Sandia National Laboratories

Exceptional service in the national interest

Energy Resilience and Microgrid Opportunities in Puerto Rico and the U.S. Virgin Islands

Matthew Lave, Ph.D.

Renewable and Distributed Systems Integration Group, Sandia National Laboratories

Energy Storage and Microgrids for Energy Resilience and Reliability Webinar Series, Session 3

April 26, 2023

This work is supported by the Department of Energy's Grid Deployment Office (GDO) and the Federal Emergency Management Agency (FEMA).

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

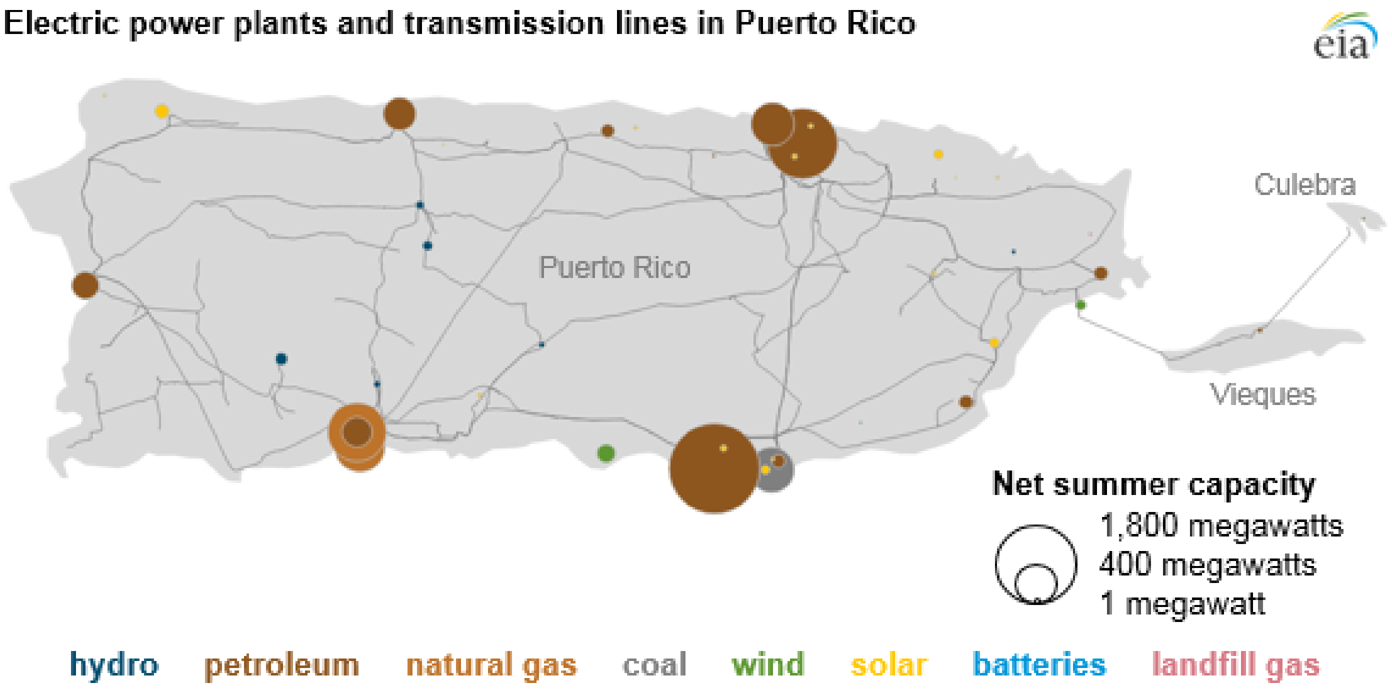
SAND2023-02699PE

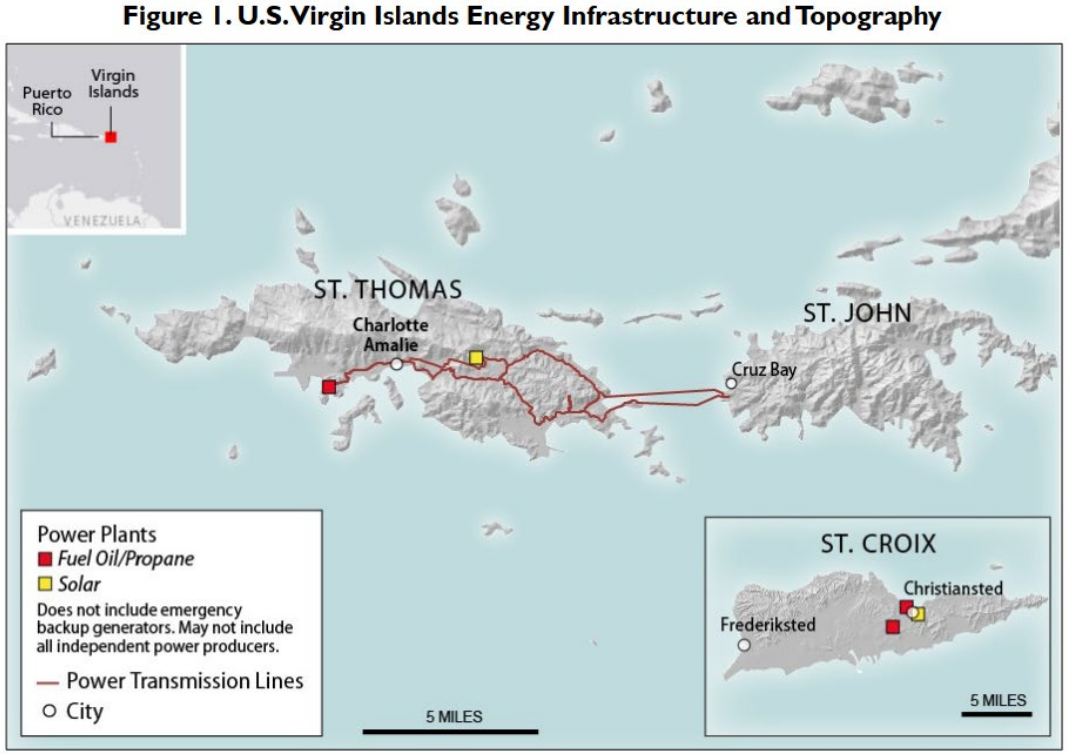
PUERTO RICO AND USVI OVERVIEW

	Puerto Rico	US Virgin Islands	
Population	3,264,000	105,870	
Peak Electric Load	2,036MW	85MW (St. Thomas / St. John)	50MW (St. Croix)

GENERATION AND TRANSMISSION IN PUERTO RICO AND USVI

- In Puerto Rico, majority of electric generation in in the south, while most electric load is in the north.
- In USVI, only one central generation location for each system





from: "EIA adds Puerto Rico data to U.S. power plant inventory" https://www.eia.gov/todayinenergy/detail.php?id=36613

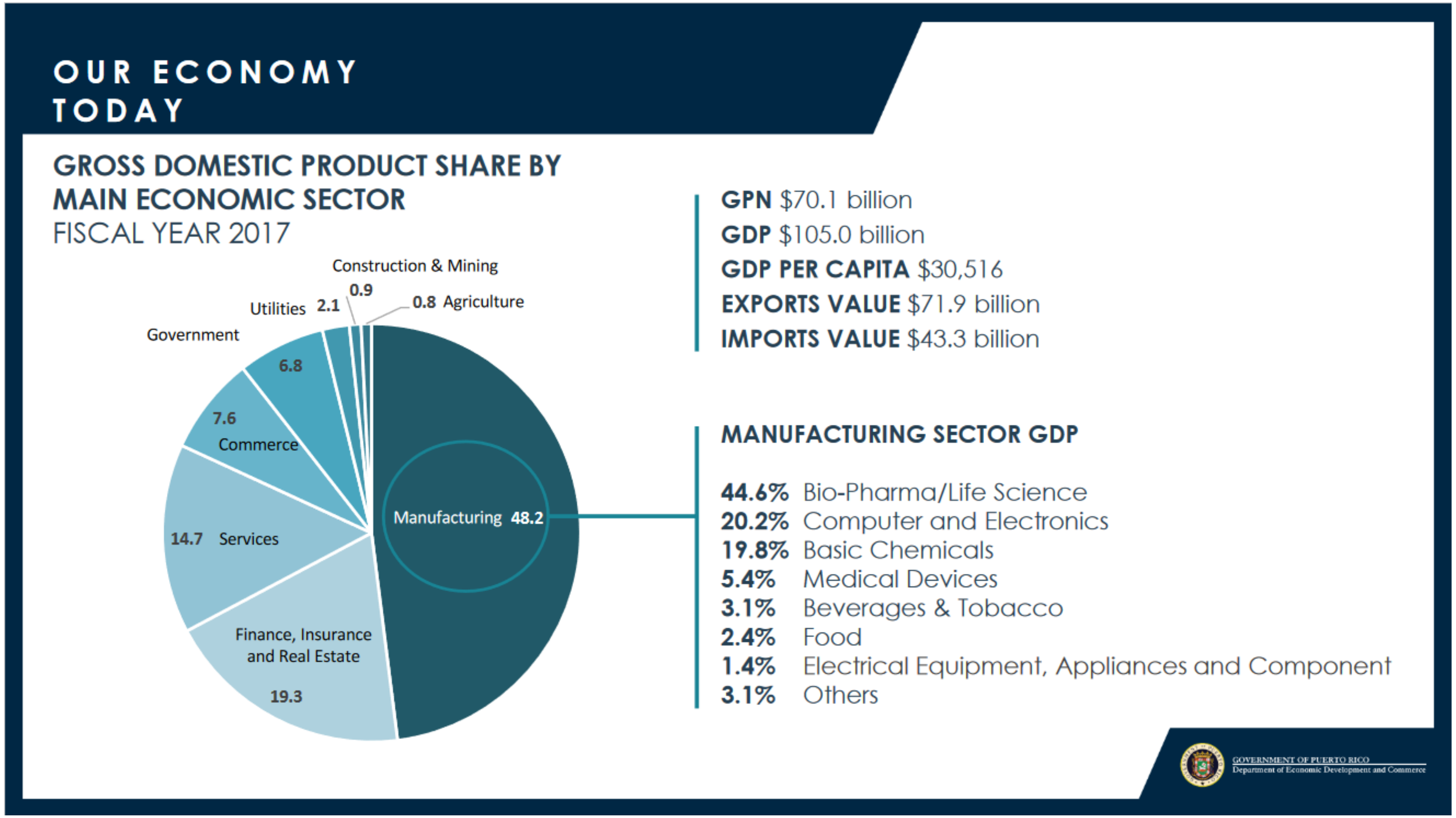
from: "Potential Options for Electric Power Resiliency in the U.S. Virgin Islands" https://sgp.fas.org/crs/row/R45105.pdf

PUSH FOR RELIABLE POWER, USVI

- Blackouts are somewhat common in the USVI
  - One central generation location for each island system – single failures can result in blackout
  - Few large generators with limited spinning reserves
  - Overhead lines are susceptible to damage
- Several residential customers have generators to maintain A/C, refrigeration, etc. during outages
- Several industrial customers has switched to their own generation
  - Resorts
  - Oil refinery
  - Rum distilleries

PUSH FOR RELIABLE POWER, PUERTO RICO

- In 2017, the average outage duration in Puerto Rico was 850 minutes per year…while the average outage frequency was 4.8 events per year.
- In contrast, mainland U.S. customers experienced average outages of 470 minutes per year and 1.4 events per year for the same year.



from: "Renewing Growth in Puerto Rico: Evaluating the Island's Transition to Distributed Solar Energy" https://jpia.princeton.edu/news/renewing-growth-puerto-rico-evaluating-island%E2%80%99s-transition-distributed-solar-energy

from: https://www.ddec.pr.gov/images/PDEI.pdf

PUSH FOR RESILIENT POWER, USVI

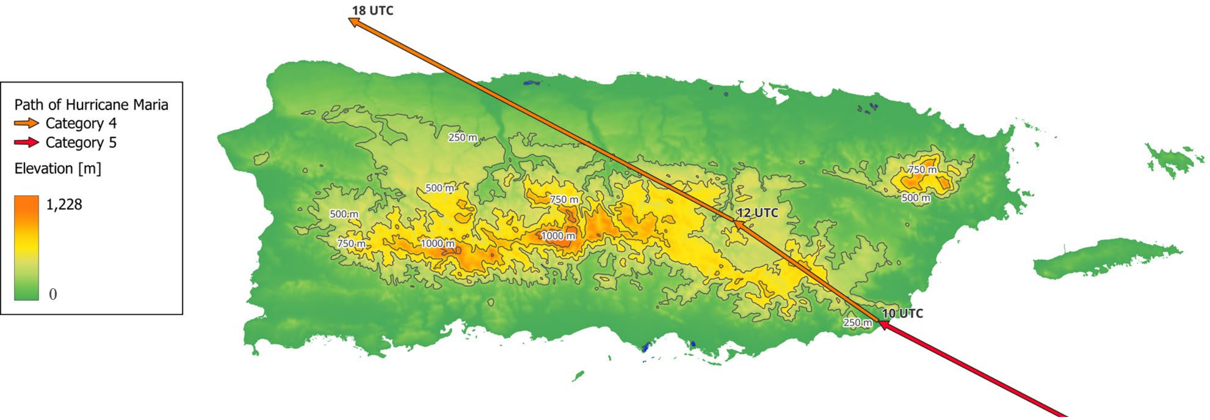
- Hurricanes Irma and Maria stressed the need for not just reliable but also resilient power
  - Nearly 100% of electricity customers lost electricity
  - Electrical transmission and distribution networks in the Territory were significantly damaged: 60% on St. Croix, 80% on St. Thomas, and 90% on St. John.
  - Electricity restored to 100% of eligible customers across the territory by January 2018.
- Companies with their own generation often restored faster
  - The Buccaneer Hotel (St. Croix) reportedly maintained power throughout the Hurricanes and was housing for FEMA responders almost immediately.

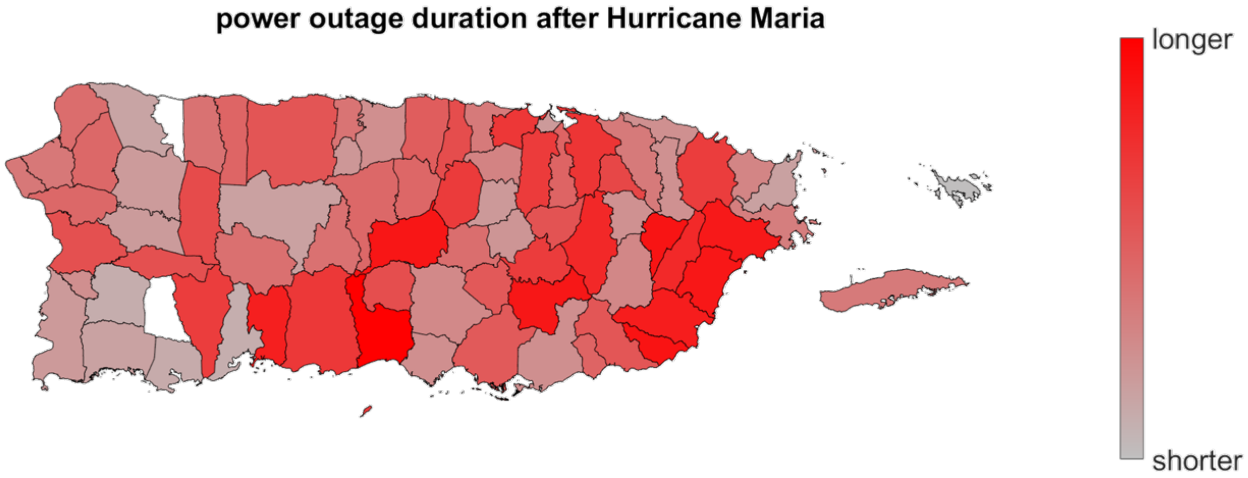
Interdependent Infrastructure Resilience in the U.S. Virgin Islands: Preliminary Assessment https://faculty.nps.edu/dlalders/usvi/NPS-OR-18-005.pdf

PUSH FOR RESILIENT POWER, PUERTO RICO

- Hurricanes Irma and Maria stressed the need for not just reliable but also resilient power
  - It took 328 days, or roughly 11 months, for the island to restore power to all of the customers who lost it during the hurricane, which marked the longest blackout in U.S. history. https://abcnews.go.com/Technology/puerto-ricos-power-grid-struggling-years-hurricane-maria/story?id=90151141
  - Outage restoration took much longer in certain locations, often due to difficult to access areas that needed to be restored (e.g., transmission lines over canyons).

- To support their workers and facilities, some companies provided generators to water treatment plants, sent generators/fuel/supplies home with workers, or even linked building-by-building backup generators into a microgrid





SANDIA EFFORTS TO SUPPORT MICROGRID DEVELOPMENT

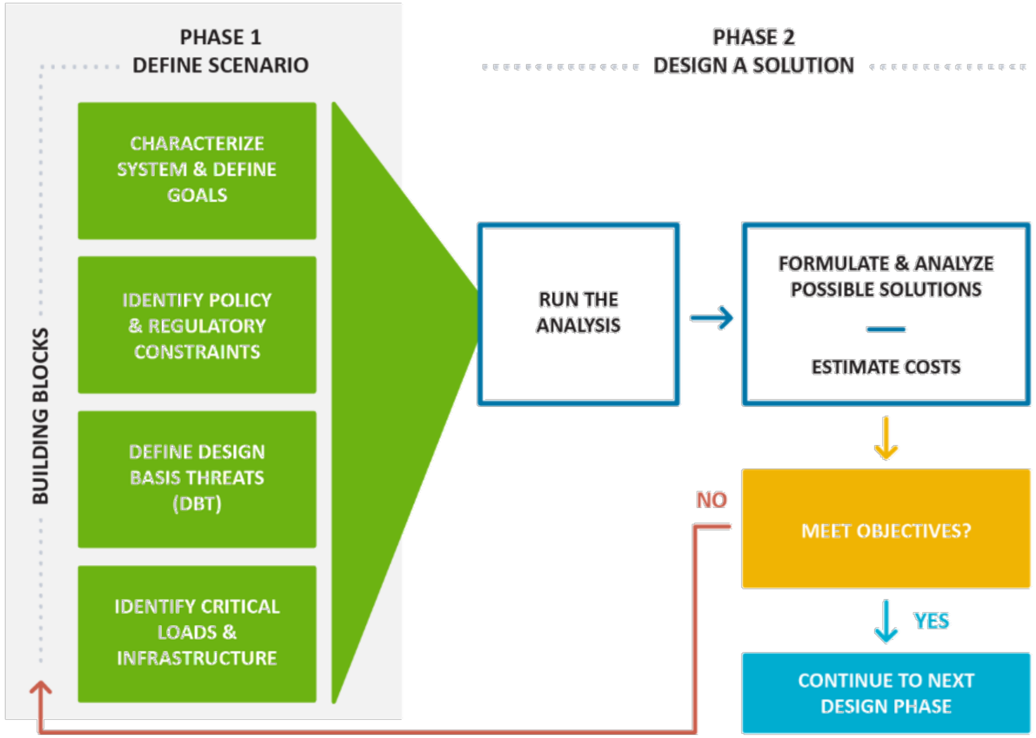
Sandia has developed and applied many tools, methodologies, and analysis to help support microgrid development in Puerto Rico and the US Virgin Islands

Action	Determine if a microgrid is the right solution, and what goals that microgrid should achieve.	Identify where the microgrid should be located and how large it should be to provide the desired critical services.	Find the optimal mix of generation resources to serve the identified critical loads.
Tool	Microgrid Design Methodology guidebook and workshops	Resilience Node Cluster Analysis Tool (ReNCAT)	Microgrid Design Toolkit (MDT)

MICROGRID DESIGN METHODOLOGY

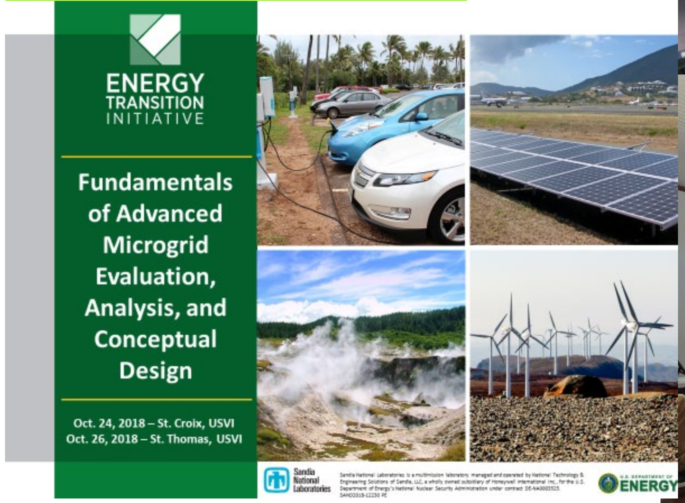
To support development of microgrids to meet community needs, Sandia assembled the Microgrid Conceptual Design Guidebook and presented workshops on the Microgrid Design Methdology.

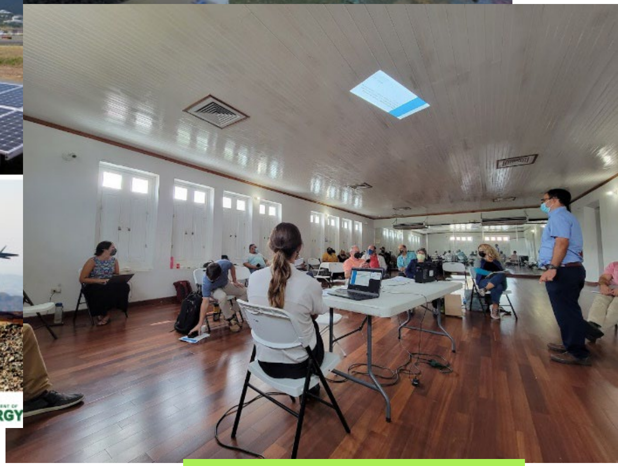
Steps to develop a conceptual design



Culebra, PR

St. Croix and St. Thomas, USVI





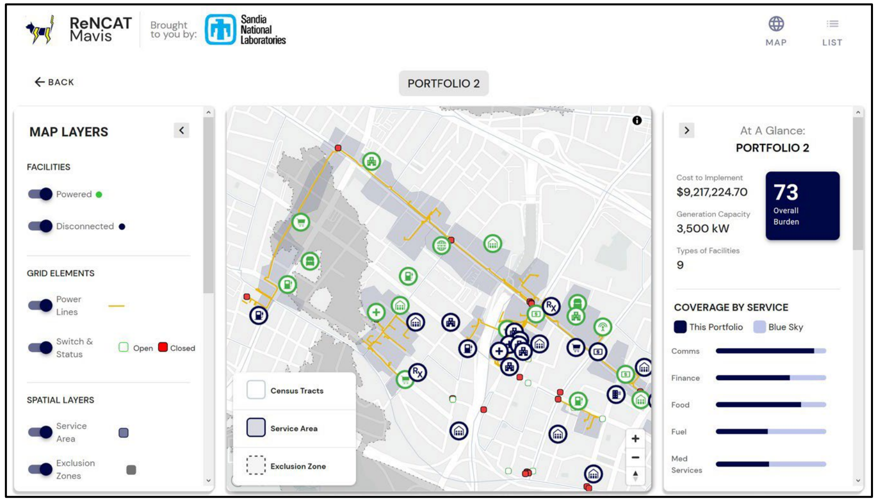
Vieques, PR

RESILIENCE NODE CLUSTER ANALYSIS TOOL (ReNCAT)

ReNCAT (Resilience Node Cluster Analysis Tool) helps identify clusters of critical services. These clusters are candidate locations for microgrids.

Version 1

- Calculation-based tool
- Divides area into grid and sums up service points in each cell to determine potential microgrid locations
- Only considers locations of critical infrastructure and provided services



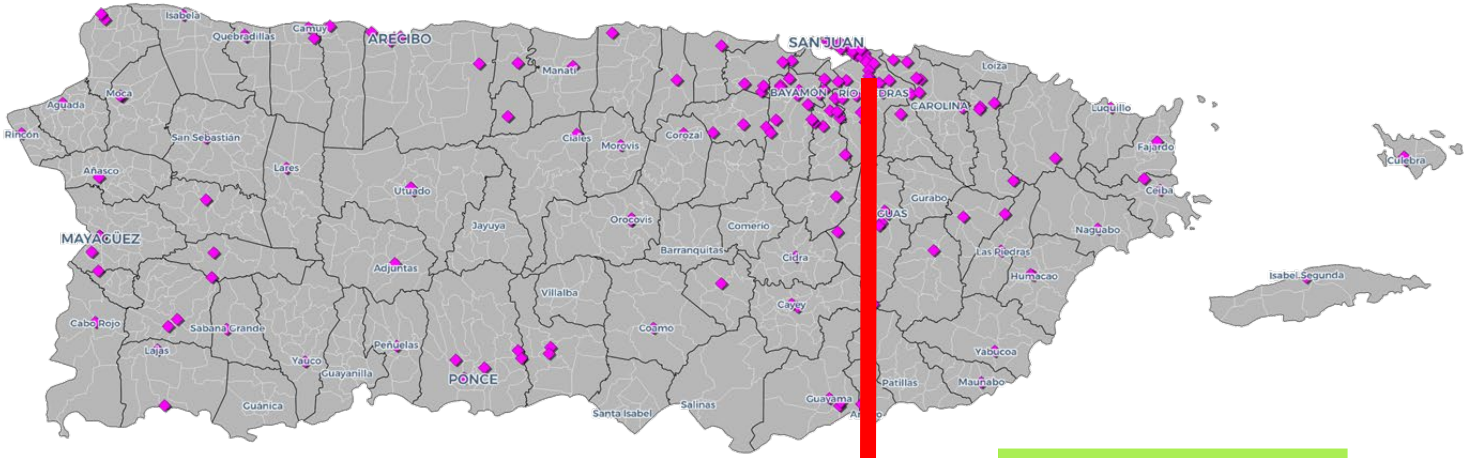
Version 2

- Optimization tool
- Uses distribution system layout and identifies which sub feeders to energize based on critical infrastructure locations and services
- Calculates burden to residents to obtain critical services

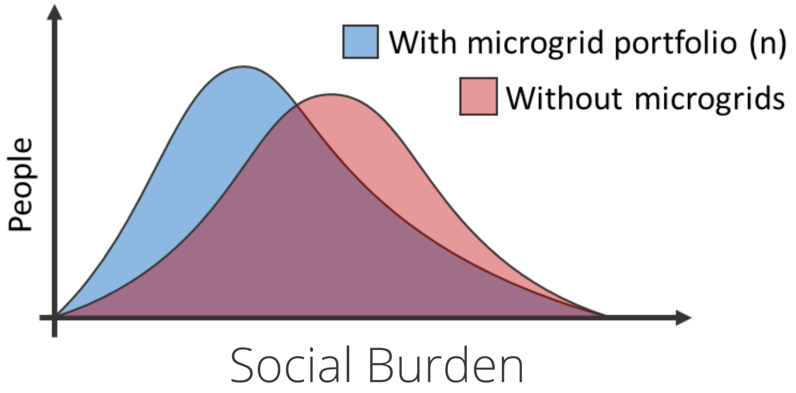
https://energy.sandia.gov/wp-content/uploads/2022/12/ReNCAT_The-Resilient-Node-Cluster-Analysis-Tool.pdf

FINDING VALUABLE LOCATIONS FOR MICROGRIDS WITH ReNCAT

ReNCAT Version 1 was applied to determine a portfolio of 159 microgrids across Puerto Rico that could help reduce the impact to people during and after a power grid outage, as quantified through the social burden metric.



Example ReNCAT microgrid which contains a school that also serves as an emergency shelter.



Social burden is a measure of the amount of effort it takes people to obtain their critical services: food, water, medicine, etc. Higher social burden means more effort expended. The goal of ReNCAT microgrids is to reduce the social burden.

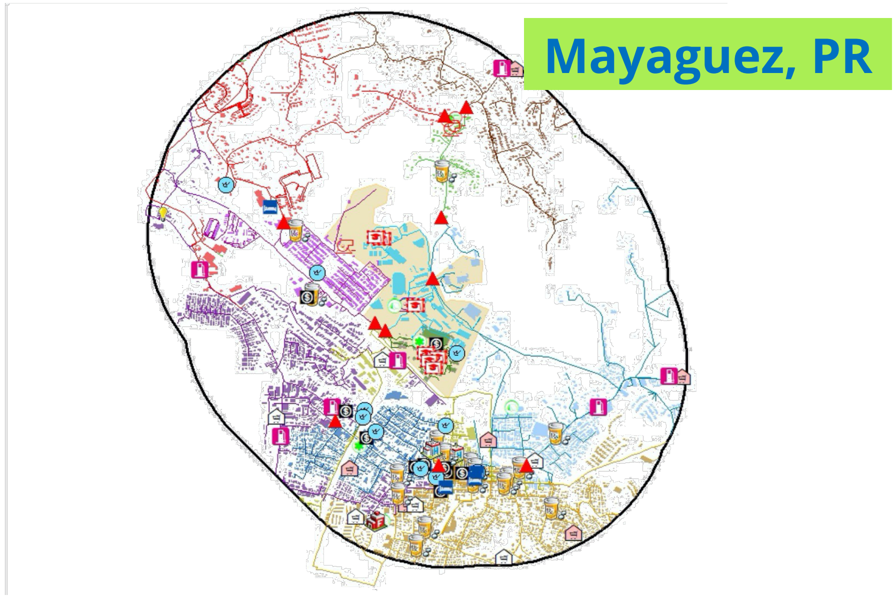
$$social\ burden = \sum_{inf}\sum_{pop}\frac{Effort_{inf,pop}}{Ability_{pop}}$$

inf =infrastructure service categories
pop = population groups

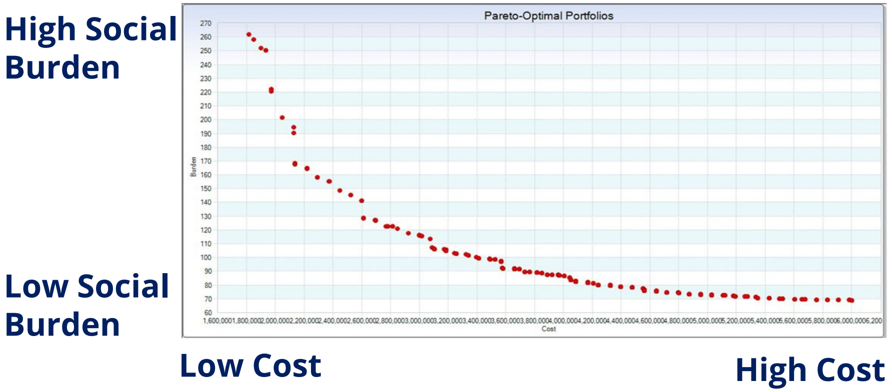
https://www.osti.gov/biblio/1481633-analysis-microgrid-locations-benefitting-community-resilience-puerto-rico

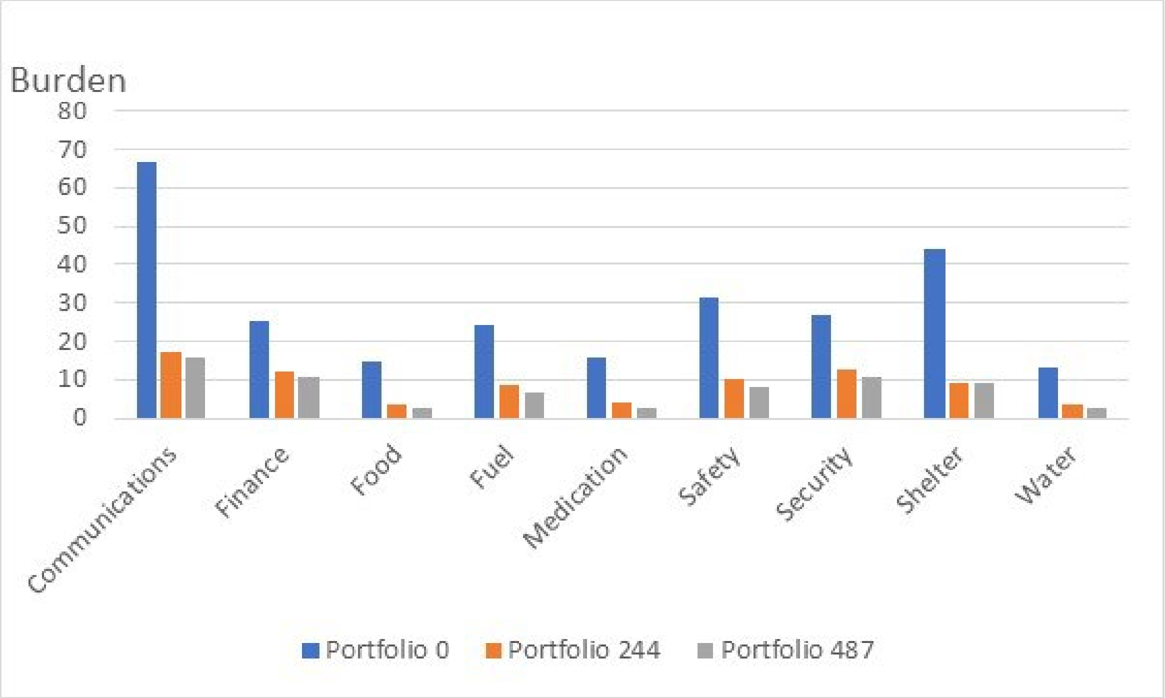
EVALUATING MICROGRID SIZING TRADEOFFS WITH ReNCAT

ReNCAT Version 2 is being applied to understand the tradeoffs between larger microgrid footprints encompassing more critical services but at higher cost, and smaller footprints.



Portfolio	Cost	Burden
0	$1,818,731.23	261.78
244	$4,171,282.91	81.53
487	$6,002,682.91	68.85





Work performed by University of Puerto Rico, Mayaguez under contract with Sandia

IMPACTED AREAS AS CANDIDATES FOR MICROGRIDS


Journal of Renewable and Sustainable Energy

Graph theory and nighttime imagery based microgrid design

Cite as: J. Renewable Sustainable Energy 14, 036302 (2022); https://doi.org/10.1063/5.0083188
Submitted: 22 December 2021 • Accepted: 26 April 2022 • Accepted Manuscript Online: 27 April 2022 • Published Online: 31 May 2022

Melvin Lugo-Alvarez, Jan Kleissl, Adil Khurram, et al.

ARTICLES YOU MAY BE INTERESTED IN

Evaluation of energy storage systems for sustainable development of renewable energy systems–A comprehensive review
Journal of Renewable and Sustainable Energy 14, 032702 (2022); https://doi.org/10.1063/5.0075623

Data-driven fluid mechanics of wind farms: A review
Journal of Renewable and Sustainable Energy 14, 032703 (2022); https://doi.org/10.1063/5.0091980

Techno-economic assessment of application of particle-based concentrated solar thermal systems in Australian industry
Journal of Renewable and Sustainable Energy 14, 033702 (2022); https://doi.org/10.1063/5.0086655

APL Machine Learning
Open, quality research for the networking communities
Now Open for Submissions
LEARN MORE

AIP Publishing

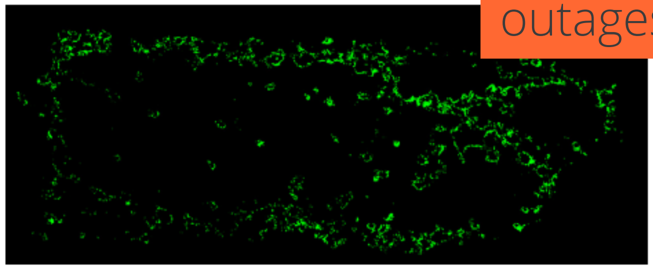
J. Renewable Sustainable Energy 14, 036302 (2022); https://doi.org/10.1063/5.0083188 14, 036302

© 2022 Author(s).

https://aip.scitation.org/doi/full/10.1063/5.0083188

Work performed by University of California, San Diego under contract with Sandia

outages



population

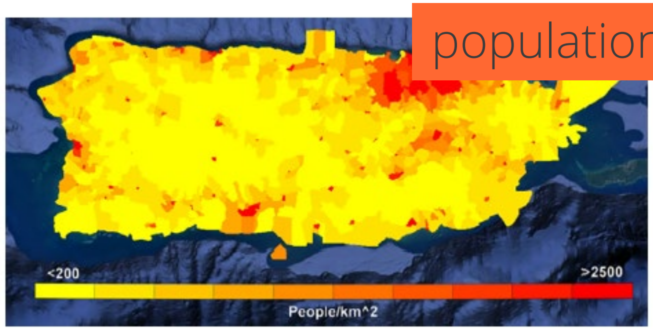
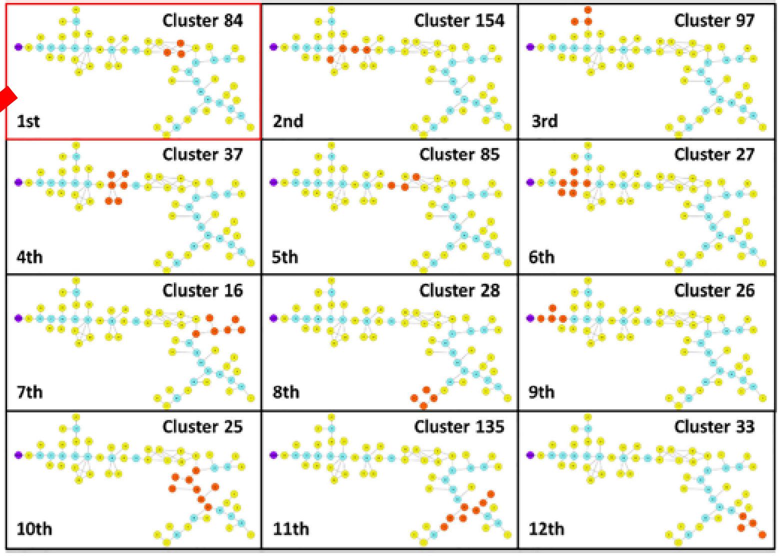


TABLE I. Decision matrix for asset scoring.

Score	Asset type	System load size	Accessibility	Photovoltaic potential
5	Radio, water, telecom, shelters, super-markets, restaurants, fuel	<10 kW	More than one paved access point in good condition requiring no special vehicles for access	>=135% of Load
4	Healthcare facilities	<50 kW	Single paved access point in good condition (e.g., dead-end road, cul-de-sac) requiring no special vehicles for access	<135% of Load
3	Police stations, firefighting stations, other emergency personnel	<100 kW	Well maintained unpaved access point(s), requiring an off-road capable vehicle for access	<100% of Load
2	Govt. offices, courthouses, schools, postal offices, public buildings	<500 kW	Paved or unpaved access point(s) are in poor condition	<75% of Load
1	Places of worship, private businesses	<1 MW	Access point(s) are susceptible to damage or danger (e.g., areas prone to flooding, landslides, black ice)	<50% of Load
0	Residential loads	>1 MW	Requires special vehicle for access (all-terrain vehicle, amphibious, aircraft) regardless of access point status	<25% of Load

Jayuya, PR

FIG. 13. Map of cluster 84 containing assets 19, 20, 21 and no interconnection points. The orange line is the common circuit line. The orange polygons are asset roof areas.



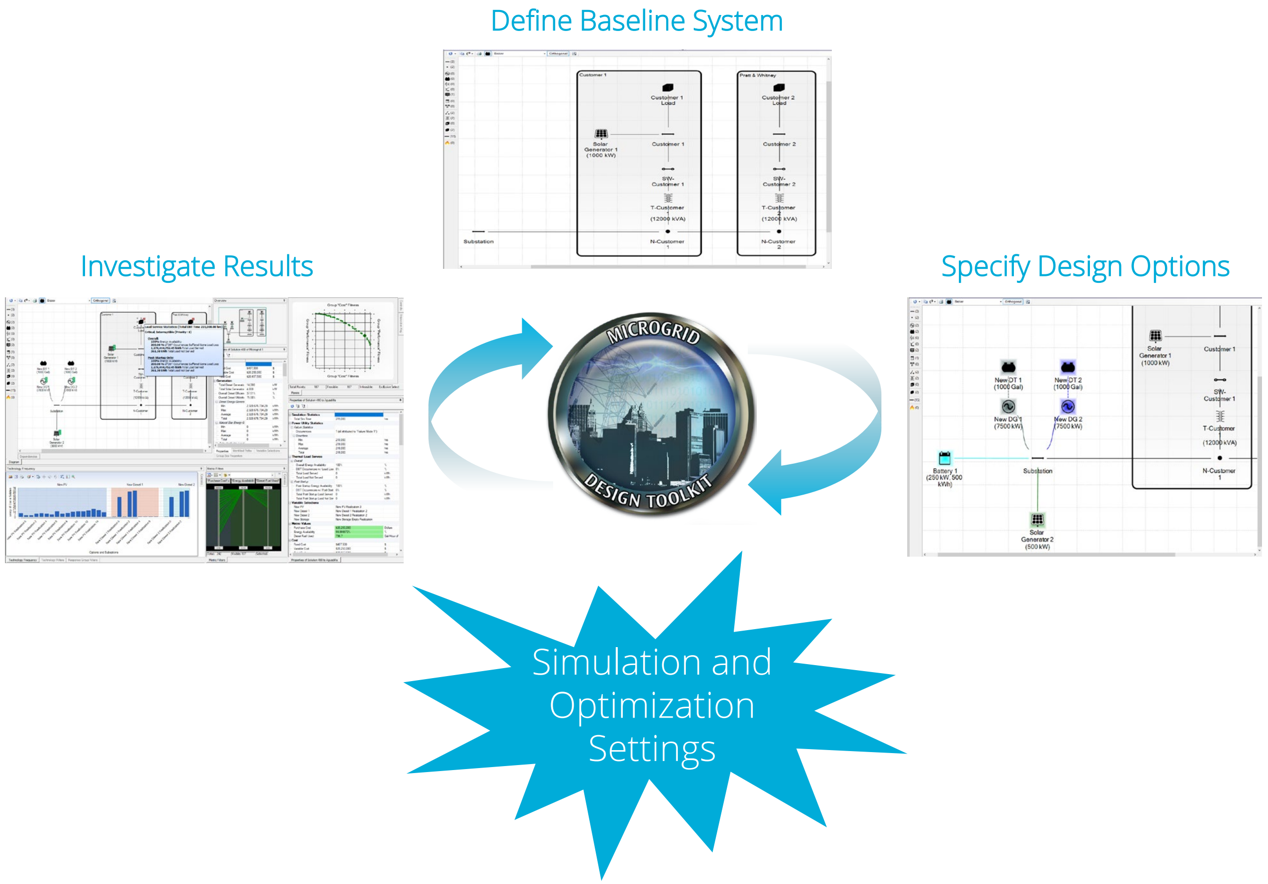
MICROGRID DESIGN TOOLKIT (MDT)

MDT is a visual design and trade-space optimization capability for microgrids.

- Runs a **multi-objective optimization** algorithm to characterize performance and reliability of candidate microgrid designs.

Using the MDT, a designer can:

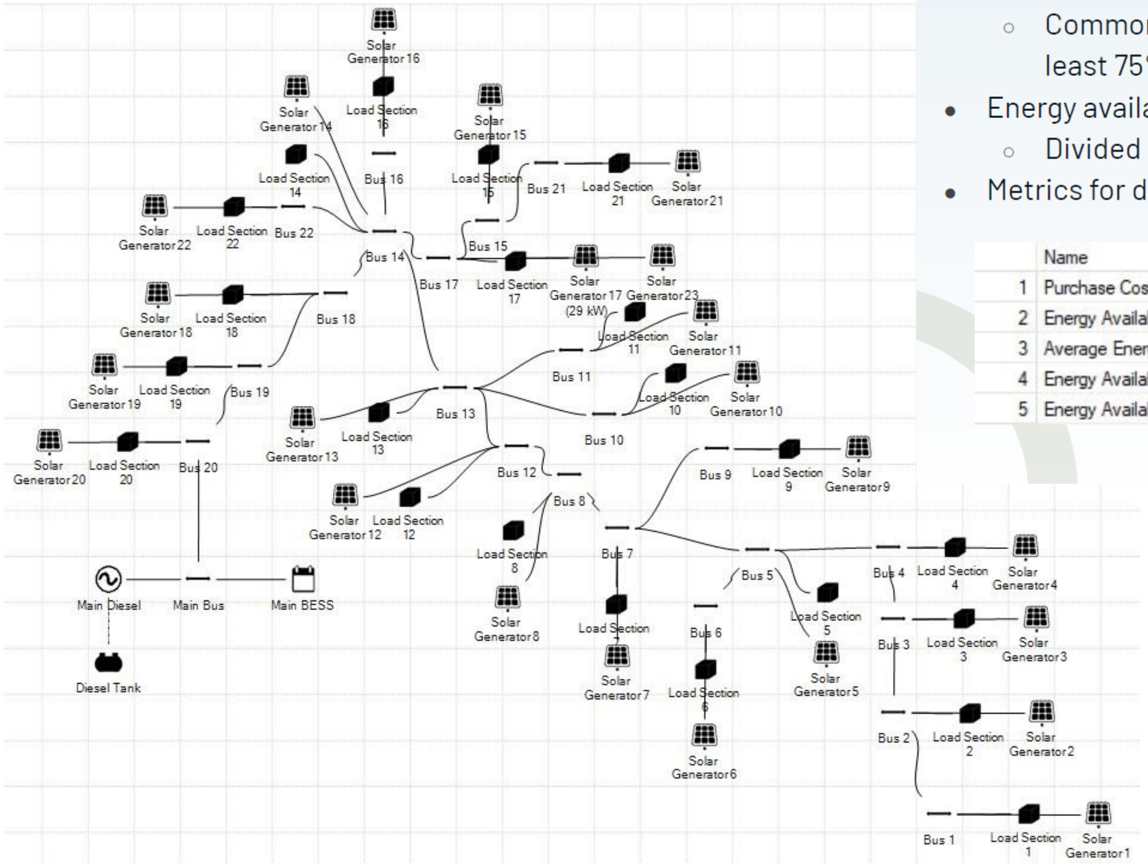
- Effectively search through **very large design spaces** for efficient alternatives
- Gain a quantitative understanding of the **trade off relationships** between design objectives (cost and performance for example).
- Identify "no brainer" choices to **reduce the number** of design considerations
- Perform **what-if analysis** by altering the input without loss of information to include or not include certain features in a run of the solver
- Perform hypothesis testing by **manually generating solutions and comparing** to the solutions found by the MDT



https://energy.sandia.gov/download-sandias-microgrid-design-toolkit-mdt/

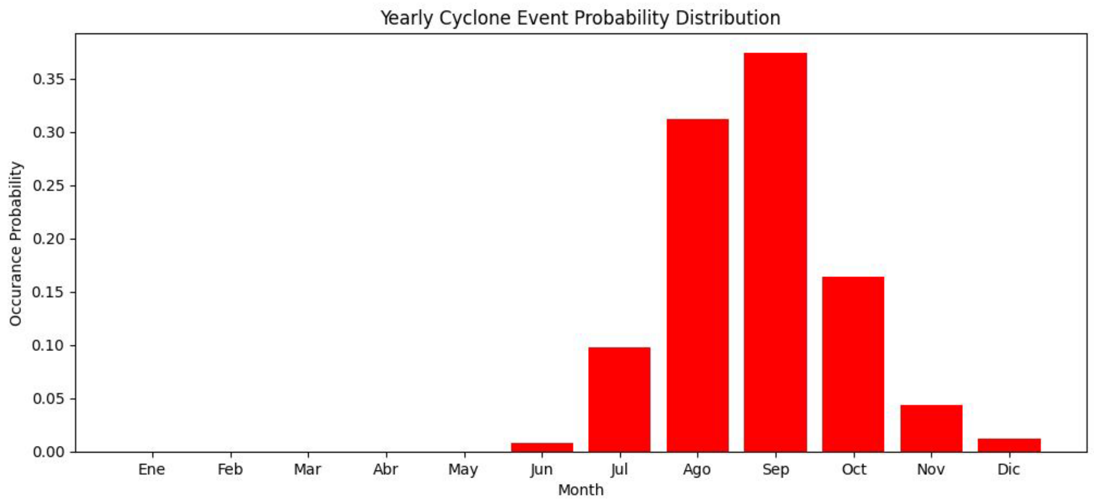
MDT APPLIED IN PUERTO RICO

Community Microgrid in PR



- Cost metrics.
  - The community was assigned $1.2 million.
- Average energy supplied by renewables.
  - Commonly considered that a microgrid is considered renewable if the average DER penetration is at least 75%.
- Energy availability.
  - Divided into different importance categories.
- Metrics for diesel will also be included.

	Name	Selected	Units	Improvement Type	Limit	Objective	Relative Importance	Limit Stiffness
1	Purchase Cost	☑	Dollars	Minimize	1100000	750000	1	Medium
2	Energy Availability (Residencia	☑	%	Maximize	75	90	1	Medium
3	Average Energy Supplied by R	☑	%	Maximize	80	100	1	Medium
4	Energy Availability (Comercios)	☑	%	Maximize	80	95	1	Medium
5	Energy Availability (Acueducto	☑	%	Maximize	95	99	1	Medium

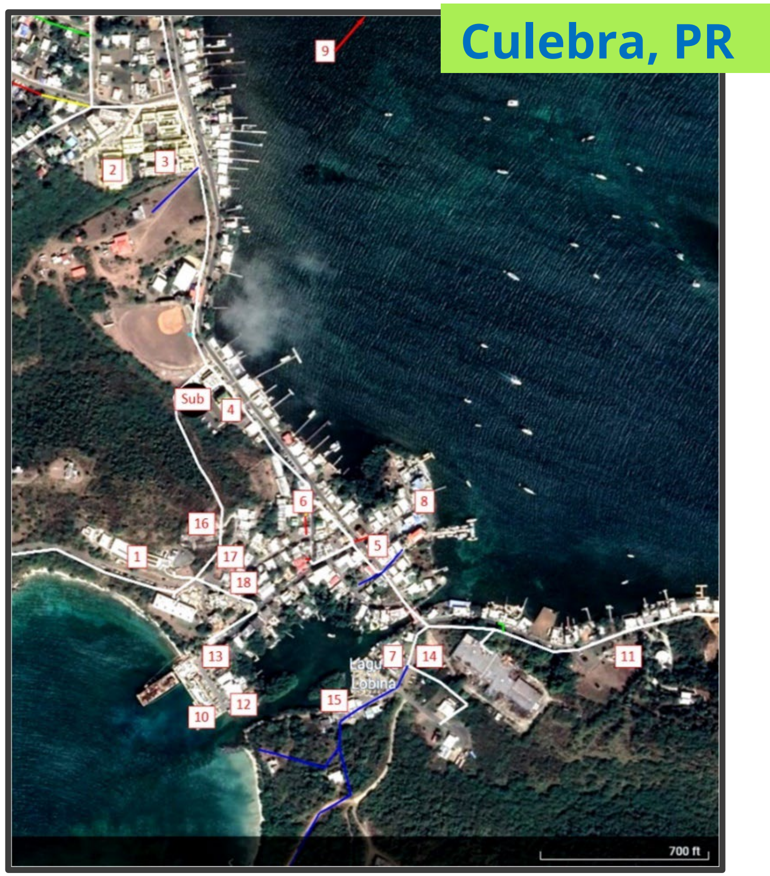


Work performed by University of Puerto Rico, Mayaguez under contract with Sandia

MDT APPLIED IN PUERTO RICO

Summary of Initial Findings

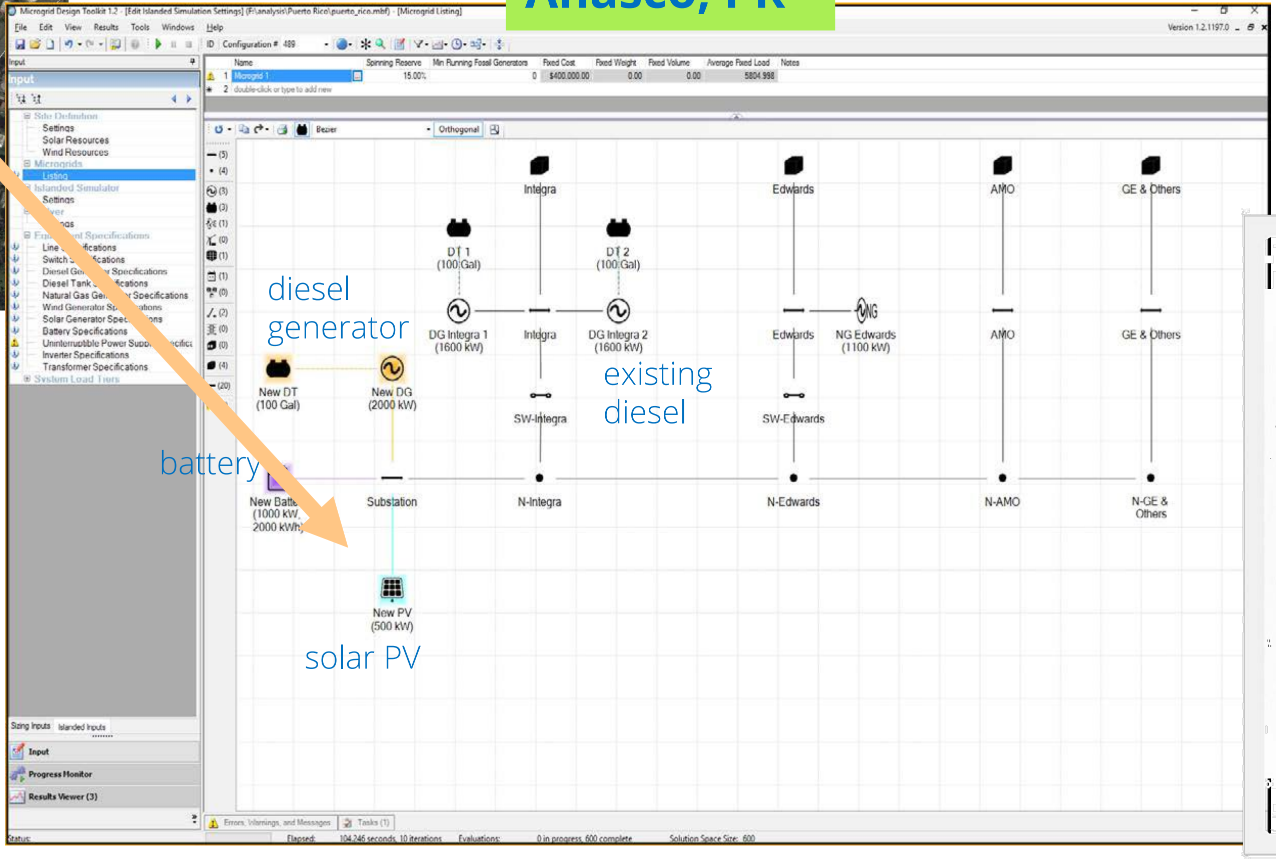
- Combinations of solar PV, batteries, and existing diesel generators were evaluated
- Costs may be reduced if more diesel is used, but there are resulting performance tradeoffs such as higher emissions, fuel supply risk, increased maintenance, etc.
- Similarly, costs may be reduced if energy availability is reduced (i.e., if some outages are permissible)
- System sizing, especially for solar PV must be considered in locations such as Culebra where flat land is extremely limited and there are competing uses

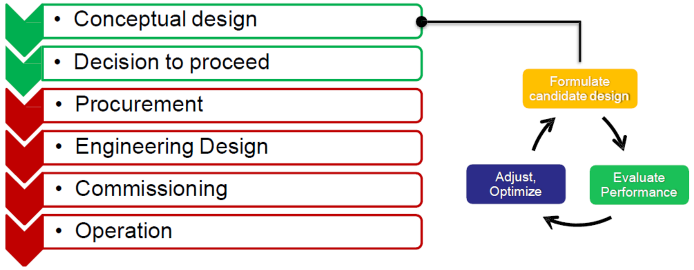


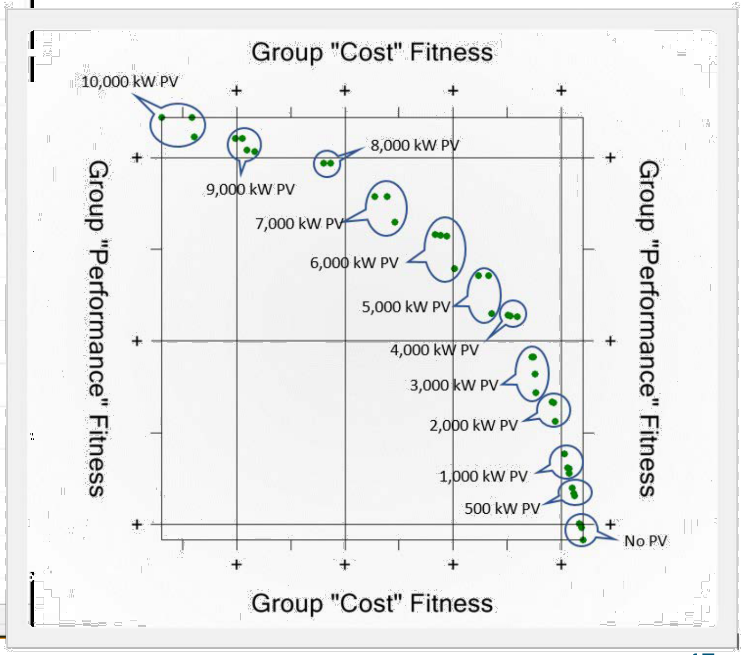
MDT APPLIED IN PUERTO RICO

MDT used to help design industrial microgrids in Puerto Rico to prepare for an RFP process.

Anasco, PR







https://www.osti.gov/servlets/purl/1640919

SUMMARY

- Microgrids can be an appealing option in vulnerable island areas to improve reliability and resilience
- Microgrids solutions should be designed deliberately
  - Define and iterate on goals, threats, and constraints
  - Identify microgrid locations which include high value critical services
  - Optimize the portfolio of generation resources to best meet the objectives including cost and performance
- Sandia tools and methodologies can be used to help understand the tradeoffs of various microgrid options.
- While this presentation focused on applying these tools in Puerto Rico and the US Virgin Islands, they can be easily applied to other locations.