SAND2026-25709PE

Virtual Webinar

An Assessment of Wind-Hybrid Microgrids Using Sandia's Microgrid Design Toolkit (MDT)

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Presenter Introduction

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Areas of interest

- Grid resilience, distributed energy resource integration, distribution system power flow analysis, and other grid related studies

Education/Licensure

- Professional Engineer License – 2012
- Masters of Science, Electrical Engineering, New Mexico State University – 2005
- Bachelors of Science, Electrical Engineering, New Mexico State University – 2004

Agenda

1. **Background and Introduction**
2. **Hybrid Microgrid Design Analysis**
    1. Methodology Overview
    2. Microgrid Boundaries
    3. Renewable Resource Assessments (Wind & PV)
    4. Microgrid Design Toolkit (MDT) Analysis and Results
3. **Hybrid Microgrid Spatial Analysis**
    1. Spatial Analysis Objective
    2. Wind Turbine Models and Foundation Footprints
    3. Detailed Case Study
    4. All Cases Results Overview
4. **Q&A**

Background

History: Puerto Rico's reliance on a centralized grid has proven vulnerable, especially to natural disasters like Hurricane Maria. Microgrids, particularly hybrid ones, have emerged as a crucial solution for enhancing energy resilience and sustainability on the island [1].

Outage Example – Hurricane Maria (2017):

- *Hurricane Maria was a category 5 hurricane that hit Puerto Rico on September 20, 2017, knocking out power to 100% of Puerto Rico's electric customers [2].*

Need for Resilience: The frequent power outages and long recovery times following disasters underscore the need for localized, independent power systems that can operate autonomously.

Impact Examples – Post-Hurricane Irma and Maria (2018):

- *Following Hurricane Irma, which struck Puerto Rico in September 2017 shortly before Hurricane Maria, power was restored to 99% of customers by August 2018 after being out for nearly 11 months in many areas [3].*
- *The aftermath of these storms caused approximately 2,975 indirect fatalities [4].*

Introduction

- Puerto Rico has approximately **400 MW of installed PV capacity [5]**, driven by high solar irradiance and ease of deployment.
- Wind energy adoption is more limited, with about **100 MW of installed wind capacity [6]**, but interest and investment are increasing.
- Diversifying the energy mix with wind supports **resilience and sustainability** objectives outlined in Puerto Rico's Integrated Resource Plan [7].
- This study focuses on integrating wind, PV, and battery energy storage systems (BESS) for conceptual hybrid microgrid designs using Sandia's **Microgrid Design Toolkit (MDT) [8]**.
- **Spatial analysis** complements the MDT energy and cost optimization by addressing land use constraints.

Hybrid Microgrid Design Analysis

Hybrid Microgrid Design Analysis Methodology Overview

- Selected candidate microgrid **sites with high wind potential** using meteorological data from CariCOOS, NOAA, and NDBC [9].
- **Solar resource** was assessed using National Laboratory of the Rockies (NLR) PVWatts online tool [11].
- Developed **microgrid boundaries** including critical and residential loads using GIS building data and consumption factors [12].
- Generated hourly **load demand profiles** per building type via NLR's REopt tool [13] and local survey data.
- Performed **MDT optimization** for six cases per site varying wind capacity (0% to 100%) combined with PV and BESS.
- Evaluated **trade-offs** in BESS sizing, PV and Wind capacity, and cost to identify optimal conceptual microgrid designs.

SUMMARY OF METEOROLOGICAL STATIONS OF INTEREST

Location	Station	Latitude	Longitude	Height (m)
Las Mareas	XMRS	17.9286	-66.1597	8.8
San Juan	SJNP4	18.4589	-66.1164	15
Fajardo	XREY	18.2894	-65.6320	13.4
Vieques	ESPP4	18.0939	-65.4714	8.5
Arecibo	AROP4	18.4806	-66.7022	6.4
Aguadilla	XAGU	18.4330	-67.1566	4.3
Yabucoa	YABP4	18.0550	-65.8331	6.4
Mayaguez	MGZP4	18.2175	-67.158889	8.4

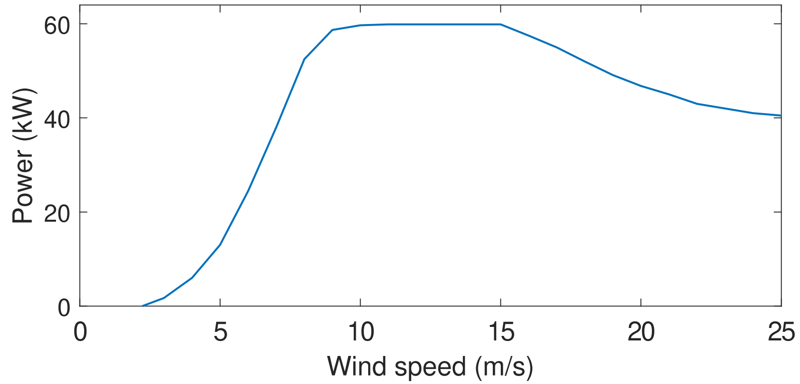
Wind Speed Resource Assessment

To estimate wind power production, the power curve of a commercially available NPS 60C-24 [14] wind turbine was used to convert wind speed data into energy.

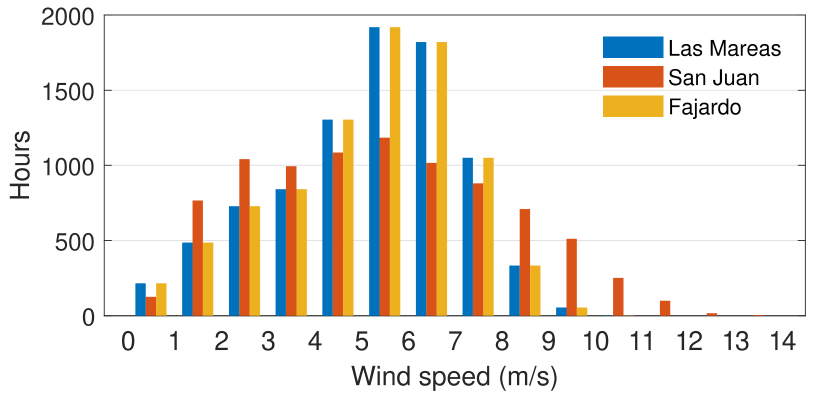
The annual wind energy generation estimation and capacity factor at each location.

- *The capacity factor is a metric that quantifies the actual electricity generation of a power plant or a group of generators over a specific period. It is calculated by dividing the annual generation by the product of the capacity and the number of hours in that period.*

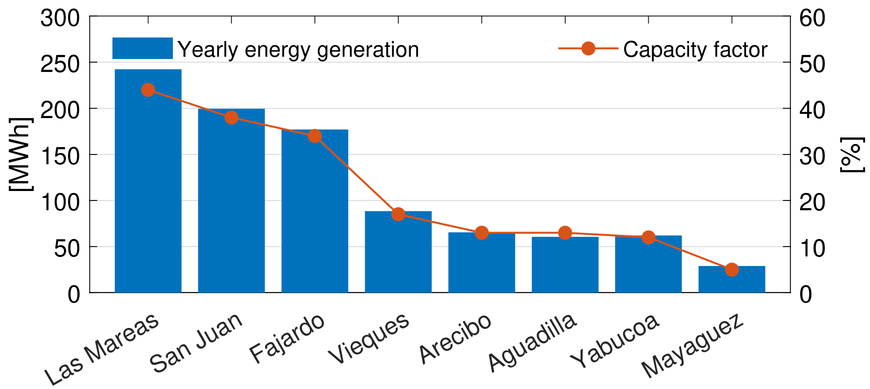
Las Mareas, San Juan, and Fajardo turn out to be the top three locations yielding rich wind resources, with capacity factors of approximately 45%, 38%, and 34%, respectively.



Power curve of the wind turbine generator NPS 60C-24.



Wind speed distribution at selected sites.

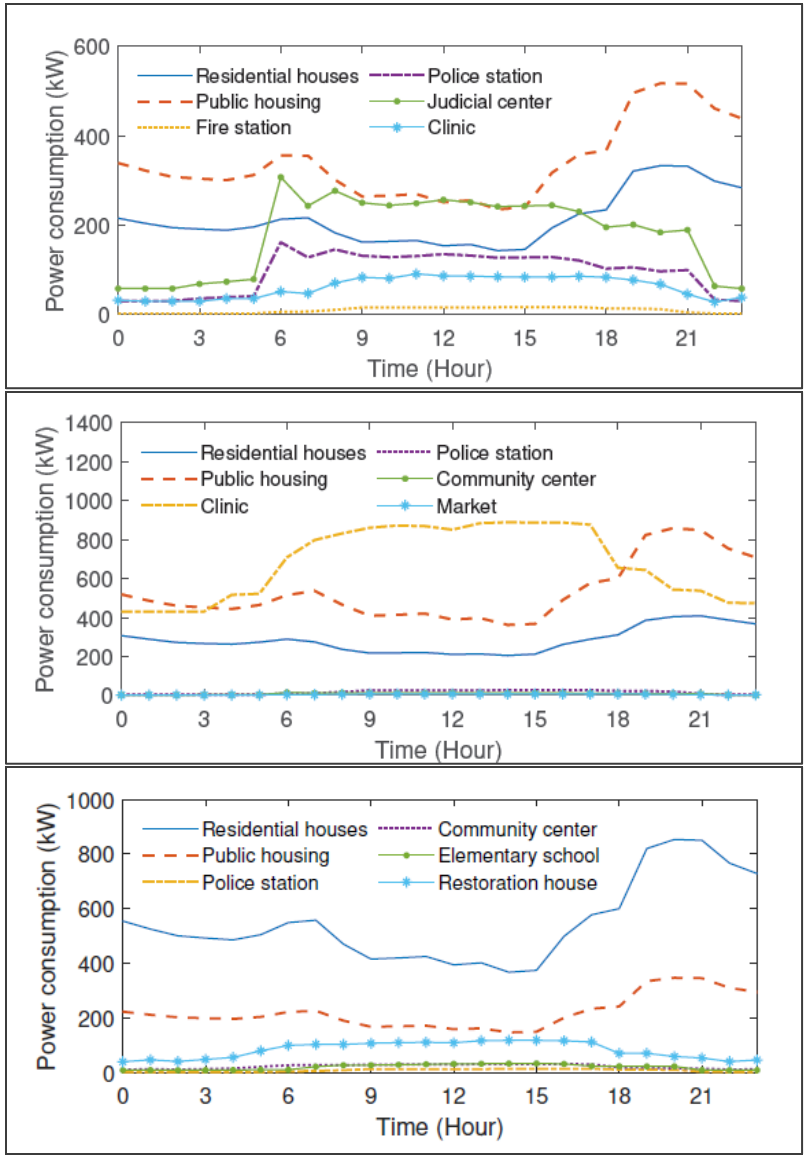


Annual wind power generation at weather stations and their capacity factors.

Hybrid Microgrid Boundaries and Load Profiles

- Defined microgrid boundaries in Las Mareas, San Juan, and Fajardo to include critical infrastructure (e.g., hospitals, fire stations) and residential loads using GIS building footprint data.
- Measured building roof areas from publicly available GIS layers, taking multi-story buildings into account, to estimate energy consumption per building type using kWh/ft² factors [12].
- Generated hourly load demand profiles using REopt [13] and local consumption surveys, aggregated per microgrid site.

Boundary defined for a potential microgrid in Las Mareas.



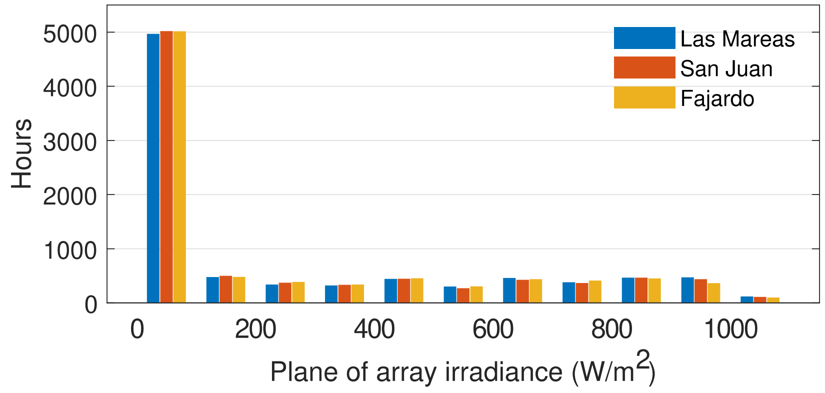
Average daily power consumption in Las Mareas, San Juan, and Fajardo.

Solar Resource Assessment and Power Calculation

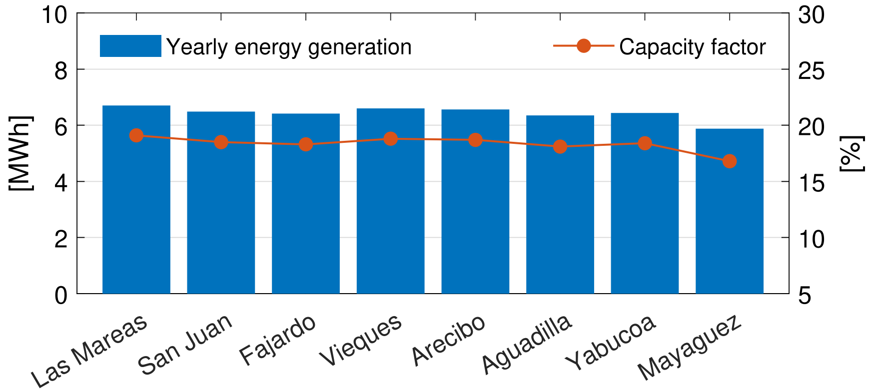
The solar energy potential can be evaluated from solar irradiance data. In this study, **NLR's PVWatts** was utilized for solar power estimation [11].

Given the parameters of the PV system, **PVWatts** returns hourly power production (W) for an entire year based on the meteorological data and solar irradiance available.

A summary of the annual energy production of the PV system at selected locations, as well as their corresponding capacity factors is shown. Note that the solar energy resource is relatively consistent across the entire area of Puerto Rico, with capacity factor around 20% at all locations.



Solar irradiance distribution at selected sites.



Annual PV power generation at weather stations and their capacity factors.

What is Microgrid Design Toolkit (MDT)?

- Sandia's decision support tool for **microgrid design and optimization**.
- **Evaluates combinations** of generation, storage, and loads.
- Performs **trade-space analysis** on cost, reliability metrics such as energy availability, and many others.
- Supports **scenario-based** outage and resilience assessments.
- Outputs **optimal** asset sizing, energy availability, and upfront cost estimates.
- Aids **early-stage microgrid planning** and design decisions.

MDT Analysis and DBT Setup

MDT Analysis:

- Evaluated six microgrid cases per site, varying wind turbine capacity from 0% (PV-only) to 100% (wind-only) in increments of 20%, combined with PV and BESS.
- Optimization objectives: minimize cost while achieving 100% energy availability (load served).
- Trade-space exploration of generation capacity, BESS sizing, and cost.
- Asset sizing increments and cost increments defined for PV, wind, and BESS components to guide optimization granularity [15,16].

Asset	Increment	Cost/Increment
PV	500 kW	$666 k ($1,331/kW)
Wind	600 kW	$3.17 M ($5,289/kW)
BESS	489.5 kW/ 1,958 kWh	$976 k/unit

DBT Setup:

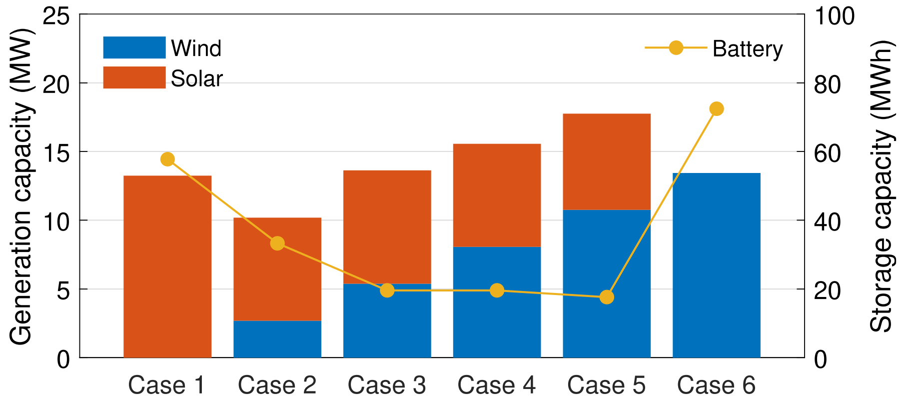
- Simulated a 30-day utility outage occurring approximately once per year over a 130-year horizon (~120 outage events).

Hybrid Microgrid MDT Results

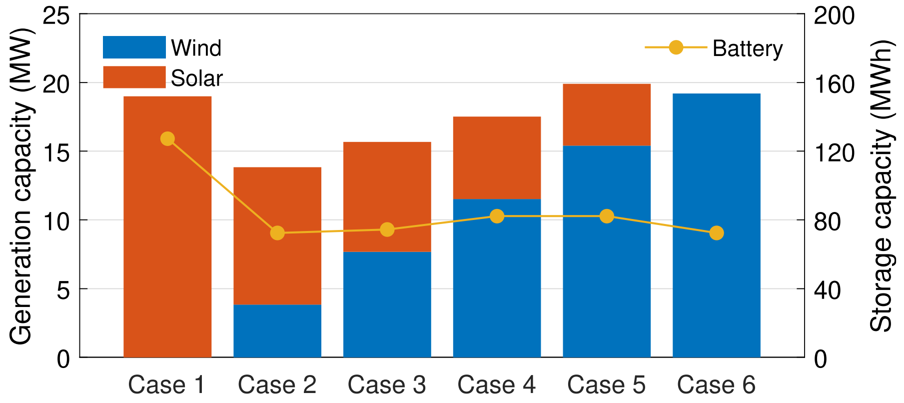
Key finding: Locations with strong wind resources show reduced total capacity and BESS needs when wind is integrated.

- **Las Mareas and San Juan:**
  - Case 2 resulted in the lowest total PV and wind capacity needed.
  - Case 2 (20% wind) showed a significant reduction in BESS size from the PV only case.
- **Fajardo:** Case 3 (40% wind) provides the smallest BESS size, although it is not much less than the PV-only scenario. Unlike the two other locations, the integration of wind does not significantly reduce the size of the BESS compared to the PV-only case.

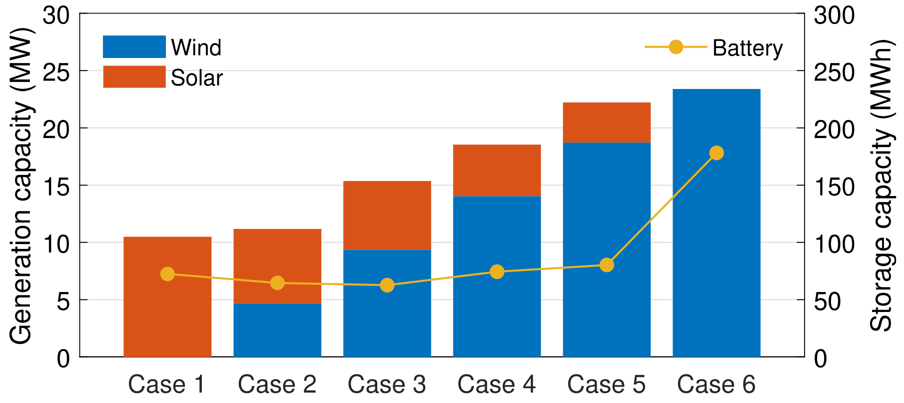
Wind complements PV by providing generation outside daylight hours.



Las Mareas at various wind integration levels.



San Juan at various wind integration levels.

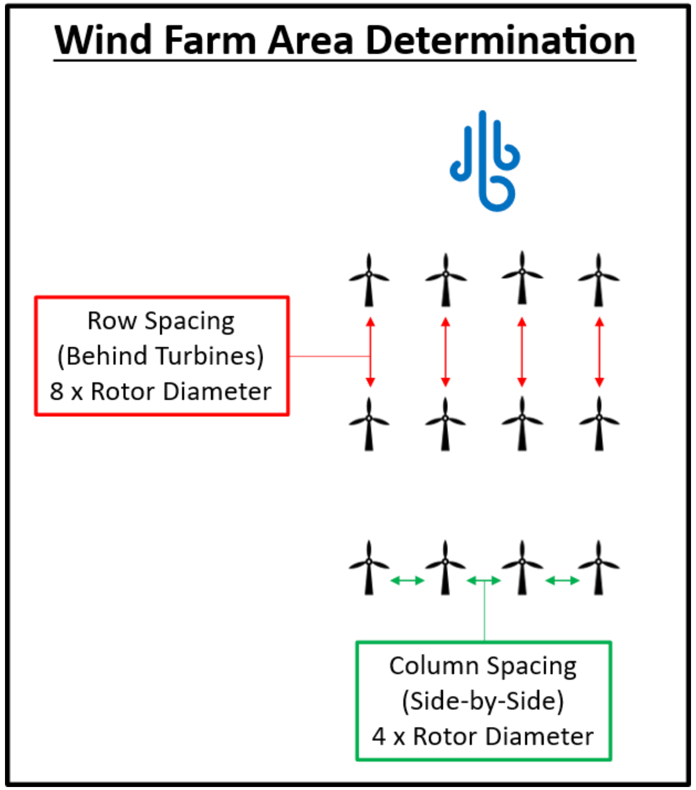


Fajardo at various wind integration levels.

Hybrid Microgrid Spatial Analysis

Spatial Analysis Objectives

- **Objective**: Evaluate land use trade-offs between wind turbines and PV arrays in microgrid designs.
- **Two Spatial Aspects**:
  - Total land area required
  - Total “unusable land”- land area required for turbine foundations vs. PV land footprint
- **Importance**: Land availability and efficient use are critical for microgrid siting in Puerto Rico.



Source: NS Energy Business, 2026

Source: Better Energy, 2026

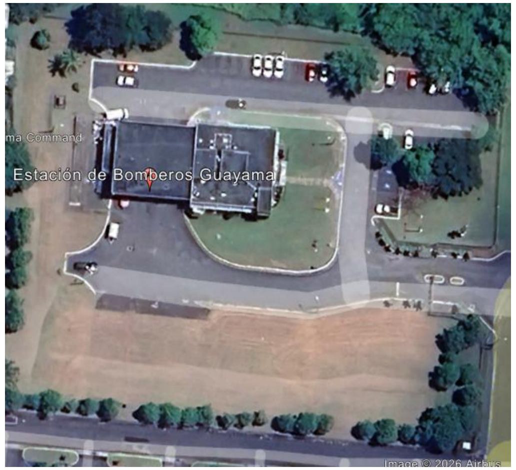
Wind Turbine Models and Foundation Parameters

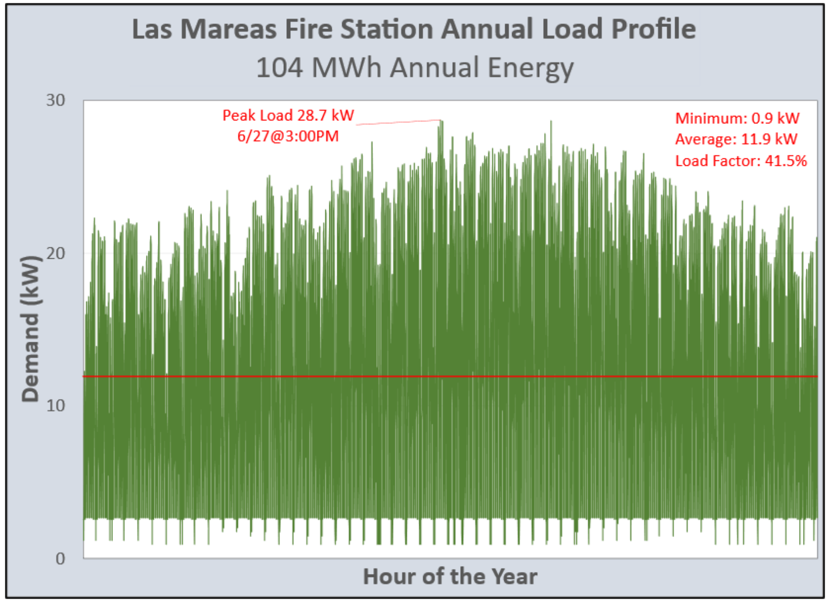
- Three wind turbine models were studied with foundation footprint area examples obtained from installations at NLR. We refer to these as Small, Medium, and Large (see table below).
- We did not include access roads, substations, O&M buildings, etc. in the unusable land calculations for wind farms.
- The spatial footprint of a wind turbine is variable depending on factors such as site soil and wind capture, which depends on rotor diameter, hub height, and the wind resource characteristics at that height.

Turbine	Rotor Diameter (m)	Rated Power (kW)	Foundation Area (m^2)	Foundation Power Ratio (kW/m^2)
Small	9.6	15.6	20.9	0.75
Medium	11.7	25	29.25	0.94
Large	24.4	60	45.6	1.3

Detailed Case Study – Las Mareas Fire Station

- The load demand profile estimated for the fire station in the Las Mareas hybrid microgrid study was used for the spatial analysis MDT simulations, selected for its demand compatibility with the turbines selected for the study.
- Wind and solar resource profile assumptions used in the hybrid microgrid study were used in the MDT analysis.
- Wind and PV costs were derived from the NLR ATB [15].
- BESS cost estimates were derived from Tesla Megapack pricing [16].
- Assumed 4 acres/MW PV footprint.

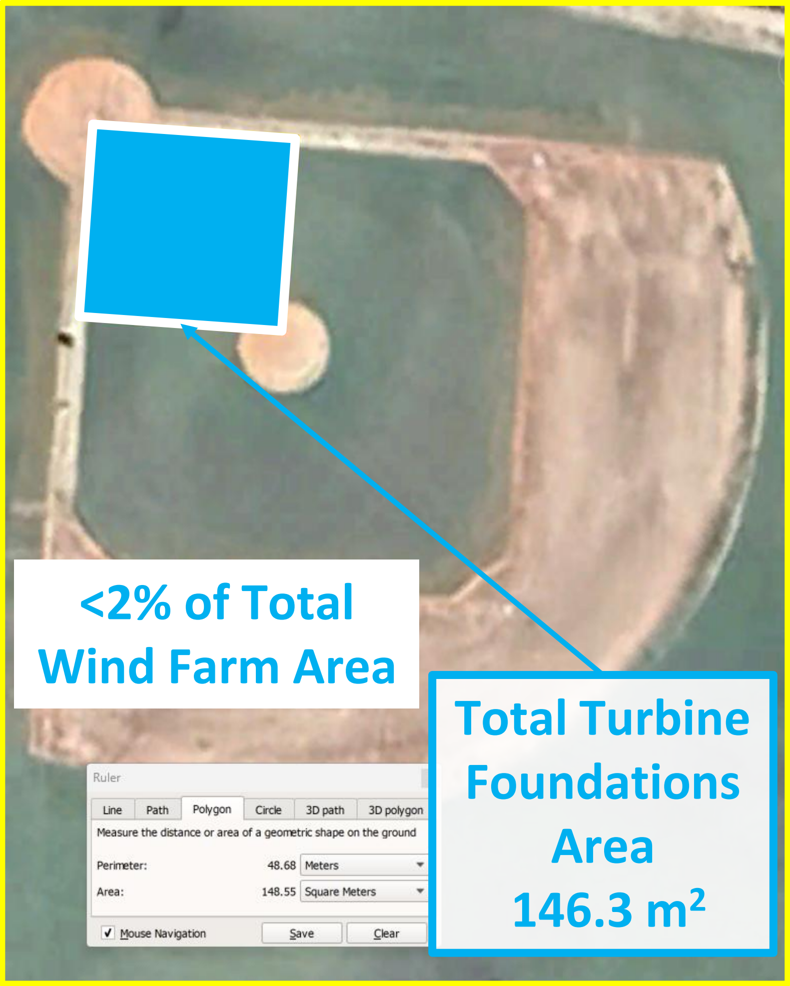


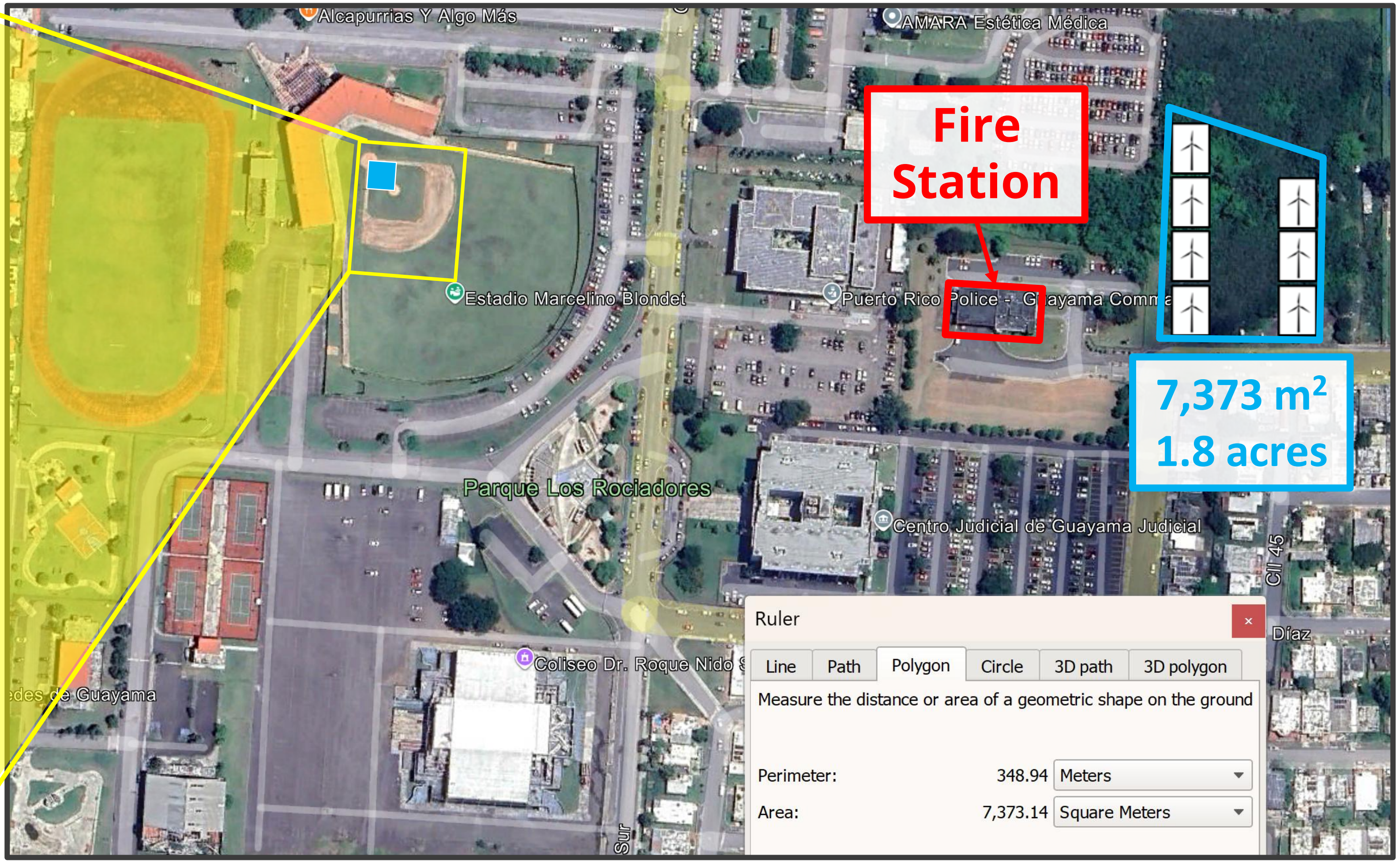


Asset	Cost Assumption	Notes
Residential Wind	$6,513/kW	Small
Commercial Wind	$5,153/kW	Medium and Large
PV	$1,805/kW	Commercial 2026 Conservative
BESS	$112/kW, $319/kWh	Website cost +30%

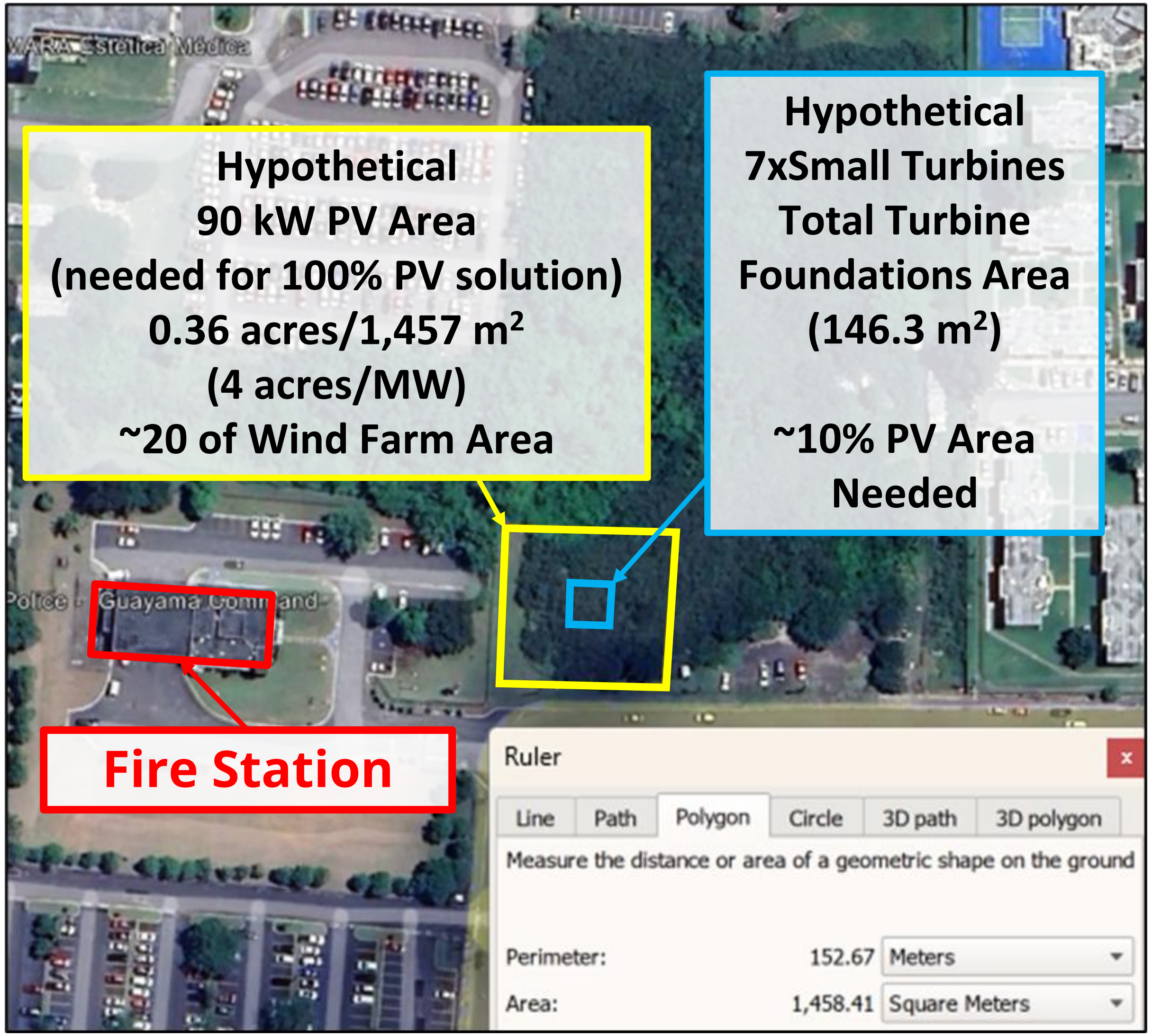
Las Mareas Fire Station Small Turbines and BESS Only

Seven Small Turbines (109.2 kW) and 196 kW/1300 kWh BESS required for 100% energy availability.





Las Mareas Fire Station PV and Wind Spatial Comparisons



Spatial Analysis for Las Mareas and San Juan – All Results

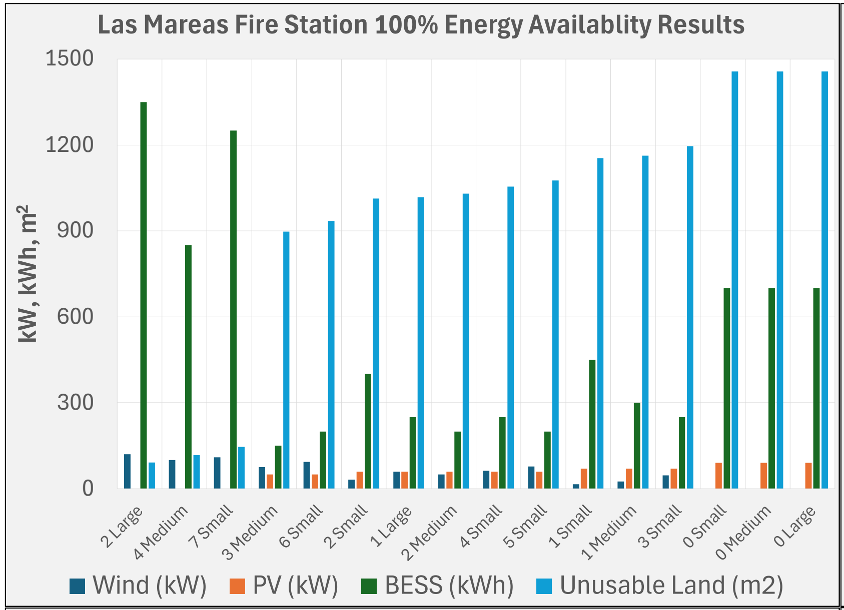
- As with the Las Mareas Fire Station, the Escuela Manuel Gaetan Barbosa (MGB) from the San Juan hybrid microgrid study was selected as an additional site for the spatial analysis, due to its similar demand.
- All three wind turbine types were simulated for each location with the local wind resource assumptions applied.
- A baseline wind case for each turbine was simulated with BESS only, and then the number of turbines needed in that case was reduced by one all the way down to zero (PV and BESS only case).
- 100% and 96% energy availability results were collected to observe trends for designs serving less than 100% energy availability.

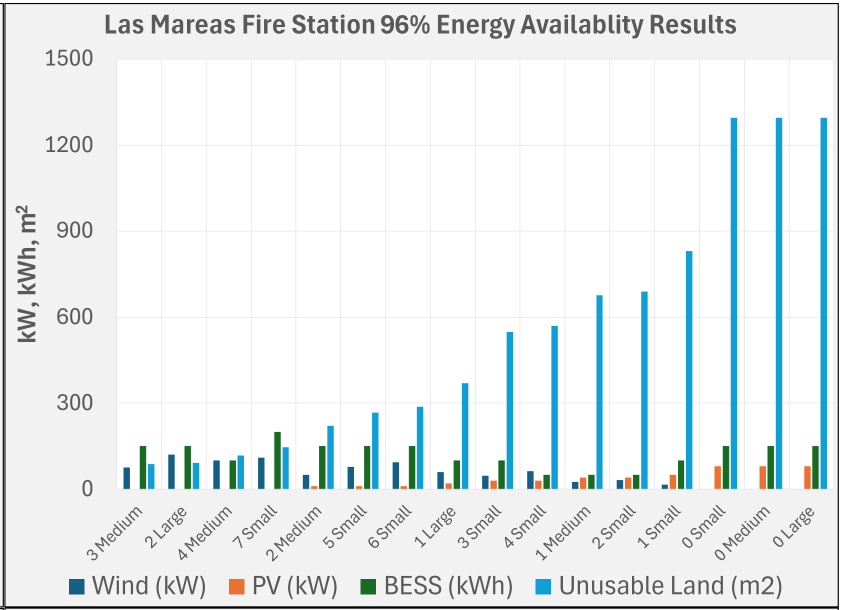
Site	Peak Demand (kW)	Annual Energy (MWh)	Load Factor
Las Mareas Fire Station	28.7	104	41.5%
San Juan Escuela MGB	29.6	90	34.7%

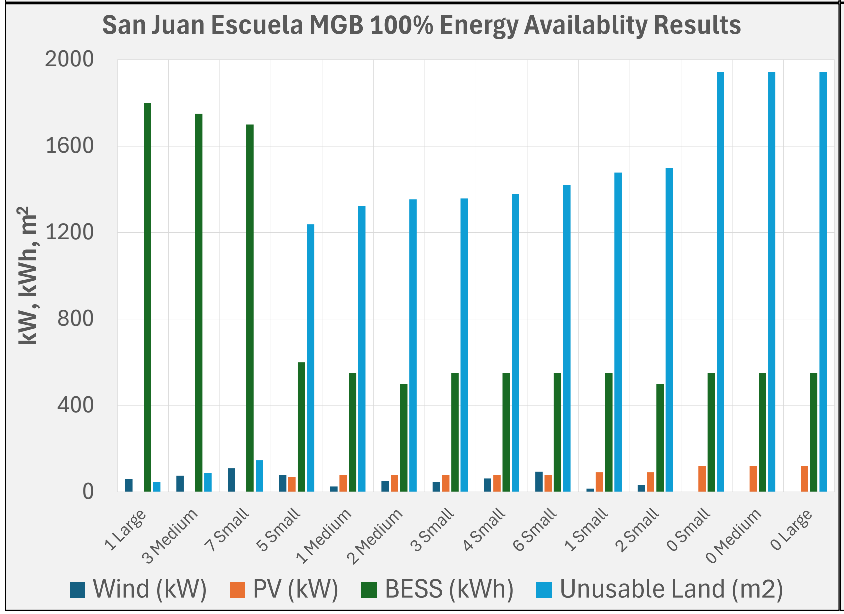
Site	Turbine	Capacity Factor
Las Mareas	Small	43.6%
Las Mareas	Medium	48.4%
Las Mareas	Large	52.7%
San Juan	Small	34.2%
San Juan	Medium	40.4%
San Juan	Large	46.2%

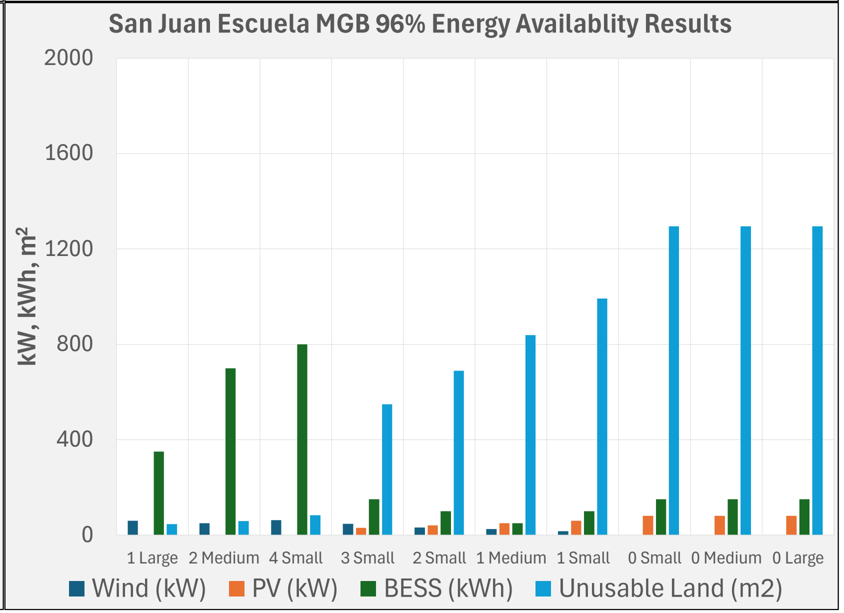
Spatial Analysis for Las Mareas and San Juan – All Results

- Sorted by lowest-to-highest unusable land (light blue), left to right on the x-axis.
- With sorting, systems with PV (orange) are increasingly to the right of the x-axis.
- BESS ratings (green) are relatively high on the far left.
- Wind ratings (dark blue) vary greatly along the entire axis but are not present in the highest unusable land cases on the right.









Spatial Analysis Land Use – PV vs. Wind Foundations

- **Hybrid microgrid designs enable substantial land savings compared to PV-only solutions**, especially when optimized turbine selection and sizing are applied.
- Minimum total **unusable land in hybrid cases varies by turbine type and site**, with Medium turbines achieving the lowest land footprint (897 m² in Las Mareas). Note there were no "hybrid" cases for Large in San Juan.
- Large turbines, with **larger capacity and smaller foundation footprint per kW**, provide the best land use efficiency in wind-only cases.
- Las Mareas generally shows lower total unusable land than San Juan for comparable turbine types and configurations, due to the **better wind resource**.

Max and Min Total Unusable Land (m²) at 100% Energy Availability

Site	Turbine	PV Only Cases (m²)	Wind Only Cases (m²)	Max Hybrid Case Land (m²)	Min Hybrid Case Land (m²)
Las Mareas	Small	1,457	146	1,196	935
Las Mareas	Medium	1,457	117	1,162	897
Las Mareas	Large	1,457	91	1,017	1,017
San Juan	Small	1,943	146	1,499	1,238
San Juan	Medium	1,943	88	1,354	1,324
San Juan	Large	1,943	46	N/A	N/A

Spatial Analysis Cost Summary – Energy Availability Impact

- Reducing energy availability from **100% to 96% can yield average cost savings of 7% to 28%**, depending on site and turbine type.
- Small turbines show the largest absolute and percentage savings due to **smaller incremental sizing capability**.
- Large turbines, despite **higher capacity factors and commercial cost advantages**, have smaller but still meaningful savings.
- Las Mareas site exhibits greater savings potential than San Juan, reflecting **stronger wind resources**.
- Cost savings primarily stem from **reduced BESS and PV sizing requirements** at lower energy availability targets.
- These savings highlight the critical **trade-off between resilience and cost** in microgrid design.

Cost Savings Moving from 100% to 96% Energy Availability

Site	Turbine	Max Savings ($k)	Average Savings ($k)	Average Savings (%)
Las Mareas	Small	936	280	28%
Las Mareas	Medium	561	120	15%
Las Mareas	Large	566	150	18%
San Juan	Small	864	180	22%
San Juan	Medium	497	90	12%
San Juan	Large	120	40	7%

Thank You

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Questions?

References (1 of 2)

[1] D. M. Kammen et al., “Microgrids for Resilient Energy Systems: The Case of Puerto Rico,” Energy Policy, vol. 147, 2020, Art. no. 111875, doi: 10.1016/j.enpol.2020.111875.

[2] U.S. Department of Energy, “Puerto Rico Power Grid Status Report Following Hurricane Maria,” Oct. 2017. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/10/f38/DOE%20Puerto%20Rico%20Power%20Grid%20Status%20Report%20-%20Oct%202017.pdf

[3] Federal Emergency Management Agency, “Puerto Rico Hurricane Irma Recovery Update,” Aug. 2018. [Online]. Available: https://www.fema.gov/press-release/20210826/puerto-rico-hurricane-irma-recovery-update

[4] N. Kishore et al., “Mortality in Puerto Rico after Hurricane Maria,” New England Journal of Medicine, vol. 379, no. 2, pp. 162-170, 2018.

[5] U.S. Energy Information Administration (EIA), “Electric Power Monthly,” Puerto Rico Data, 2025. [Online]. Available: https://www.eia.gov/electricity/data/state/

[6] American Wind Energy Association (AWEA), “U.S. Wind Industry Annual Market Report,” 2024. [Online]. Available: https://www.awea.org/resources/publications-and-reports/market-reports

[7] Puerto Rico Energy Bureau, “Puerto Rico Integrated Resource Plan,” 2023. [Online]. Available: https://energia.pr.gov/irp/

[8] Sandia National Laboratories, “Microgrid Design Toolkit (MDT),” Advanced Microgrids Program. [Online]. Available: https://energy.sandia.gov/programs/electric-grid/advanced-microgrids/microgrid-design-toolkit/.

References (2 of 2)

[9] J. Choi, J. E. Quiroz, R. T. Brito, R. Darbali-Zamora, E. E. Aponte-Bezares and M. S. Lave, "An Assessment of Wind-Hybrid Microgrids in Puerto Rico Using Microgrid Design Toolkit," 2024 56th North American Power Symposium (NAPS), El Paso, TX, USA, 2024, pp. 1-6, doi: 10.1109/NAPS61145.2024.10741697.

[11] National Laboratory of the Rockies, “PVWatts Calculator,” [Online]. Available: https://pvwatts.nrel.gov/.

[12] U.S. Energy Information Administration - EIA - independent statistics and analysis, “Energy Information Administration (EIA)- About the Commercial Buildings Energy Consumption Survey (CBECS).”

[13] National Laboratory of the Rockies, “REopt Tool,” [Online]. Available: https://reopt.nlr.gov/tool.

[14] Northern Power Systems, “NPS 60C-24 Wind Turbine Technical Specifications,” Northern Power Systems, 2020. [Online]. Available: https://www.northernpower.com/products/nps-60c-24/.

[15] National Laboratory of the Rockies, “Annual Technology Baseline (ATB) – Electricity Technologies,” 2024. [Online]. Available: https://atb.gov/electricity/2024b/technologies.

[16] Tesla, Inc., “Megapack – Design Your Energy Storage Solution,” 2026. [Online]. Available: https://www.tesla.com/megapack/design. [Accessed: Aug. 25, 2026].