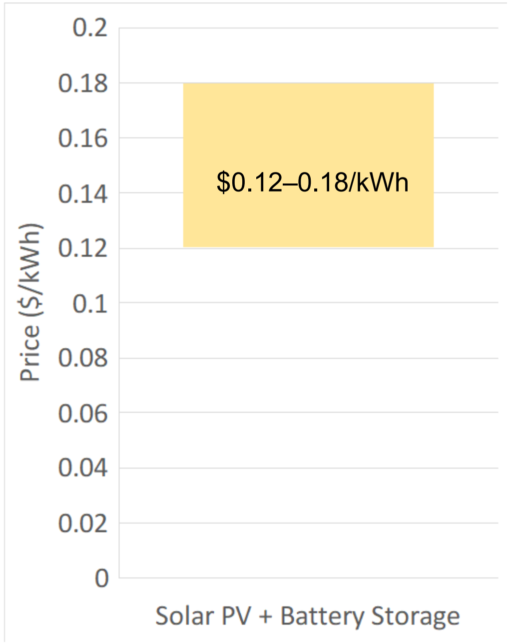
4. Costs and Financing of Solar PV on Islands

Cost of Solar + Battery Storage on Islands

- A growing number of solar PV + battery storage systems are being built around the world at an unsubsidised cost of between US$0.12–0.18/kWh

- For example, In Hawaii, which is a very dynamic market for solar PV + battery storage development, a recent basket of seven different projects have been put forward with contract prices ranging from US$0.12–0.16/kWh

- Looking wider around the world, a similar picture emerges, with several solar PV + battery storage projects quoting prices in the range of US$0.13–US$0.18/kWh. A collection of over 60 projects planned in French overseas territories yielded an average price of US$0.134/kWh.



Typical range of costs for solar PV + Battery Storage

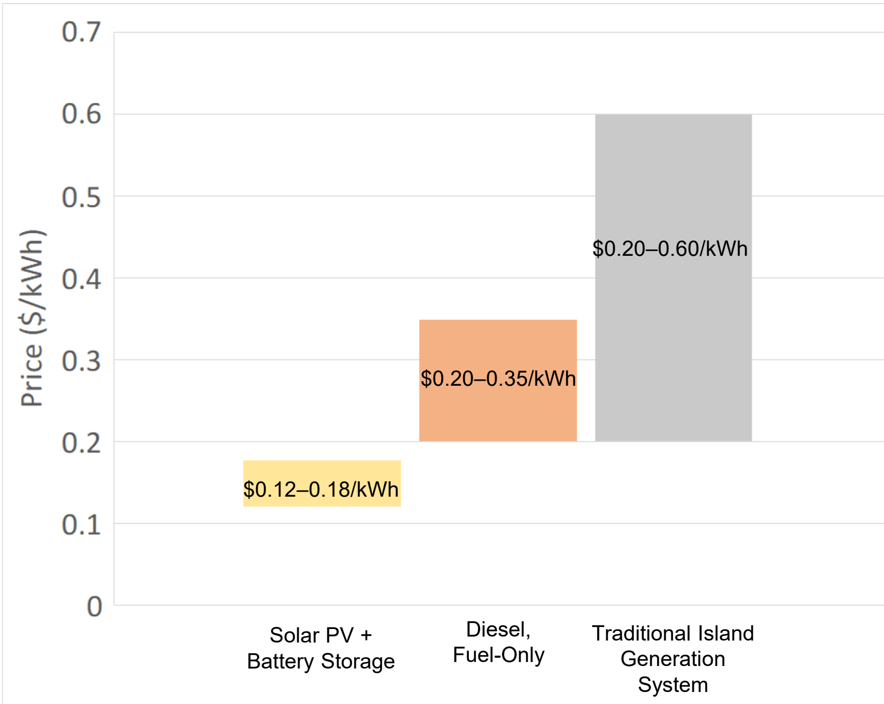
(The units of measurement are 'financial cost / energy provided'. A common example is US$/kWh.)

Source: https://www.energy-storage.news/news/french-island-tenders-push-down-solar-plus-storage-prices-by-40

Cost Competitiveness

- Solar PV + Battery Storage is very often a smaller cost than the energy provided by traditional, thermal generation, which is typically in the range of US$0.20–0.60/kWh
- With fuel-only generation costs for diesel systems typically ranging from US$0.20–0.35/kWh, these are still higher than Solar PV + Battery Storage

Illustrative Cost Ranges



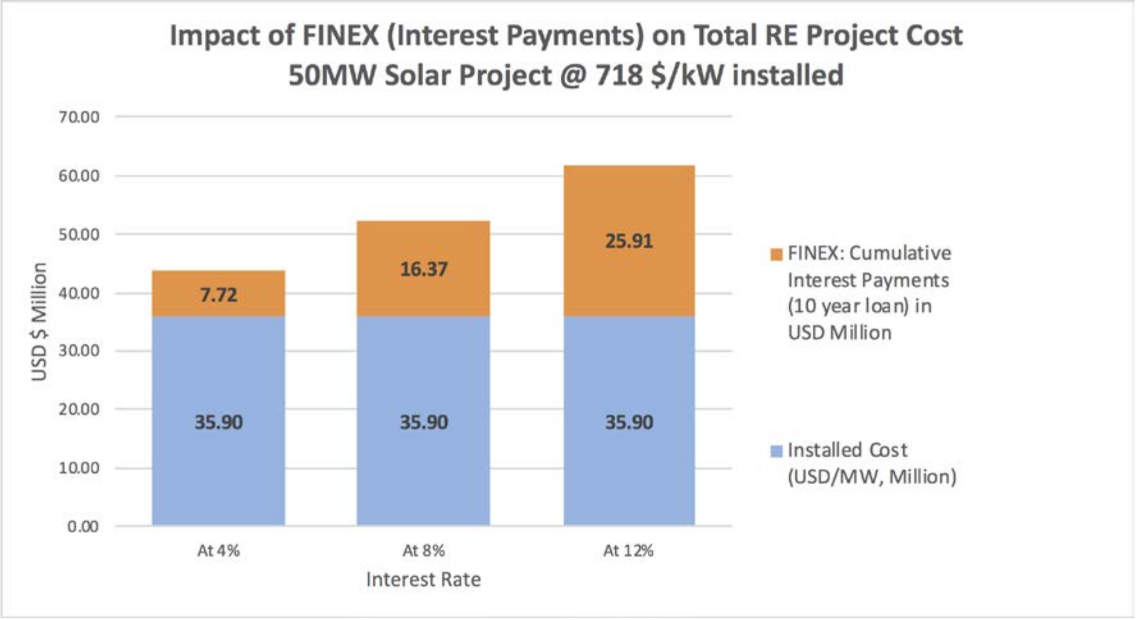
Typical range of costs for various generation technologies

Source: E3 Analytics 2019

Financing

Financing Costs Matter a Lot

- Some projects put forward by large corporates, for instance, are financed via green bonds, with borrowing costs of between 1.375% and 3.25%
- This represents far lower borrowing costs than available to many of the smaller companies active in the sector.
- **The cost of financing has a direct and large impact on the actual cost of financing solar power in island regions**
- Islands can reduce FINEX by introducing stable, long-term policies

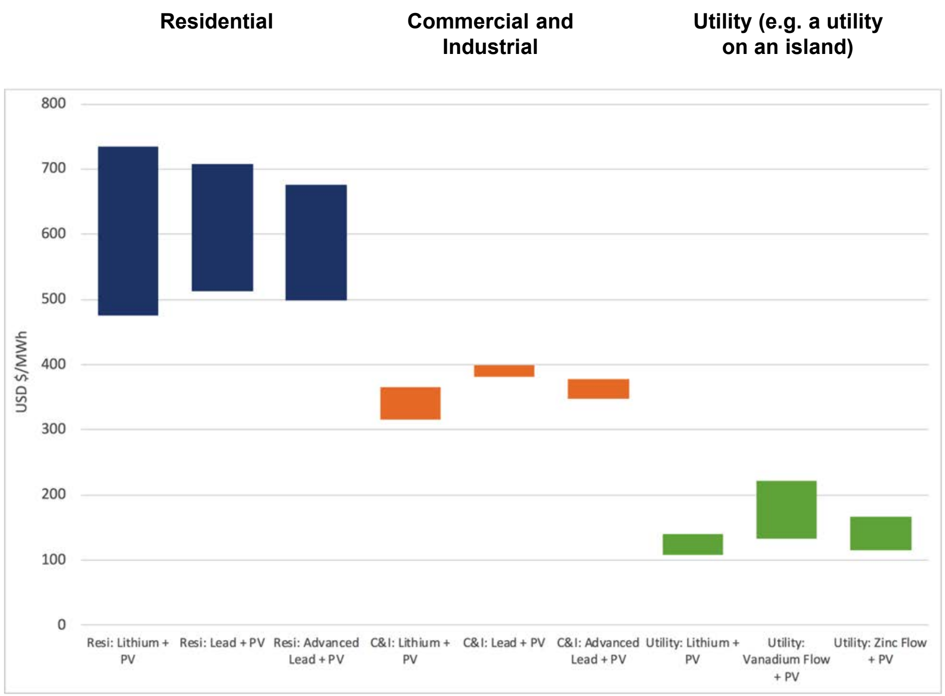


Source: E3 Analytics 2018

Source: https://www.engie.com/en/journalists/press-releases/engie-bonds-of-which-green-bond

Financing

- The chart on the right shows some cost ranges for solar PV + battery storage, according to three categories.
- **Residential** is the most expensive – this is the cost for end-users purchasing and setting up solar PV + battery storage in a residential setting
- **Commercial** and industrial is less expensive than residential as companies in this sector are large, and able to benefit from the scale required for their power generation.
- **Utility-scale** projects are by far the cheapest, and show similar prices to those presented on the previous slides

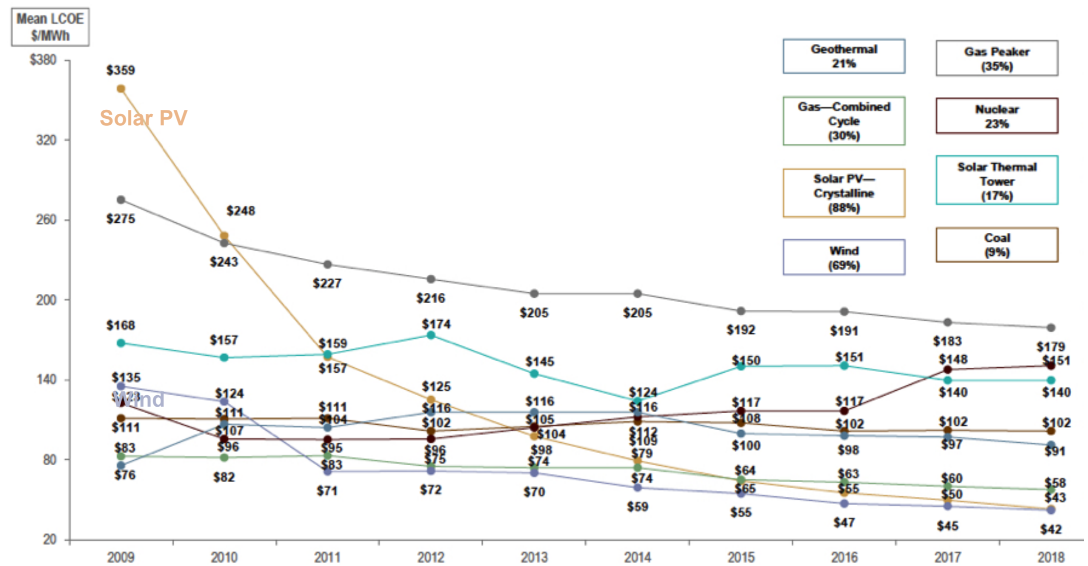


Levelized Cost of Solar+Storage Systems in Various Applications (US$/MWh): 2018

Source: E3 Analytics 2019, based on Lazard 2018b

Comparing Costs - LCOE

- The costs of power generation technologies are typically compared using the metric of the levelized cost of energy (LCOE).
- LCOE enables different generation sources to be compared with one another and to plot their relative cost-competitiveness over time
- The figure on the right provides an overview of how the LCOE of different generation technologies has evolved since 2009 for a range of conventional and renewable technologies



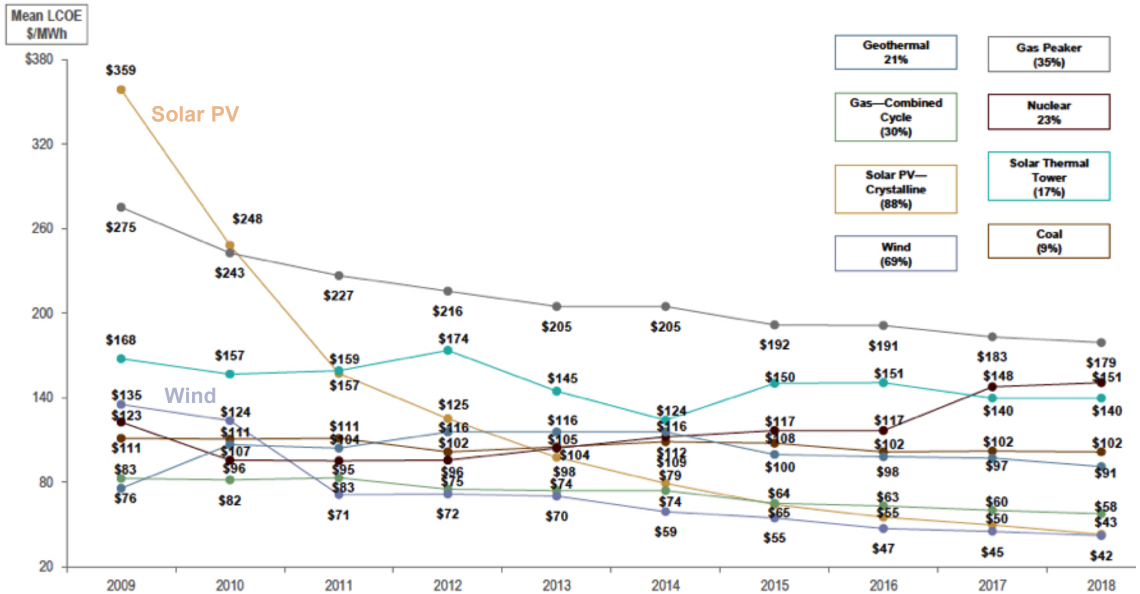
Levelized Cost of Electricity from Various Generation Technologies, in $/MWh (2018)

Source: Lazard 2018[a]

(This dataset is not specific to SIDS (which should be expected to be somewhat higher there do to their remoteness), but it still provides a good overview of energy costs and cost trends for various renewable energy types)

Comparing Costs - LCOE

- Solar has emerged as among the lowest cost sources of new power supply
- This is a remarkable shift in the power sector, where renewable energy technologies like solar have until recently (2010) been among the costliest forms of generation.



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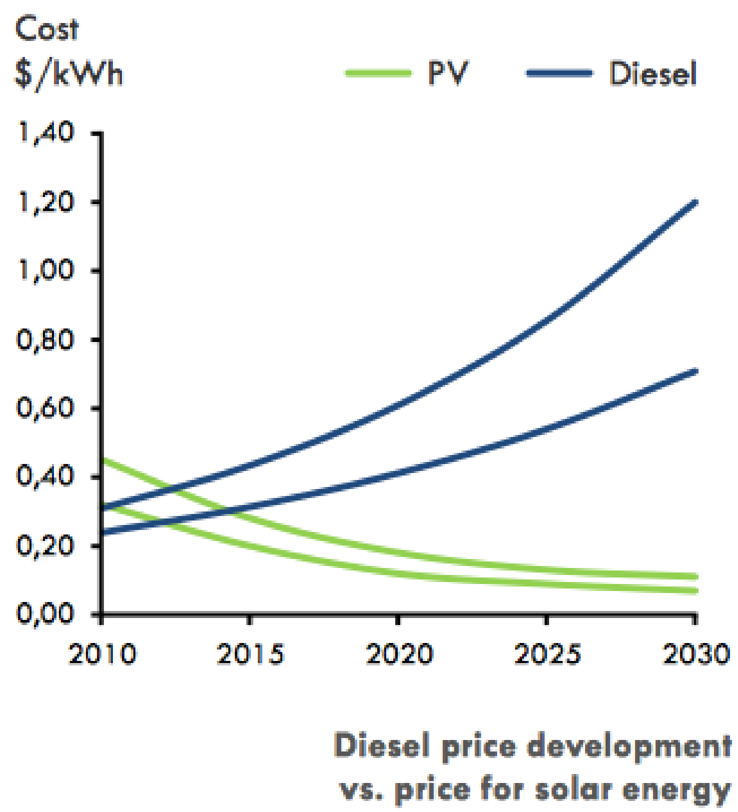
Source: Lazard 2018[a]

(This dataset is not specific to SIDS (which should be expected to be somewhat higher there do to their remoteness), but it nevertheless provides a good overview of energy costs and cost trends for various renewable energy types)

Cost of Maintenance – Solar PV vs. Diesel

- Operational expenses (OPEX) of power generation are of particular concern for island communities due to their remoteness.
- Solar installations typically have a large CAPEX, yet low running costs, which include washing the panels, replacing the inverter (usually every 5-10 years) and routine electrical maintenance.
- Diesel generators have a constant running cost due to the need for fuel, cleaning and filter changes. Though cheap to begin with, their cost tends to increase over time.



CAPEX and OPEX costs of solar PV vs diesel (2014)

Source: https://reneweconomy.com.au/remote-infrastructure-doesnt-need-fossil-fuels-34557/

Key Issues and Considerations

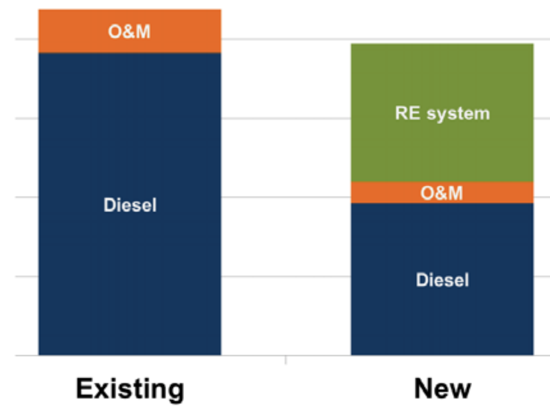
- The need for **local skills** in island regions remains a major barrier
- **Project costs (both CAPEX and OPEX) are often** (significantly) **higher** than in mainland regions
- **Financing costs** are also often higher
- Island-based PV systems need to be **adapted to island contexts**: salt spray, wiring, rust, weather events, etc.
- Island utilities are in many cases **loss-making**, making them unreliable off-takers for larger-scale solar projects

5. Case Studies

Tasmania - Diesel to Hybrid Conversion

CASE STUDY – KING'S ISLAND

- King's Island:
  - Population 1,600
  - 2.5MW peak load
  - 6MW diesel; 12GWh pa
  - 450km of 11kW power lines
- Government owned business – 100 year history. Utility responsible for generation, distribution and retail.
- In 2014, a study was completed and it was found that additional renewable energy and energy management technologies can offer significant cost and performance benefits – lower LCOE.



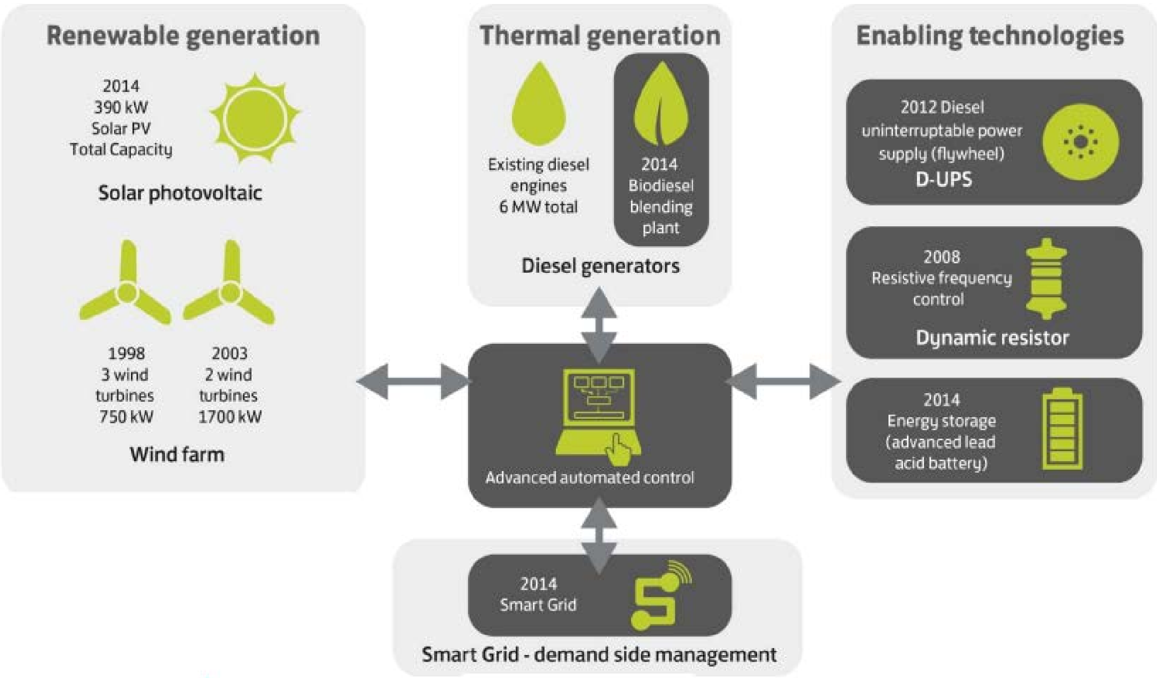
LCOE reduction

Sources: https://www.ises.org/sites/default/files/webinars/Webinar_2016_08_Gamble.pdf

Tasmania - Diesel to Hybrid Conversion

CASE STUDY – KING'S ISLAND

- Now has operational:
  - Hybrid grid including wind, solar, diesel, biogas
  - Energy storage
  - Demand management including load shedding
  - Real time data provided to customers
- Provides AUS $2m savings per year
- Since 2015 has provided over 3,000 hours of 100% renewable generation



Sources: https://www.ises.org/sites/default/files/webinars/Webinar_2016_08_Gamble.pdf

Scotland – Remote Communities

CASE STUDY

- Fair Isle (55 inhabitants), and Canna and Sanday (15 inhabitants) can be frequently cut off from the mainland for long periods due to weather and sea conditions.
- Prior to 2018, both islands had relied solely on diesel powered generators.
- Both islands installed projects in 2018 combining wind, solar and energy storage
- The communities utilised public finance. In this case, £1.5 million funding from the Government's Low Carbon Infrastructure Transition Programme (LCITP) and £250,000 from Highlands and Islands Enterprise.

FAIR ISLE

- 5km long island
- Previously, power supplied by wind and diesel; homes without electricity between 11.30 pm and 7.30 am
- Now all 55 inhabitants have instant power at any time

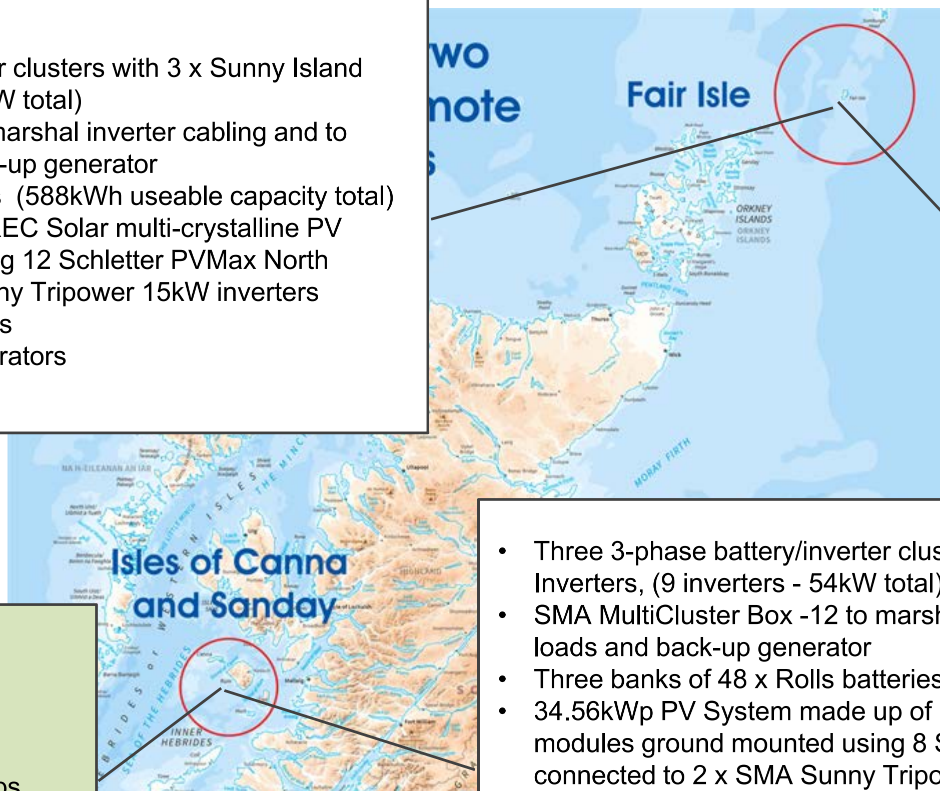
CANNA AND SANDAY

- 7km long island group
- Previously, power supplied by diesel
- Now all 55 inhabitants have instant power at any time

Sources: https://www.pv-magazine.com/2018/11/20/islands-ditching-diesel-in-favor-of-renewables/
http://www.windandsun.co.uk/news/two-of-the-uk%E2%80%99s-most-remote-island-communities-get-sustainable-24-hour-electricity.aspx
https://www.heraldscotland.com/news/17415879.fair-isles-renewable-energy-offers-potential-for-economic-growth/
http://www.windandsun.co.uk/news/two-of-the-uk%E2%80%99s-most-remote-island-communities-get-sustainable-24-hour-electricity.aspx
https://www.heraldscotland.com/news/17415879.fair-isles-renewable-energy-offers-potential-for-economic-growth/
https://www.telegraph.co.uk/news/2018/06/11/scottish-island-home-six-people-gets-first-ever-road

Scotland – Project Details

- Seven 3-phase battery/inverter clusters with 3 x Sunny Island Inverters, (21 inverters - 126kW total)
- SMA MultiCluster Box -36 to marshal inverter cabling and to connect island loads and back-up generator
- Seven banks of Rolls batteries (588kWh useable capacity total)
- 51.8kWp PV System - 192 x REC Solar multi-crystalline PV modules ground mounted using 12 Schletter PVMax North frames, connected to 3 x Sunny Tripower 15kW inverters
- 3 x 60kW Harbon wind turbines
- 2 x 80kW back-up diesel generators



POWER PROVIDED FOR:
- Houses for 55 inhabitants
- Post Office and shop
- B&B visitor accommodation
- Primary School
- Community Hall
- Two churches
- Fire Station
- Airstrip
- Scottish Water facility
- Harbour
- Lighthouse
- Fair Isle Bird Observatory

POWER PROVIDED FOR:
- Houses for 15 inhabitants
- Cafe and shop
- B&B visitor accommodation
- Farm buildings and workshops
- Primary School
- Two churches
- Harbour buildings

- Three 3-phase battery/inverter clusters each with 3 x Sunny Island Inverters, (9 inverters - 54kW total)
- SMA MultiCluster Box -12 to marshal inverter cabling and to connect island loads and back-up generator
- Three banks of 48 x Rolls batteries (225kWh useable capacity total)
- 34.56kWp PV System made up of 128 x REC-270PE multi-crystalline PV modules ground mounted using 8 Schletter PVMax North frames and connected to 2 x SMA Sunny Tripower 20kW 3ph inverters
- 6 x 6kW SD wind turbines with SMA Wind inverters
- 2 x 60kW back-up diesel generators (one used at a time)
- Remote monitoring is enabled using an SMA Data Manager allowing us to view performance over the internet and adjust operating parameters remotely if needed.

Source: http://www.windandsun.co.uk/news/two-of-the-uk%E2%80%99s-most-remote-island-communities-get-sustainable-24-hour-electricity.aspx

The Pacific Islands Region

- The Pacific region features thousands of islands.
- Many island countries have made tremendous progress in scaling solar power in recent years:
  - Cook Islands
  - The Philippines
  - Palau
  - Tonga
  - Marshall Islands
  - Vanuatu
  - Etc.
- The **economics** are increasingly the dominant driver

Caribbean

- The Caribbean region is home to over 28 island nations and more than 7,000 individual islands with a combined population of around 40 million, and all of the islands are liable to experience extreme weather events that may lead to destruction of infrastructure.

- Following an extreme weather event, access to fuel often becomes hard to achieve, putting communities at risk of loss of power.

Forecast for the path of Hurricane Maria, 2017

Source: http://www.looppng.com/global-news/caribbean-islands-prepare-hurricane-maria-66671

Sources: https://www.renewableenergyworld.com/articles/2018/10/solar-pv-energy-storage-systems-take-charge-in-the-caribbean.html
https://psmag.com/environment/the-essential-caribbean-renewable-power-revolution

Caribbean – Focus on Puerto Rico

CASE STUDY – BUILDING RESILIENCE

- Hurricane Maria hit Puerto Rico in September 2017, widely damaging its electricity grid and making supply of emergency thermal generators very challenging
- Before Hurricane Maria, Puerto Rico drew only 2.4 percent of its electricity from renewable energy, mostly from five solar farms and two wind farms.
- PREPA, the public utility, has a short-term aim to ramp up renewable power production to 18 percent of the island's generating capacity.
- Independent power production has also grown in the hurricane's aftermath:
  - Low-income communities or public service entities received donations of solar microgrid systems
  - Wealthier individuals or businesses installed their own solar panels, inverters and battery packs

A part of a micro-grid solar power project in Puerto Rico

Source: https://www.mcclatchydc.com/news/nation-world/national/article217653250.html

Sources: https://www.mcclatchydc.com/news/nation-world/national/article217653250.html

Island Regions

- Solar PV plus energy storage technologies, coupled with financing solutions, are becoming an increasingly popular option for homeowners, businesses and utilities in island regions around the world

- This combination of technologies presents a tremendous opportunity to increase resiliency and boost energy security, while keeping power rates stable

6. Concluding Remarks

Concluding Remarks

- It is more challenging and therefore more expensive to provide maintenance services to traditional power generating assets on islands.
- Solar PV and battery storage technology requires higher CAPEX investment, but lower OPEX.
- This puts solar PV and battery storage solutions at a significant advantage when considering optimal power generation assets on islands.
- The major challenges that remain are access to **low-cost financing** to cover upfront CAPEX requirements along with **skills training** to improve the integration of solar power into island grids

Ta'u Island – 100% renewable power

Source: https://www.independent.co.uk/news/science/tau-island-powered-solar-energy-tesla-solarcity-renewable-energy-a7443326.html

Concluding Remarks

- **Learning by doing** is also powerful: curtailment rates in Santo Antão (Cabo Verde) went down significantly after the first 18-months of operation, due largely to onsite learning by local staff

- The need for island-based PV systems to be **adapted to island contexts is key:** island wear-and-tear is different from that in mainland regions

- Supporting the **bankability** (creditworthiness) of island utilities is also important to attract new investment

Ta'u Island – 100% renewable power

Source: https://www.independent.co.uk/news/science/tau-island-powered-solar-energy-tesla-solarcity-renewable-energy-a7443326.html

Concluding Remarks

- The **risks of customer-sited solar+storage** undermining the economics of traditional utilities in islands are arguably high and growing
- As higher-income customers drop off the system, this increases the pressure on utilities
- In addition, island utilities have to manage multiple threats (climate, frequent storms, depopulation and out-migration, decreasing load growth, ageing infrastructure, etc.)
- This points to the need to **seek out win-win solutions**, including solutions that allow local utilities to be partners in the transition to sustainable power systems in island regions

Ta’u Island – 100% renewable power

Source: https://www.independent.co.uk/news/science/tau-island-powered-solar-energy-tesla-solarcity-renewable-energy-a7443326.html

7. Further Reading

Further Reading

- **IRENA - Renewable energy for islands**
  104 pages of slides listing many recent renewable energy projects on islands
  https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2016/IRENA_Path_to_Prosperity_Islands_2016.pdf

- **TH Energy – Renewable Energy on Islands**
  Links to databases of projects and other informative reports
  https://www.th-energy.net/english/platform-renewable-energy-on-islands/

- **IRENA – Renewable energy and links with tourism**
  Energy trends and opportunities
  https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2014/IRENA_RE_Island_Tourism_report_2014.pdf

Thank you for your time!

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6. Knowledge Checkpoint: Multiple Choice Questions