Puerto Rico Grid and Recovery Post Hurricane Maria

Fire Mitigation & Grid Resiliency Panel

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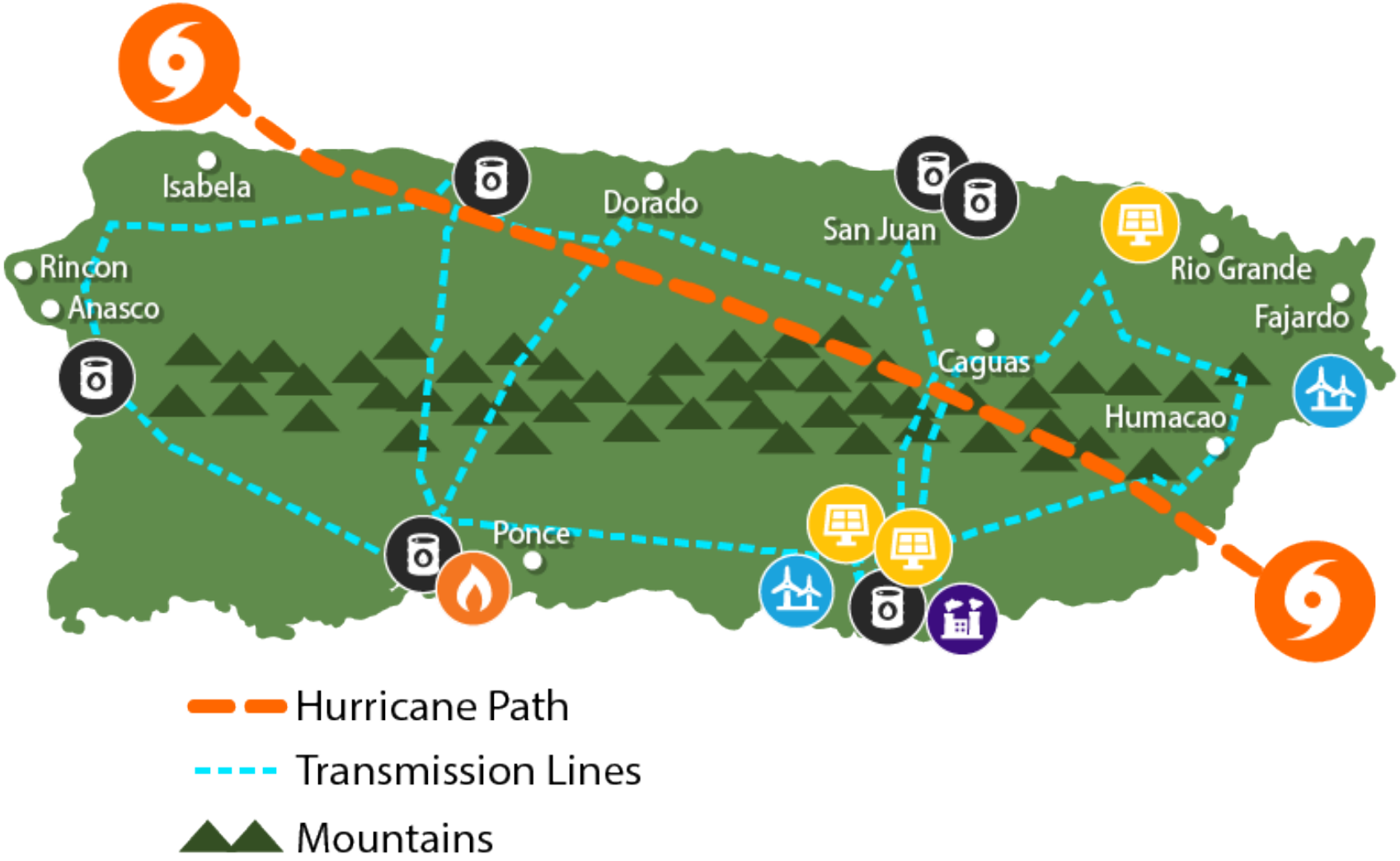
Overview of Storms

- 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



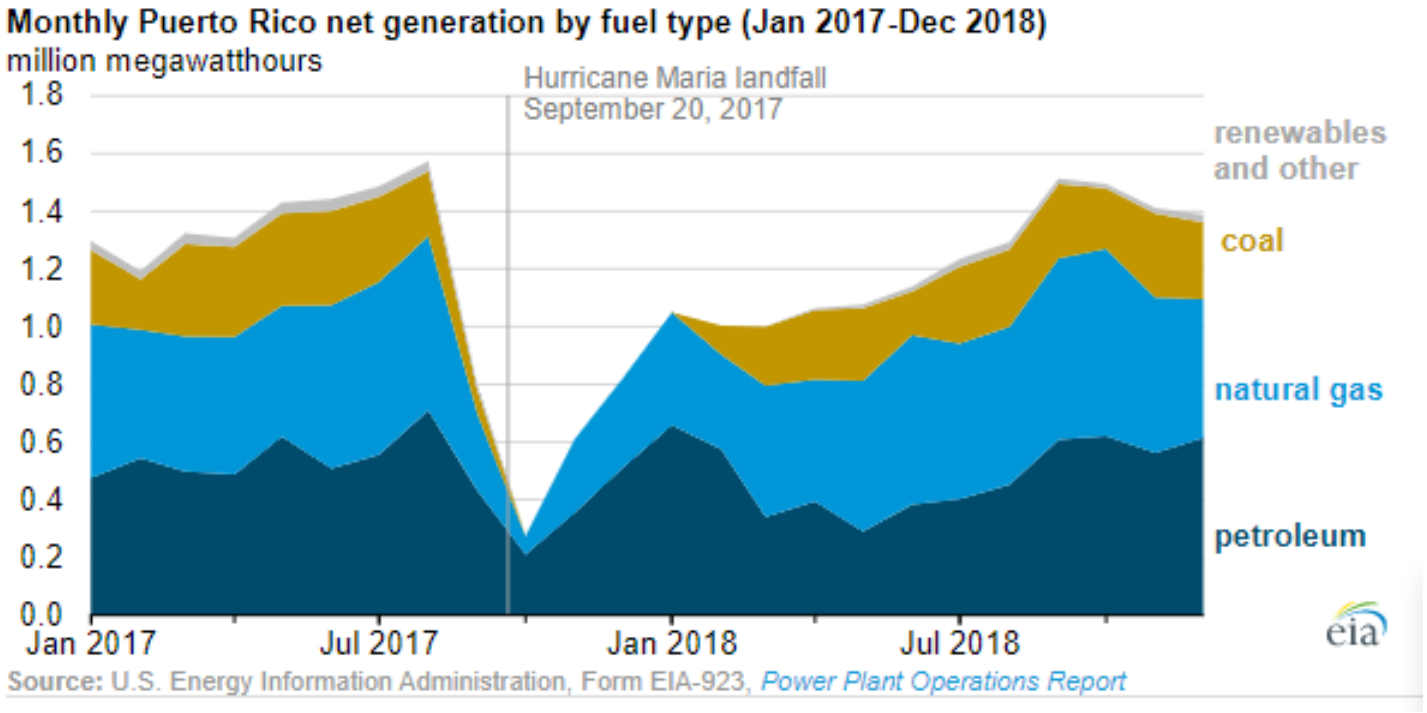
Impact of Storms on Grid Assets

- 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

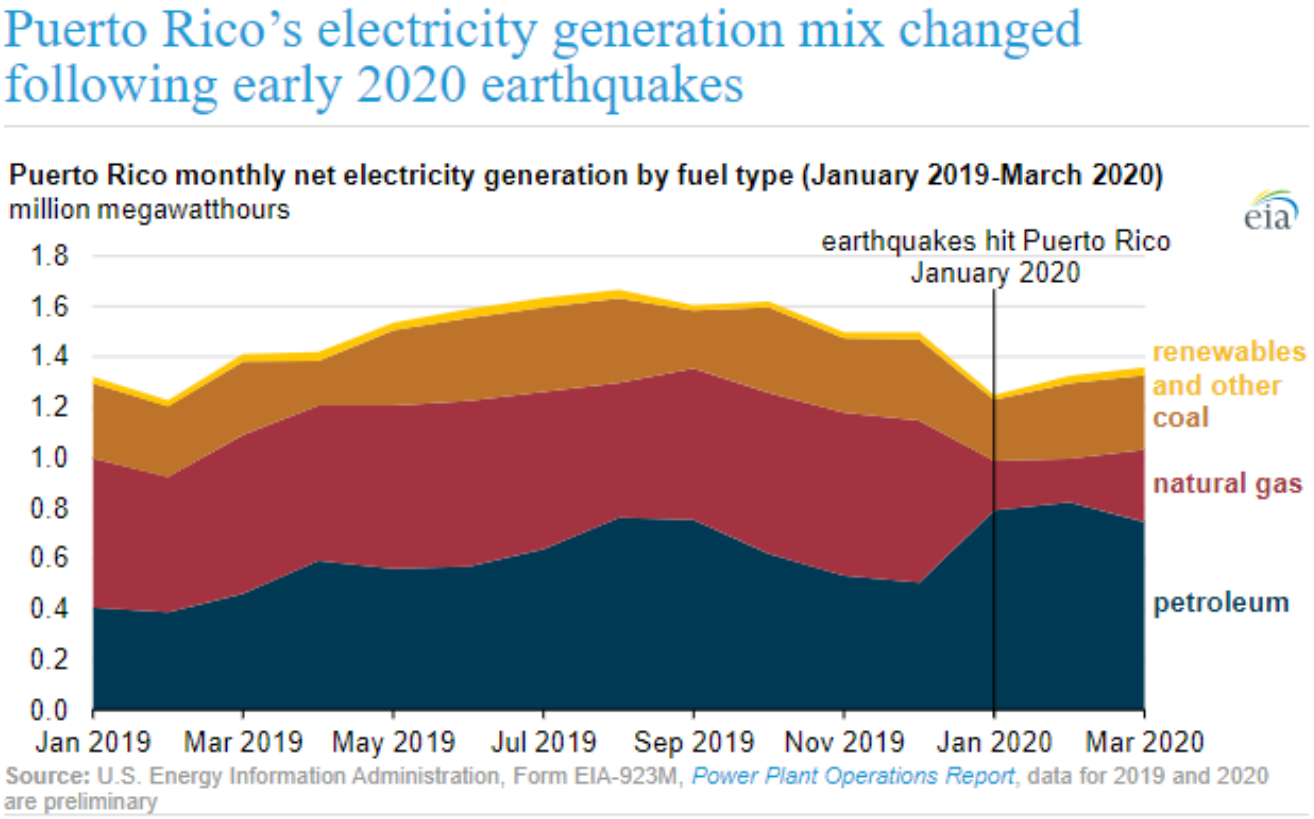
NOVEMBER 25, 2019

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



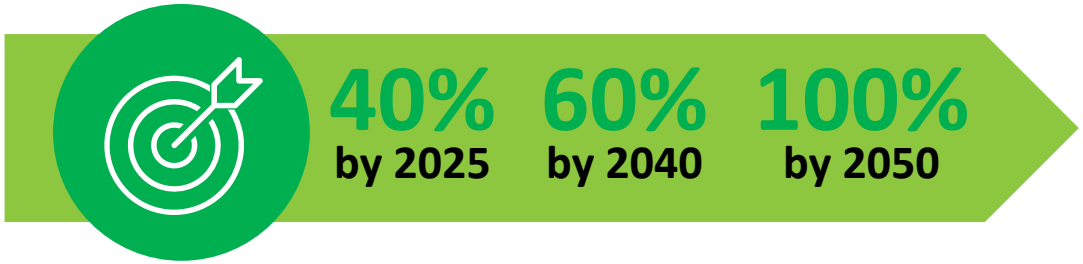
Earthquake Aftermath

- **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 Energy Public Policy

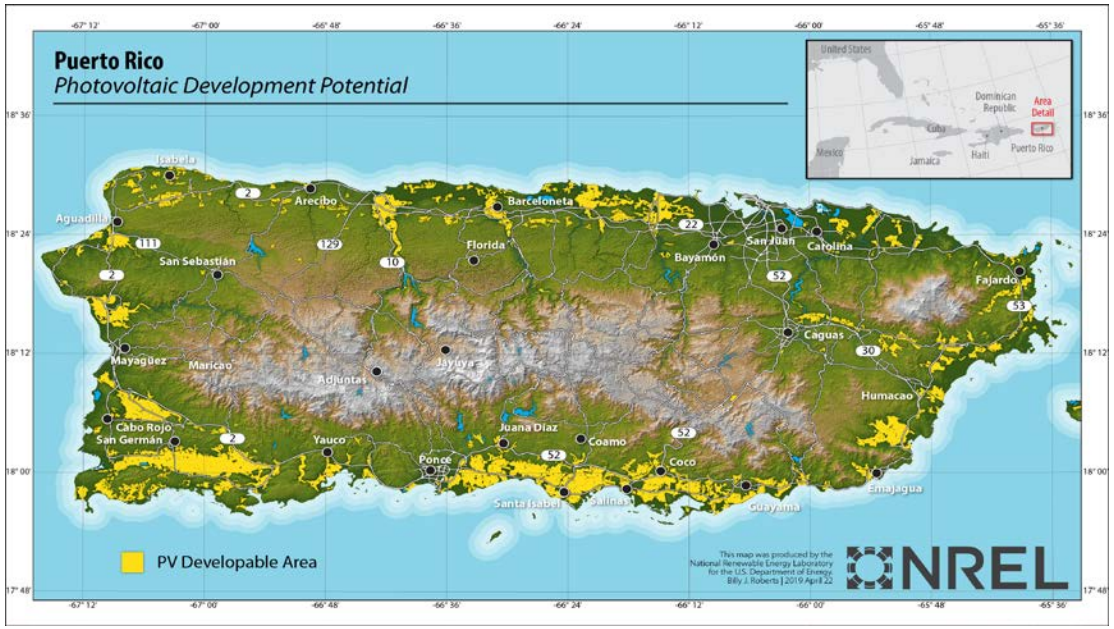
Act 17 2019 requires PREPA to procure the following portions of its power needs through renewable energy:

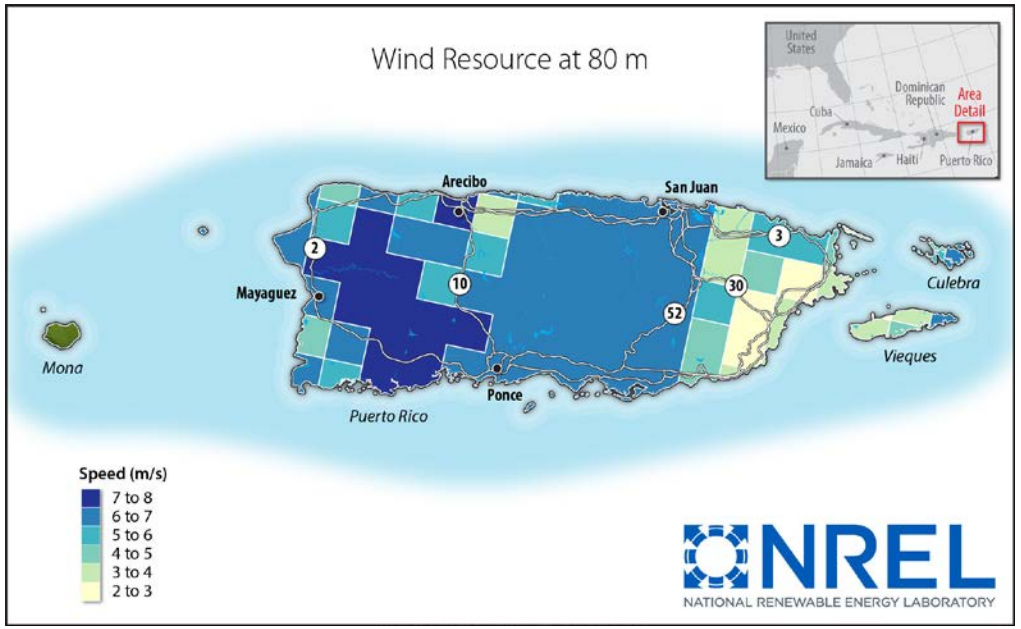


2020 Integrated Resource Plan (IRP)

- **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

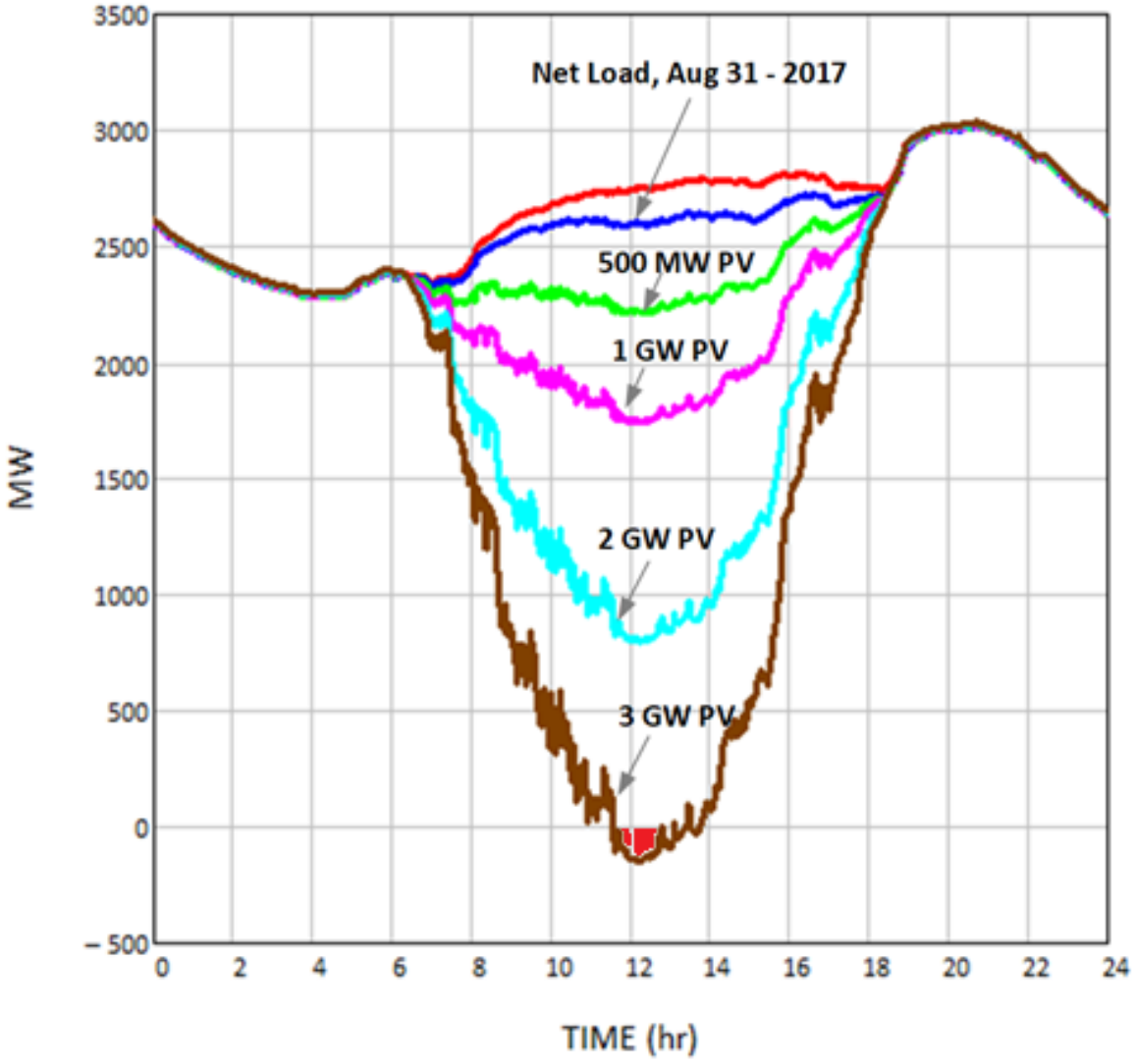
Renewable Resource Potential





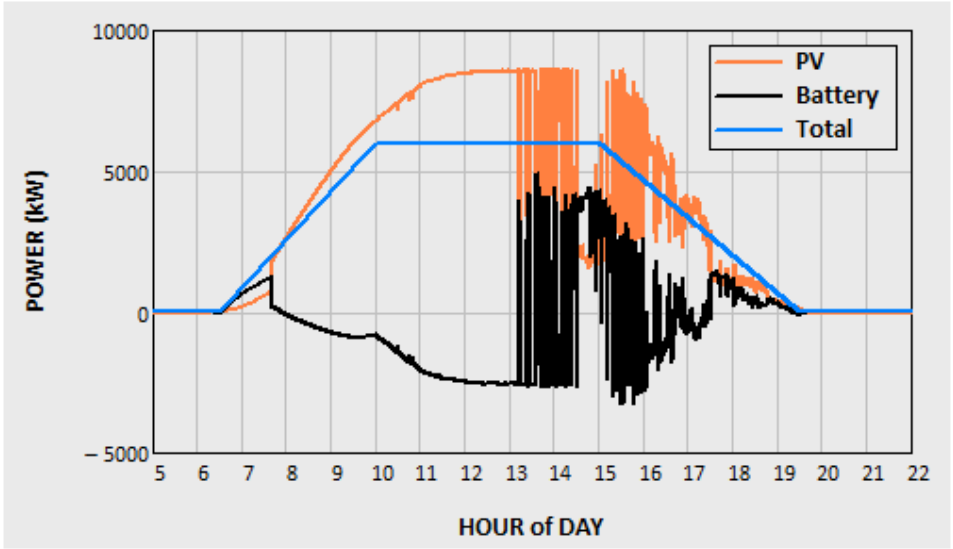
NREL Analysis of Utility-Scale and distributed Solar PV Development Potential Found Greater Than 20 GW Total each.

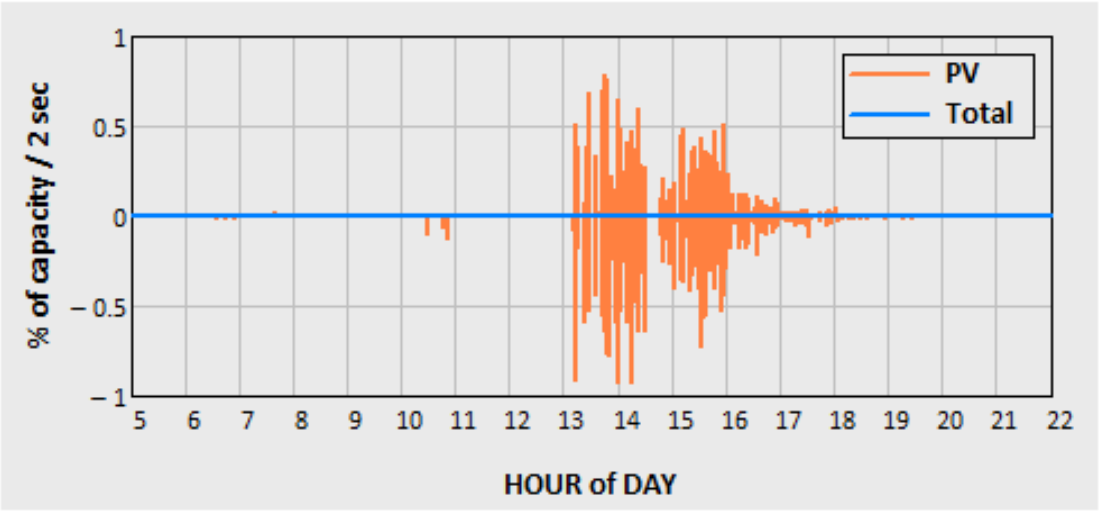
PV-storage plants

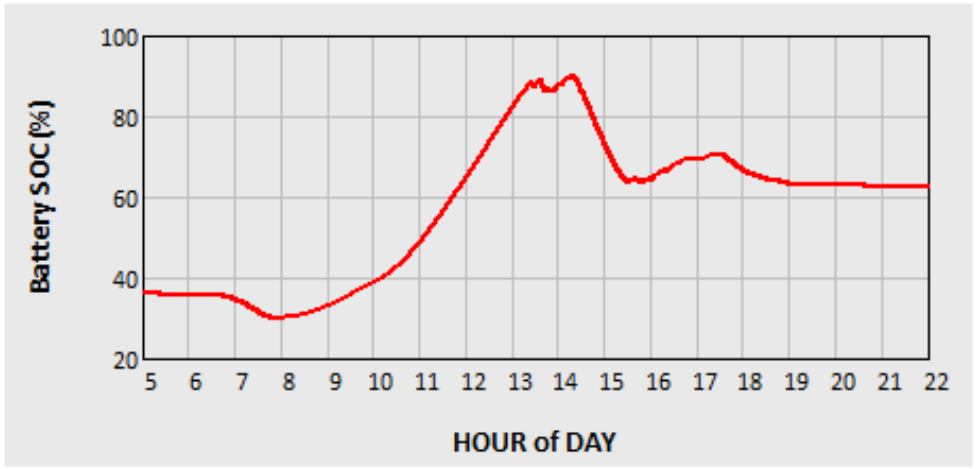


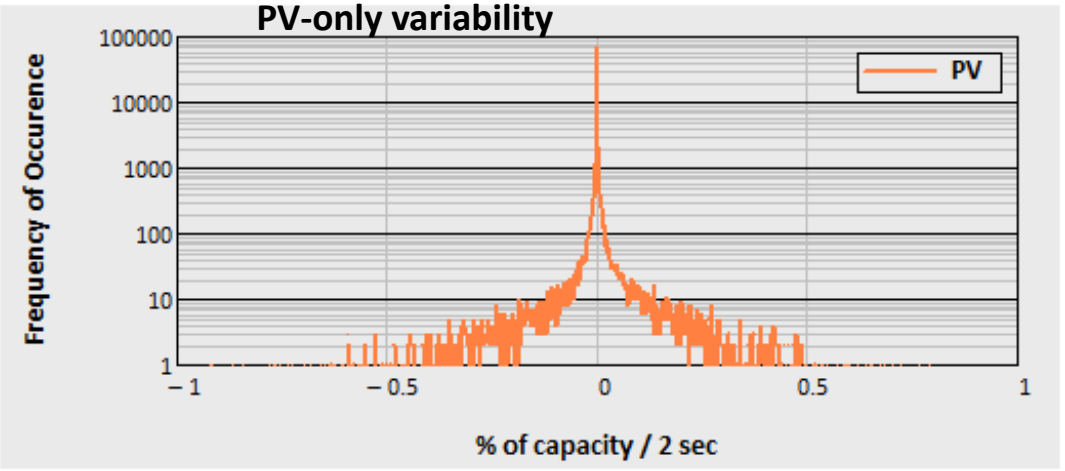
- Provide dispatchability for variable generation in Puerto Rico
- Aggregate ramp limiting, variability smoothing, cloud-impact mitigation on system levels
- Provision of spinning reserves
- AGC functionality
- Renewables forecast error correction services
- Primary frequency response (programmable droop 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)

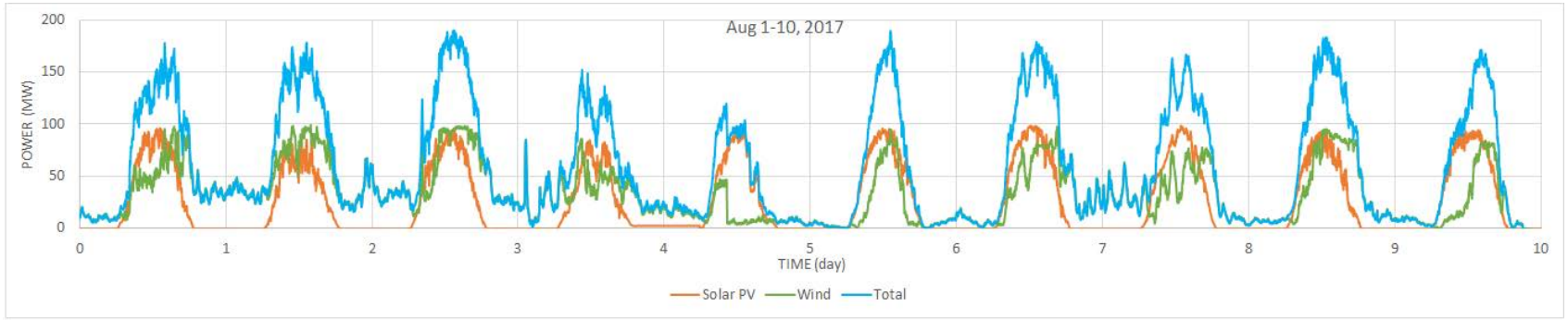


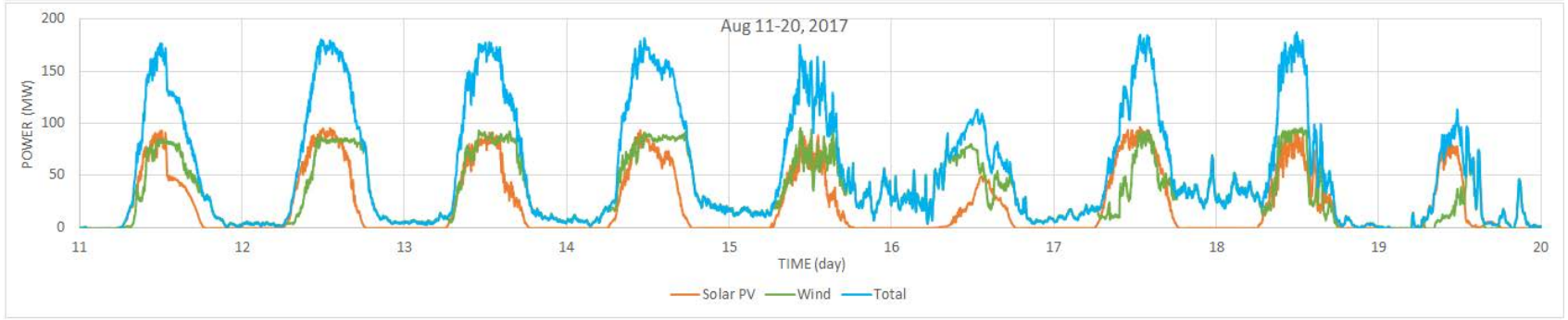


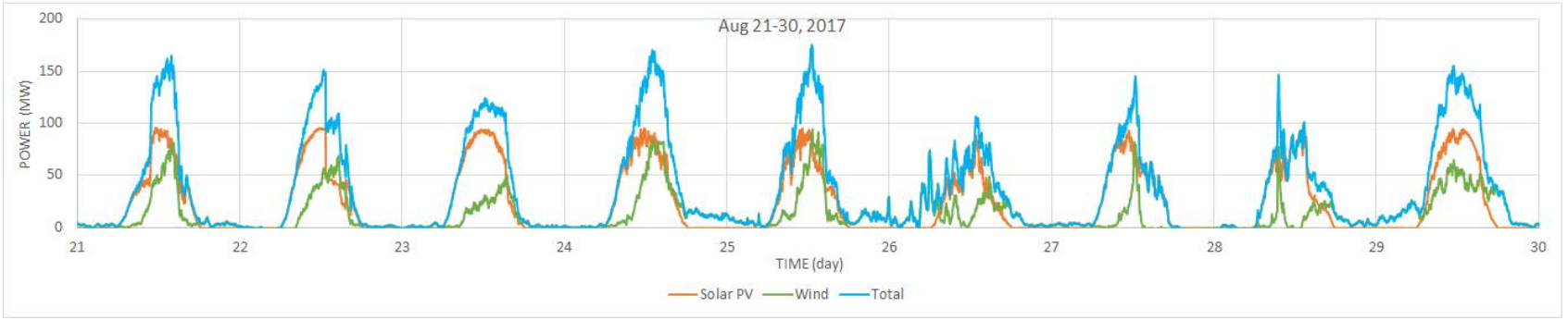




Puerto-Rico Wind and Solar Generation (2-sec data from Aug 2017)



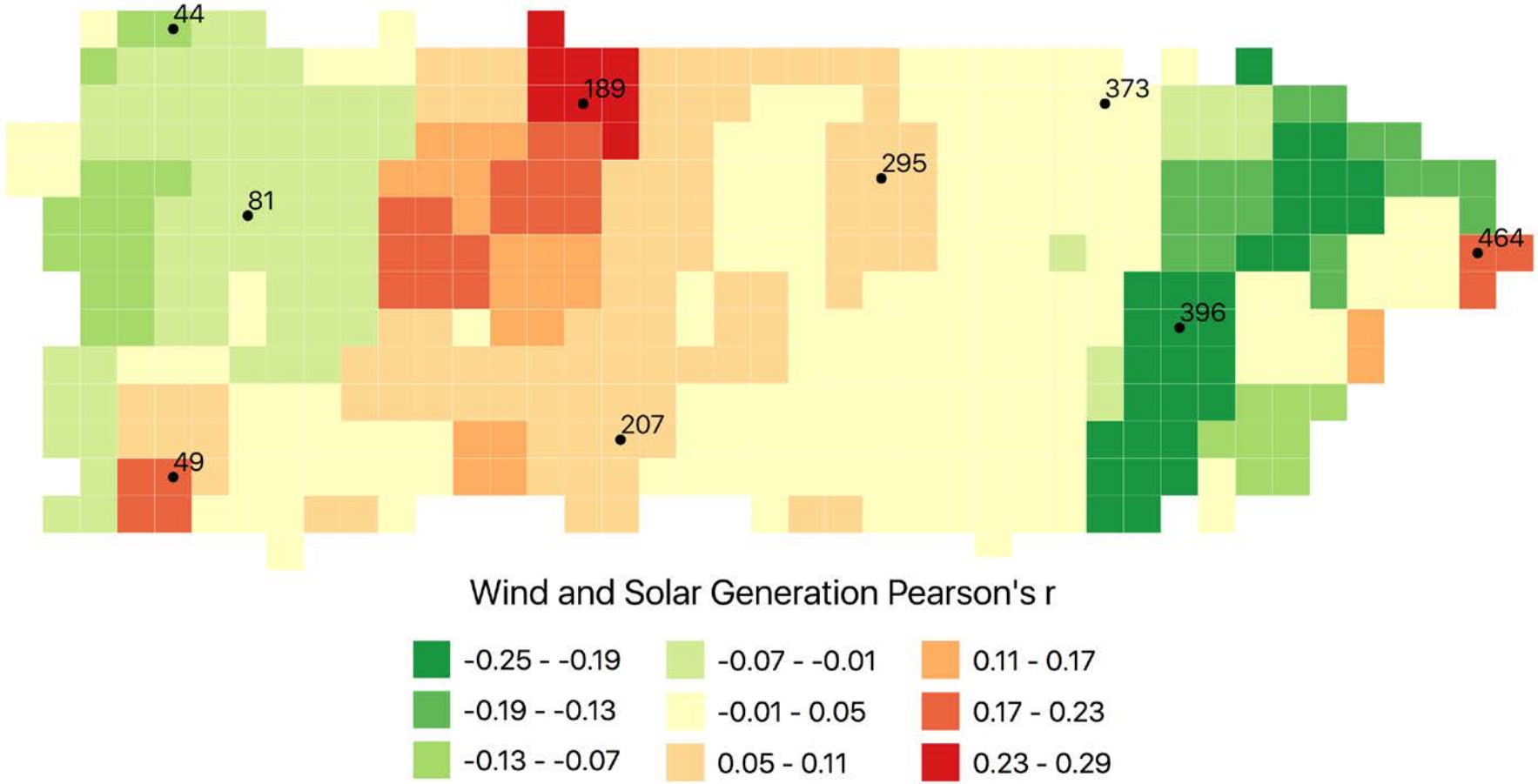




- No temporal complementarity between wind and solar generation is observed (for the existing sites)
- More analysis is needed for identifying hybridization potential in PR

Wind and Solar resource Correlation

negative correlation is good



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:

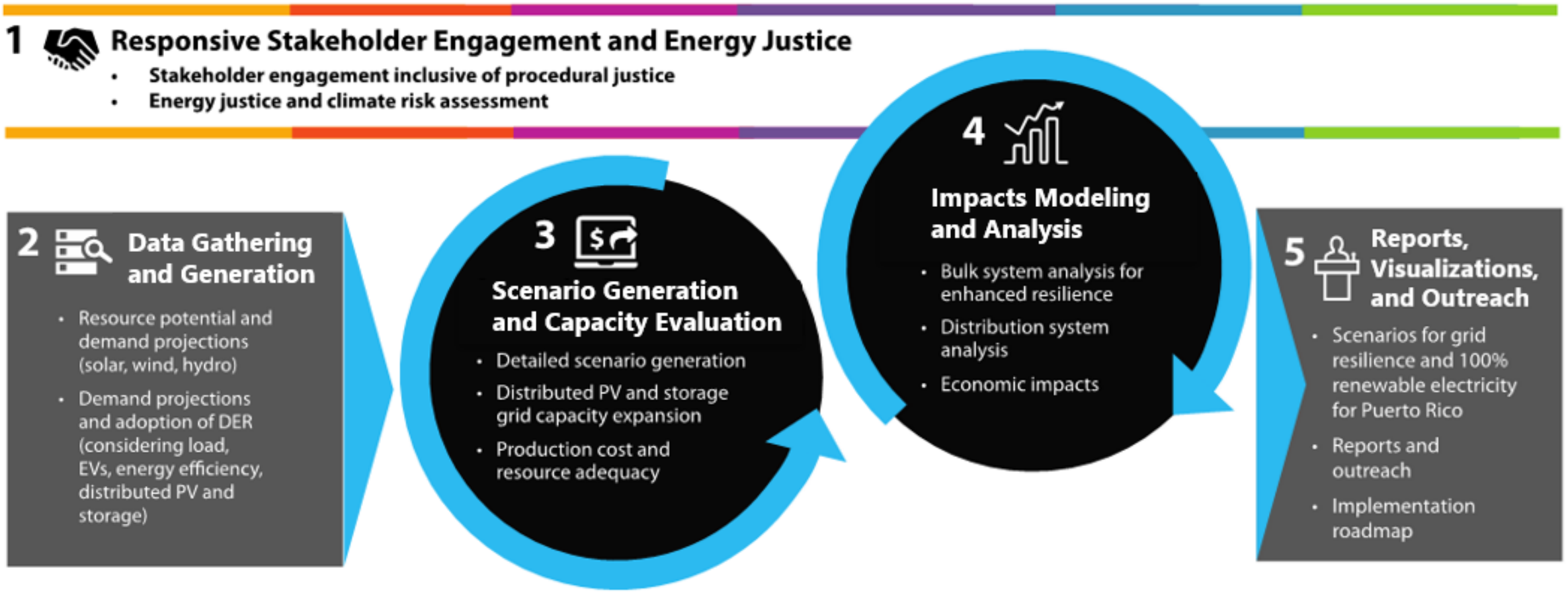
- **Site:** focuses on the area and environment surrounding the PV system.
  - Debris
  - Flooding
- **Mechanical:** concentrates on the structural hardware that secures the PV system.
  - Modules
  - Fasteners
  - Racking
- **Electrical:** follows the path of energy, from the PV modules to its connection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

Photo by Dennis Schroeder, NREL 58003

Distributed Roof-Mounted Checklist

Photos by Don Jenket, Design by Fred Zietz, NREL

Puerto Rico 100% Renewable Energy Study



Questions?

Thank you

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