Workshop on Energy Planning Resources for Puerto Rico

San Juan | March 19, 2019
Mayaguez | March 22, 2019
8:30 a.m. – 4:30 p.m.
Agenda

Welcome and Introductions
Overview and Panel Discussion
Break
Presentations on Data and Tools
Facilitated Discussion on Data, Tool, and Training Priorities
Report-Out from Discussion
Next Steps
Welcome and Introductions

• **Facilitators**
  – Dr. Elaine Ulrich, Senior Advisor, Solar Energy Technology Office, U.S. Department of Energy (DOE)
  – Robin Burton, Research Analyst, Strategic Energy Analysis Center, National Renewable Energy Laboratory (NREL)

• **Purpose**
  – Present stakeholders in energy sector planning in Puerto Rico – including utilities, regulators, policymakers, ratepayers, renewable energy developers, and community representatives – with existing tools, data, and modeling results that may be helpful to energy professionals in Puerto Rico
  – Collect feedback on desired and most useful tools and data to advance the transition of Puerto Rico’s energy system to a more reliable, secure, and affordable system

• **In Small Groups**
  – Name, affiliation, your goals for today
  – Choose one person to report out
DOE Multi-Lab Modeling Phase II

Stakeholder workshop and training

Elaine Ulrich, Ph.D.
elaine.ulrich@ee.doe.gov
The Solar Energy Technologies Office funds early-stage research and development in three technology areas: photovoltaics, concentrating solar power, and systems integration with the goal of improving the affordability, reliability, and performance of solar technologies on the grid.

Cutting-edge technology development that drives U.S leadership and supports a growing and skilled workforce.

Research and development to address integration of solar to the nation’s electricity grid.

Relevant and objective technical information on solar technologies to stakeholders and decision-makers.
DOE Solar Office Funds 300+ Active Projects

Projects and partners in 47 states plus the District of Columbia

- 40% of projects at national labs
- 25% of projects with universities
- 35% of projects with businesses & non-profits*

Note: SETO has funded past projects in Kentucky, Louisiana, and Wyoming.
*2% of state and local government
Solar is One of the Fastest Growing Energy Sources in America

In 2017, solar PV represented **32%** of all new electricity capacity installed in the United States.

Solar energy represented **30%** of new capacity additions **over the past 5 years** and now supplies **2%** of the nation’s annual U.S. electricity.
250,000+ U.S. Jobs in the Solar Industry

Since 2010, solar employment has grown by 168%

The median wage for solar installers is $21 per hour, increasing to $30 per hour for supervisors or foremen

9x national job growth rate in the last 5 years

Manufacturing is on the rise and is the 2nd largest sector in the solar industry, growing 48% since 2010

The solar energy industry is one of the fastest growing industries in the U.S. Driven by falling costs, total solar installed capacity is now **58.3 GW** with nearly **two million solar systems** operating across the country.

**U.S. Solar: Falling Costs, Rising Deployment**

Progress and Goals: 2030 Photovoltaics Goals

The office invests in innovative research efforts that securely integrate more solar energy into the grid, enhance the use and storage of solar energy, and lower solar electricity costs.

*Levelized cost of electricity (LCOE) progress and targets are calculated based on average U.S. climate and without the ITC or state/local incentives. The residential and commercial goals have been adjusted for inflation from 2010-17.
Puerto Rico Electricity Sector Overview

NB: Most data from 2014-16
Electricity price comparison, Puerto Rico
Recent PR Grid Integration Work

“Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV”

- National Renewable Energy Laboratory
- Funded by Solar Energy Technologies Office
- Conclusion: AES Ilumina PV (Guayama) plant can provide Automatic Generation Control, frequency response faster than synchronous generators, and voltage droop support to PREPA’s grid, with existing hardware and proper communication protocols

During a significant amount of the test period over a few days, AES PV was the only plant participating in AGC.
Recent Hawaii PV Work

“Optimization of a Virtual Power Plant to Provide Frequency Support”

• Sandia National Laboratory
• Funded by Solar Energy Technology Office
• Conclusion: Solar PV can reduce cost of grid operations by reducing O&M of synchronous generators, even when compensating for curtailment ($20k/day savings using PV as reserves for FW22 on Lanai, Hawaii)
• [http://prod.sandia.gov/techlib/access-control.cgi/2015/1511070r.pdf](http://prod.sandia.gov/techlib/access-control.cgi/2015/1511070r.pdf)
Most areas receive over 5 kWh/sq.m./day

*NB: 4km resolution*
Previous Work in Puerto Rico

“Review of PREPA Technical Requirements for Interconnecting Wind and Solar Generation”
• NREL, funded by EERE OSP
• Conclusion: Fourteen recommendations were made to PREPA regarding aligning its Minimum Technical Requirements (MTRs) with standard or best practice, not all followed.

“NGA Policy Academy on Targeting Clean Energy for Economic Development
• Funded, primarily, by EERE OSP
• Conclusion: Resources were made available to Puerto Rico as Act 57 was drafted.
Previous Work in Puerto Rico

“Feasibility Study of Solar PV on Landfills in Puerto Rico”

• NREL, funded by EERE Intergovernmental Program Office (runs the State Energy Program)

• Conclusion: In 2011, Fifteen sites were evaluated for PV. Solid economics at PPA rates similar to AES Ilumina, if installation costs aligned with 2011 national average ($4/Watt).
  • 2015 National average was $3/AC-Watt, with some near $2

• http://www.nrel.gov/docs/fy11osti/52181.pdf
• http://www.nrel.gov/docs/fy11osti/49237.pdf
PR Wind Background Info

- Two existing Wind IPP, ~$0.14/kWh, using economic resource on southern part of PR
- Low granularity map, https://windexchange.energy.gov/files/u/visualization/image/50m_VI.jpg
- Certain sites can be better than others, see e.g. St. Thomas https://www.nrel.gov/docs/fy15osti/63094.pdf
The page discusses Landfill Gas, Waste-to-Energy initiatives in Puerto Rico. Here are the key points:

1. EPA has ordered most landfills in PR to close. [Source](https://www.epa.gov/sites/production/files/2016-09/documents/puerto_rico_landfills_fact_sheet_final_0.pdf)
3. SJ could produce 2-4 million gallons of diesel annually. [Source](http://senado.pr.gov/SiteCollectionDocuments/energia/7%20Presentacion_Energia_Renovable_PR_AR_ET_Dr._Colucci.pdf)
4. Landfills and other brownfields can host solar. [Source](https://archive.epa.gov/region02/PR_Landfills_Solar/web/pdf/52181.pdf)

### Puerto Rico Landfill Consent Orders and Consent Decree - Closure Status

<table>
<thead>
<tr>
<th>Landfill</th>
<th>Closure Status</th>
<th>Recycling &amp; Composting Program Required</th>
<th>New Cell Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aguadilla</td>
<td>Closed April 2010</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Arecibo</td>
<td>After reaching final capacity (circa 2020)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Arroyo</td>
<td>Permanent waste (required June 2019)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Cayey</td>
<td>Permanent waste (required January 2018)</td>
<td>Yes</td>
<td>Under consideration</td>
</tr>
<tr>
<td>Florida</td>
<td>Overdue - permanent waste receipt (required June 2016)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Isabela</td>
<td>June 2020 (only limited waste now being received)</td>
<td>Yes</td>
<td>Planned</td>
</tr>
<tr>
<td>Juncos</td>
<td>Permanent waste (required December 2014 - Extended)</td>
<td>Yes</td>
<td>Under construction</td>
</tr>
<tr>
<td>Lajas</td>
<td>December 2017</td>
<td>Yes</td>
<td>Planned</td>
</tr>
<tr>
<td>Moca</td>
<td>After reaching final capacity (circa 2019)</td>
<td>Yes</td>
<td>Planned</td>
</tr>
<tr>
<td>Santa Isabel</td>
<td>Interim closure completed September 2014</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Toa Baja</td>
<td>Permanent waste (September 2014 (achieved September 2015) and closure thereafter per closure plan schedule (pending))</td>
<td>Yes</td>
<td>Operational</td>
</tr>
<tr>
<td>Vega Baja</td>
<td>Permanent waste (July 2013 (achieved July 2015) and closure thereafter per closure plan schedule (pending))</td>
<td>Yes</td>
<td>Operational</td>
</tr>
</tbody>
</table>
PR Ocean Resource

- Near-shore depths provide thermal gradient necessary for useful work
- Recoverable wave potential 20TWh/year, EPRI

Hydro

- ~100MW potential from existing sites in disrepair
Phase 1&2 Analysis Working Vision
A Multi-Year Transition

Phase 2 shift toward validation of proposals for Federal investment
• Focus on immediate needs related to HUD CDBG-DR, while still addressing long-standing technical and institutional issues.
• Build confidence in funding decisions by agencies without mission in electricity system investment or operations.
• Identify assets and solutions serving HUD priority areas of low-moderate income areas

2018-2020
➢ Complete all final repairs; selected T&D upgrades
➢ Resolve financial uncertainties & ownership
➢ Develop initial microgrids
➢ Start institutional assessment & changes
➢ End enhanced lab technical assistance

2022
➢ Complete all T&D upgrades
➢ Complete initial phase of public-private partnerships (including microgrids)
➢ Complete institutional changes

2027
➢ Plan for sustainable improvements
➢ Stable regulatory structure and functioning market for advanced services

energy.gov/solar-office
## Phase 2 Lab Work Supporting Federal Funds

<table>
<thead>
<tr>
<th>Issue</th>
<th>Lab</th>
<th>Phase 1 Deliverable Available for CDBG-DR Action Plan</th>
<th>Phase 2 Available to Validate CDBG-DR Proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity expansion: focus on Palo Seco</td>
<td>ANL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Fuels impacts: focus on LNG for PR &amp; region</td>
<td>ANL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Telecom impacts</td>
<td>ANL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Transmission priorities</td>
<td>PNNL</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>T&amp;D benefit-cost</td>
<td>PNNL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Protection schemes, incl. real-time sensor info</td>
<td>ORNL</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Renewables capacity expansion and integration</td>
<td>NREL</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Bulk storage placement</td>
<td>SNL</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Microgrid placement</td>
<td>SNL</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>DER and microgrid interconnection</td>
<td>SNL, NREL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>End-of-line communities resiliency</td>
<td>SNL, NREL</td>
<td></td>
<td>Y</td>
</tr>
<tr>
<td>Training for grantees and other stakeholders</td>
<td>NREL, SNL, PNNL</td>
<td></td>
<td>Y</td>
</tr>
</tbody>
</table>
Phase 2 Lab Work Coordination

Joint OE-EE active project management, with OE staff on day-to-day coordination (S. Walls and A. Breckel)
- Quarterly all-task calls, similar to GMI
- OE – Single lab weekly/bi-weekly calls
- Inter-office weekly/bi-weekly mtgs
- Coordination among capacity expansion, production cost, integration, and protection modelling and analytical efforts
- Coordination among other existing efforts, e.g., GIS resiliency tools at PNNL, SNL, ANL, NREL

Outputs delivered to:
- Flexible, quick response allocations at each performer lab to be leveraged as analytical insights needed by HUD, FEMA, other fed. partners (e.g., OMB)
- Info sharing with Puerto Rico Gov’t (COR3, PREC/Energy Bureau, PREPA, etc.)
- Training and open source tools focused on university, industry groups, municipalities, others.
- Training opportunities made available to USVI, given HUD/FEMA role there
Phase 2 Topics

**Fuels/Interdependencies**
- LNG Infrastructure
- Telecom Infrastructure
- Solar Resource and Supply Curves

**Bulk Power System**
- Investment Support Tools
- Capacity Expansion Modeling (AURORA)
- Production Cost Modeling (FESTIV)
- System Stability Modeling (Epfast)
- Dynamic Modeling (MAFRIT)

**Transmission**
- Protection and R/T Info
- Risk-Based Contingency Analysis
- Grid Asset Benefit-Cost Evaluations

**Distribution & Edge**
- System Advisory Model & PVWatts
- DER Interconnection Standards
- DER Feeder Hosting Methodology
- Contingencies, Operations, and Storage Sizing for Islandable Sections
- GIS Resiliency Improvement Tool

**Lead Lab Key:**
- ANL
- NREL
- ORNL
- PNNL
- SNL
30 Technical Recommendations by Subject Matter Area
Recommendations by Subject Matter

Transmission and Distribution -1

1. Investments in grid improvements should be based on detailed modeling, such as load flow modeling and contingency analysis, to identify the optimal resiliency and hardening benefits for the transmission system. Re-routing transmission infrastructure does not now, in the absence of analysis demonstrating its merit, present sufficient benefit to justify the cost. Load flow and contingency analysis will reveal which lines should be re-routed to increase both day-to-day reliability and resilience in the case of an event. This modeling will help right-size and prioritize grid investments, which could otherwise have the potential to put significant upward pressure on rates.

2. Recovery plans should provide for enhanced and enforced operations and maintenance to mitigate the disruption caused by the next event. For example, guy wire anchors of transmission infrastructure and static wire continuity need to be maintained to harden and add resiliency. Other materials, such as stainless steel or composite anchors, may be needed to replace some components at existing installations.

3. There are no recommended modifications to the current voltages associated with the Transmission and Distribution (T&D) infrastructure as they are suitable for the current and projected electrical needs of the island. However, a long term strategy to maintain standardization with typical mainland voltage will help future mutual aid response.

4. USDA Rural Utilities Service (RUS) standards should be adopted where feasible and appropriate to standardize equipment and design, which will aid with replacement in both regular and emergency situations. USDA RUS standards govern the engineering and component specification of all voltage ranges of electrical transmission and distribution networks used by every rural electric utility in North America that borrows from RUS. PREPA was an active RUS borrower until 2010, so restoring the power grid to meet applicable RUS standards should be an attainable objective to prepare the utility for near term emergencies and long term investments. Thus, as part of the reconstruction phase, Puerto Rico’s grid should be restored, at a minimum, to RUS standards as well as other applicable standards (e.g., NESC, NEC, NERC-CIP, NIST cybersecurity framework).

5. All replaced poles and towers should be of a design and material to survive 150 mph sustained winds. If funds are available, electricity transmission towers installed specifically for temporary emergency restoration after Hurricanes Irma and Maria should be considered for replacement as soon as practicable, potentially by monopoles. Many round monopole structures rode through the storm effectively.

6. The PREC should coordinate a joint study with the Puerto Rico Telecommunications Board to determine and enforce safe loading requirements of distribution poles carrying both electric and telecommunications infrastructure. Federal agencies can participate as necessary and appropriate.
7. Implement industry best practices in a comprehensive vegetation management program to protect the integrity of grid assets.

8. Substation assets should be hardened, including transformers, circuit breakers, associated switchgear, and especially control equipment, including protective relays and communications gear. Revised Flood Insurance Rate Maps (FIRM) should be used to site substation assets to avoid Base Flood Elevation (BFE) + 3.0 feet or 0.2% flood elevation, whichever is higher. In addition, siting should be outside of the floodplain whenever possible and existing critical stations should be raised and/or waterproofed accordingly. Besides relocation, detailed power system simulation will provide insights on which assets to harden and in what priority.

9. Based on modeling results, strategic, judicious undergrounding of distribution lines should be considered in limited appropriate circumstances. Based on experiences in Hurricanes Katrina and Sandy, undergrounding of lines in coastal areas could present risk of salt-water intrusion; other considerations are the depth of the island’s water table and subsurface rock. Any underground distribution lines in a floodplain should conform to 10 CFR Part 1022.

10. For the benefit of both day-to-day and in-event scenarios, recovery plans should include a strong modern Energy Management System, Remote Terminal Units, and other equipment providing real-time information and control capability to utility operators. For example, AMI for metering to serve as an operational tool providing real-time information that can, if implemented appropriately, improve service to industrial customers and reduce non-technical losses (caused by actions external to the power system such as theft) by enabling targeted inspections of anomalous readings. Also, this intelligence could empower a predictive maintenance program.

11. Analysis of the existing communication infrastructure available to support grid monitoring and control functionality should be performed. This analysis would include: inventory and document the existing fiber optic cable plant; research ownership of existing cables; determine fiber connections and fiber terminations availability for secure utility applications; analyze availability and functional performance and cybersecurity of the existing communication termination equipment at the substations; identify suitable solutions to support “last mile” communications to enable system monitoring and control functions, sensors and other equipment; distribution automation, support; AMI data backhaul; and other applications and functions.

12. Analysis should be conducted to determine the value of deliberate sectionalizing of the grid.
13. Evaluate the siting of key generation facilities so that, to the extent practicable, they are co-located with key load centers to reduce the criticality of the transmission system when recovering from anticipated extreme events in the future. In particular, analysis on re-powering Palo Seco with alternative fossil fuels is recommended.

14. Ensure the generation mix complies with all relevant legal and regulatory requirements, both local and Federal. Preliminary analysis shows that moving toward a more diverse fuel portfolio, including alternative fossil fuels, renewable energy and energy efficiency, will produce significant cost reductions. Fuel-efficient load-following combustion turbines could greatly improve fuel efficiency as compared to conventional steam turbine power plants. However, as with grid infrastructure, detailed modeling, such as production cost, capacity expansion analysis and detailed machine modeling, can help determine the best course of action to integrating new generation sources for Puerto Rico.

15. Given PREPA’s pre-storm estimated sales in 2026, as few as three of PREPA’s current power plants may satisfy estimated load in ten years, when combined with purchased power. Any hardening efforts should focus on those plants, including the Costa Sur power plant. As other facilities are retrofitted, especially Palo Seco, to comply with Mercury and Air Toxic Standards (MATS) and other relevant legal requirements, detailed hardening assessments should be undertaken.

16. Evaluate the extent to which integrating small and flexible generation assets near load centers into a more intelligent system could reduce the number of critical failure points.

17. While much of PREPA’s generation that was operational before the storm was not significantly compromised by Hurricanes Irma or Maria, a program of hardening generation assets would ensure continued resilience to weather events, beginning with critical central plants regardless of ownership. The current excess of generation affords the opportunity to model energy interdependencies and assess fuel contingencies, including shipping concerns, source of fuels, storage locations, and the impact of disruption and emergency response. Analysis can indicate where to prioritize dual fuel generation capability and sufficient levels of on-site fuel storage.
18. Recovery plans should include analysis to determine the potential applicability and optimal locations for microgrids, including their specialized role in the system (e.g., serving critical infrastructure in urban areas, serving unique needs of industrial customers, or serving remote communities). This analysis should include the availability of generation resources, fuels, load type, and the boundaries of microgrids.

19. Microgrid designs should rely on a suite of existing tools (e.g., DER-CAM, and the Microgrid Design Tool – see Appendix D) to help design and value microgrids, once their location(s) has been identified.

20. Communities that have required generator assets for extended periods of time should consider microgrids and the potential to leverage temporary generation that has been in service over the past few months.

21. Analysis as part of the recovery plan should consider and evaluate different pathways to contain grid failures during future events, and the different roles of transmission sectionalization and microgrids in providing reliability and resilience.

22. Interdependencies between electric power and other key sectors, specifically water, waste water, waste, telecommunications, transportation, and public health and safety, should be assessed and considered when infrastructure funding decisions are made. Potential alignment and sequencing of federal funding across different agency programs that support various sector infrastructures, possibly across multiple areas of the islands would be beneficial. The analysis identified in this report will support that goal.

23. Microgrids may prove effective at ensuring the availability of critical services during an event. Analysis can help prioritize critical infrastructure for hardening, for example, through a critical infrastructure resiliency bank.
Recommendations by Subject Matter

On-Going System Operations, Management, and Planning

24. Training and capacity building, particularly on asset management, system planning, and data collection should be supported as a part of all infrastructure expenditures, including Integrated Resource Planning, Energy Assurance Planning, and cost of service accounting.

25. PREPA, PREC, and other Commonwealth agencies and instrumentalities should be resourced to draft and execute staff training plans as part of expenditures on infrastructure. To the extent necessary, PREPA should identify skills gaps within its technical and engineering staffs, and identify whether other groups (such as Administrative and General) are right-sized to forecasted sales and engineering needs.

26. The recovery plan should call on the utility to identify a core team responsible for IRP submissions and other regulatory affairs, set aside sufficient resources for their work and data collection, and utilize additional training from relevant national organizations.

27. The Puerto Rican State Office of Energy Policy or its successor should immediately draft an updated Energy Assurance Plan, which should be reviewed on an annual basis.

28. Ensure that any and all funded projects are consistent with approved and vetted long-term plans that provide reasonable assurances of compliance with all local and federal laws and regulations.

29. The Governor and PREPA should update mutual aid agreements to facilitate the rapid sharing of emergency aid and resources and ensure that Incident Command Systems are primed to quickly provide support during the next event.

30. Consider additional legislation and regulation that may improve reliability and resiliency including, without limitation: regulations that prescribe design and installation standards for all T&D towers and poles to withstand 150 mph wind speed, regardless of material; all critical electricity system assets should be located at BFE + 3 feet or the 0.2% flood elevation, whichever is higher, or sited outside the flood plain entirely, if possible (see note in Section C1 of this report); and an annual review of the Energy Assurance Plan, and all associated components, including mutual assistance agreements, and technical and logistical procedures for Incident Management Teams. To the extent feasible in order to enhance operational efficiencies and interoperability, regulatory agencies should consider and adopt relevant NERC reliability standards to be implemented by the Commonwealth.
Panel Discussion

• **Topic**
  Identifying priority needs for improving the capacity of Puerto Ricans to engage in energy transition efforts

• **Panelists**
  – Gabriel Perez, Regional Manager Caribbean Region, Blue Planet Energy Systems (and ACONER board member)
  – Ingrid M. Vila Biaggi, President/Co-founder, Cambio
  – Lillian Mateo Santos, Associate Commissioner, Puerto Rico Energy Bureau
  – Thomas R. McOsker, CEO, BCMG
• **Topic**
  Identifying priority needs for improving the capacity of Puerto Ricans to engage in energy transition efforts

• **Panelists**
  – Ernesto Rivera Suárez, President, Renewable Solutions Engineering (and former president of ACONER)
  – Ruth Santiago, Lawyer
  – Thomas King, Founding Director, Fundación Borincana
NREL Tools You Can Use

Nate Blair
National Renewable Energy Laboratory (NREL) at a Glance

- **Employees,** plus more than 1,700
- **World-class** facilities, renowned technology experts
- **Partnerships** with industry, academia, and government
- **Campus** operates as a living laboratory
- **National economic impact** $872M annually

- **400** early-career researchers and visiting scientists
Tool Selection Criteria and Features

Selection Criteria:
- NREL-developed tools
- Free, publicly available, user-driven tools
- Goal is open-source; some accessible via API

Features:
- Inputs for tools that contain financial analysis are or can be modified to reflect low- and middle-income (LMI) customers
## NREL Tools – user-driven and publicly available

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Data or tool</th>
<th>Users</th>
<th>Question it answers</th>
<th>Training available</th>
<th>Open source</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Solar Radiation Database (NSRDB)</td>
<td>Both</td>
<td>Developers, engineers, or planners, Researchers</td>
<td>What is the level of solar irradiance at my site?</td>
<td>User manuals, support forum, and data download steps online</td>
<td>Yes</td>
</tr>
<tr>
<td>State and Local Energy Data (SLED)</td>
<td>Data</td>
<td>Developers, engineers, or planners, State or local policymakers</td>
<td>What is the sector level breakdown of energy and emission data for my jurisdiction (or sub-jurisdictions)?</td>
<td>Easy-to-use data portal</td>
<td>n/a</td>
</tr>
<tr>
<td>BEopt</td>
<td>Tool</td>
<td>Developers, engineers, or planners, Home, business, or building owners, Researchers</td>
<td>What are cost-optimal efficiency packages for various levels of whole-house energy savings for my building design?</td>
<td>Training videos and publications in support menu on website</td>
<td>No</td>
</tr>
<tr>
<td>Community Solar Scenario Tool (CSST)</td>
<td>Tool</td>
<td>Developers, engineers, or planners, Utilities and regulators, State or local policymakers</td>
<td>What are the costs and benefits to various audiences of a single community solar project?</td>
<td>Tool documentation is included as cell comments</td>
<td>No</td>
</tr>
<tr>
<td>Jobs and Economic Development Impact (JEDI) models</td>
<td>Tool</td>
<td>Developers, engineers, or planners, Utilities and regulators, State or local policymakers, Home, building, or business owners</td>
<td>What are job and other economic development impacts of renewable energy projects in my jurisdiction?</td>
<td>Instructions online and in ‘About Jedi’ tab in the spreadsheet tool</td>
<td>Yes</td>
</tr>
<tr>
<td>PVWatts</td>
<td>Tool</td>
<td>Developers, engineers, or planners, Home, business, or building owners</td>
<td>What is the possible performance and annual value of my solar project?</td>
<td>Help button on website provides documentation</td>
<td>Yes</td>
</tr>
<tr>
<td>REopt Lite (full REopt on next slide)</td>
<td>Tool</td>
<td>Developers, engineers, or planners, State or local policymakers, Home, business, or building owners, Researchers</td>
<td>What combination of solar PV, wind, and energy storage will help my site minimize energy costs or sustain a grid outage? (For PR, supports solar plus storage only for now, not wind)</td>
<td>User manual and demo video online</td>
<td>In process</td>
</tr>
<tr>
<td>ResStock</td>
<td>Tool</td>
<td>Developers, engineers, or planners, Utilities and regulators, State or local policymakers, Home, business, or building owners</td>
<td>What energy efficiency measures are likely to yield the highest savings in my jurisdiction?</td>
<td>Documentation, publications and a webinar available online</td>
<td>Yes</td>
</tr>
<tr>
<td>System Advisor Model (SAM)</td>
<td>Tool</td>
<td>Developers, engineers, or planners, State or local policymakers, Researchers</td>
<td>What are the costs, cash flow, and performance predictions for my solar, wind, or geothermal project?</td>
<td>Quick start guide and extensive help menu within software; webinars online</td>
<td>Yes</td>
</tr>
</tbody>
</table>
National Solar Radiation Database (NSRDB)

A collection of meteorological and solar irradiance data sets for the U.S. and a growing list of international locations. The data are publicly available at no cost to the user, and can be downloaded or viewed using the Data Viewer.

**Question it answers**
- What is the level of solar irradiance at my site?
- How can I choose optimal locations for solar installations?

**Relevance to PR**
- Data available for PR; developers are currently updating with increased resolution. Can help energy planners choose optimal locations for solar installations.

**Target users**
- Developers, engineers, or planners
- Researchers

**Training available**
- User manuals, support forum, and data download steps online

**Open source**
- Yes

**Link**
- [https://nsrdb.nrel.gov/](https://nsrdb.nrel.gov/)
- [https://maps.nrel.gov/nsrdb-viewer](https://maps.nrel.gov/nsrdb-viewer)
Energy Profiles provide comprehensive energy use and activity data to help cities plan and implement clean energy projects, and include summary reports on: greenhouse gas emissions, electricity generation, natural gas and other fuel source costs, renewable energy resource potential, transportation, buildings, and industry data. The Toolbox is full of resources to help cities take action.

**Question it answers**
What is the sector level breakdown of energy and emission data for my jurisdiction (or sub-jurisdictions)?

**Relevance to PR**
Does not have PR data but could be used as comparator in like microclimates and demographics.

**Target users**
- Developers, engineers, or planners
- State or local policymakers
- Researchers

**Training available**
Documentation, publications and a webinar available online.

**Open source**: n/a

**Link**
https://apps1.eere.energy.gov/sled/#/
Building Energy Optimization Tool (BEopt)

Evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. Provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, location, and utility rates. Discrete envelope and equipment options reflecting construction materials and practices are evaluated.

**Question it answers**
What are cost-optimal energy efficiency packages for various levels of whole-house energy savings for my building design?

**Relevance to PR**
In optimization mode PR users could manually enter cost data rather than using default national averages. Could also be used for investigating energy savings of different efficiency measures.

**Target users**
- Developers, engineers, or planners
- Home, business, or building owners
- Researchers

**Training available**
Training videos and publications in support menu on website

**Link**
https://beopt.nrel.gov/
Community Solar Scenario Tool (CSST)

Provides a "first cut" analysis of different community or shared solar program options. Allows users to see how various inputs impact the economics of a project from both a potential customer's perspective as well as that of the sponsoring utility.

**Question it answers**
What are the costs and benefits to various audiences of a single community solar project?

**Relevance to PR**

**Target users**
- Developers, engineers, or planners
- Utilities and regulators
- State or local policymakers

**Training available**
Tool documentation is included as cell comments

**Open source**
No

**Link**
https://www.nrel.gov/energy-solutions/csst.html
**Jobs and Economic Development Impact (JEDI) models**

User-friendly tools that estimate economic impacts of constructing and operating power generation and biofuel plants at local and state levels. Based on user-entered project-specific data or default inputs (derived from industry norms), JEDI estimates the number of jobs and economic impacts to a local area that can reasonably be supported by a power plant, fuel production facility, or other project.

**Question it answers**

What are job and other economic development impacts of non-solar renewable energy projects in my jurisdiction?

**Relevance to PR**

Does not have PR data but could be used as comparator in like microclimates and demographics

**Target users**

- Developers, engineers, or planners
- Home, building, or business owners
- Utilities and regulators
- State or local policymakers

**Training available**

Instructions online and in ‘About Jedi’ tab in the spreadsheet tool

**Open source:** Yes

**Link**

https://www.nrel.gov/analysis/jedi/about.html
PVWatts*

A calculator that estimates the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. Allows users to easily develop estimates of the performance of potential PV installations. Uses newest data from the NREL National Solar Radiation Database (NSRDB).

**Question it answers**
What is the possible performance and annual value of my solar project?

**Relevance to PR**
PR data is included and available at a 4km grid scale

**Target users**
- Developers, engineers, or planners
- Home, business, or building owners

**Training available**
Help button on website provides documentation

**Open source**
Yes

**Link**
https://pvwatts.nrel.gov/

*Also available in SAM with expanded capabilities*
REopt Lite*

A decision support tool used to optimize energy systems for buildings, campuses, communities, and microgrids. Recommends an optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings and energy performance goals. REopt Lite is a subset of the full model’s capabilities available at no cost to the user.

**Question it answers**
What combination of solar PV, wind, and energy storage will help my site minimize energy costs or sustain a grid outage?

**Relevance to PR**
Supports solar and storage in PR only, not wind at this time. Does not have drop-down for selecting rates for PR, but advanced users with data can use custom feature

**Training available**
User manual and demo video online

**Open source:** In-progress; API

**Link**
https://reopt.nrel.gov/tool

*Additional REopt technologies and services available from NREL by agreement*
ResStock

Performs large-scale residential energy analysis by combining public and private data sources, statistical sampling, detailed sub-hourly building simulations, and high-performance computing to help users identify which home improvements save the most energy and money.

Question it answers
• What energy efficiency measures yield the highest savings in my jurisdiction?
• How do opportunities vary by household income?

Relevance to PR
Does not have PR data but could use PR data from Census Bureau, along with other local data sources and local expert knowledge.

Target users
✓ Utilities and regulators
✓ State or local policymakers
✓ Non-profits, academic researchers, and program implementers

Training available
Documentation, publications, and webinar available online; customized trainings available

Link
https://resstock.nrel.gov/

Open source: Yes
A free computer program that calculates a renewable energy system’s hourly energy output over a single year, and the cost of energy for a renewable energy project over the life of the project. These calculations are done using detailed performance models, a cash-flow finance model, and a library of reasonable default values for each technology and target market.

**Question it answers**
What are the costs, cash flow, and performance predictions for my solar (PV or CSP), wind, or geothermal project?

**Relevance to PR**
The tool can access solar data for Puerto Rico using the gridded solar data via the NSRDB.

**Training available**
Quick start guide and extensive help menu within software; webinars online. Typically requires a larger investment in knowledge and time to use.

**Target users**
- Developers, engineers, or planners
- State or local policymakers
- Researchers

**Open source**
Yes; API available

**Link**
https://sam.nrel.gov/about
## NREL Tools — used for in-house analysis

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Customers</th>
<th>Description</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distributed Generation Market Demand (dGen) model</td>
<td>✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers</td>
<td>A geospatially rich market-penetration model that simulates the potential adoption of distributed energy resources (DERs) for residential, commercial, and industrial entities in the United States through 2050. dGen is used primarily as an exploratory tool to determine how different factors will affect DER deployment</td>
<td><a href="https://www.nrel.gov/analysis/dgen/">https://www.nrel.gov/analysis/dgen/</a></td>
</tr>
<tr>
<td>Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV)</td>
<td>✓ Developers, engineers, or planners ✓ State or local policymakers</td>
<td>A multiple-timescale, interconnected simulation tool that includes security-constrained unit commitment, security-constrained economic dispatch, and automatic generation control sub-models. FESTIV simulates the behavior of the electric power system to help researchers understand the impacts of variability and uncertainty on power system operations</td>
<td><a href="https://www.nrel.gov/grid/festiv-model.html">https://www.nrel.gov/grid/festiv-model.html</a></td>
</tr>
<tr>
<td>Multi-Area Frequency Response Integration Tool (MAFRIT)</td>
<td>✓ Developers, engineers, or planners ✓ Utilities and regulators ✓ Researchers</td>
<td>The only software tool of its kind that integrates primary frequency response (turbine governor control) with secondary frequency response (automatic generation control). MAFRIT simulates the power system dynamic response in full time spectrum with variable time steps from millisecond to days under both normal and event conditions. Places emphasis on electric power systems with high penetrations of renewable generation</td>
<td><a href="https://www.nrel.gov/grid/modeling-tools.html">https://www.nrel.gov/grid/modeling-tools.html</a></td>
</tr>
<tr>
<td>(ReEDS)</td>
<td>✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers</td>
<td>Capacity planning and dispatch model for the North American Electricity system</td>
<td>[<a href="https://www.nrel.gov/analysis/ree">https://www.nrel.gov/analysis/ree</a> ds/index.html](<a href="https://www.nrel.gov/analysis/ree">https://www.nrel.gov/analysis/ree</a> ds/index.html)</td>
</tr>
<tr>
<td>REopt</td>
<td>✓ Developers, engineers, or planners ✓ State or local policymakers ✓ Utilities and regulators ✓ Researchers</td>
<td>A decision support tool used to optimize energy systems for buildings, campuses, communities, and microgrids. Recommends an optimal mix of renewable energy, conventional generation, and energy storage technologies to meet cost savings and energy performance goals</td>
<td><a href="https://reopt.nrel.gov/about/">https://reopt.nrel.gov/about/</a></td>
</tr>
<tr>
<td>Hawaii Energy Visualization Initiative (HEVI) tool</td>
<td>✓ State or local policymakers ✓ Utilities and regulators</td>
<td>A custom capacity and dispatch modeling system that can quickly provide insights on cross-sectoral questions. This tool is customized in partnership with the user (typically energy office or university) and NREL based on locally available data and information</td>
<td><a href="https://www.energy.gov/eere/energy-modeling-tool">https://www.energy.gov/eere/energy-modeling-tool</a></td>
</tr>
</tbody>
</table>
Argonne National Laboratory
### Tools with Potential Application for Puerto Rico

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Description</th>
<th>POC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resilient Electricity Market Design, Operations, and Planning (ALEAF)</td>
<td>Power market design, operations, and planning tool.</td>
<td>Zhi Zhou</td>
</tr>
<tr>
<td>Estimating Physical Repair Times at Critical Infrastructure Facilities (RESTORE)</td>
<td>A stochastic model of the steps required to restore a system following an incident.</td>
<td>Jim Kavicky</td>
</tr>
<tr>
<td>Quick Turn-Around Cascading Power Outage Estimation (EPfast)</td>
<td>A deterministic model that explores the tendency of power systems to spiral into uncontrolled islanding triggered by either man-made or natural disturbances.</td>
<td>Edgar Portante</td>
</tr>
<tr>
<td>Bulk-Level Power and Distribution-Level System Restoration Planning and detailed Cascading Power Outage Estimation (EGRIP)</td>
<td>A simulation of cascading blackouts, considering dynamics, monitoring, protection, control, and re-dispatch.</td>
<td>Feng Qiu and Chen Chen</td>
</tr>
<tr>
<td>Petroleum Interdependency Tool (POLfast)</td>
<td>A steady-state compensated supply/demand model that estimates potential regional supply shortfalls, determines mitigating measures, and estimates the potential increase in the price of petroleum and related impacts on the regional gross domestic product (GDP).</td>
<td>Steve Folga</td>
</tr>
<tr>
<td>Hurricane Customer Outage Forecasting (HEADOUT)</td>
<td>A spatial and relational model to predict outages electric customers due to tropical cyclones. The tool generates detailed results providing customer outage estimates and identifies assets at risk from storm surge; used in pre-landfall real-time analysis during hurricane season, for emergency preparedness exercises, and for system planning.</td>
<td>Leah Talaber</td>
</tr>
<tr>
<td>Emergency Management, Common Operating Picture, and Situational Awareness (onVCP/vBEOC)</td>
<td>The tools provide situational awareness and Common Operating Picture for drills/exercises and during actual events; SimCell allows to Run emergency preparedness exercises more efficiently.</td>
<td>Ed Tanzman</td>
</tr>
<tr>
<td>Integrated Water-Energy Systems Assessment Framework (IWESAF)</td>
<td>The tool links various models to evaluate impacts of water availability and riverine thermal regime on power plant operation, short-term power grid dispatch, and long-term planning.</td>
<td>Eugene Yan</td>
</tr>
<tr>
<td>Large-scale dynamics cascading simulation, analysis, and visualization (Dynamics Security Analysis Toolkit (DSATI))</td>
<td>A tool for transient security assessment, cascading failure dynamics simulation, steady-state security, optimal generation dispatch, transient-security constrained dispatch</td>
<td>Guenter Conzelmann</td>
</tr>
<tr>
<td>Liquefied Natural Gas Supply Disruption Analysis Tool (LNGfast)</td>
<td>This tool analyzes the LNG supply-demand chain in the Caribbean region, optimizes inter-terminal maritime transportation between a set of supply ports and a set of sparsely distributed receiving ports with given LNG demands</td>
<td>Steve Folga</td>
</tr>
<tr>
<td>Analysis of wired and wireless communication systems (TelcoFast)</td>
<td>Tool used to assess the redundancy and resilience of the wireline and wireless communications sectors, has been modified to predict hurricane impacts on the commercial communications sector in Puerto Rico</td>
<td>Steve Folga</td>
</tr>
</tbody>
</table>

Point of Contact: Mark C. Petri
mcpetri@anl.gov
Pacific Northwest National Laboratory (PNNL)
GridPIQ: Grid Project Impacts Quantification Web Calculator

Contact: Karen Studarus  karen.studarus@pnnl.gov

Screening tool for grid projects – various technologies (e.g. energy storage, PV) and impacts (e.g. inter-hour ramping, emissions, peak power)

Question it answers

“If Only I Could Quickly and Easily...”

• Ask many “what if?” questions about my system
• Screen grid project ideas
• Visualize grid time series

• Compare assumptions
• Sanity check results
• Check for knock-on benefits or unintended consequences
• Document benefits of my project or product
• Leverage many data sources in one place

Target users

✓ Developers, engineers, or planners
✓ Researchers
✓ State or local policymakers

Open source

Mainly, open and transparent methods

Training available

Instructions, and user tutorial example projects built into the online tool

Link

gridpiq.pnnl.gov

Relevance to PR

Some data available for PR. Can help energy planners choose optimal locations for solar and storage installations.
EGRASS is an easy-to-use online tool (web and mobile versions) for map-based distribution system decision support. EGRASS connects users with scientific research and study results to aid decisions for recommending candidate technologies deployments to improve resiliency and reliability for the critical end-use loads.

**Question it answers:** Help me decide which critical loads need...
- Remote-Controlled Switches
- Reclosers
- Fault Location, Isolation, and Service Restoration (FLISR)
- Self-Healing System
- Standalone Backup Generation
- Microgrids

**Relevance to PR**
Developed for PR, built on Puerto Rico data. Under continuing development with new features being added.

**Training available**
In development, user interface is designed to aid the user

**Target users**
- Developers, engineers, or planners
- Researchers
- State or local policymakers

**Open source**
Not yet

**Link**
http://egrass-test.pnl.gov
Tools Overview

D. Tom Rizy
Email: dtom@ornl.gov
Phone: (865) 574-5203
Oak Ridge, Tennessee
## ORNL Tools — user-driven and publicly available

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Data or tool</th>
<th>Brief Description</th>
<th>Question it answers</th>
<th>Users</th>
<th>Training available</th>
<th>Open source</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAGLE-I</td>
<td>Both</td>
<td>Provides monitoring of the energy infrastructure assets, reporting energy outages, displaying potential threats, and coordinating emergency response and recovery.</td>
<td>During an extreme event what critical infrastructure will be impacted? What is the current number of customers without power?</td>
<td>✓ Emergency responders ✓ Government personnel ✓ Industry, utility companies</td>
<td>User manuals</td>
<td>No</td>
</tr>
<tr>
<td>MADRA - Microgrid Assisted Design for Remote Areas</td>
<td>Data</td>
<td>Integration of modeling systems to provide a microgrid analysis platform capable of providing technical analysis for designers to make appropriate design decisions.</td>
<td>What is the most optimal design of a microgrid based on user’s needs? What is the cost of a microgrid?</td>
<td>✓ Developers, engineers, or planners ✓ Researchers</td>
<td>User manuals, support forum, and installation instruction available</td>
<td>Yes</td>
</tr>
<tr>
<td>MOVARTI</td>
<td>Tool</td>
<td>Evaluates voltage/reactive power (VAR) issues</td>
<td>Where are or will be reactive power issues on the grid? What is the value of a VAR?</td>
<td>✓ Utility engineers and planners ✓ Researchers</td>
<td>Available upon request</td>
<td>No</td>
</tr>
<tr>
<td>GridEye/FNET</td>
<td>Tool</td>
<td>Unique wide-area grid monitoring network can captures electrical grid’s dynamic performance continuously in real time and uses monitoring devices that are essentially GPS time synchronized single-phase phasor measurement units.</td>
<td>What is the health of the electric grid? What event triggered an outage? How do we validate our models?</td>
<td>✓ Developers, engineers, or planners ✓ Researchers ✓ Utility companies</td>
<td>User manuals, support forum, and data download steps online</td>
<td>No</td>
</tr>
<tr>
<td>THYME</td>
<td>Tool</td>
<td>Simulation tool using C++ for studying the interaction of controls, communications, and electro-mechanical dynamics in a power system.</td>
<td>How will loads impact the electric grid? How can I best utilize communication and sensor technologies?</td>
<td>✓ Developers, engineers, or planners ✓ Researchers</td>
<td>Available upon request</td>
<td>Yes</td>
</tr>
</tbody>
</table>
EAGLE-I provides capabilities for monitoring energy infrastructure assets, reporting energy outages, displaying potential threats to energy infrastructure, and coordinating emergency response and recovery. DOE provides EAGLE-I as a service to other Federal, State, and local Agencies and Departments and to first-responders in accordance with DOE’s Emergency Support Function-12 (ESF-12) mission.

**Question it answers**
During an extreme event what critical infrastructure will be impacted?
What is the current number of customers without power?

**Target users**
- Emergency responders
- Government personnel
- Industry, utility companies

**Training available**
User manuals,

**Link**
https://eagle-i.doe.gov/login

**Relevance to PR**
Assist in coordinating emergency response and recovery during extreme events such as hurricanes.

**Open source**
No

DOE’s EAGLE-I, managed by ORNL, collects energy-sector infrastructure data into a real-time, shareable platform accessible via online portal.
MADRA is an integration of modeling systems to provide open source microgrid analysis platform for remote off-grid applications. This comprehensive design support tool for remote off-grid microgrids is capable of providing technical analysis for designers to make appropriate design decisions satisfying user-defined objectives and constraints for cost and reliability.

**Question it answers**

What is the most optimal design of a microgrid based on user’s needs?

What is the cost of a microgrid?

**Relevance to PR**

Identify design and cost of deploying microgrids either with industrial stakeholders (PRIDCO) or through the utility company (PREPA)

**Target users**

- Developers, engineers, or planners
- Researchers

**Training available**

User manuals, support forum, and installation instruction available

**Open source**

Yes

**Link**

https://daac.ornl.gov/SERVICES/guides/SDAT.html

Software can be delivered on request

A MADRA screen capture displaying the GIS Interface
MOVARTI Management & Optimization of VARs for Future Transmission Infrastructure

MOVARTI is an integrated VAR planning tool that has several unique functions. User can identify VAR-related issues for existing and future power grids comprised of diversified generation sources especially the intermittent renewables, and/or with system topology/configuration changes. New voltage stability indices (VSI) can be defined to incorporate such generation diversity. The tool provides VAR size, location, and type (static or dynamic) planning solutions by performing multi-scenario static power flow and post-contingency dynamic voltage stability analysis. Additionally MOVARTI can perform VAR benefit analysis to assess the value streams of a VAR planning result or to find the optimal solution of VAR source investment with constraint budget.

Question it answers
Where are or will be reactive power issues on the grid?
What is the value of a VAR?

Relevance to PR
Help energy planners choose optimal locations for generation systems and understand future reactive power issues

Target users
✓ Utility engineers and planners
✓ Researchers

Training available
Available upon request

Open source
No

Link
GridEye/FNET

GridEye is a unique wide-area grid monitoring network that provides independent observation of the entire electrical grid’s dynamic performance continuously and in real time. FNET/GridEye uses monitoring devices that are essentially GPS time synchronized single-phase phasor measurement units (or PMUs) to capture the dynamic responses (frequency, voltage and phase angle) of the grids to major disturbances such as generator trips and load shedding, as well as provide insight into inter-area oscillations. Since the monitors (which are referred to as frequency disturbance recorders, or FDRs) are connected at 110V, they do not require extensive installation as is the case for PMUs at high voltage substation.

Question it answers
What is the health of the electric grid?
What event triggered an outage?
How do we validate our models?

Relevance to PR
Currently being used to provide wide area situational awareness for PREPA.

Target users
✓ Utility companies
✓ Developers, engineers, or planners
✓ Researchers

Training available
User manuals, support forum, and data download steps online

Open source
No

Link
http://fnetpublic.utk.edu
THYME
Toolkit for Hybrid Modeling of Electric Power Systems

THYME is an open source simulation tool for studying the interaction of controls, communications, and electro-mechanical dynamics in a power system. This is not a simulation package like PSS/E, PSLF, and other similar, power system simulators. THYME is a C++ library for building simulators that integrate its modules for power system dynamics with existing simulators for communication networks, discrete control systems, and discrete event simulation packages in general.

**Question it answers**
How will loads impact the electric grid?
How can I best utilize communication and sensor technologies?

**Relevance to PR**
Assist in the modeling of power system and communication networks on the island. Also aid in impact and use of specific communication technologies.

**Target users**
- Developers, engineers, or planners
- Researchers

**Training available**
Available upon request

**Open source**
Yes

**Link**
https://web.ornl.gov/~nutarojj/thyme/docs/

Wide area monitoring and control of electric power systems
<table>
<thead>
<tr>
<th>Tool name</th>
<th>Data or tool</th>
<th>Brief Description</th>
<th>Question it answers</th>
<th>Users</th>
<th>Training available</th>
<th>Open source</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutoBEM</td>
<td>Tool</td>
<td>Software suite for automatic detection and creation of Building Energy Models for any area of interest. Involves the semi-automated retrieval of data sources, computer vision, analysis, model creation, simulation, and analysis in a way that is replicable across cities</td>
<td>What is the technical potential for a utility to determine how much DSM potential is available at any time? How much energy efficiency potential is available for a given region?</td>
<td>✓ Developers, engineers, or planners ✓ Researchers</td>
<td>Available upon request</td>
<td>No</td>
</tr>
<tr>
<td>CoNECT - Citizen Engagement for Energy Efficient Communities</td>
<td>Both</td>
<td>Community-based computational framework that enables consumers to benchmark their consumption against peers. It uses energy usage data (utility smart meter data) as well as property and spatial data from county government offices.</td>
<td>How can a community more effective utilize its energy? How can we accelerate the adoption of new technologies?</td>
<td>✓ Utility companies ✓ City council, community leaders ✓ Service organizations</td>
<td>Available upon request</td>
<td>No</td>
</tr>
<tr>
<td>Visual- SOLAR</td>
<td></td>
<td>Aids utilities by evaluating how PV DG could help address peak shaving and postpone infrastructure upgrades.</td>
<td>How can a community more effective utilize its energy? How can we accelerate the adoption of new technologies?</td>
<td>✓ Utility companies ✓ Residential communities ✓ Developers</td>
<td>Available upon request</td>
<td>No</td>
</tr>
<tr>
<td>ORCED - Generation Economic Modeling and Dispatch</td>
<td>Tool</td>
<td>Dispatches power plants in a region to meet electricity demands for any given year by matching generation to demands.</td>
<td>What are the impacts to emissions under different generating scenarios? How will dispatch impact costs and emissions?</td>
<td>✓ Developers, engineers, or planners ✓ Researchers</td>
<td>Available upon request</td>
<td>No</td>
</tr>
<tr>
<td>OR-SAGE - Oak Ridge Siting Analysis for Power Generation Expansion</td>
<td>Both</td>
<td>Dynamic visualization database employing GIS data and spatial modeling techniques to examine potential siting options for different electric generation and ramifications of national/regional energy policy decisions.</td>
<td>Where can we site new generation based on geo-spatial constraints? Can we attain certain energy goals based on future potential generation availability?</td>
<td>✓ Developers, engineers, or integrated resource planners ✓ Researchers ✓ Energy decision makers</td>
<td>Software operated at Oak Ridge National Laboratory</td>
<td>No</td>
</tr>
</tbody>
</table>
AutoBEM is a software suite for Automatic detection and creation of Building Energy Models for any area of interest which involves the semi-automated retrieval of data sources, computer vision, analysis, model creation, simulation, and analysis in a way that is replicable across cities. As an example, this has been applied to create and simulate over 130,000 building energy models with comparison to 15-minute data from every building within a municipality. This virtual utility is then analyzed assuming different technologies and policies to quantify energy, demand, emissions, and cost savings to inform operational decisions. The goal of this work is to create a freely available initial building energy model of every building in the United States.

Question it answers
What is the technical potential for a utility to determine how much DSM potential is available at any time?
How much energy efficiency potential is available for a given region?

Relevance to PR
Help energy planners choose optimal locations for generation systems and understand future reactive power issues

Target users
✓ Developers, engineers, or planners
✓ Researchers

Training available
Available upon request

Open source
No

Link
https://evenstar.ornl.gov/autobem/virtual_epb/

Extracted geometry for 100,000+ buildings Interactive visualization on the web Create Building Energy Models

Running on ORNL’s Titan supercomputer
CoNNECT
Citizen Engagement for Energy Efficient Communities

CoNNECT is a community-based computational framework that enables consumers to benchmark their consumption against that of their peers. This multi-partner platform, established to facilitate consumer engagement for energy efficiency, utilizes energy usage data, including the smart meter data from utilities as well as property and spatial data from county government offices and creates an interactive platform to better manage energy.

Question it answers
How can a community more effective utilize its energy?
How can we accelerate the adoption of new technologies?

Relevance to PR
Help the community provide awareness of energy best practices that can be critical prior and post extreme events.

Target users
- utility companies
- city council, community leaders,
- service organizations

Training available
Available upon request

Open source
No

Link
https://info.ornl.gov/sites/publications/Files/Pub36731.pdf
Visual SOLAR

Visual-SOLAR – Visualizing Solar Radiation Potential on Building Rooftops: The unique application of Visual-SOLAR is aiding utilities to evaluate how PV distributed generation could help address peak shaving and postpone infrastructure upgrade within their service areas by taking advantage of solar radiation potential on their customers’ building rooftop. The time required to perform the analysis could be reduced from months to minutes thereby greatly reducing the up-front planning cost of solar deployment at the utility level. For the residential and commercial customers, Visual-SOLAR helps individual building owner or a group of owners (in a co-op setting) to evaluate solar energy potential available to off-set some of their current electricity consumption.

Question it answers
How can a community more effective utilize its energy?
How can we accelerate the adoption of solar technologies

Relevance to PR
Provide technical potential of solar rooftop generation that can provide more generation diversity on the island

Target users
✓ utility companies
✓ Residential communities
✓ Developers

Training available
Available upon request

Open source
No

Link
http://gistbeta2/visual_solar/
ORCED dispatches power plants in a region to meet electricity demands for any given year up to 2030. The model simulates a single region of the country for a given year, matching generation to demands. ORCED can calculate a number of key financial and operating parameters for generating units. It has been used in a variety of grid studies.

**Question it answers**
What are the impacts to emissions under different generating scenarios?
How will dispatch impact costs and emissions?

**Relevance to PR**
Calculate a number of key financial and operating parameters for generating units, including average and marginal prices, air emissions, and generation adequacy.

**Target users**
- Developers, engineers, or planners
- Researchers

**Training available**
Available upon request

**Open source**
No

**Link**
https://ornl.sharepoint.com/sites/eessd_programs/electricdelivery/Reports/ORCED%20ModelFinal.pdf#search=ORCED

**ORCED Flow Diagram**
The OR-SAGE tool is a dynamic visualization database employing both geographic information systems (GIS) data and spatial modeling techniques used at ORNL to examine both potential siting options for different types of electrical generation plants and ramifications of national & regional energy policy decisions.

Question it answers
Where can we site new generation based on geo-spatial constraints? Can we attain certain energy goals based on future potential generation availability?

Relevance to PR
Help energy planners choose optimal locations for generation systems and understand future power issues

Target users
- Developers, engineers, or integrated resource planners
- Researchers
- Energy decision makers

Training available
Software operated at Oak Ridge National Laboratory

Link
www.osti.gov/servlets/purl/1032036/

Open source
No
## ORNL Tools — user-driven and publicly available

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Data or tool</th>
<th>Brief Description</th>
<th>Question it answers</th>
<th>Users</th>
<th>Training available</th>
<th>Open source</th>
</tr>
</thead>
</table>
| CSEISMIC - Complete System-level Efficient, Interoperable Solution for Microgrid Integrated Controls | Tool         | Monitors and controls microgrid components through communication links to perform both real-time controls and energy management. Also, provides the interface between the microgrid and the power system operator/energy market | - What systems can be used to operate a microgrid?  
- How do we control networked microgrids?                                                                | ✓ Utility engineers, or planners  
✓ Microgrid developers  
✓ Researchers                                                                | Software can be downloaded from website; training available upon request               | Yes                                                      |
| SI-GRID                                                                  | Tool         | Open research platform to safely test microgrid components in low-voltage settings (below 100 volts) that mimic real-world, high-voltage applications. | - What novel control architectures can be used in the grid?  
- How can I verify new protection schemes will not negatively impact the grid? | ✓ Developers, engineers, or planners  
✓ Researchers                                                                | Software can be downloaded from website; training available upon request                | Software is open source                                                  |
| SPOT – Sensor Placement Optimization Tool                                | Both         | Platform for optimizing sensor placement strategy to enhance distribution system monitoring and resiliency. It allows the utility stakeholders to meet the monitoring and control requirements with less cost while satisfying practical constraints. | - How to determine the optimal sensor strategy (types, number and locations) when planning new sensors and reclosers? | ✓ Utility companies  
✓ Developers, engineers, or planners  
✓ Researchers                                                                | User manuals, training available upon request                                           | No                                                       |
Complete System-level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC). It monitors and controls the microgrid components through communication links to perform both real-time controls and energy management. It is also the interface between the microgrid and the power system operator/energy market for the microgrid to participate in system operation and/or energy market activities.

**Question it answers**
What systems can be used to operate a microgrid?
How do we control networked microgrids?

**Relevance to PR**
Currently being used in Southern Company’s Connected Community Neighborhood. Similar framework could be used in Puerto Rico

**Target users**
- Utility engineers, or planners
- Microgrid developers
- Researchers

**Training available**
Software can be downloaded from website; training available upon request

**Link**
https://github.com/ORNLPES/CSEISMIC

**Open source**
Yes
SI-GRID
Software-Defined Intelligent Grid Research Integration and Development

SI-GRID is an ORNL-developed open research platform to safely test microgrid components in low-voltage settings (below 100 volts) that mimic real-world, high-voltage applications. The system is accelerating science from the lab to the field. It can, for instance, test protective relays that detect electrical faults and prevent damage to the network. The platform is being used to develop and rapidly prototype technologies associated with microgrids, including power electronics–based converters, generation technologies, energy storage, protection, cybersecurity methods, communications protocols, control, optimization, standardization, and integration of DERs, buildings, and vehicles.

Question it answers
What novel control architectures can be used in the grid?
How can I verify new protection schemes will not negatively impact the grid?

Relevance to PR
Provides an environment to demonstrate advanced control schemes prior to deploying in the field with more resolution

Target users
✔ Developers, engineers, or planners
✔ Researchers

Training available
Software can be downloaded from website; training available upon request

Open source
Software is open source

Link
https://github.com/ORNLPES/
SPOT
Sensor Placement Optimization Tool

SPOT- Sensor Placement Optimization Tool is a platform for optimizing the sensor placement strategy to enhance distribution system monitoring and resiliency. It allows the utility stakeholders to meet the monitoring and control requirements with less cost and satisfying practical constraints. It contains two selected modules currently based on industry priority: distribution state estimation (DSE) module and recloser placement module. The three-phase feature is captured in DSE module to reflect practical distribution systems with asymmetrical topology and unbalanced load. Also, the impact of microgrid is modeled in recloser placement module. SPOT can help utility stakeholders develop their own optimal sensing strategies.

Question it answers
How to determine the optimal sensor strategy (types, number and locations) when planning new sensors and reclosers?

Relevance to PR
Can optimize sensor placement strategy and help utility stakeholders develop their own optimal sensing and measurement strategies and roadmaps

Target users
- Utility companies
- Developers, engineers, or planners
- Researchers

Training available
User manuals, training available upon request

Open source
No

Use cases on a realistic feeder: (a) DSE module (b) recloser placement module
## ORNL Tools – commercial tools used

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Data or tool</th>
<th>Brief Description</th>
<th>Solution it provides</th>
<th>Training available</th>
<th>Open source</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPE – Siemens Computer Aided Protection Engineering Tool</td>
<td>Tool</td>
<td>A tool for modeling electric utility protection systems. The tool comes with a large library of detailed relay models (over 6,000 relay styles, reclosers, and fuses) and the ability to add new relay models.</td>
<td>CAPE is built for engineers responsible for protection of high-voltage transmission systems and distribution systems within electric utilities and provides them with advanced tools for network and protection simulation.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PSS/E – Siemens Power System Simulator for Engineering Tool</td>
<td>Tool</td>
<td>PSS/E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance.</td>
<td>It provides advanced and proven methods in many technical areas, including: Power Flow, Optimal Power Flow, Balanced or Unbalanced Fault Analysis, Dynamic Simulation, Extended Term Dynamic Simulation, Transfer Limit Analysis, Network Reduction.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PSLF - GE Positive Sequence Load Flow Software tool</td>
<td>tool</td>
<td>PSLF is a suite of analytical tools that can simulate large-scale power systems up to 60,000 buses.</td>
<td>This power systems analysis package includes programs for load-flow, short-circuit, and transient-stability simulations.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>POM – V&amp;R Physical and Operational Margins Tool</td>
<td>Tool</td>
<td>Powerful and highly automated power systems engineering application used for the steady-state stability analysis.</td>
<td>The tool includes load flow, AC contingency analysis, power transfer, and voltage stability analyses.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>PowerWorld Simulator</td>
<td>Tool</td>
<td>PowerWorld Simulator is an interactive power systems simulation package designed to simulate high voltage power systems operation on a time frame ranging from several minutes to several days.</td>
<td>The software contains a highly effective power flow analysis package capable of efficiently solving systems with up to 100,000 buses.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>ATF (Alternative Transients Program) &amp; EMTP (Electromagnetic Transients Program) Tool</td>
<td>Tool</td>
<td>A universal program for digital simulation of transient phenomena of electromagnetic as well as electromechanical nature.</td>
<td>With this program, complex networks and control systems of arbitrary structure can be simulated. The program is being used to model the impact of high efficiency heat pumps on the electric distribution system.</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>RiverWare Both</td>
<td>Both</td>
<td>ORNL has prepared RiverWare water-constrained energy production models for hydro-systems across the U.S., including models of hourly coordination of mid-Columbia River hydropower generation and models of daily hydro-system generation in the Hudson (NY) and Penobscot (ME) Basins.</td>
<td>Modeling of time-varying maximum and minimum capabilities of hydraulically-connected generation facilities within power system dispatch.</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
ORNL Advanced Grid Modeling

**SENSING AND MEASUREMENT**
- Goal: Bringing right data to right place at right time
  - Data Calibration/Quality
  - Measurements (Data Architecture)
  - Markets (Market Data)
  - Reaction (Quality Data)
  - Event detection (Machine learning)
  - Human factors
  - Alarming

**RECOGNCITION**
- Goal: Identify patterns (in near real time) in datasets and data streams
  - VIZ
  - Dynamic models
    - EI 2030 dyn model
    - Load modeling
    - Protection modeling
    - Plexos Prod Cost Modeling

**PLANNING**
- Goal: Increase model fidelity and availability
  - Reactive Q placement (MOVART-I)
  - Dynamic models

**SYSTEM OPERATIONS & CONTROL**
- Goal: Increase simulation speed and flexibility
  - Dynamic SE/SIM

**Next-Gen EMS**
- Goal: Seamless control / protect across system
  - Stability (vol / tran / s-o)
    - MOVART-II
    - (Predictive)
  - Decision Support
    - Cognitive EMS
  - Look-ahead Dynamic Simulation
    - Parareal ALG
    - Comp Plat
    - Grid-SEER
  - Damage Coupling
    - CAPE / PSSE / ATP

**Reporting**
- Goal: Increase simulation speed and flexibility
  - Operator
  - Control
  - Protection Coupling

**Actions**
- Goal: Seamless control / protect across system
Sandia Grid Resilience Tools for Puerto Rico

PRESENTED BY

Dan Borneo
Microgrid Design Toolkit (MDT): Design Optimization and Cost-Performance Trade-off

Model details:

Name: Microgrid Design Toolkit
Type: Multi-objective optimization decision support tool for electric systems design, based on cost, reliability and availability targets
Source: Sandia, DOE/DOD co-sponsored. development
Update/availability: 2018 software, documentation, model library and use cases public download available from DOE website

Compatibility/Implementation:

Computational: Runs on PC/workstation. HPC may be required depending on system scale
RT application: Not HIL-enabled, but could be implemented through co-simulation
Uncertainty: Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities). Load-generation balance handled via time-series dispatch analysis.

Proposed Application to Resilience Modeling:

Scope: Optimizes investment options for energy systems, primarily designed for microgrids, using computationally efficient heuristics.
Processes modeled: Models network, load, storage and generation elements and their respective failure rates and mechanism.
Application: Reliability/resilience analysis of energy systems. Has been extensively applied to civilian and military microgrid design to maximize cost-benefit.
  • Military: SPIDERS, numerous DOD energy surety assessments
  • Civilian: Urban, Transportation, and Industrial microgrids

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov
Model details:

**Name:**
- **PV_LIB Toolbox** - PV performance modeling functions available in Matlab and Python
- **GridPV Toolbox** - A tool for modeling power flow and voltage patterns on distribution feeders with PV
- **PV Variability Datasets** - A collection of high frequency (1-30 sec) irradiance data samples across the US
- **Wavelet Variability Model** - A model for estimating the variability in PV plant output based on point sensors of irradiance and PV plant geometry.

**Source:** Sandia National Laboratories

**Documentation:** [https://pvpmc.sandia.gov/](https://pvpmc.sandia.gov/)

**Compatibility/Implementation:**

**Computational:** HPC not normally required (reduced order)

**RT application:** Can be adapted to Real-Time simulations

**Stochastic/Uncertainty:** Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

**Compatibility:** Fully compatible with standard distribution system simulation packages (e.g., Cyme, OpenDSS as well as MATLAB)

**Proposed Application to Resilience Modeling:**

**Scope:** Tools for modeling PV plant output as well as distribution system performance with various distributed energy resource (DER) penetrations.

**Processes modeled:** Irradiance->Cell model->Inverter Model->Distribution level model

**Application:** Model DER penetrations and the impact on the distribution grid (e.g., voltage, current, and thermal violations). Identify solar hosting capacity using quasi-static time series simulations (more accurate results than static analysis).

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov
Energy Storage Optimization & Evaluation Tool - QuEST

Model details:
Software tool for energy storage researchers and stakeholders:
• Free, open-source, easy-to-use
• Runs on Windows, Mac, or Linux
• Provides sophisticated back-end with optimization algorithms developed by researchers at Sandia and validated with numerous peer-reviewed publications
• Interfaces with other Sandia software tools such as Prescient (Production Cost Model Tool), Microgrid Design Tool (R&D 100 winner)

Prior Applications:
Internal use for analytical studies:

Proposed Application to Resilience Modeling:
Software tool allows users to:
• Analyze value of energy storage across the country
• Determine optimal sizing and placement
• Select appropriate technology
• Optimally design and manage microgrids

Outputs results that help users:
• Make investment/planning decisions
• Simulate use-cases
• Visualize data

Available on Github: https://github.com/rconcep/snl-quest

Contact: Babu Chalamala, 505-845-7185, bchalam@sandia.gov
Standard Models for Distributed and Bulk-level Wind, Solar and Energy Storage

Model details:

Name: **RExx** for wind, solar, storage; **CMPLDW** for load

Type: Positive-seq. dynamic & power flow models

Source: Sandia-led WECC Renewable Energy Task Force and Modeling and Validation Working Group, input from DOE labs, manufacturers, utilities, sw. vendors

Update: TRL 8+, available in major simulation platforms

Documentation: [www.wecc.biz](http://www.wecc.biz)

Compatibility/Implementation:

Computational: HPC not normally required (reduced order)

RT application: Can be adapted to Real-Time simulations

Stochastic/Uncertainty: Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

Compatibility: Fully compatible with standard positive-sequence base cases and simulation platforms

Proposed Application to Resilience Modeling:

Scope: **RExx**: turbine and governor, Generator/converter and excitation. **CMPLDW**: static and motor loads including single-phase stalling, and distributed PV and storage

Processes modeled: Dynamic stability of the bulk system, including recovery from severe disturbances

Application: Model centralized and distributed wind, solar and energy storage in transmission reliability/expansion and generation interconnection studies.

- Load/generation adjustable via power reference parameter
- Model documentation includes default parameter data, and suggested regional/seasonal variations.

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov
Model details:

Name: ReNCAT

Type: Microgrid design (clustering) algorithm that minimizes societal burden with respect to various threats (e.g., flooding, hurricanes, earthquakes, etc.).

Source: Sandia National Laboratories

Update: will be released to the public in 2019

Documentation: N/A

Compatibility/Implementation:

Computational: HPC not normally required (reduced order)

RT application: Can be adapted to Real-Time simulations

Stochastic/Uncertainty: Deterministic model parameters, but uncertainty can be explored via Monte Carlo analysis

Compatibility: Fully compatible with distribution system models

Proposed Application to Resilience Modeling:

Scope: Microgrid design (clustering) algorithm that minimizes societal burden with respect to various threats (e.g., flooding, hurricanes, earthquakes, etc.).

Processes modeled: Societal benefits provided by critical infrastructure, threat impacts to various types of infrastructure, distribution grid topology and optimal partitioning into microgrids

Application: Top-down modeling process for identifying potential clusters of critical infrastructure for microgrids that are resilient with respect to the modeled threats. After this analysis, MDT is typically employed to size the microgrid components.

Contact: Abraham Ellis, 505-844-7717, aellis@sandia.gov
Grid Resiliency Open-Source Optimization Toolkit

Model details:
- Implements Sandia’s Resiliency Analysis Process (RAP), highlighted in recent DOE QER and QTR
- Automatically identifies worst-case and near-worst-case transmission level attack vectors
- Automatically identifies mitigation strategies for extreme weather events
- Stochastic and robust transmission-level system optimization
- Power flow and dispatch-focused analyses
- Lab-developed, funded by DHS, DOE/OE, and DOE/EPSA

Prior Applications:
- Extreme weather mitigation for American Electric Power (AEP) - West
- Physical vulnerability assessment for American Electric Power (AEP) - East
- GMD mitigation for Pennsylvania-Jersey-Maryland Independent System Operator
- Model is under active development and extension (Advanced Grid Modeling program)
- In process of transitioning from internal Sandia tool to broader, open source deployment
- Model details informed by significant interactions with NERC and AEP

Proposed Application to Resilience Modeling:
- Provide quantitatively rigorous scenarios for NERC GridEx and related operational exercises
- Provide regional vulnerability assessments concerning physical attack vectors
- Provide rate case justification for resiliency investments through reliability-resiliency co-optimization
- Primarily for planning purposes. Turn-around times within 30 minutes possible for operations situational awareness
- Leverages multi-core cluster resources, if available
- Uncertainty is inherent in the Resiliency Analysis Process, and is explicitly modeled
- Takes PSSE as standard input format for power flow cases

Contact: Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov
**Long-Term Grid Expansion Planning Under Uncertainty**

**TIGRIS: Generation and Transmission Expansion Co-Optimization**

**Prior Applications:**
- Demonstration of benefits of both probabilistic and co-optimized expansion models, on exemplary WECC system
- Scalable HPC demonstration of co-optimization expansion model solvers
- Analysis of benefits of stochastic power grid operations, under DOE/ARPA-E and DOE/OE projects
- Model details informed by significant interactions with WECC and PJM
- Lab-developed (Sandia) tool; NREL is recent development partner
- Models are under active development and extension

**Proposed Application to Resilience Modeling:**
- Planning expansion under uncertainty to achieve specific resiliency goals
  - Expansion planning is universally focused on economics / reliability
  - Integration of resiliency metrics and operational paradigms into production cost modeling
    - Assess alternative operational strategies for improved resiliency
  - Requires HPC for practical (e.g., few-hour) turn-around times
  - Uncertainty in renewables production, demand evolution, and policy are key inputs

**Model details:**
- Transmission, generation, and storage co-optimization to ensure equitable treatment of alternative resources
- Fully integrated stochastic unit commitment and economic dispatch
- High-fidelity probabilistic treatment of solar and wind production
- Stochastic transmission level optimization
- Lab-developed, funded by DOE/SC, DOE/ARPA-E, and DOE/OE
- Couples capacity expansion and unit commitment / dispatch / power flow

**Contact:** Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov
Small Signal Stability Analysis and Modeling

Model details:

- Small signal stability refers to the response of the power system to small disturbances. Decreased mode damping results in reduced resiliency to grid disturbances.
- Sandia has developed MATLAB tools that update dynamic simulation models (e.g., PSLF) with various renewable generation scenarios and then perform modal analysis on the dynamic simulation results.

Prior Applications:

- Studies quantifying the impacts of large penetrations of renewable generation on small signal stability (e.g., WECC, NPCC)
- Control system design for a prototype PDCI damping control system
- The modal analysis GUI has been adopted by the WECC for visualizing mode shapes

Visualization of WECC 0.37 Hz mode

Proposed Application to Resilience Modeling:

- Evaluation of small signal stability margins for future grid scenarios
- Design of control systems to improve small signal stability in large power systems

Contact: Raymond Byrne, 505-844-8716, rhbyrne@sandia.gov
Model details:

Name: SCEPTRE
Type: Virtualized Emulation

SCEPTRE is unique by providing a cyber-physical interface to show how cyber-initiated events affect the physical world (and vice versa)

- Traditional SCADA test beds are burdensome
- Lab-scale hardware testing is insufficient
- Control network-only simulations are incomplete

SCEPTRE deploys live, operational environments that users can interact with. SCEPTRE is scalable, modeling the smallest of systems to large, interconnected systems (e.g., WECC). SCEPTRE environments can be built in rapid fashion and easily duplicated for parallel testing

Source: Sandia, DOE/DoD funded
Update/availability: GOTS; actively maintained with regular updates

Proposed Application to Resilience Modeling:

- SCEPTRE allows you to quickly deploy and tear down ICS and SCADA environments for:
  - Testing TTPs
  - Research and development
  - Vulnerability and malware analysis
  - Training
  - Mitigation evaluation
  - Physical effects modeling

- High fidelity virtualized emulation

- Running actual, to-spec ICS/SCADA network protocols
- Near real-time (limited only by end process simulation)
- Runs in virtual machines on commodity x86 cluster hardware, with extensive Hardware in the Loop support
- Seamless composability with other models has been demonstrated at multiple levels

Contact: Brian Gaines, 505 845-7329 bgaines@sandia.gov
Instrumented ICS/SCADA Malware Analysis Testing Environment

Example: CRASHOVERRIDE Malware Analysis

Model details:
Name: Instrumented ICS/SCADA Malware Analysis Environment
Type: Hardware-in-the-Loop (HITL) with Virtualized Emulation
• Balance between fidelity (HITL), flexibility, and speed (rapid environment design and setup)
• Emulations permit parallel testing, rapid environment reset, and aggressive testing regimes without risk of “bricking” devices
• Highly instrumented to provide deep introspection and data collection for post experiment analysis
• Evaluate “what if” scenarios and potential mitigations
Source: Sandia, DOE/DoD funded
Update/availability: GOTS; actively maintained reverse engineering and analysis environment

Prior and Current Applications:
• CRASHOVERRIDE
  • Rapid instantiation of sandboxed malware analysis environment (with HITL) CRASHOVERRIDE malware analysis. One of the first detailed dynamic studies of the malware, resulting in meaningful results and proposed mitigations.
• J-BASICS
  • Testing and evaluation of ICS TTPs assisting IT/OT personnel to detect, mitigate, and recover from nation-state level cyber threats.
• Field Device Assessment Methodology (FDAM)
  • Thorough vulnerability assessments at the field device level.
• Artificial Diversity and Defense Security (ADDSEC)
  • Development of moving target defense and dynamic defense technologies

Proposed Applications:
• TRISIS malware analysis
  • TRISIS malware analysis similar to previous studies, e.g. CRASHOVERRIDE
• Continued development and improvement of mitigation strategies
  • Improvement of ICS situational awareness tools (WeaselBoard, Archimedes, etc.)
• Predictive threat analysis with proactive results

Proposed Application to Resilience Modeling:
• The Malware Analysis Testing Environment provides a sandbox for improving Sandia ICS capabilities against real world malware
• SCEPTRE
  • Comprehensive ICS/SCADA modeling and simulation capability that captures the cyber/physical impacts of targeted cyber events on critical infrastructure and control systems.
• Archimedes
  • Network-level ICS situational awareness tool, identifying trends and detecting anomalies in control system data signals
• PLC Extraction and Analysis Tool (PEAT)
  • Automate firmware, logic, and configuration extraction from ICS field devices for verification and indicators of compromise.
• WeaselBoard
  • Situational awareness at the field device level. WeaselBoard sits on PLC backplanes, examining communications between modules. Behavioral analysis enables detection of zero-days and other control system anomalies

Contact: Brian Gaines, 505 845-7329 bgaines@sandia.gov
EM/EMP/GMD Modeling Capabilities

Model details:

ATLOG: analytical, frequency-domain and time-domain codes based on transmission line theory for electric utility grid; models EMP excitation of transmission line conductors, including coupling to lossy or perfectly-conducting ground or air; treats both insulated and bare, infinite and finite wires above-, on-, or under-ground.

Xyce: massively parallel circuit simulator (SPICE style) for coupled EM to transmission line modeling, including detailed device-level models (transformers, etc.). Capable of transient, AC, DC and harmonic analysis. Can include radiation aware devices models.

Prior Applications:

ATLOG: fast turnaround method: offered as an alternative option to a full-wave solution - useful to quickly assess a wide variety of scenarios and determine relative impact over a wide parameter space and is not limited in the length of the line; does not require an expert user and can be used in an operator-mode for damage assessment

Xyce: 46 transmission lines, 33 switching substations, 5 transformers

Proposed Application to Resilience Modeling:

ATLOG: to be used as a source building block for sections of the grid to calculate decay lengths of both common and differential modes of EMP coupling to transmission line infrastructure and calculate detailed coupling effects to switching, SCADA, and other devices within substations and switchyards

Xyce: to evaluate city-wide to regional scale electrical grid response to an EMP event, including transmission and distribution infrastructure; step-up, step-down, and switching substations; and transformers

Contact: Craig Lawton, 505-844-4895, crlawto@sandia.gov
System of Systems Analysis Toolset (JOEI)

Model details:

**Name:** System-of-Systems Analysis Toolset (SoSAT) / Joint Operational Energy Initiative

**Type:** Large-scale custom discrete event simulation code. System of Systems Analytic Toolkit provides an analytic framework for system of system trades

**Source:** Sandia, DOD sponsored development

**Scope:** Energy systems and subsystems (e.g., vehicles, energy generators/resources, energy infrastructure). Evaluates operational energy utilization in a large area of operations

**Uncertainty:** Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities)

Implementation:

**Prior Applications:** Used by DOD to evaluate operational energy utilization in a large geographic area of operations (e.g., COCOM)

- Evaluates key energy (efficiency) technologies (e.g., storage technologies, renewables etc.)
- Evaluating fuel use benefits of key vehicle technologies (e.g., Auxiliary Power Units reduce fuel use over mission cycle)

**Update/availability:** 2018 software Version 3.0, documentation, model library and use cases, training. Extensive V&V by the DOD

Contact: Craig Lawton, 505-844-4895, crlawto@sandia.gov

Proposed Application to Resilience Modeling:

**Proposed Scope:** Model can be easily modified for application to more general energy domains/infrastructures for use as an energy resilience evaluation framework

**Processes modeled:** Simulates network, load, storage and generation elements and their respective failure rates and mechanism

**Computational:** Runs on PC/workstation. Supports parallel computing (cluster) environments for large scale analyses

**Uncertainty:** Explicit representation of uncertain/stochastic parameters (e.g., failure probabilities)
Facilitated Small Group Discussions
Facilitated discussion on data, tool, and training priorities

• In small groups, discuss where additional tool training or investment is needed to address Puerto Rico stakeholder needs for long term stability of electric system
• Choose a group member to write down priority topics and post on the wall
• Goal is to get top 2-3 needs on data and tools and 1-2 priorities for DOE related to that space
• Possible group table topics are:
  – Solar resource data (how to get it, what it’s going to look like after phase 2) – with Nate
  – Facilitation of Distributed Energy Resources (DERs) on the grid (residential) – with Dan
  – Microgrids, resilience, and critical infrastructure – with Rob
  – Energy efficiency – with Adam
  – Training needs and local capacity – with Elaine
  – Finance – with Elaine
  – Community-oriented solutions – with Robin
Report-Out from Discussion

• Facilitators and participants report out on top priorities
• Participants go around the room and put dots on their top priorities
Next Steps
• Discussion focused on:
  – Potential solutions
  – Available resources
  – Making connections
Concurrent Afternoon Sessions

• **Option 1. System Advisor Model (SAM) User Group Session.**
  This three-hour, hands-on session provides an overview of SAM and related tools and solicits feedback from users on Puerto Rico specific needs. Also covers the National Solar Radiation Database (NSRDB), PVWatts, Utility Rate Database, Jobs and Economic Development Impacts (JEDI) tool and other relevant data and tools. Suitable for anyone interested in individual system simulations.

• **Option 2. HEVI and MAFRIT/FESTIV Tools Overview and Discussion.**
  Learn more about NREL’s capacity expansion modeling tool Hawaii Energy Visualization Initiative (HEVI), and grid modeling tools Multi-Area Frequency Response Integration Tool (MAFRIT) and Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV) in this three-hour session.

• **Option 3. Energy Efficiency Tools and Resources.**
  Attend this session for a more in-depth discussion on energy efficiency needs in Puerto Rico and available resources.
Thank You!

NREL/PR-6A20-73835