



SETO Resilience Workshop

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(with contributions from Gil Bindewald)

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Two GAO Reports from March 2021

GAO-21-346 (Climate Resilience) and 21-274 (Hurricane Resilience)

- **Recommendation 1:** *Resilience R&D Roadmap*
 - The Secretary of Energy should establish a plan, including timeframes as appropriate, to guide the agency's efforts to develop tools for resilience planning, such as performance measures for resilience, a framework for resilience planning, and additional information on the cost of long-term power outages.
- **Recommendation 2:** The Secretary of Energy should take steps to better leverage the National Laboratories' emerging grid resilience efforts and technologies by developing a formal mechanism to share this information with utilities.



Resilience Defined by PPD 21 for Feds

The term "resilience" means the ability to **prepare for and adapt to changing conditions** and **withstand and recover rapidly** from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.

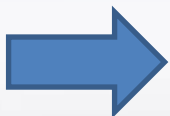
– *Presidential Policy Directive 21 (Feb. 2013)*

For more definitions, see Hosseini et al., "A review of definitions and measures of system resilience," Reliability Engineering and System Safety (2016) (reviewing over 60 definitions and frameworks); Ayyub, "Systems resilience for multihazard environments: definition, metrics, and valuation for decision making," Risk Analysis 34 (2) (identifying over 150 definitions of resilience)

Elements of Federal Definition of Resilience

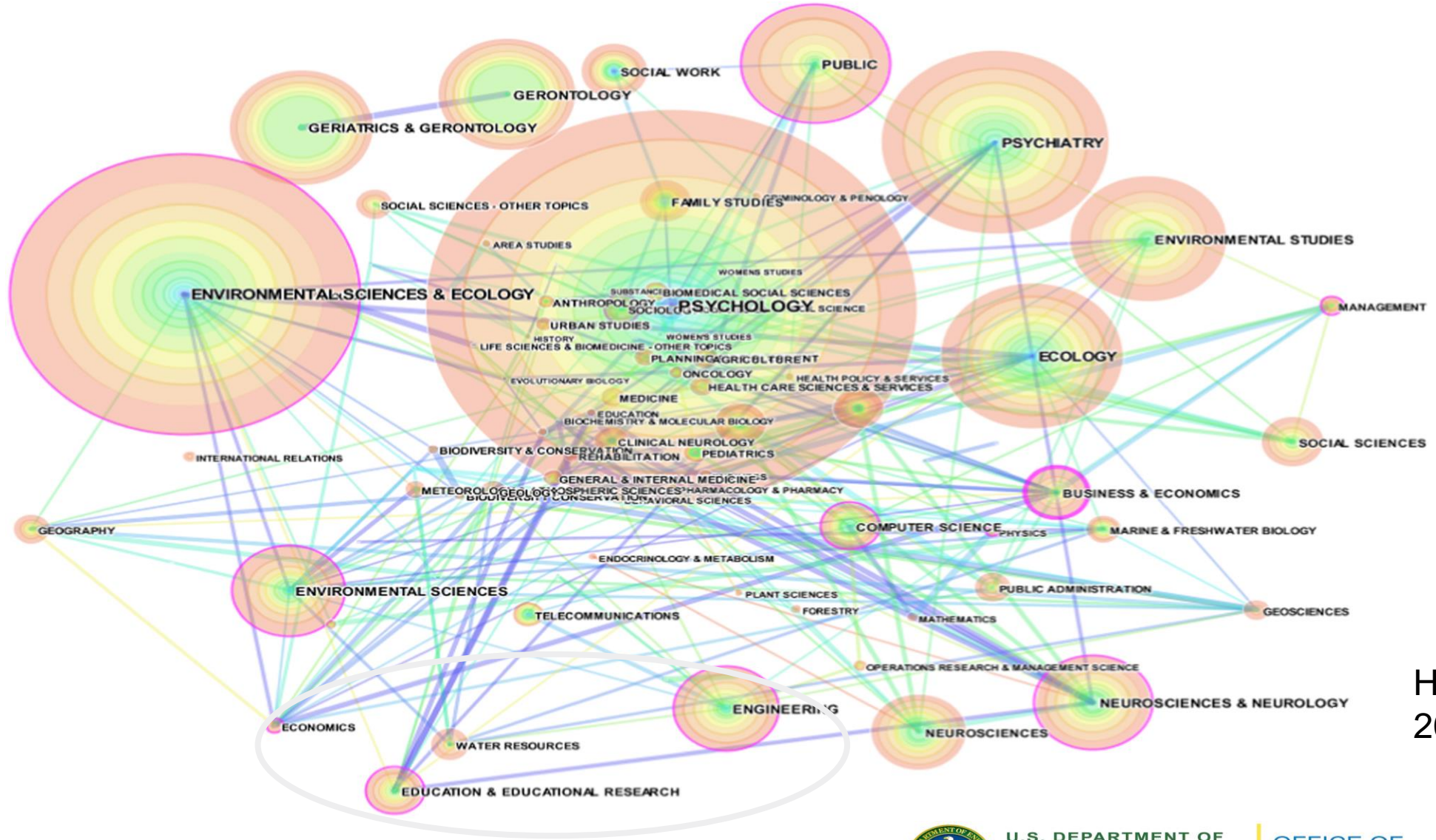
Language from PPD21

- **Planning capability** – “ability to prepare for”
- **Strong / hardened** – “withstand”
- **Efficient redundancies** – “recover rapidly”
- **Multiple equilibria** – “adapt to changing conditions”
- **Threat neutral / Multi-Hazard** – “deliberate attacks, accidents or naturally occurring”



Resilience is not solely about adapting in the moment, but depends on robust planning, preparation, and prudent investment.

Domain Distribution of Peer Reviewed Papers on Resilience 2000-2015

Hosseini
2016

Capacities required to meet resilience definitions

Three temporal phases

- Pre-event / mitigation stage
- During an event
- Immediate post-event

Baselining capacity

- Describe normal pre-event conditions, operating parameters
- End use

Planning capacity

- Expected behavior during event
- Frequency of expected component failures during single threat
- Expected end use (consequence)
- Anticipate stable equilibria

Recovery capacity (Expected recovery behavior)

- Mitigate initial impact (stockpiling, hardening, redundancy)
- Accurate impact diagnosis in real time
- Accurate consequence prognosis
- Understanding mitigative effects of different recovery behaviors
- Ability to communicate to direct resources

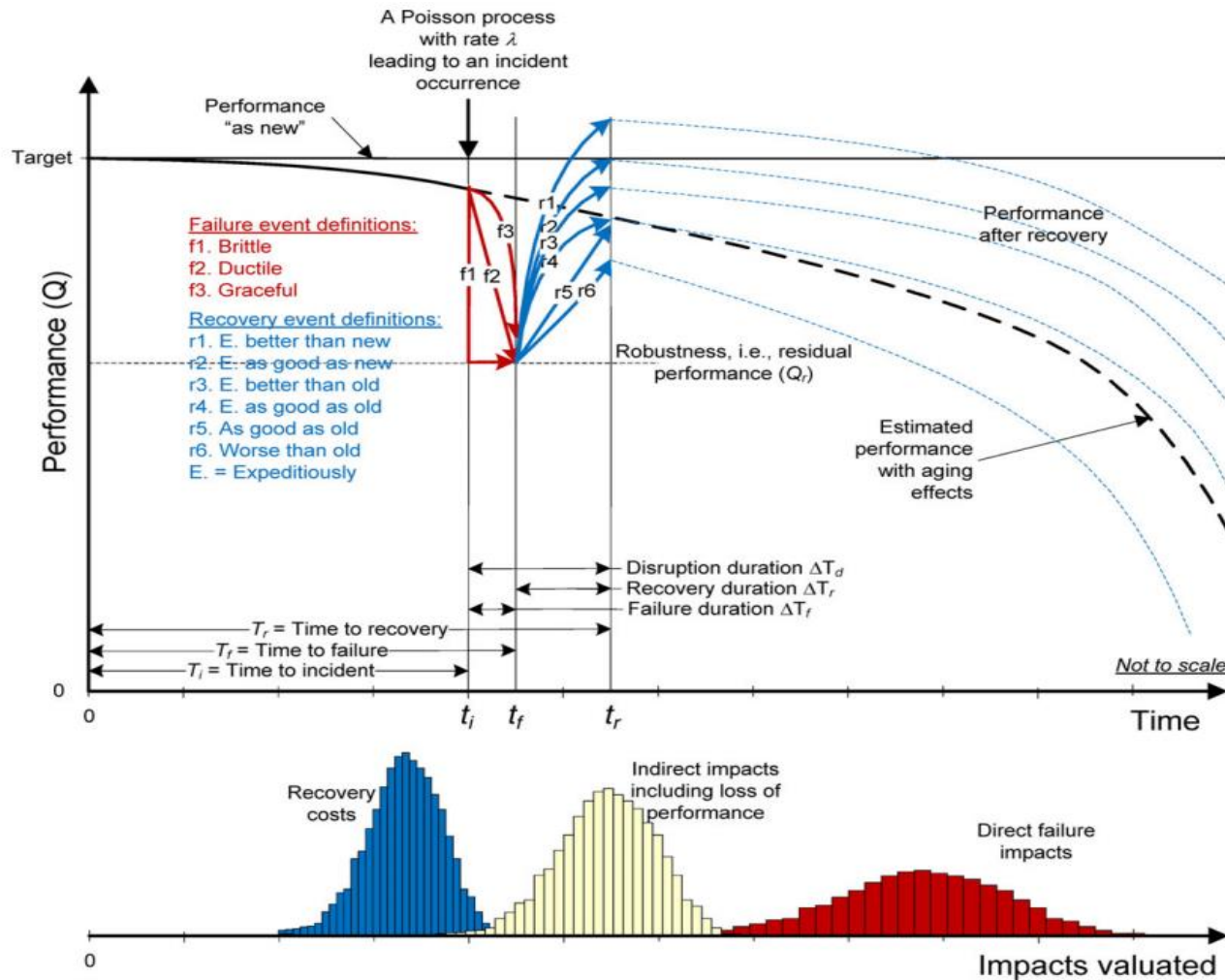
(Implied) Pre-event financial capacity for mitigation

- Infrastructure to enable anticipated equilibria

(Implied) More than just asset performance



A complex resilience triangle (Ayyub 2017)



Proposed definitions of resilience metrics.

Ayyub, "Systems resilience for multihazard environments: definition, metrics, and valuation for decision making," Risk Analysis, 34 (2) (2014)

- Is "resilience" minimizing the area of a triangle representing asset down time... OR...
- Is "resilience" an emergent property of a system with changing boundary conditions?
- See, e.g., Haines, "On the Definition of Resilience in Systems," Risk Analysis, (2009); Park et al., "Integrating Risk and Resilience Approaches to Catastrophe Management in Engineering Systems," Risk Analysis (2013); Bowers et al., "Team Resilience as a Second-Order Emergent State: A Theoretical Model and Research Directions," Frontiers in Psychology (2017).

Federal Role (not comprehensive)

1. Complement local response capacity (FEMA NDRF)

- States have police power and exercise control over the provision of electric service within their territory (i.e., choose performance measure y axis in “resilience triangle”)

2. Build local/regional planning capacity, both pre-event and recovery

- Accurate baselines
- Data collection, standardization, etc.
- Standard heuristics, failure probabilities under given stress
- Investment prioritization frameworks, best practice (GAO)

3. Support an accurate consequence prognosis capability

- Accurately identify rapidly evolving conditions during an event
- Select and implement appropriate mitigation actions in near-real-time

4. Provide financing for resilience assets (e.g., FEMA BRIC)

- Assets might not fit state electricity regulatory paradigm (“used & useful”)
- Assets might not generate or support revenue



OE Focus Areas To Achieve Resilience



- **Understand context of resilience question at hand**
 - Threat/event characterization, demand/behavior profiles
 - Burden to access critical services (Bobby)
- **Analyze existing asset and/or system flexibility**
 - Prioritize availability or consequence mitigation?
- **Identify technology gaps and potential solutions**
 - Modeling; real-time diagnosis; sensors; DER & microgrids; controls; metrics & maturity models
- **Link bulk power and edge:** From mutually-informed to co-optimized
- **Coordinate objectives and facilitate decision-making**
 - Establish framework for key stakeholders to evaluate trade-offs

OE's new division

Energy Resilience Division

- Used to be TPTA
- Has a DAS (vacant)
- Focused on recovery and critical energy infrastructure
- Jenn DeCesaro occupies director role (on detail)
- Johanna Zetterberg is current Managing Director
- Aaron Ng, Rebecca Asch (RCoP)
- Puerto Rico Phase 3
- Partners with EERE on Energy Transitions Initiative
- Early stages of a FOA to help communities with resilience planning challenges, inspired by Rooftop Solar Challenge



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IEEE Resilience Report, Oct 2020

Consistent with GMLC 1.1 Resilience Metrics

“The investment will depend on **a good understanding of the consequences**, which should guide the overall investment.”

“There is no ‘one-size-fits-all’ solution for resilience metrics and investments as they are dependent on various factors (regional, functional, regulatory, and business). Therefore, it is **impossible to have simple, industry-accepted resilience metrics addressing all-inclusive events** affecting resilience.”

“A comprehensive approach to developing a resilience plan must include the **active involvement of diverse stakeholders**—starting with regulators and policymakers at the federal and state levels.”

“Resilience Framework, Methods, and Metrics for the Electricity Sector” from the Power & Energy Society



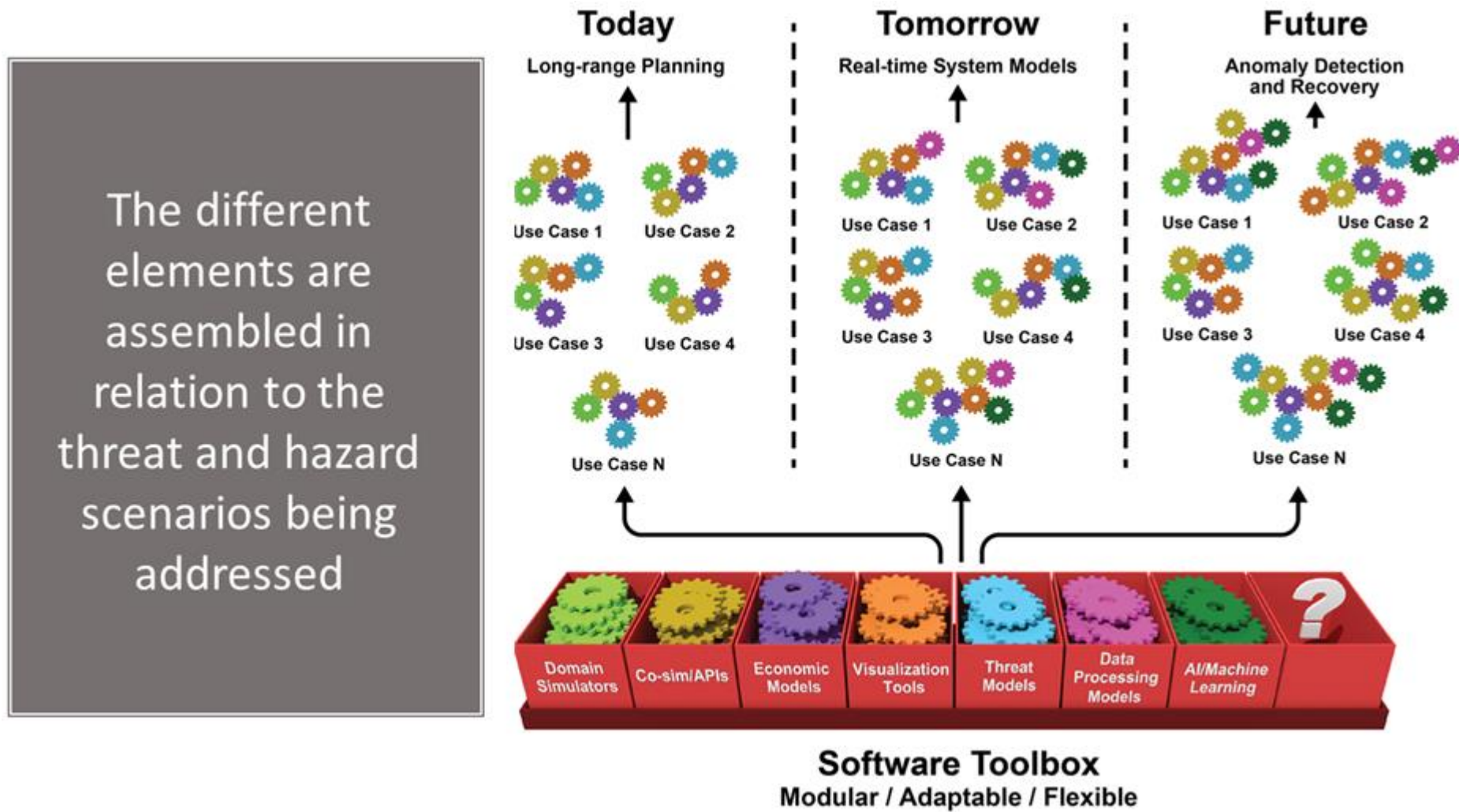
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Uses of Modeling

- Facilitate understanding of complex data
- Demonstrate physics of dynamic power system
- Confidently estimate parameter values that cannot be directly measured
- Predict (simulate) potential events/scenarios
- Evaluate optimal resilience design
 - For example, placement of energy storage
- Ultimate goal is to support investment decisions by relevant local authorities
 - Relying on their goals too set key parameters

NAERM is a “toolbox” of modular software elements



Maria Recovery Work “Buckets”

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:

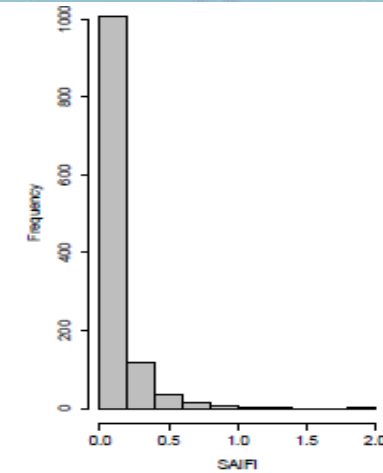
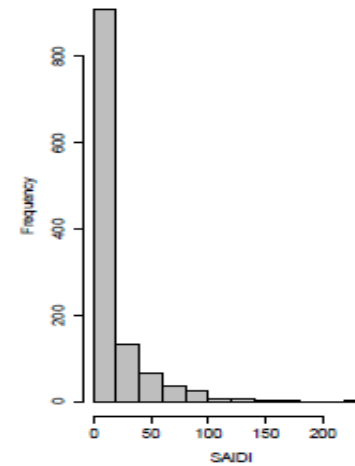
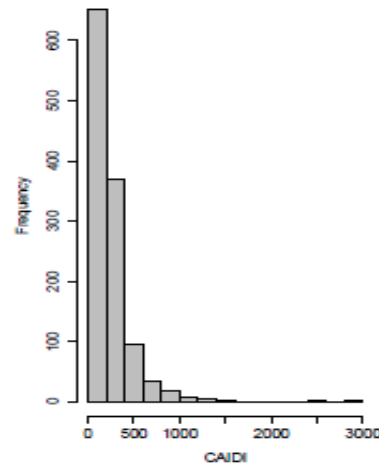
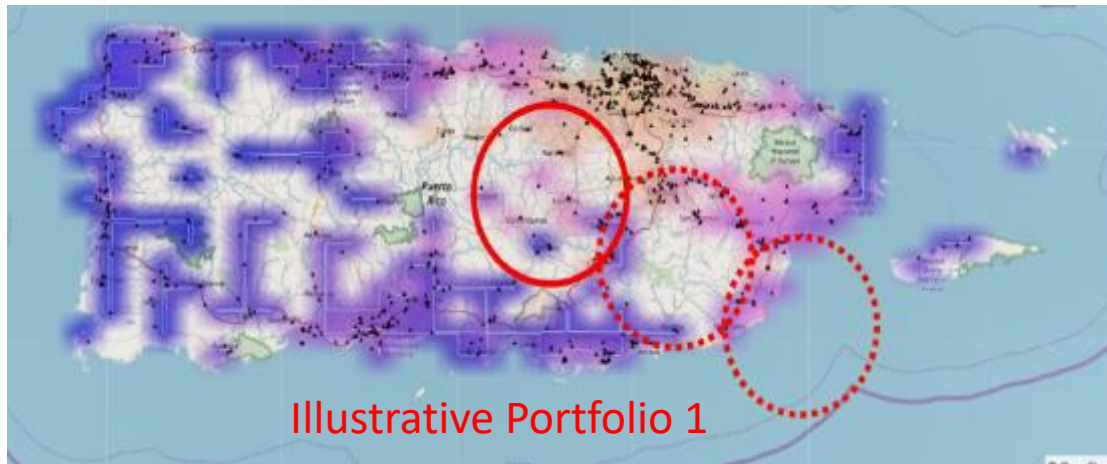
- ANL
- NREL
- ORNL
- PNNL
- SNL



Tools deployed in recovery efforts

Name	Website	Open access?
HEADOUT, TelcoFast, EPfast,	http://www.gss.anl.gov/resilient-infrastructure-initiative/	Limited
Dynamic Contingency Analysis Tool (DCAT)	https://www.osti.gov/biblio/1311621 (NB: Work with PSS/E)	Y
ReNCAT for resilient community microgrids	https://energy.sandia.gov/energy/ssrei/gridmod/resilient-electric-infrastructures/	Pending
Microgrid Design Tool	https://energy.sandia.gov/download-sandias-microgrid-design-toolkit-mdt/	Y
CAPE for protection schemes	https://www.electrocon.com/capeintro.php	License
AURORA	http://epis.com/aurora/long_term_expansion.php	License
ReOPT	https://reopt.nrel.gov/	Y
PV Watts & SAM	https://pvwatts.nrel.gov/ https://sam.nrel.gov/	Y
FESTIV and MAFRIT	https://www.nrel.gov/grid/modeling-tools.html	Y
Addt'l program languages: C#, Julia, Python, SQL		

BPS Dynamics + Distribution Outages



BPS availability + Normal feeder performance = Priority location DER/MG deployment?

Not necessarily . . .

Questions?

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