



Puerto Rico Grid and Recovery Post Hurricane Maria

Fire Mitigation & Grid Resiliency Panel

Murali Baggu, Laboratory Program Manager – Grid Integration




Overview of Storms



- Irma hit the island on Sept. 6, knocking out power to almost a million customers.
- Two weeks later Maria hit, crossing almost the entire island from southeast to northwest.
- PREPA was still restoring power to hundreds of thousands of customers knocked out by Irma when Maria hit and caused a systemwide collapse.
- The double punch knocked out 80% of Puerto Rico's electric grid.
- This resulted in the largest blackout in U.S. history and the second largest in the world.

Path of Hurricane Maria



-  Hurricane Path
-  Transmission Lines
-  Mountains

Impact of Storms on Grid Assets

- The two hurricanes that hit Puerto Rico two weeks apart in 2017 resulted in a systemwide collapse and a U.S.- and global-record-setting blackout.
- Damage occurred to all elements (generation, distribution, and transmission) of Puerto Rico's already fragile energy system.
- FEMA allocated \$3.2 billion for direct assistance and coordinated electricity grid restoration.
- Making a bad situation worse, a 2020 earthquake damaged the island's largest generation plant.

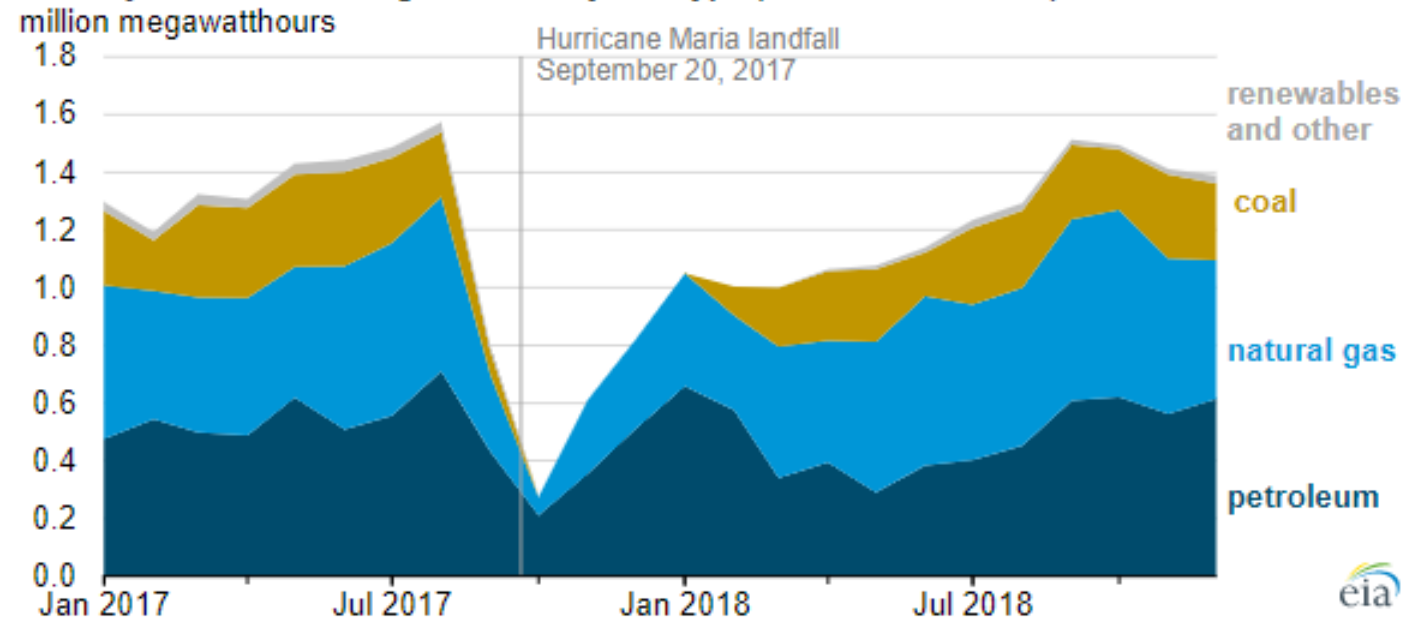


Generation Restoration

NOVEMBER 25, 2019

Puerto Rico electricity generation returned to pre-2017 hurricane levels one year later

Monthly Puerto Rico net generation by fuel type (Jan 2017-Dec 2018)

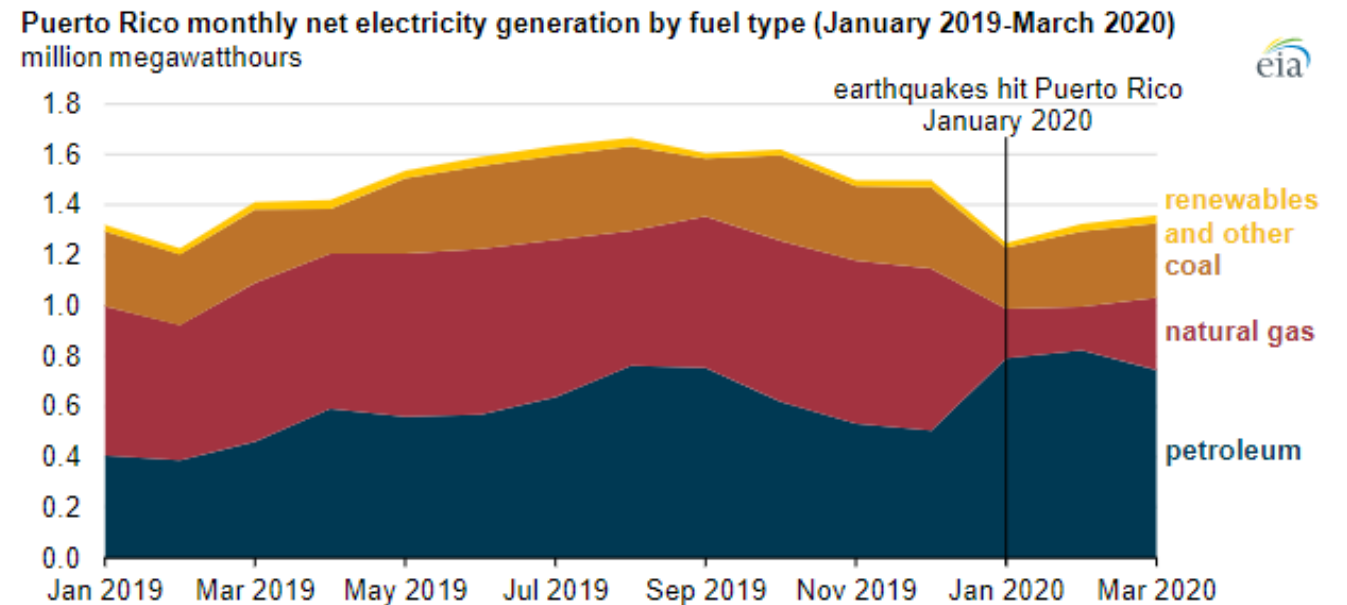


Source: U.S. Energy Information Administration, Form EIA-923, *Power Plant Operations Report*

Earthquake Aftermath

- **Costa Sur, the island's largest power plant was severely damaged.**
- Costa Sur was producing roughly 40% of Puerto Rico's electricity.
- Power was restored to 99% of customers within a week, but the earthquake affected the energy mix of the entire island.

Puerto Rico's electricity generation mix changed following early 2020 earthquakes



Source: U.S. Energy Information Administration, Form EIA-923M, *Power Plant Operations Report*, data for 2019 and 2020 are preliminary

Puerto Rico Energy Public Policy

Act 17 2019 requires PREPA to procure the following portions of its power needs through renewable energy:



40%
by 2025

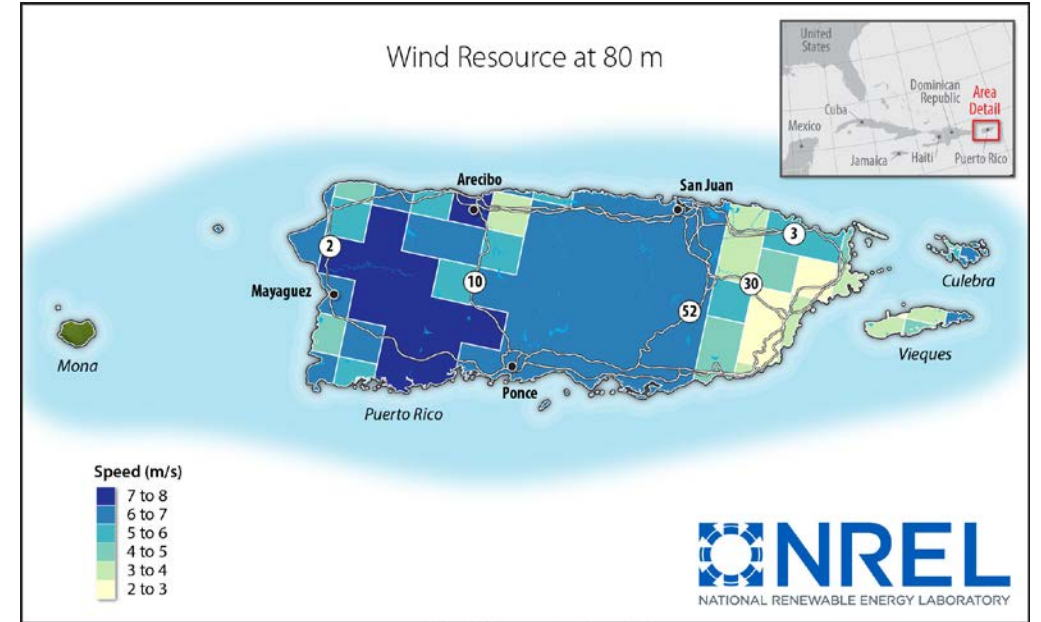
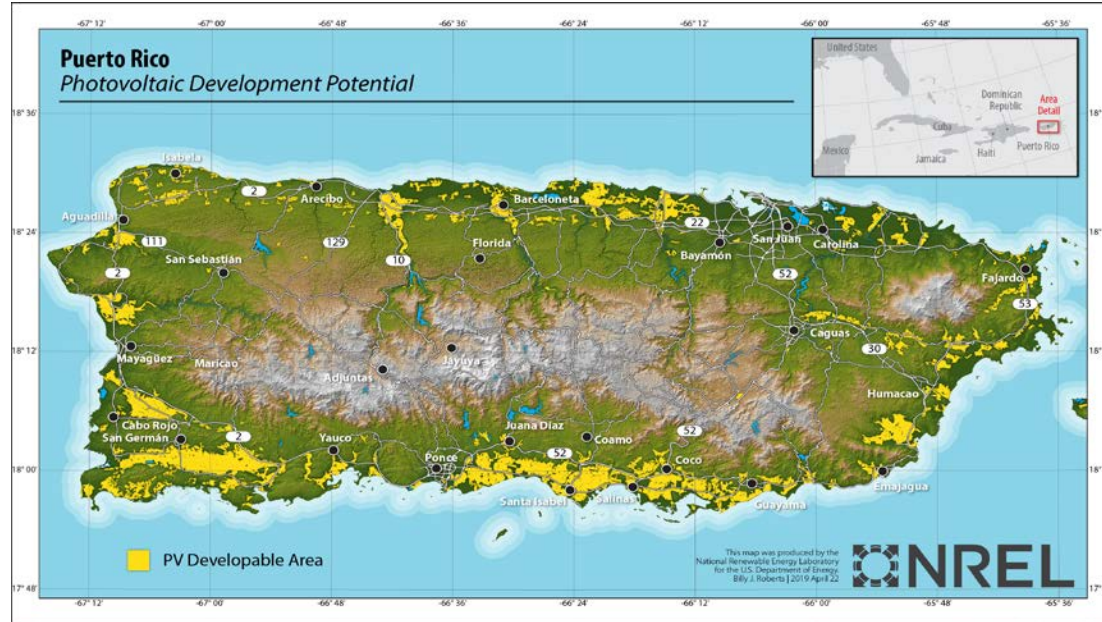
60%
by 2040

100%
by 2050

2020 Integrated Resource Plan (IRP)

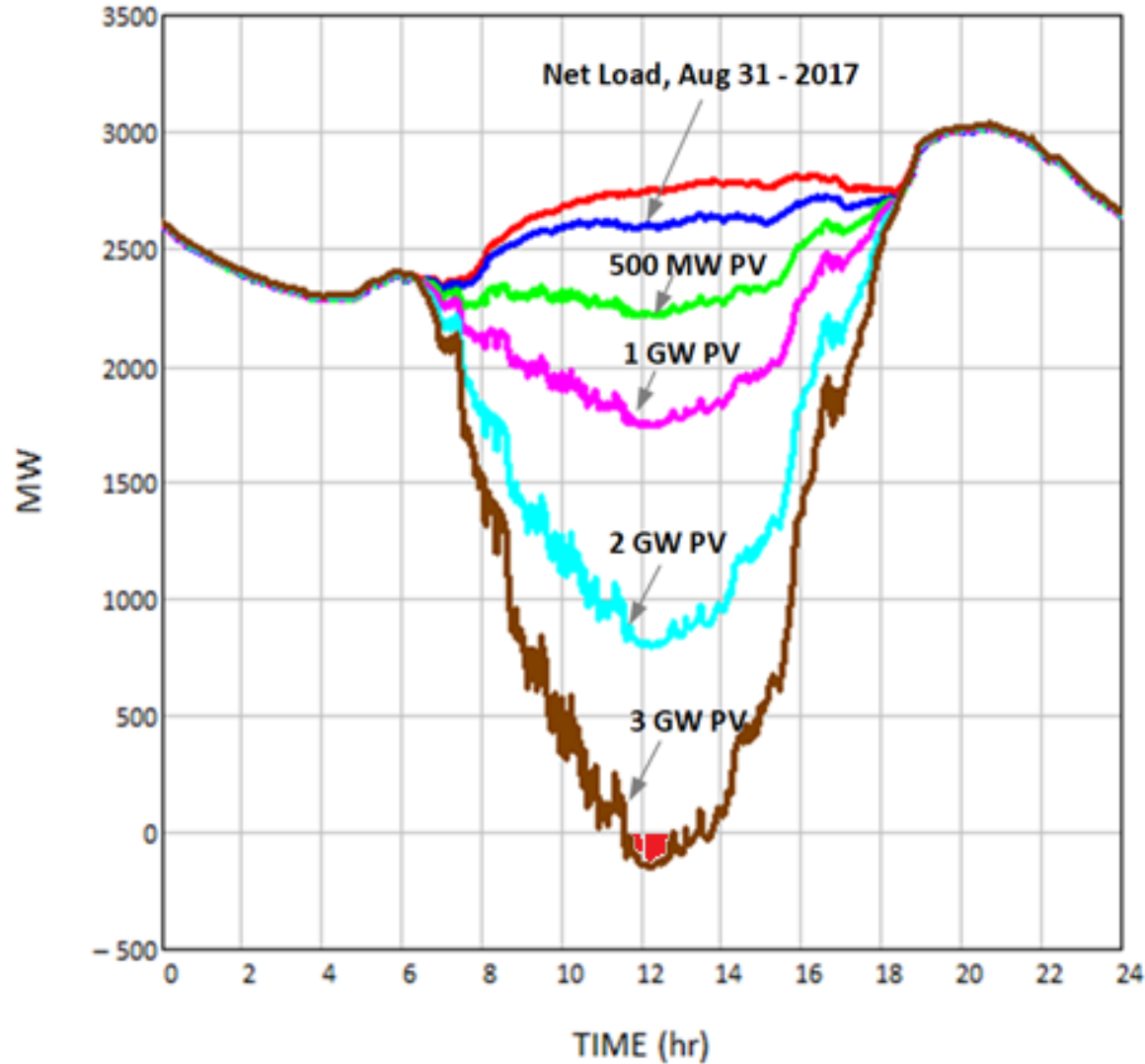
- Retire a significant number of oil-fired thermal units in the next 5 years
- Retire the AES coal-fired power plant by 2027
- Retire Aguirre diesel-fired combined cycle units 1 and 2 by 2030
- Limit the development of new gas turbine peaking units to 81 MW
- Integrate renewable generation projects to achieve the renewable portfolio standard in Act 17

Renewable Resource Potential



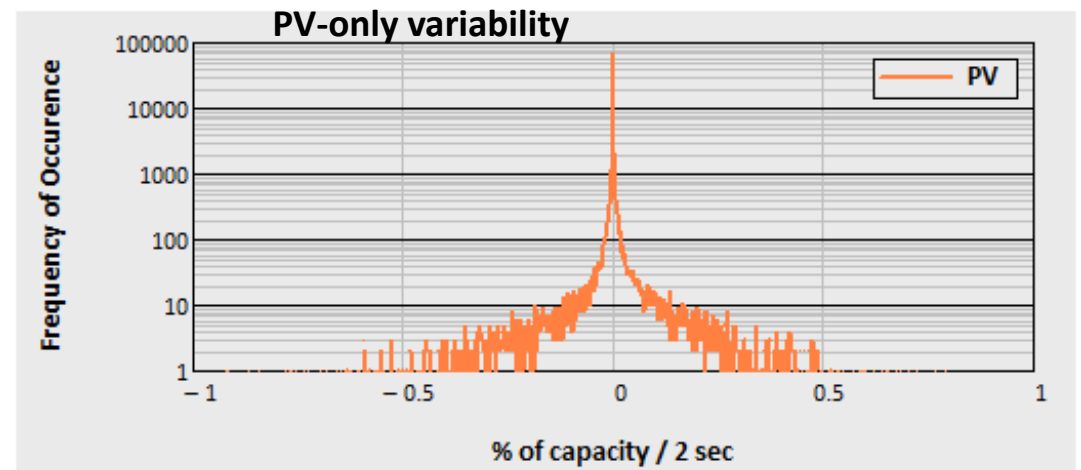
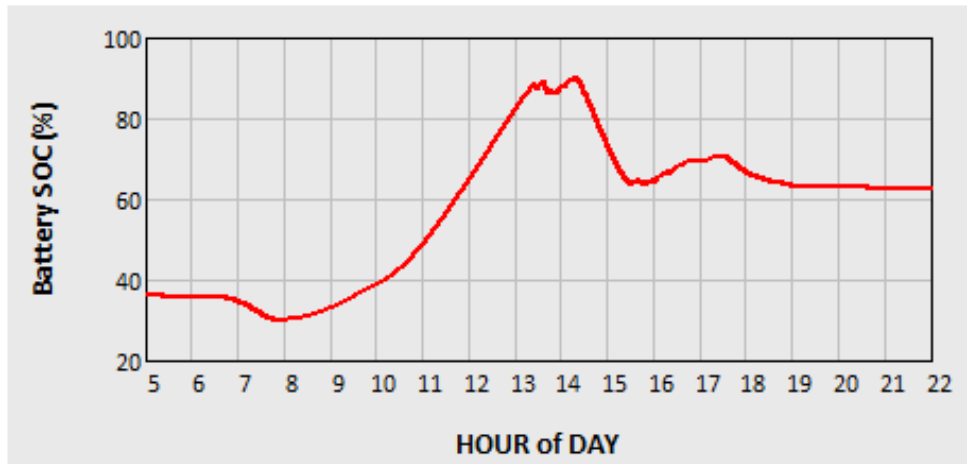
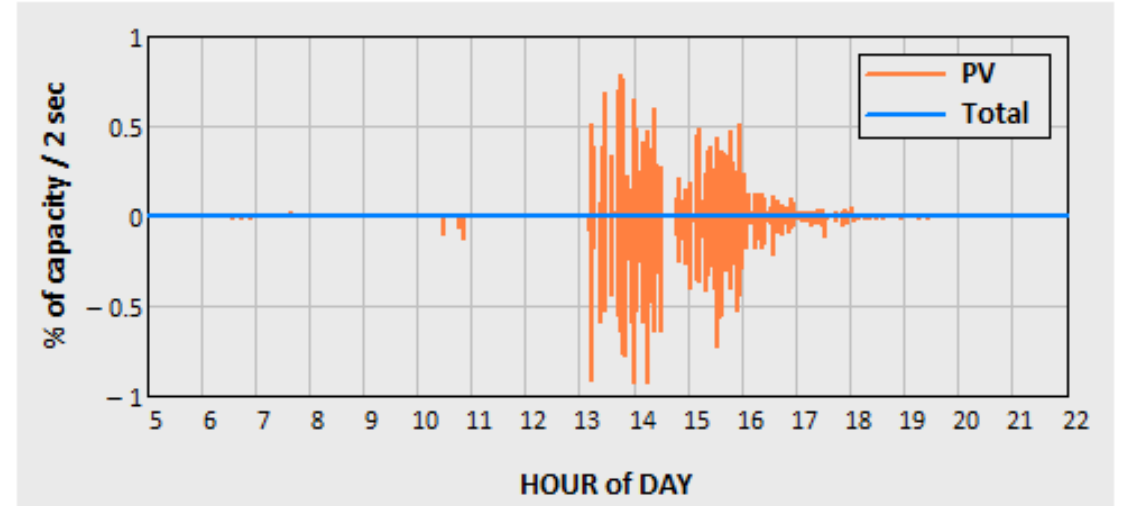
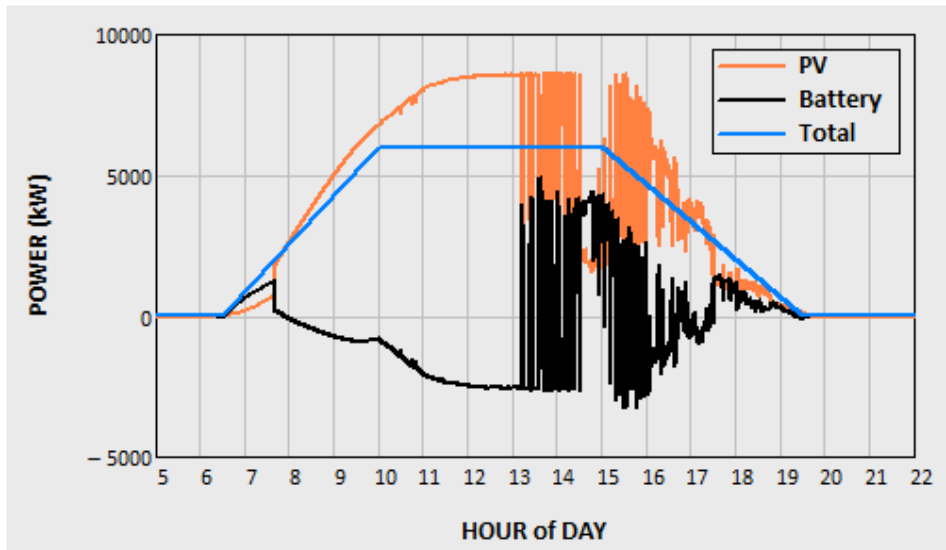
NREL Analysis of Utility-Scale and distributed Solar PV Development Potential Found Greater Than 20 GW Total each.

PV-storage plants

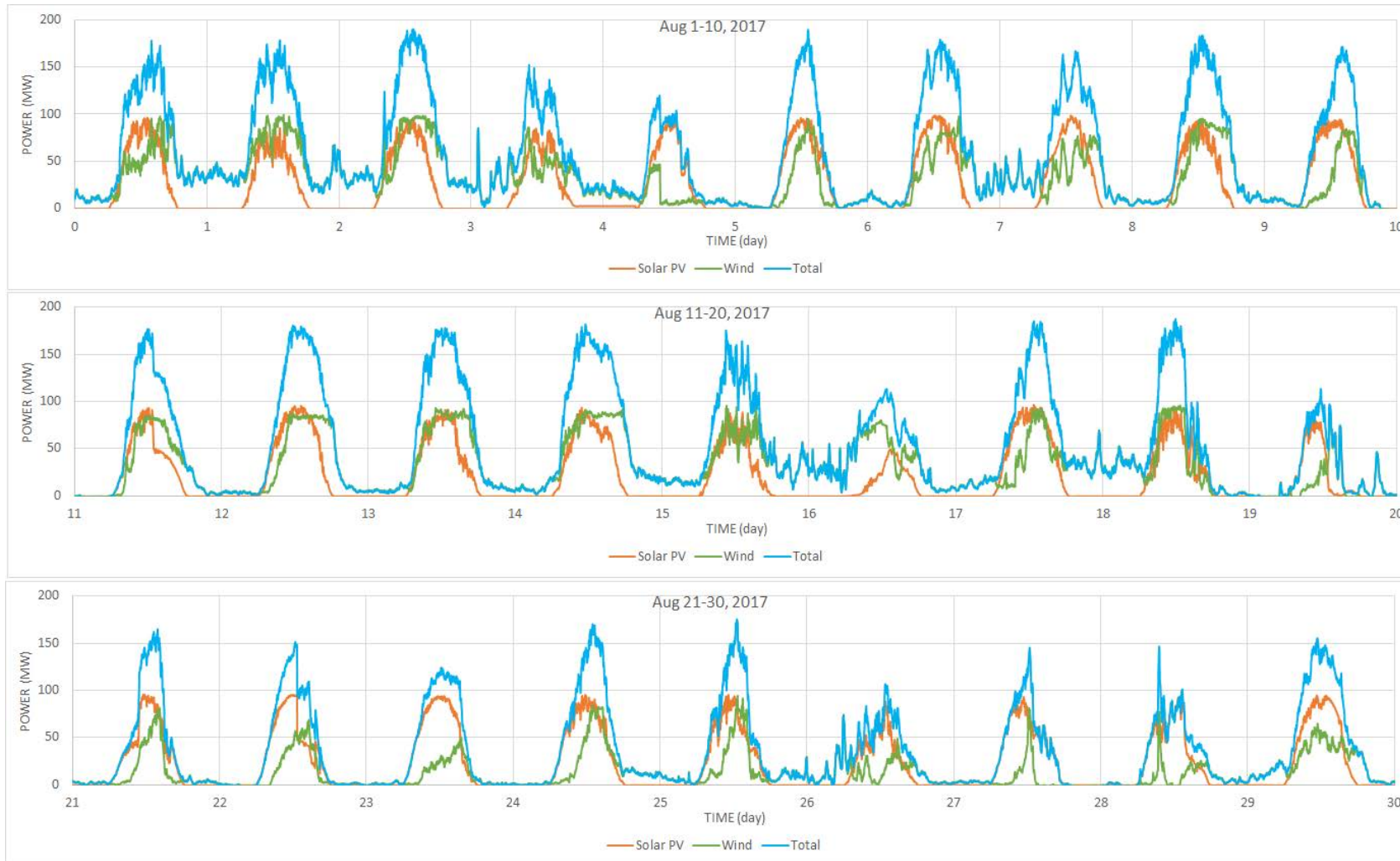


- Provide dispatchability for variable generation in Puerto Rico
- Aggregate ramp limiting, variability smoothing, cloud-impact mitigation on system levels
- Provision of spinning reserves
- AGC functionality
- Renewables forecast error correction services
- Primary frequency response (programmable droop control)
- Fast frequency response (FFR)
- Inertial response:
 - programmable synthetic inertia for a wide range of H constants emulated by BESS
- Reactive power/voltage/power factor control
- Advanced controls: ability of the plant to modulate its output for provision of power system oscillations damping, wide-area stability services
- Stacked services

PV-storage hybrid operation (flexibility + dispatchability)



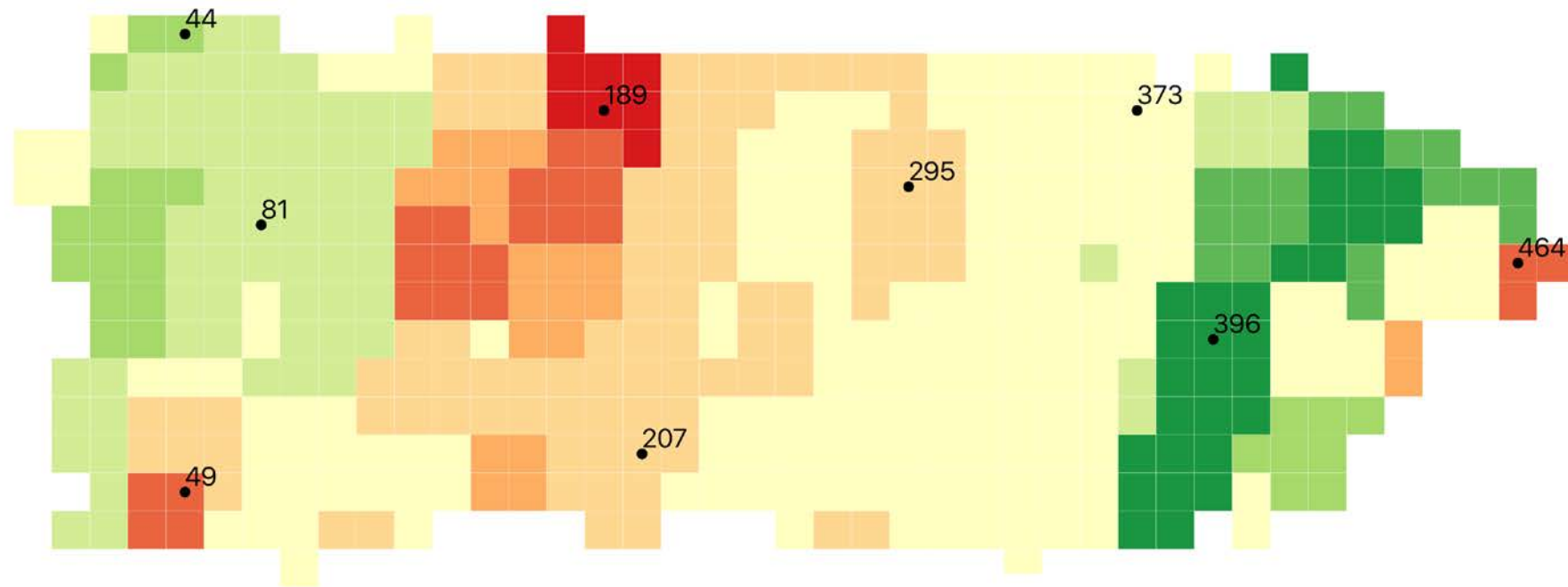
Puerto-Rico Wind and Solar Generation (2-sec data from Aug 2017)



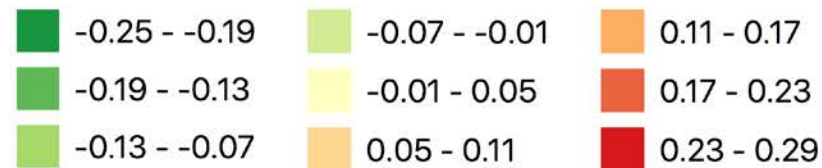
- No temporal complementarity between wind and solar generation is observed (for the existing sites)
- More analysis is needed for identifying hybridization potential in PR

Wind and Solar resource Correlation

negative correlation is good



Wind and Solar Generation Pearson's r



Demand Response Applications & Considerations

Motivation for Demand Response in Puerto Rico

- DR reduces peak generation needs and can shift load to times of high VRE generation. This decreases Puerto Rico's reliance on fuel imports and accelerates the retirement of fossil-fuel peaker plants to meet PR goals.
- DR reduces customer electricity consumption and/or shifts consumption to times of lower rates, resulting in lower electricity costs. DR programs can also have financial incentives for participating ratepayers.
- DR increases load flexibility and helps grid operators more efficiently match the supply of VRE (e.g., solar PV and wind turbines) to demand at each hour of the day in order to achieve Puerto Rico's 100% RPS goal by 2050.
- DR contributes to system resiliency and reliability by giving system operators more flexibility to match demand with supply on a regular basis and conduct more targeted load shedding on an emergency basis.

Pre-storm Checklists

Checklists are divided into three main topic areas:

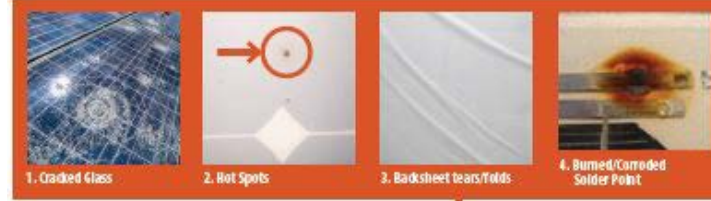
- **Site:** focuses on the area and environment surrounding the PV system.
 - Debris
 - Flooding
- **Mechanical:** concentrates on the structural hardware that secures the PV system.
 - Modules
 - Fasteners
 - Racking
- **Electrical:** follows the path of energy, from the PV modules to its connection to the grid or household.
 - Connectors, Wiring, and Supports
 - Waterproofing



Distributed Roof-Mounted Checklist

Photovoltaic System Damage

PV Modules



PV Cable Connectors



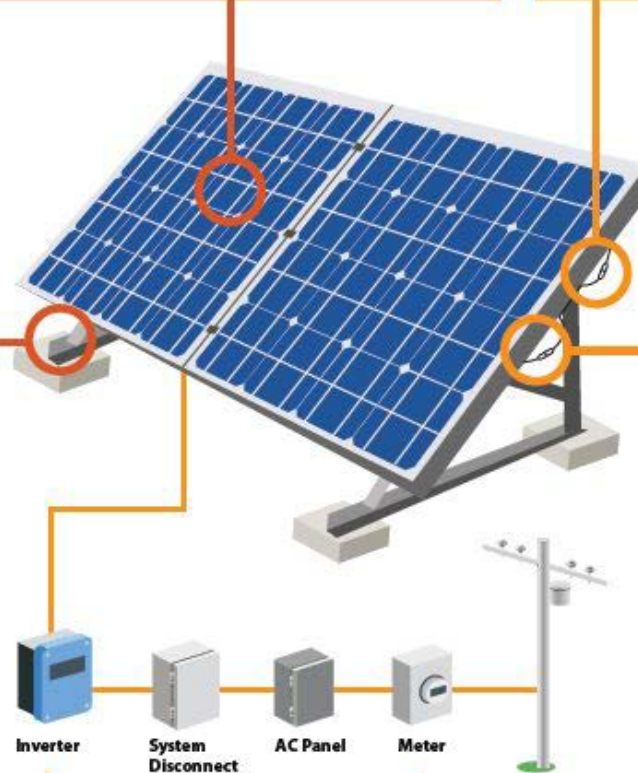
Racking



Power Cables



Environment



Electrical



Photos by Don Jenket, Design by Fred Zietz, NREL

The images shown are merely examples and system components may look different. Ask your installer if you are uncertain about any parts of your system.

Puerto Rico 100% Renewable Energy Study

1 Responsive Stakeholder Engagement and Energy Justice

- Stakeholder engagement inclusive of procedural justice
- Energy justice and climate risk assessment

2 Data Gathering and Generation

- Resource potential and demand projections (solar, wind, hydro)
- Demand projections and adoption of DER (considering load, EVs, energy efficiency, distributed PV and storage)

3 Scenario Generation and Capacity Evaluation

- Detailed scenario generation
- Distributed PV and storage grid capacity expansion
- Production cost and resource adequacy

4 Impacts Modeling and Analysis

- Bulk system analysis for enhanced resilience
- Distribution system analysis
- Economic impacts

5 Reports, Visualizations, and Outreach

- Scenarios for grid resilience and 100% renewable electricity for Puerto Rico
- Reports and outreach
- Implementation roadmap



Questions?

Thank you

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