Pacific Northwest
NATIONAL LABORATORY

Benefit Cost Analysis – Puerto Rico Transmission Grid

December 17, 2019

Mark Weimar
Laurie Miller
Eric Poehlman

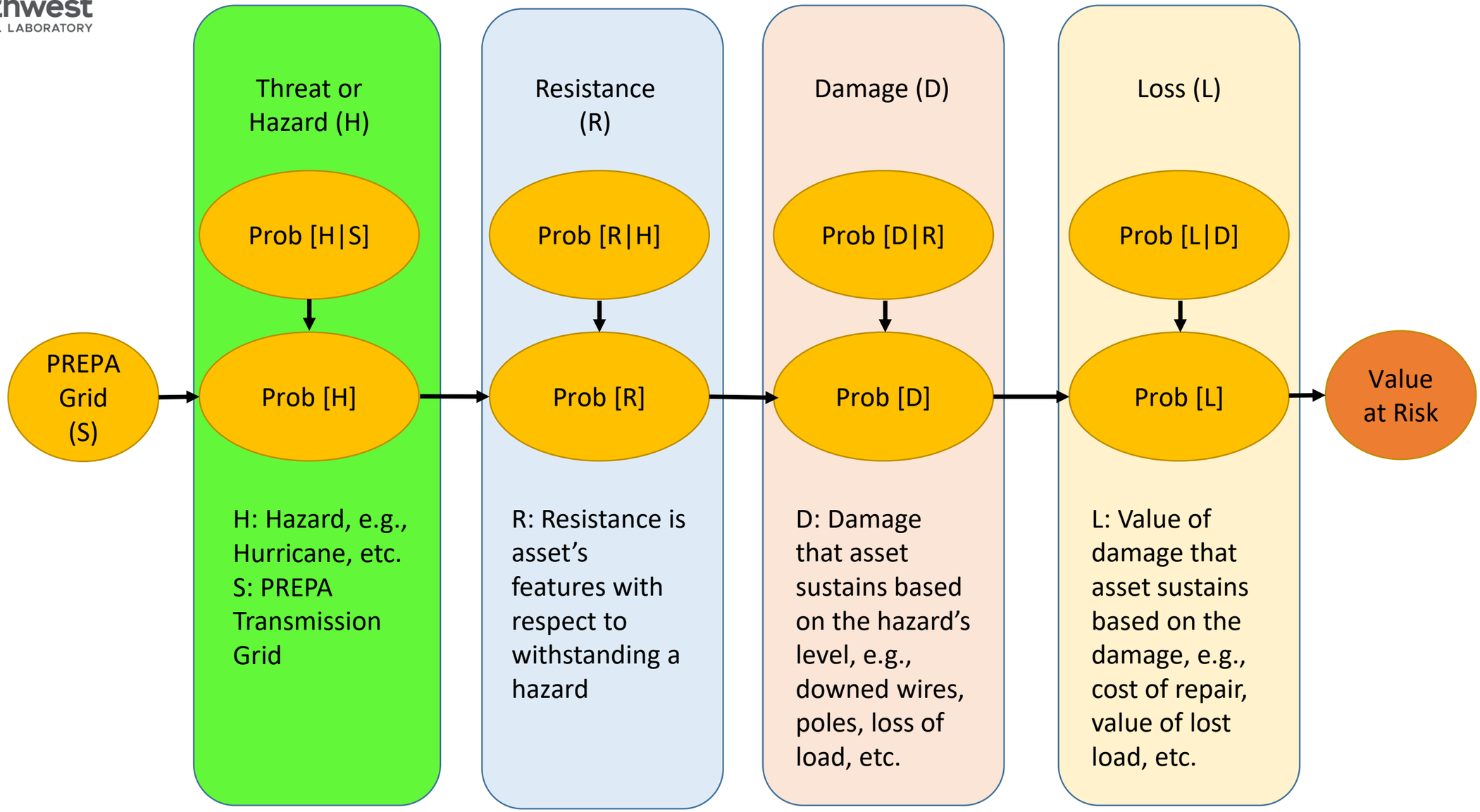
U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

Approach to Valuing Resilience

- Standard approach to calculating the Value-at-Risk
  - Probability of hazards
    - Natural hazards
    - Man-made hazards
    - Threats, such terrorist attacks
  - Infrastructure characteristics or resistance
  - Probabilities of failure, given asset characteristics
  - Infrastructure value
    - Assets damaged
    - Value of lost load
    - Human injuries and death
    - Etc.
- Approach can handle any hazard or threat, provided that data exist

Methodology



Puerto Rico Analysis Overview

- Benefit Cost Analysis using Probability and Fragility Function methodology to determine improvements to transmission grid
- Evaluated the baseline and compared with the three alternatives below
- Three example alternatives evaluated:
  - Implementing Vegetation, Guy Wire, and Anchor Management (VGWAM)
  - VGWAM plus strategic undergrounding
  - VGWAM plus complete 115 kV minigrid system
- Conducted lifecycle analysis of implementing the alternatives
  - Probabilities of hazard's annual occurrence by category
- Methodology implemented in an Excel model with *Monte Carlo* simulation
  - Probabilistic implementation based on 167 years of data on hurricane occurrence
  - Atmospheric scientist suggested using past history, despite potential for future increases
    - Implemented approach such that both increasing frequency and intensity can be or not be implemented, depending on decision maker input

Puerto Rico Example

- Collected data on damages from hurricanes by Category
  - Physical damages for most hurricanes since Hugo
    - Do earlier hurricane damages reflect current grid conditions?
- Used ANL's HEADOUT model to get initial outages
  - HEADOUT only provides how much of the grid loses electricity and doesn't reflect lost load time
    - Only have total outage minutes for Maria, which we estimated

Model Assumptions

- Puerto Rico Electric Power Authority (PREPA) and Puerto Rico Losses for Hurricane Maria
  - Lost load – 2.6 GWh
  - Average retail price - $0.24/kWh
  - Lost revenue – $618 Million
  - Transmission O&M/mile - ~$40K/mile
- Ran a *Monte Carlo* analysis based on historical probability of each category of hurricane to hit Puerto Rico
  - Assumed probability of number of occurrences during a single year
  - Then calculated the probability of the category for each occurrence that year

Most Likely Results

Color	Legend
	Best for category
	Weight for each category
	Scoring section
	Best alternative

Alternative	Net Present Value ($Mil.)	NPV Savings ($Mil.)	Benefit Cost Ratio	PV of Costs ($Mil.)	Capital Cost ($Mil.)	Annual O&M Cost ($Mil.)	Capital / Annual O&M ($Mil.)	NPV Savings / Annual Cost ($Mil.)	Average MWh Lost	Average MWh Savings	Weighted by Criteria
Baseline	37,508					102			88,302		
Alternative 1	23,621	13,886	23	597	146	36	4	384	52,981	35,321	
Alternative 2	18,477	19,030	9	2,074	1,697	38	45	500	36,836	51,466	
Alternative 3	11,483	26,025	9	2,742	2,412	38	63	684	18,147	70,155	
Weights		10%	20%			10%	15%	30%		15%	
Alternative 1		0.53	1.00			1.00	0.06	0.56		0.50	0.61
Alternative 2		0.73	0.39			0.95	0.70	0.73		0.73	0.61
Alternative 3		1.00	0.41			0.95	1.00	1.00		1.00	1.31

- Highlighted boxes indicate best of each criteria
- Values were normalized within each criteria
- Values then weighted and totaled to obtain best alternative

Conclusions

- Developed a methodology that allows analysis of resilience alternatives for the Puerto Rico Electric Power Authority (PREPA) grid
- Provides a basis to justify resilience investments for PREPA
- Range analysis should be applied to understand the strength/weakness of the associated results
- If all of the current assumptions are correct:
  - The minigrid provides the best outcome, given the current weighting of the decision criteria
  - Important to emphasize that the minigrid results may not be accurate if vegetation, guy wire, and anchor management isn't fully implemented
  - Combining underground transmission with VGWAM made undergrounding feasible
    - In addition, the undergrounding with distributed generation allowed for a larger proportion of the total load to continue operating
- Worst case outcomes still provided feasible results

Pacific Northwest
NATIONAL LABORATORY

Thank you

References

- Baik S, S Sirinterlikci, JW Park, A Davis, M Granger, Morgan. 2019. “Estimating Residential Customers’ Costs of Large, Long-Duration Blackouts.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory.
- Coles GA, SD Unwin, GM Holter, RB Bass, and JE Dagle. 2011. “Defining resilience within a risk-informed assessment framework.” *Int. J. Risk Assessment and Management*. 15(2/3):171–185.
- Ebrahimi R, A Babaee, and M Hoseynpoor. 2011. “Customer Outage Costs on a Distribution Feeder.” *Australian Journal of Basic and Applied Sciences*. 5(7) 588-595
- Eyer J and A Rose. 2019. “Mitigation and Resilience Trade-offs in Electricity Outages.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory.
- FEMA–Federal Emergency Management Administration. *Module 4-5: What are the Strengths and Weaknesses of the Community Vulnerability Assessment Tool: New Hanover County, North Carolina Model*. Available at https://training.fema.gov/hiedu/docs/hazrm/fema%20module%204-5.doc.
- FEMA–Federal Emergency Management Administration. *Step 3: Vulnerability Assessment*. Available at https://www.fema.gov/media-library-data/20130726-1524-20490-7825/fema452_step3.pdf.
- FEMA–Federal Emergency Management Administration. 2018. *Threat and Hazard Identification and Risk Assessment (THIRA) and Stakeholder Preparedness Review (SPR Guide*). Available at https://www.fema.gov/media-library-data/20130726-1524-20490-7825/fema452_step3.pdf.
- International Organization for Standardization. 2018. *ISO 31000-Risk Management*. Available at https://www.iso.org/iso-31000-risk-management.html.

References

- Martin DM and M Mazzotta. 2018. “Non-monetary valuation using Multi-Criteria Decision Analysis: Sensitivity of additive aggregation methods to scaling and compensation assumption.” *Ecosystem Services* 29:13–22.
- Pantelli M, C Pickering, S Wilkinson, R Dawson, and P Macarella. 2017. “Power System Resilience to Extreme Weather: Fragility Modeling, Probabilistic Impact Assessment and Adaptation Measures.” *IEEE Transaction on Power Systems.* 32(5):3747–3757.
- Preston BL, SN Backhaus, M Ewers, JA Phillips, CA Silva-Monroy, AF Tarditi, J Looney, and TJ King Jr. 2016. *Resilience of the U.S. Electricty System: A Multi-Hazard Perspective*. U.S. Department of Energy. Available at http://www.osti.gov/scitech/.
- Porter K. 2018. *A Beginner’s Guide to Fragility, Vulnerability, and Risk*. University of Colorado Boulder. p. 112. http://spot.colorado.edu/~porterka/Porter-beginners-guide.pdf.
- Proag S-K and V Proag. 2014. “The Cost Benefit Analysis of Providing Resilience.” In *Procedia Economics and Finance.* 18(2014):361–368. 4th International Conference on Building Resilience, Salford Quays, UK.
- Roark J. 2019. “Evaluating Methods of Estimating the Cost of Long-Duration Power Outages.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory
- Salman AM and L Yue. 2018. “A Probabilistic Framework for Multi-hazard Risk Mitigation for Electric Power Transmission Systems Subjected to Seismic and Hurricane Hazards.” In *Structure and Infrastructure Engineering.* DOI: 10.1080/15732479.2018.1459741.
- Schellenberg J, M Collins, M Sullivan, S Hees, and S Bieler. 2019. “Data Landscape: Challenges and Opportunities.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory.

References

- Shawhan D. 2019. “Using Stated Preferences to Estimate the Value of Avoiding Power Outages: A Commentary with Input from Six Continents.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory.
- Wing S and IT Allison. 2019. “Economic Consequence Analysis of Electric Power Infrastructure Disruptions: An Analytical General Equilibrium Approach.” In *Frontiers in the Economics of Widespread, Long-Duration Power Interruptions.* Eds. PH Larsen, AH Sanstad, KH LaCommare, JH Eto. Lawrence Berkeley National Laboratory.
- Sullivan MJ, J Schellenberg, and M Blundell. 2015. *Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States*. Lawrence Berkeley National Laboratory. LBNL-6941E.
- Sullivan M, MT Collins, J Schellenberg, PH Larsen. 2018. *Estimating Power System Interruption Costs: A Guidebook for Electric Utilities*. Lawrence Berkeley National Laboratory. LBNL-2001164.
- Weimar MR., DM Anderson, B Kravitz, RT Dahowski, SA Brown, JM Niemeyer, A Somani, and KS Judd. 2018. *Methodology for Valuing Resilience to Severe Events for the Department of Energy Sites*. Pacific Northwest National Laboratory. Richland, WA. PNNL-27257.
- DOE–U.S. Department of Energy. 2017. *Valuation of Energy Security for the United States*. Washington DC. Available at https://www.energy.gov/sites/prod/files/2017/01/f34/Valuation%20of%20Energy%20Security%20for%20the%20United%20States%20%28Full%20Report%29_1.pdf
- LBL ICE calculator: https://icecalculator.com/home and supporting materials: https://emp.lbl.gov/projects/economic-value-reliability-consumers