U.S. DEPARTMENT OF ENERGY

Energy Resilience Solutions for the Puerto Rico Grid

Final Report

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United States Department of Energy
Washington, DC 20585

List of Acronyms

Act 57	Act for the Transformation and Energy Relief of Puerto Rico, 2014
ADMS	Advanced Distribution Management Systems
AIS	Automated Information Sharing
AMI	Advanced Metering Infrastructure
ANL	Argonne National Laboratory
ARRA	American Recovery and Reinvestment Act
BFE	Base Flood Elevation
CAIDI	Customer Average Interruption Duration Index
CHP	Combined Heat and Power
CILT	Contributions in Lieu of Taxes
CIP	Critical Infrastructure Protection
CRS	Congressional Research Service
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DHS	United States Department of Homeland Security
DOD	United States Department of Defense
DOE	United States Department of Energy
DSCR	Debt Service Coverage Ratio
EMAC	Emergency Management Assistance Compact
ESF#12	Emergency Support Function 12 – Energy
FEMA	Federal Emergency Management Agency
FEMP	Federal Energy Management Program
FIRM	Flood Insurance Rate Map
FOMB	Financial Oversight and Management Board
GDP	Gross Domestic Product
GMLC	Grid Modernization Laboratory Consortium
GSA	General Services Administration
ICS	Incident Command System
INESI	Institute for Island Energy Sustainability
IMT	Incident Management Team
IRP	Integrated Resource Plan
ISAC	Information Sharing and Analysis Center
IT	Information Technology
LBNL	Lawrence Berkeley National Laboratory
LCOE	Levelized Cost of Electricity
LIPA	Long Island Power Authority
LNG	Liquefied Natural Gas
MATS	Mercury and Air Toxins Standard
MSW	Municipal Solid Waste
NARUC	National Association of Regulatory Utility Commissioners
NASEO	National Association of State Energy Officials
NEMA	National Electrical Manufacturers Association
NERC	North American Electric Reliability Corporation
NESC	National Electrical Safety Code
NIST	National Institute of Standards and Technology

NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NYPA	New York Power Authority
ORNL	Oak Ridge National Laboratory
OT	Operational Technology
PMA	Power Marketing Administration
PREC	Puerto Rico Energy Commission
PREPA	Puerto Rico Electric Power Authority
PROMESA	Puerto Rico Oversight, Management, and Economic Stability Act
PUC	Public Utility Commission
PV	Photovoltaic
RMI	Rocky Mountain Institute
RPS	Renewable Portfolio Standard
RSF	Recovery Support Function
RUS	Rural Utilities Service
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SNL	Sandia National Laboratory
T&D	Transmission and Distribution
UPR	University of Puerto Rico
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USVI	United States Virgin Island
UTIER	Irrigation & Electrical Workers Union
W2E	Waste-to-Energy

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Executive Summary

The eye of Hurricane Maria careened just south of the United States Virgin Island of St. Croix in the early hours of September 20, 2017, and landed in Yabucoa, Puerto Rico, shortly thereafter. Arriving with maximum winds just below the threshold of category 5 intensity, the wind, rain, and storm surge during Maria's eight hours over Puerto Rico combined to disrupt nearly all water, electricity, and telecommunications services.

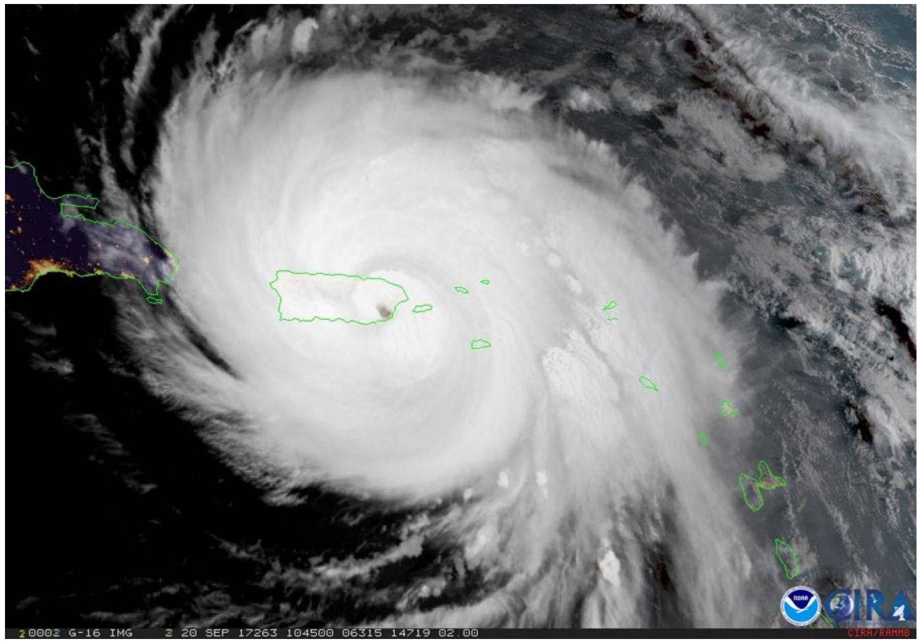

Figure 1: Hurricane Maria Making Landfall Over Puerto Rico September 20, 2017 (Credit: NOAA; CIRA)

Hurricane Maria was the second strongest storm on record to hit Puerto Rico.[1] As of 8:00 PM EDT on September 20, the Puerto Rico Electric Power Authority (PREPA) reported near 100% of total customers in Puerto Rico without power, with the exception of facilities running on generators. The outage threatened the health, safety, and economic wellbeing of the nearly 3.5 million U.S. citizens who inhabit the territory and further stressed the regional economy. A recent report by the National Oceanographic and Atmospheric Administration (NOAA) estimated that the monetary value of the total damage caused by Hurricane Maria in Puerto Rico exceeded the next most costly hurricane to hit the Commonwealth by an order of magnitude.[2]

[1] 1928 Okeechobee hurricane, also known as the San Felipe Segundo hurricane, was the strongest hurricane on record to hit Puerto Rico.
[2] NOAA, National Hurricane Center Tropical Cyclone Report: Hurricane Maria (Apr. 5, 2018) https://www.nhc.noaa.gov/data/tcr/AL152017_Maria.pdf. This report estimates that the total damage to the Commonwealth ranges from $65-115 billion.

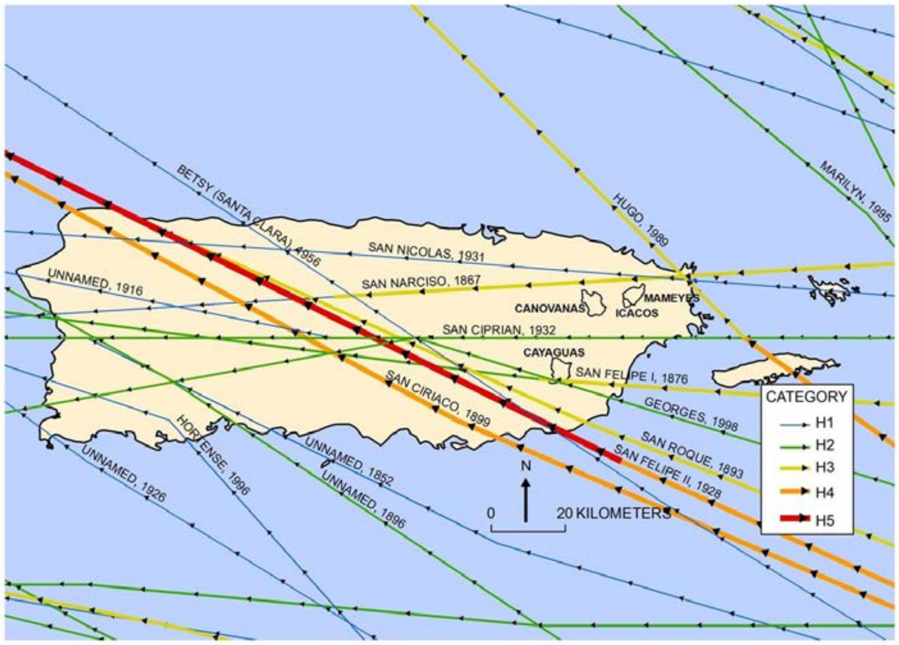

Figure 2: Sampling of Historic Hurricanes to Hit Puerto Rico (Credit: Sheila Murphy, USGS)

While this scale of restoration and recovery would challenge any community, Puerto Rico has already faced economic and workforce issues which exacerbated the difficulty of restoration efforts and dimmed the prospects of a quick recovery. Out-migration of skilled power engineers and line workers, driven by a variety of factors, has accelerated in pace from 2010 through the close of 2017, with more Puerto Ricans now living in the continental United States than in the Commonwealth. The loss of human capital caused by this out-migration will further challenge Puerto Rico's ability to re-start its economy.

Despite such adversity, the people of Puerto Rico have shown tremendous strength and resilience as they restore and rebuild their homes and communities. Leveraging the electricity grid to spur economic growth in Puerto Rico's various communities and economic sectors, including health care, manufacturing, tourism, and agriculture, is essential to revitalization of the island. Essential services from energy-enabled critical infrastructure including water, waste water, waste, telecommunications, and transportation must be consistently and reliably operational to support safety and health. Additionally, manufacturing and retail operations must be open and employable to support economic wellbeing. A strong recovery and revitalization is important not only to the region, but also to the United States as a whole.

Maintaining and enhancing the resilience of the electric grid at fair and reasonable costs can provide service and value to Puerto Rican communities. Yet, no single investment in energy infrastructure at one point in time will achieve resilience. The energy infrastructure of Puerto Rico must be designed, built, managed, and maintained in such a way to withstand environmental and man-made disasters, ameliorate disruptions when they inevitably occur, recover quickly, and incorporate lessons learned into post-event planning and operations. This is a continual process of improvement, one involving a reassessment and adaptation of solutions and technologies to address changing needs.

In support of those goals, this report contains resilience recommendations for the Government of Puerto Rico to consider for incorporation into its recovery plans—including the plan specified by Section 21210 of P.L. 115-123 (2018), and to provide useful insights for the disbursement of any federal appropriations intended to rebuild or improve the energy infrastructure in the Commonwealth of Puerto Rico.[3] Given the breadth of interdependencies across sectors, assessment of potential alignment and sequencing of funding across different agency programs that support various sector infrastructures would be beneficial. The report also notes where additional analysis is needed to more precisely articulate resilience-related, investment-grade suggestions regarding the design and specification of the electricity system in Puerto Rico.

Although additional analysis is necessary to further specify some of this report's recommendations that support resilience, recommendations that can be acted on today to improve the performance of the system are as follows:

1. The Governor and PREPA should immediately ensure that updated, effective mutual aid agreements and Incident Command System are primed to quickly provide support during the next event.
2. The Puerto Rico Energy Commission (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.
3. Electricity transmission towers installed specifically for temporary emergency restoration should be considered for prioritized replacement, potentially by monopoles. Many round monopole structures withstood the storm effectively.
4. The PREC, in coordination with PREPA, should implement microgrid regulations in line with accepted industry standards and practices; and establish effective, efficient, and reasonable interconnection requirements and wheeling regulations. These regulations will allow customers to design their systems in a manner that support the reliability and resilience of the broader electricity grid.
5. The Puerto Rican State Office of Energy Policy or its successor, in coordination with other appropriate Commonwealth agencies and instrumentalities, should immediately commence drafting of an updated Energy Assurance Plan. This plan should provide for, among others, the use of the Incident Command System including the immediate establishment of a standing Incident Management Team.

[3] For example, in early April the U.S. Department of Housing and Urban Development announced the largest single amount of available Disaster Recovery Community Development Block Grant funds, including over $20 billion for Puerto Rico and the U.S. Virgin Islands, https://www.hud.gov/press/press_releases_media_advisories/HUD_No_18_028.

Several recommendations require further analysis to fortify the recommendations; the analysis should be conducted, to the extent practical, with the support and engagement of PREPA and the Government of Puerto Rico, includes the following:

1. **Power flow –** assesses power system operations, including generator dynamics and protective relay coordination [used to identify power system needs, evaluate technology options, and help prioritize resilience investments, e.g., transmission enhancements]
2. **Production cost and capacity expansion –** informs economic dispatch strategies and long-term planning [used to understand how resource investments, system costs, and load are impacted by key policy and technology sensitivities]
3. **Microgrids, energy storage, and system segmentation –** identifies where clusters of generation and load provide maximum community benefit [used to identify prepositioning of emergency generation, local hardening of infrastructure, and adjustment of emergency procedures]
4. **Infrastructure interdependencies –** characterizes reciprocal relationships within the energy sector (e.g., electricity-petroleum, electricity-LNG), as well as cross-sector infrastructure like telecommunications and/or water [used to investigate supply disruption impacts and identify mitigation approaches]

A summary of the DOE’s specific recommendations can be found in Appendix C.

A. Introduction

A1. Purpose

This report contains recommendations for the Government of Puerto Rico to consider for incorporation into its recovery plans, including the plan that Congress specified in Section 21210 of P.L. 115-123 (2018). [4] The recommendations reflect principles of resilience,[5] and are intended to inform investments that use federal appropriations in the energy infrastructure in the Commonwealth of Puerto Rico (hereafter “Commonwealth” or “Puerto Rico”).[6]

These recommendations address some near-term actions and identify where further analysis is needed to make more technically-informed investment decisions. The recommendations should highlight where coordination across agencies and sectors may improve the resilience of infrastructure in Puerto Rico. While each of the recommendations, if implemented, would improve the resilience, a resilient energy system is not achieved through a single investment or series of investments at a given time.

Rather, resilience results from an on-going focus on identifying and undertaking sound investments, operating and maintenance procedures, and planning practices. Each of the decisions in this iterative process should aim to enhance the ability of the system to withstand likely stresses, ameliorate disruptions when they inevitably occur, recover quickly, and incorporate lessons learned into post-event planning and operations.

This report is NOT a grid modernization roadmap or implementation strategy for Puerto Rico. It recognizes that capital investment alone will likely be insufficient to achieve Puerto Rico’s goal of an electric sector that is technically reliable, resilient, and affordable; after all, most investments will have longer-term obligations associated with operations and maintenance costs. Thus, success ultimately depends on the leadership and commitment of the Government of Puerto Rico and entities such as PREC and PREPA to carefully identify Puerto Rico’s electricity needs, assess the options, and make their own determination of a strategy that meets long term goals and instills confidence for existing and new industries to invest on the island.

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[4] This section reads, in relevant part: “Not later than 180 days after the date of enactment of this subdivision and in coordination with the Administrator of the Federal Emergency Management Agency, with support and contributions from the Secretary of the Treasury, the Secretary of Energy, and other Federal agencies having responsibilities defined under the National Disaster Recovery Framework, the Governor of the Commonwealth of Puerto Rico shall submit to Congress a report describing the Commonwealth’s 12- and 24-month economic and disaster recovery plan . . .”.

[5] See, e.g., National Academies of Sciences, Engineering, and Medicine. 2017. Enhancing the Resilience of the Nation's Electricity System. Washington, DC: The National Academies Press, http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=24836.

[6] Given the differences between the Commonwealth and the United States Virgin Islands (USVI), the USVI are not addressed in this report. However, DOE staff and experts at the National Labs are working with their USVI counterparts to improve resilience and reliability of the energy system for the benefit of the American citizens there.

A2. Existing Long-Term Recovery Visions and Principles

On December 13, 2017, DOE convened experts from the community of public and private energy stakeholders who had expressed interest in supporting the long-term recovery of Puerto Rico (hereafter “December meeting”). The event stimulated continued dialogue on forming a cohesive set of recommendations, based on the expert opinion of the varied stakeholders, ensuring a strong technical rational for Puerto Rico’s energy investment decisions.

By the time of the December meeting, several participants had already issued their own vision, roadmap, or recommendations for the restoration, recovery, and further modernization of the Puerto Rican electricity grid. These publications varied greatly in their depth, detail, and scope. A summary of these publications can be found in Appendix B.

All plans appeared to agree that modernization would serve recovery objectives, and all agreed on the need to diversify and harden infrastructure against possible future disasters. Many participants expressed the desire for a single vision for the future of Puerto Rico’s electricity sector. The Commonwealth itself must establish that vision and ensure the appropriate governance mechanisms are available to accurately reflect the needs of customers in that vision, as well as guarantee accountability within the management of the energy sector to honor that vision.

A3. Recommendations for Immediate Action

This report considered and integrated plans and materials from multiple resources. Many of the recommendations in this report require further analysis to refine into investment-grade decisions. However, while this analysis continues, the following recommendations can be acted upon today to improve the performance of the electricity system:

1. The Governor and PREPA should immediately ensure that updated, effective mutual aid agreements and Incident Command System are primed to quickly provide support during the next event.
2. The Puerto Rico Energy Commission (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.
3. Electricity transmission towers installed specifically for temporary emergency restoration should be considered for prioritized replacement, potentially by monopoles. Many round monopole structures rode withstood the storm effectively.
4. The PREC, in coordination with PREPA, should implement microgrid regulations in line with accepted industry standards and practices; and establish effective, efficient, and reasonable interconnection requirements and wheeling regulations. These regulations will allow customers to design their systems in a manner that support the reliability and resilience of the broader electricity grid.
5. The Puerto Rican State Office of Energy Policy Office or its successor, in coordination with other appropriate Commonwealth agencies and instrumentalities, should immediately commence drafting of an updated Energy Assurance Plan. This plan should provide for, among others, the use of the Incident Command System including the immediate establishment of a standing Incident Management Team. Besides preparing for the next hurricane season, moving immediately will leverage the local presence of utility industry

response professionals working with PREPA and federal staff in the Joint Field Office. Finally, the Southern States Energy Board may be able to facilitate peer-to-peer information sharing and lessons learned from other states and utilities.

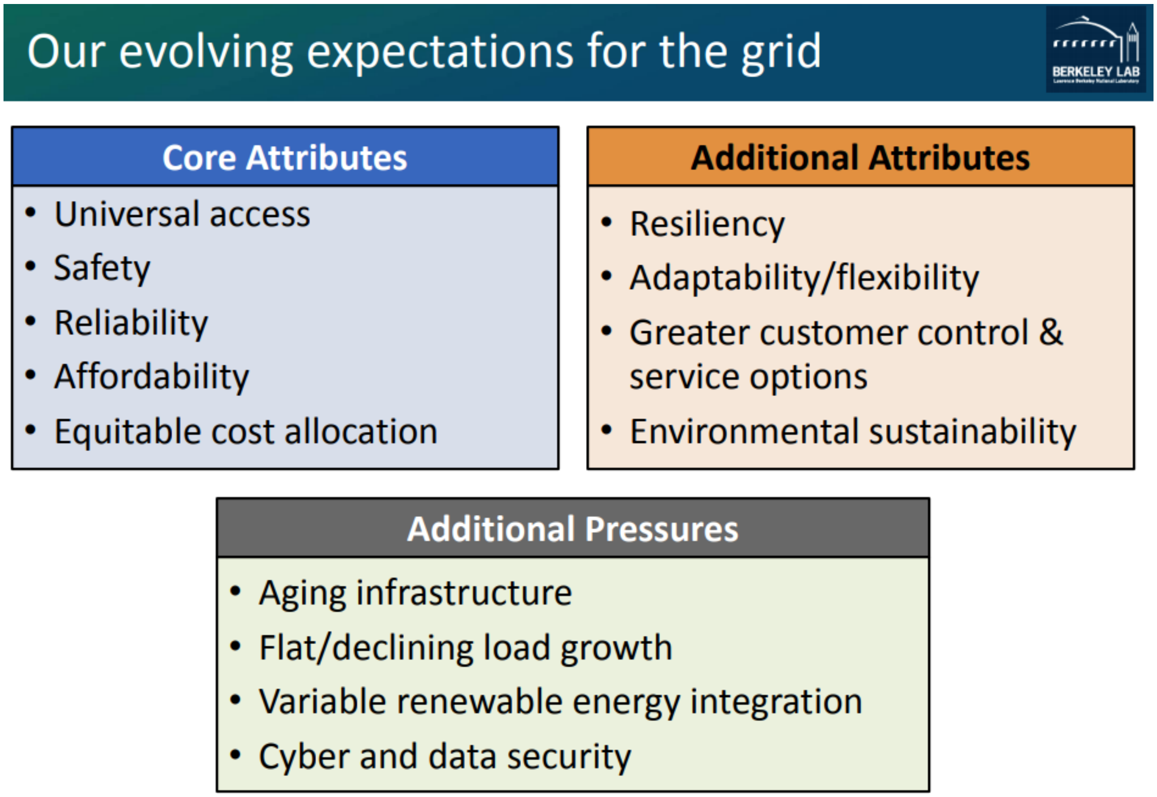

Figure 3: Expectations for the Grid (Source: LBNL)[7]

[7] https://emp.lbl.gov/sites/default/files/feur_9_webinar_value-added_services_20171106_fin.pdf.

B. The Pre-Storm Condition of the Electricity System

B1. Portfolio Considerations

As became clear in the December meeting and subsequent discussions, four common goals recur in discussions of the electricity system in Puerto Rico: 1) a reliable electricity supply, 2) with consistent power quality, 3) at foreseeable and manageable cost, 4) that maximizes use of local resources. These goals must be met under the constraints of underinvestment in an already aging infrastructure, unimplemented legal requirements regarding improvements to electricity system governance and investment decisions, and declining load.

B2. System Performance

This section will rely primarily on two PREC Orders and quote from them often. The first, Final Resolution and Order PREPA Rate Review, was issued on January 10, 2017 in Docket CEPR-AR-2015-0001 ("Rate Review Order").[8] While this document contains a wealth of information on PREPA's system and operations, other documents in this docket, such as the Expert Reports dated Nov. 23, 2016, are also full of information on these issues and comparisons to standard practice in the states. The PREC summarized its findings of fact, conclusions of law, and Commission Directives over pages 162-184. There are 120 Commission Directives regarding improvements of PREPA's system, operations, and legal compliance.

The second document, the Final Resolution and Order on the First Integrated Resource Plan for PREPA ("IRP Order") in docket CEPR-AR-2015-0002 is dated Sept. 26, 2016, shortly after the passage of the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA). In subject matter, it is less wide-ranging than the Rate Review Order, with its findings of fact and conclusions of law on pages 93-101. It details the changes that will be made to PREPA's system, with a schedule and competitive bidding requirements for many items.

- "PREPA's officials and consultants describe an inefficient bureaucracy with high absenteeism, overly staffed with non-value-added administrative personnel. Procedures for budgeting and spending do not provide sufficient information on individual project plans and completion. On major capital projects, PREPA was often unable to provide basic explanations, work-plans, or other due diligence documentation." *Rate Review Order*, p. 3
- "PREPA's own witnesses describe PREPA's physical situation to be an 'ailing grid,' 'degraded infrastructure,' and a 'deteriorated' transmission system." *Rate Review Order*, p. 16

On another metric, PREPA's forced outage factor of plants averaged 6.87% over 2010-15, but ended that period at nearly 27%. Some units were completely out of service for extended periods of time, while the best performing plant was fired by natural gas supplied by Gas Natural Fenosa, majority owner of EcoEléctrica, achieving an availability rate of 97% and average capacity

[8] http://energia.pr.gov/numero_orden/cepr-ap-2015-0001/.

factor of 65%. Outage information is covered extensively in the Rate Review Order, over pages 65-72.

Three key metrics for electric system performance are System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI). For background on these metrics and why they are valuable, see "Tracking the Reliability of the U.S. Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions" from Lawrence Berkeley National Laboratory (LBNL).[9]

During the period measured, PREPA's SAIFI was calculated at 11.61, which is an order of magnitude higher than the U.S. average. PREPA exceeded its SAIDI goal of 10 hours by 60%, a goal which was above the75th percentile of U.S. utilities. PREPA's CAIDI was 180 minutes, up from 140 in 2013 - up nearly 30% since forbearance began.[10] The American Public Power Association collects self-reported reliability data for publicly-owned utilities, "Evaluation of Data Submitted in APPA's 2013 Distribution System Reliability & Operations Survey."[11] PREPA's metrics exceed the averages and third quartile statistics for each of those categories.

B2A. Reducing Political Influences Over Infrastructure Decisions

Most energy reform legislation in Puerto Rico has sought to reduce the political influence over PREPA's decision-making, and the PREC addressed that topic as follows:

- "The quadrennial turnover of managers with each new political administration, the political pressures from elected officials to avoid necessary rate increases, the failure of government agencies to pay their electricity bills on time, the irresponsible initiation and termination of expensive capital projects, the high levels of electricity theft, the work rules that prevent efficient use of well-paid employees, the poor recordkeeping and antiquated administrative procedure, the compensation schemes that prevent PREPA from recruiting and retaining qualified and experienced personnel – all this must come to a halt, to be replaced by a universal commitment to the good of the Commonwealth." Rate Review Order, pp. 23-24
- "This situation is not sustainable. Until PREPA's financial situation improves, it cannot borrow new money. If it cannot borrow new money,[12] it cannot repair its deteriorating physical infrastructure, prepare that infrastructure for a future of renewable energy, pay salaries sufficient to attract and keep excellent workers, and modernize its system so as to enable consumers to save money on their electric bills. The path to transforming PREPA into a reliable, cost-effective, environmentally sound and customer-responsive company – a

[9] https://emp.lbl.gov/sites/all/files/lbnl-1092e.pdf. See also, Institute of Electrical and Electronics Engineers, "IEEE Benchmark Year 2016 Results for 2015 Data", http://grouper.ieee.org/groups/td/dist/sd/doc/Benchmarking-Results-2015.pdf.

[10] "Final Resolution and Order: PREPA Rate Review," Docket CEPR-AR-2015-0001, dated January 10, 2017 ("Rate Review Order"), available on www.energia.pr.gov, p.18.

[11] http://studylib.net/doc/18456145/2013-distribution-system-reliability-and-operations-report#.

[12] PREPA entered Title III of the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) in April 2017.

company central to Puerto Rico's economic recovery – must begin with a plan for stabilizing PREPA's finances."[13]

B3. Assumptions on Demand

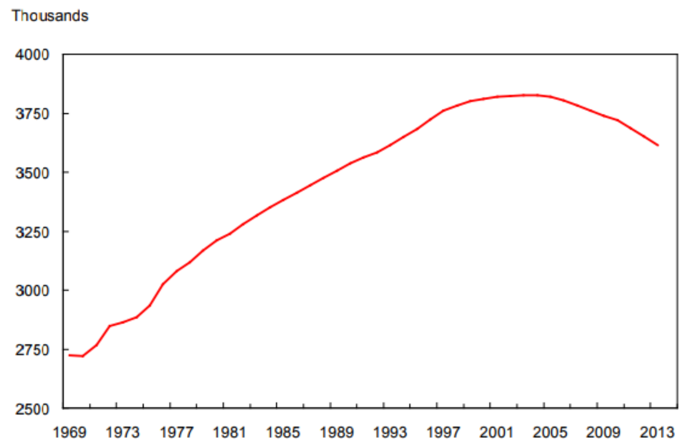

Figure 4: Puerto Rico Economic Activity Index, from Government Development Bank of Puerto Rico

Before its economic crisis, the population size of Puerto Rico was comparable to Oregon, three times that of Hawaii and five times that of Alaska. Currently, its GDP per capita is lower than any state. Similarly, while the United States ranks near the top in the World Bank's "Doing Business" metrics, Puerto Rico sits at 64.[14] Sustained economic hardship on the island has accelerated the out migration of citizens which had already resulted in an estimated 500,000 people departing for the mainland in the past decade. Early estimates suggested approximately 100,000 people have fled Puerto Rico since Hurricanes Irma and Maria hit.[15]

Puerto Rico has five times the combined populations of the territories and Freely Associated States. Although median income is comparable to the other insular areas, Puerto Rico has maintained a manufacturing base, dependent in part on favorable treatment under the federal tax code. As a consequence, the Puerto Rico energy system is larger than all of the others combined by installed capacity.

In its pre-storm Fiscal Plan, PREPA predicts just over 13,000,000 MWh sales in 2026, roughly equivalent to 1500MW average load and 2250MW peak. A similar number was released in the Fiscal Plan from early 2018. Given that existing installed capacity exceeds 5,000MW, and the existing transmission system was designed to accommodate this capacity, significant declines to load in the next 10-15 years will be an important consideration for future investment plans.

These portfolio considerations underscore the need to further analyze power flow, production cost, and other scenarios, to provide reasonable amount of certainty that any investments are well targeted and integrated into cost-reflective tariffs to support an affordable and reliable power system.

B3A. Energy Efficiency and Demand Response

As noted by the 2016 Congressional Task Force on Economic Growth in Puerto Rico, "The price of electricity in Puerto Rico is high, while the ability of some residents of Puerto Rico—where

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[13] "Final Resolution and Order: PREPA Rate Review," Docket CEPR-AR-2015-0001, dated January 10, 2017 ("Rate Review Order"), available on www.energia.pr.gov, p.12.

[14] The World Bank, *Doing Business Economic Rankings*, http://www.doingbusiness.org/rankings.

[15] https://naturalresources.house.gov/calendar/eventsingle.aspx?EventID=403224.

the median annual income is $18,626—to pay is low."[16] Energy efficiency programs have short lead times, can help optimize capital expenditures, reduce the need to import fuels, and alleviate the energy burden on low income households.[17] Demand response, with its ability to shape load, can limit the need for capital projects with low utilization rates and limit ramping stress on generators. However, these benefits must be balanced against the need for other enabling infrastructure requirements (e.g., communications upgrades).

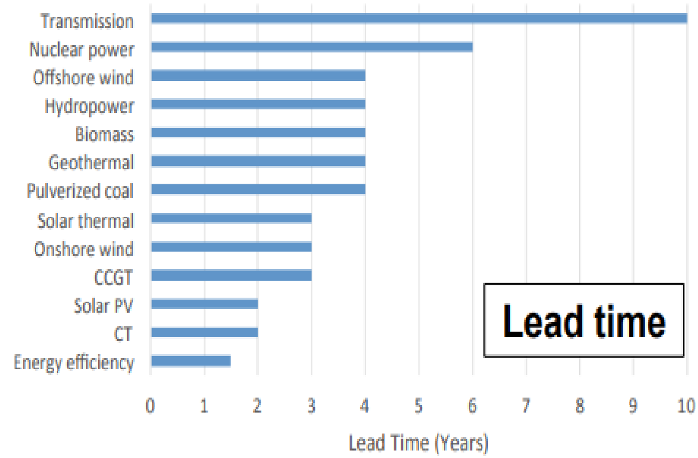

Figure 5: Lead times for electricity projects (Source: LBNL)

Local law requires energy efficiency in building codes, improvements in government energy use, reductions in subsidies to local government that distorts the cost of consumption, and the promotion of cost effective end-use energy efficiency measures. The rapid conversion to Light Emitting Diodes for public lighting, for example, has the potential to reduce the overall cost of municipal lighting by up to 80%. For efficiency in public buildings, DOE's Federal Energy Management Program (FEMP) maintains expertise in Energy Savings Performance Contracts, a procurement mechanism that requires little to no up-front capital. This is an area where resources to establish effective training and enforcement of existing requirements may produce the system benefits contemplated by local law.

B3B. Infrastructure Interdependencies

As was observed during Hurricane Maria, interdependencies among infrastructure systems with electric power can cause cascading failures across various essential services. These dynamics are not fully understood, and infrastructure planning does not yet effectively incorporate interdependency considerations. It is also difficult to monetize the benefits associated with an avoided disruption due to interdependency.

For example, during Hurricane Maria, the loss of cellular and data services in Puerto Rico was sometimes a direct result of the power issues, not necessarily damage to the communications infrastructure. In order to make efficient investments that mitigate risk effectively and increase the resilience of Puerto Rico, capital planning decisions must address interdependencies between the electric power system and other critical infrastructure that provide much needed services, such as hospitals, water, waste water, waste, telecommunications, and transportation, to counter

[16] Congressional Task Force on Economic Growth in Puerto Rico, "Bipartisan Report to the House and Senate", p. 37 (Dec. 2016).
[17] https://emp.lbl.gov/sites/default/files/feur_6_webinar_future_of_resource_planning.pdf.

the cascading effects of power losses. A better understanding of the complex interactions among critical infrastructure will help Puerto Rico prepare for, respond to, and recover from future disasters.

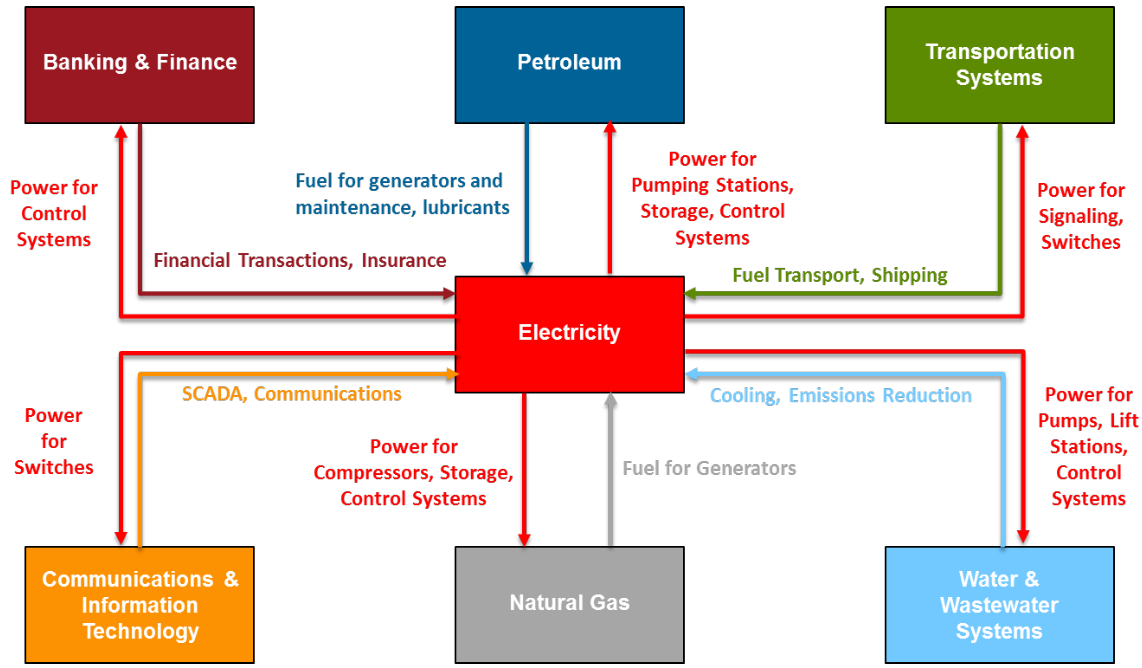

Figure 6: Electric Power Interdependency Examples (Source: ANL)

To address interdependencies between electric power and other critical infrastructure, Puerto Rico should conduct, with the engagement of federal agencies as appropriate, an analysis to identify interdependencies and to help coordinate large-scale, regional infrastructure projects. Furthermore, given the breadth of interdependencies across sectors, assessment of potential alignment and sequencing of federal funding across different agency programs that support various sector infrastructures, potentially across multiple areas of the islands including Puerto Rico and U.S. Virgin Islands, would be beneficial. The analysis identified in this report will support that goal.

B3Ba. Cyber-Resilience

As the electricity system grows in intelligence, the impact of malicious and unintentional cyber threats has become an increasingly important issue for the electric sector. Electric utilities face cyber threats to both the business and operational components of their outfits. The increased automation of the electric grid has allowed grid operators to more efficiently and reliably operate their networks. However, these same digital technologies have simultaneously increased dependence on telecommunications networks and provided new avenues for cyber adversaries to potentially gain control of operational components and disrupt electricity service.[18]

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[18] U.S. Department of Energy, *Quadrennial Energy Review: Second Installment*, January 2017, https://www.energy.gov/epsa/quadrennial-energy-review-second-installment.

Each utility must identify its own unique vulnerabilities and design mitigation options tailored to its individual information technology (IT) and operational technology (OT) networks. This can include taking concrete steps such as embedding cybersecurity in utility procurement processes.[19] Additional actions can be informed by industry best practices as outlined in frameworks including the National Institute of Standards and Technology's (NIST) Framework for Improving Critical Infrastructure Security, the North American Electric Reliability Corporation's (NERC) critical infrastructure protection (CIP) standards, and DOE's Energy Sector Cybersecurity Framework Implementation Guidance and Risk Management Process.

The Federal government uses an array of authorities and capabilities to prepare for, respond to and mitigate cyber incidents that affect private networks. These include preparedness tools to assist utilities in improving their cybersecurity posture, such as DOE's Cybersecurity Capability Maturity Model (C2M2), incident response support, and post-incident recovery assistance. DOE has developed over 40 tools and technologies that can assist energy delivery providers to mitigate, respond, and survive a cyber-attack.[20] Robust frameworks for information sharing within and between the electricity industry and government are another critical resource for ensuring the electric sector is able to mitigate the impact of cyber adversaries. A better understanding of the complex interactions among critical infrastructure will help Puerto Rico prepare for, respond to, and recover from future disasters.

[19] https://energy.gov/sites/prod/files/2014/04/f15/CybersecProcurementLanguage-EnergyDeliverySystems_040714_fin.pdf.
[20] https://www.energy.gov/oe/cybersecurity-energy-delivery-systems-ceds-fact-sheets.

C. Recommendations by Subject Matter

C1. Transmission and Distribution

RECOMMENDATIONS

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.[21]
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.

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[21] See Appendix A.

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.[22] 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.

C1A. Context for Transmission Recommendations

There were failures in the transmission infrastructure resulting from the extreme winds (and debris-driven entangling). Multiple transmission towers collapsed due to guy wire anchor rod failures. The DOE field team postulates that anchor rod corrosion was the root cause of these failures.

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[22] FEMA has acknowledged that storms exceed base flood elevation (BFE) levels, and that prudent design often exceeds BFE levels [See FEMA's 2013 publication: *Designing for Flood Levels Above the BFE After Hurricane Sandy*]. While 'FEMA 100-year flood plus three feet' has been adopted as a design guideline for some utilities, technical analysis should be conducted to assess the specific level of risk for Puerto Rico and utilities should consider utilizing the 0.2% flood elevation as a resilience elevation.

Notably, however, many of the "dead end"[23] structures that are designed to limit the cascade of neighboring tower failures performed as designed, thereby limiting the extent of the damage to the overall transmission line infrastructure.

DOE assesses that the design of the transmission infrastructure is fundamentally sound. However, DOE recommends an enhanced program to mitigate corrosion of the guy wire anchor rods, improved right-of-way maintenance for access to structure locations, and updating of materials to more robust industry standard components. Non-destructive evaluation (NDE) inspection (i.e. ultrasonic) targeted by modeling and analysis may prove particularly valuable to improving reliability.

Furthermore, DOE recommends implementing a compliance driven vegetation management program to remove encroachment of taller vegetation and danger trees from the rights-of-way.

Many of the transmission lines were originally routed through difficult-to-access mountainous terrain. Subsequently, new roads crossing these mountain areas have been constructed. Therefore, the opportunity exists to consider building new transmission corridors along these roads that would facilitate better vegetation management access, as well as quicker access by heavy equipment to repair damaged infrastructure during future storm events. The DOE recommends that these new transmission lines be considered based on an assessment of overall system requirements based on detailed modeling and engineering studies. However, re-routing transmission infrastructure does not, in the absence of analysis demonstrating its merit, present sufficient benefit to justify the cost.

Finally, the DOE team assesses that the current voltages associated with the T&D infrastructure (230 kV for the backbone transmission infrastructure, with supporting 115 kV transmission infrastructure and lower voltage sub-transmission assets) is suitable for the current and projected electrical needs

Pole Attachment & Wind Loading Standards

Best practices for third-party (e.g., communication) infrastructure attachments to power system distribution infrastructure includes both clearance and structural assessments to confirm compliance with applicable safety codes (including specifically the National Electrical Safety Code) to assess safe clearances are maintained between energized and non-energized cables on each structure and above the ground surface below. This also includes an assessment to ensure that the structural integrity is maintained to support the increase in vertical and wind load to each structure. Therefore, DOE recommends that the utility establish, manage, and maintain a joint-use program that sets criteria for third-party attachments to verify required clearances are maintained and structural integrity is maintained as required by the applicable safety codes.

[23] https://en.wikipedia.org/wiki/Dead-end_tower. A dead-end tower is a fully self-supporting structure used in construction of overhead power lines. Since dead-end towers require more material and are heavier and costlier than suspension towers, it is uneconomic to build a line with only self-supporting structures. Dead-end towers are used at regular intervals in a transmission line to limit the cascading tower failures that might occur after a conductor failure.

of the island. It is anticipated that these voltages would continue to be in common use by U.S. electric utilities in the foreseeable future. Therefore, design and accessibility to equipment should be readily available. Standardization using typical mainland voltage will help future mutual aid response.

C1B. Context for Distribution Recommendations

There were significant failures in the distribution infrastructure, including many failed wood poles. The DOE assessment of these failures concludes that many of these failures were likely caused by overloading caused by communication system attachments to these poles. The DOE team is uncertain to the extent that the communication industry providers were required to conduct structural loading assessments of these attachments.

The DOE team also surmises that there was deferred maintenance associated with testing the integrity of the poles associated with the distribution infrastructure. DOE recommends that PREPA follow industry best practices for a comprehensive testing program to identify and replace wood poles that are in need of replacement. In addition, there should be careful consideration of cost-effective alternatives to wood as a material for distribution poles. Possible wood alternatives could include 3D printing/additive manufacturing of poles designed with desired characteristics to endure Puerto Rico's unique conditions.

The DOE assesses that enhanced vegetation management would have been a decisive factor limiting the extent of the damage to the distribution infrastructure. This is a common theme that has plagued the electricity industry for many years. Over the past few decades, there has been significant progress in industry practices associated with vegetation management for utility infrastructure. DOE recommends that PREPA follow industry best practices for a comprehensive vegetation management program to protect the integrity of their distribution assets, particularly during extreme weather events.

Some examples of these best industry practices[24] include:

Routine Maintenance

- Most utilities trim trees back 10 feet from the circuit in accordance with National Electrical Safety Code (NESC) standards.
- While it is not possible to trim trees for hurricanes, the elimination of overhangs and subsequent tree fall-ins on lines must be a priority and goes a long way toward eliminating tree-related outages.
- It is imperative to have consistent and adequate financial resources to carry out the vegetation management mission. The underlying problem is that vegetation management budgets are easy to cut when the utility faces budgetary issues, so it is crucial to get the company board's approval for a vegetation management program that meets well-defined specifications.

[24] https://bear.warrington.ufl.edu/centers/purc/docs//presentations/events/hurricane-hardening/R0507_PURC_Report_on_the.pdf.

- When engaged in tree trimming, it is imperative to follow tree trimming standards such as ANSI A300 standards, to the greatest extent possible.
- Continuity of tree trimming crews ensures consistent, high quality and adherence to standards in vegetation management for the utility and its customers.

Restoration

- Coordinate vegetation management and debris removal with line work so tree crews stay ahead of line crews in the process.
- Assign a grounding crew to accompany several tree crews in case tree clearance requires lines and facilities be grounded if necessary.
- With regard to line crews being brought in from out of the service territory, have readily available pre-printed or electronic material (maps, procedures, FIRMs, etc.) and easy to complete paperwork and documentation.
- There is also likely tree damage that has not affected lines during the storm but may affect lines well after the storm. Extra crews should patrol and clear potentially dangerous timber and limbs before causing damage to existing lines.

C1C. Substations

The DOE team observed that several substations were flooded (both salt water in coastal areas affected by storm surge, and fresh water associated with rainfall induced flooding). The DOE team recommends that the newly revised FIRMs be studied and that substation assets found within flood areas are re-sited to avoid these areas, or raised and/or waterproofed accordingly using flood-resistant materials, and anchors as required to survive these events.[25] In addition to avoiding these areas, recommendations are to raise substations to the 0.2% flood elevation if possible. This is particularly important for key substations that are deemed essential to the reliability of the overall T&D infrastructure or associated with key generating assets.

These aforementioned substation assets need to include transformers, circuit breakers, associated switchgear, and especially control equipment including protective relays and communications gear. The New York Power Authority (NYPA) has extensive experience in this area and provided recommendations for substation improvements.[26] See Appendix B.

C1D. Selective Segmentation

To better enable system recovery and/or black start restoration, there might be operational benefits for segmenting the transmission system into smaller portions. While this would be done

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[25] FEMA P-348, Protecting Building Utility Systems from Flood Damage. February 29, 2017, https://www.fema.gov/media-library-data/1489005878535-dcc4b360f5c7eb7285acb2e206792312/FEMA_P-348_508.pdf.

[26] New York Power Authority, et al., Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico, December 2017, New York Power Authority, https://www.governor.ny.gov/sites/governor.ny.gov/files/atoms/files/PRERWG_Report_PR_Grid_Resiliency_Report.pdf.

out of necessity following a large-scale event, there could be some advantages to pre-selecting which segments are likely able to survive a future event, and proactively plan for segmenting the transmission system accordingly. These portions of the system would be identified to include a mix of generating assets, including black-start capable units, along with appropriately sized load, so that when the distribution system is undergoing restoration activities, and enough load would be present to constitute minimum generation capabilities, stable portions of the system could be energized and maintained prior to the longer transmission lines being repaired and energized. These portions of the system could then be re-energized with each other later in the restoration process.

A key enabler of this technology is synchrophasor technology, which provides a time-synchronized measurement of both the magnitude and phase angle of voltages across the network. This enables independent synchronous islands within the overall system to operate independently, and can also facilitate re-synchronization as assets are restored.

Another benefit of pre-planning this segmented mode of system operation is coordinating the protection and control systems. Under normal system conditions, protective relay coordination makes necessary assumptions about available fault current, and the protection settings are coordinated to provide the appropriate balance between speed and selectivity. However, during an emergency, quickly and effectively developing new protection settings may be difficult; having a pre-planned system segmentation strategy could greatly enhance the overall restoration timeline. The preplanned segmentation can be activated in preparation for emergency operations in anticipation of storms or other emergencies.

Implementing this idea requires analyzing the available clusters of generation and load, including a realistic assessment of the robustness and flexibility of the various generation sources. Priority loads would then be identified, and T&D pathways connecting these generations with these loads would be assessed. Then an operational plan for selective segmentation would be characterized to proactively separate into these segments, thus reducing the exposure to damage and increasing the likelihood of maintaining survivability of localized energized subsystems. If a segment requires full black-start restoration, those plans would be optimized for each individual segment, with the associated protection and controls in place to more quickly enable that recovery.

C2. Generation

RECOMMENDATIONS

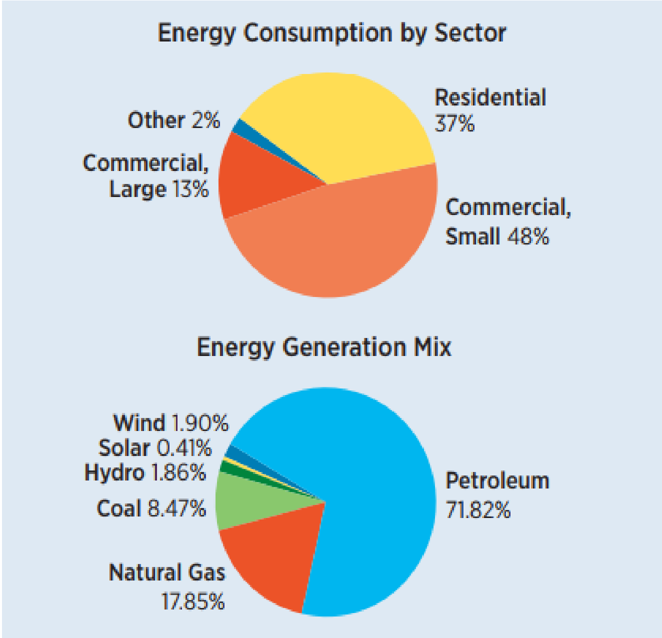

Figure 7: Existing Generation Mix and Energy Consumption in Puerto Rico [Pre-storm]
(Source: NREL - https://www.nrel.gov/docs/fy15osti/62708.pdf)

1. 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.
2. 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.
3. 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.
4. 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.
5. 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.

C2A. Context for Generation Recommendations

A variety of legal requirements, some Federal and most local, will prompt significant changes to the fuel portfolio, operations, and costs of operating the electricity system in Puerto Rico. In particular, the electricity system must evolve to reduce the dependence on imported fuels; and comply with local laws regarding central station efficiency, the energy mix, end-use energy efficiency, and environmental law requirements.

Preliminary analysis, summarized in Appendix A, indicates that these changes to the generation portfolio have the potential to reduce fuel expenditures by 10% compared to business as usual, with a similar reduction to Levelized Cost of Electricity (LCOE). Preliminary analysis also shows that right-sizing investment in the grid is equally important to controlling the overall cost of the system.

In part because of favorable economic forecasts related to natural gas, displacing oil imports with U.S. natural gas has been one of the explicit goals of Puerto Rico energy sector reform. In its report, the Bipartisan Congressional Task Force stated: "Few, if any, observers question the conventional wisdom that Puerto Rico should take steps to reduce its disproportionate reliance on petroleum and increase its use of natural gas—of which the United States is now the world's largest producer—and renewable energy sources like solar power if economically viable."

Electricity System Assets

- 4,878 MW of Generation Owned by PREPA
  - >90% Capacity Uses Heavy Fuel Oil
- 2,416 Miles of Transmission
- 30,675 Miles of Distribution
- 334 Substations
- 961 MW of Independent Power Production
  - Natural Gas, Coal, Hydro, Wind, and Solar

Puerto Rico already has one natural gas import terminal, supplying a power plant called EcoEléctrica, supplied by gas from Trinidad & Tobago and other international markets. Bringing more natural gas into Puerto Rico will require the expansion of the import capacity at EcoEléctrica and/or the construction of another import terminal. The original design and permitting for EcoEléctrica would allow it to expand to import more Liquefied Natural Gas (LNG), but would require a pipeline along the southern coast to Aguirre power plant or a pipeline through the mountains to San Juan. Both of these pipelines have been pursued in the recent past, but both were halted or cancelled.[27] In lieu of a pipeline to Aguirre, whose access to the Caribbean is interrupted by a marine preserve, the Roosevelt Roads Redevelopment area could provide a large enough brownfield to accommodate a new gas import terminal and power plant.

In order to increase the use of natural gas from the United States, and thereby reduce foreign fuel imports, the gas must be transported in compliance with the Jones Act, overseen by the Maritime Administration of the Department of Transportation. There are currently no Jones Act compliant

[27] A former senior official at PREPA testified that "the cancellation of the south gas pipeline in 2009 was not optimal", Rate Review Order, p. 79.

vessels available to deliver large volumes of U.S. LNG to Puerto Rico. There may be no capacity at U.S. shipyards to build a Jones Act compliant ship for LNG transport before the mid-2020s. In addition to large volumes of LNG, smaller volumes of LNG could be transported to Puerto Rico in ISO containers. DOE is aware of at least one company that provided small-scale LNG shipments to Puerto Rico earlier this year.

As generation infrastructure is modernized, the flexibility that modern equipment fired by alternative fossil fuels becomes a critical characteristic. According to an international partnership between the Electric Power Research Institute, International Energy Agency, National Renewable Energy Laboratory (NREL), and others, "Flexibility can also reduce overall system costs and consumer prices, via more efficient power system operation. Flexibility might also improve environmental impacts of power system operations via increased optimization of demand response, more efficient use of transmission, and reduced renewable curtailments."[28]

As stated above, modeling will help identify the optimal size, location, and fuel type of generation assets. This additional analysis could inform the level of federal support needed to complement private sector investment. Given PREPA's pre-storm estimated sales in 2026, as few as three of PREPA's current power plants may satisfy load in ten years, when combined with purchased power. Any hardening efforts should focus on those plants, including the LNG-fired Costa Sur plant. As other facilities are retrofitted to comply with MATS and other relevant legal requirements, detailed hardening assessments should be undertaken.

In addition, solar PV and energy efficiency enjoy short lead times relative to other energy infrastructure projects, and so have the potential to realize recovery benefits more quickly. Energy storage can provide valuable ancillary services to the grid, and complement the renewable energy generation required by local law.

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[28] 21st Century Power Partnership, "Flexibility in 21st Century Power Systems" (2014), http://www.nrel.gov/docs/fy14osti/61721.pdf.

Turning Disaster into Opportunity for a Resilient Community in Greensburg

On May 4, 2007, a tornado destroyed or damaged 95% of the homes and businesses in Greensburg, Kansas. The town turned disaster into opportunity and created a plan to rebuild as a sustainable community with the help of the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL), among others. For three years, DOE and NREL experts worked with city leaders, business owners, residents, and other state, federal, and local agencies to identify ways to incorporate energy efficiency and renewable energy technologies into the town's rebuilding efforts. Through energy modeling, education, training, and onsite assistance, DOE and NREL helped renovate and rebuild homes in Greensburg that, on average, use 40% less energy than similar buildings built to code—surpassing the 30% energy savings goal the town originally set. The town of Greensburg focused on rebuilding to Leadership in Energy and Environmental Design (LEED) certifications, achieving many "firsts" for the country and the state of Kansas, including:

- The first LEED Platinum municipal building in the state
- The first LEED Platinum critical access hospital in the United States
- The first residential LEED Platinum building in Kansas

Greensburg also installed solar PV and wind energy turbines to take advantage of local renewable resources.

C2B. Increases in Renewable Energy

In order to meet legal requirements regarding the transition away from heavy fuel oil, local law requires 20% of sales to be supplied by renewable energy by 2035, indicating approximately 1200 MW of renewable electricity capacity. Using PREPA's pre- and post-storm load forecasts, average daily load will be approximately 2000MW. Thus, by another metric like capacity, the current Renewable Portfolio Standard (RPS) target of sales would translate to an ambitious but still achievable goal.[29]

The delivered cost of electricity from independent renewable power producers, from PPAs signed in 2014, compared favorably with the cost of PREPA's heavy fuel oil-fired plants. The cost of renewable technology has decreased, and the knowledge of how to integrate these technologies into the grid has increased, in the intervening years.

[29] The Hawaiian Electric Companies delivered renewable electricity amounting to 27% of sales in 2017. https://www.hawaiianelectric.com/clean-energy-hawaii/clean-energy-facts.

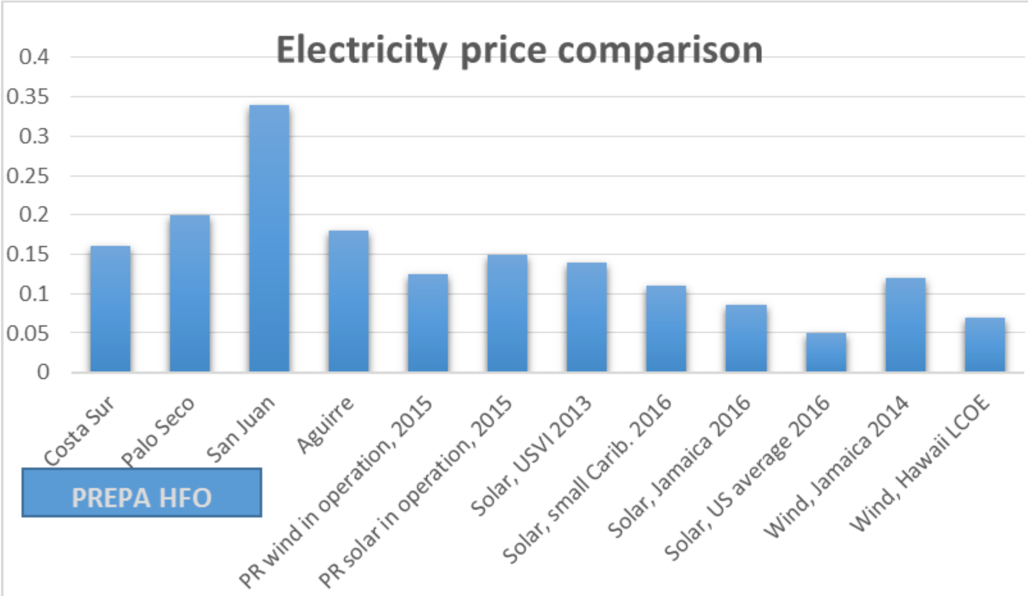

Figure 8: Electricity Price Comparison (Source: DOE, EERE)

Puerto Rico has no fossil fuel or geothermal resources available locally. The University of Puerto Rico (UPR) conducted an analysis of the technical potential of several renewable resources, concluding that the potential renewable resources available to Puerto Rico – including wind, solar, hydro, and biomass resources – could provide large amounts of energy to the island. A narrower study from NREL indicated using brownfield sites for solar photovoltaic (PV) would provide economic power from potentially contaminated land.

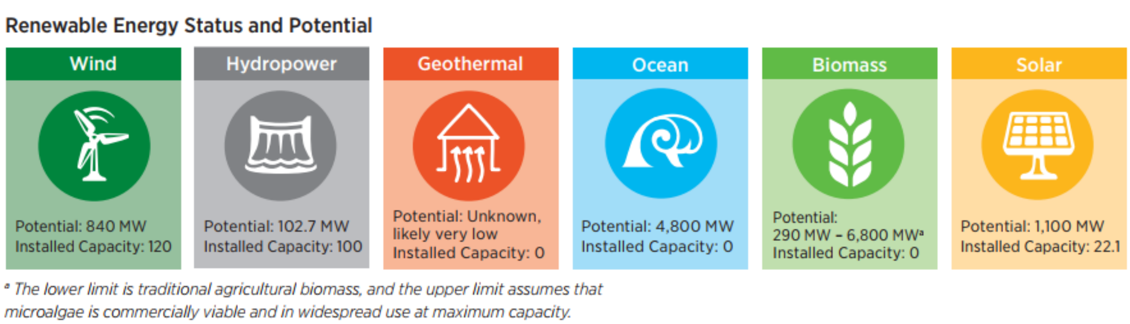

Figure 9: Renewable Energy Potential (Source: DOE)

Puerto Rico has traditional biomass resources, and could explore the feasibility of importing biomass pellets from the Southeastern U.S., especially as the AES coal-fired plant license is set to expire in the next ten years. Another alternative fuel source available locally is Municipal Solid Waste (MSW). Most of the active 29 landfills in Puerto Rico are beyond capacity, and the U.S. Environmental Protection Agency (EPA) has reached agreements to close twelve of them. Each of those twelve agreements includes a recycling program, creating the feedstock sorting infrastructure that can facilitate Waste-to-Energy (W2E). W2E can reduce the amount of waste headed to a landfill and generate electricity; an evaluation of W2E in the U.S. Virgin Islands indicated favorable economics including the cost of limited environmental mitigation. While in use in the U.S., W2E technology, and anaerobic digestion in particular, is a common waste treatment solution in Europe.

A recent study by NREL used an existing solar PV plant in Puerto Rico to provide frequency response and other grid support services for PREPA's grid. Using existing infrastructure, the study showed, on an actual system, how renewable energy can be effectively and efficiently integrated into PREPA's system – and outperform traditional operational practices. That same study showed this to work in Texas, and a similar study showed this to work in California. Another study, by Sandia National Laboratory, showed how distributed PV can be operated as a virtual power plant on a small grid to provide certain grid support services more cost effectively than traditional operations.

Finally, the energy storage that can be used to complement variable renewable generators have been shown to provide black start capability for natural gas turbines,[30] indicating that a holistic view of these assets can identify different optimal configurations than were available in the twentieth century. As the electricity system in Puerto Rico transitions towards a modern grid, it will be important to ensure these kinds of contributions are considered toward any minimum renewable power requirements.

As part of the 2015 IRP process, PREPA estimated that 322MW of distributed solar will come online through 2035, supplying approximately 17% of the legally required minimum of renewable electricity. This private investment in distributed generation will be facilitated if clear expectations regarding interconnection and remuneration are set and adhered to consistently by all relevant parties.

C3. Microgrids

RECOMMENDATIONS

1. 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.
2. 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.
3. 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.

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[30] Imperial Irrigation District in California used a 33MW/20MWh battery to black start a 44MW combined cycle natural gas turbine in 2016.

4. 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.
5. 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.
6. 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.

C3A. Context for Microgrid Recommendations

There are two types of microgrids: grid-tied and remote. Grid-tied microgrids can run in parallel with the grid or remain islanded for a certain duration of time. The key feature is that these microgrids have access points to the grid which are connected. Grid-tied microgrids vary significantly in size and sophistication, while remote microgrids serve small isolated populations often not served by the main grid.

DOE defines microgrids as follows: "A group of interconnected loads and distributed energy resources (DER) within clearly defined electrical boundaries that act as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island mode. A remote microgrid is a variation of a microgrid that operates in island conditions"[31]

The DOE team observed that recovery for remote mountainous communities was significantly delayed compared with the more densely populated areas associated with major metropolitan areas. DOE believes that there is an opportunity for distributed generation and energy storage, deployed in microgrids, to provide resilience enhancement to these communities. While there is economic and reliability value in being connected to the PREPA system during normal conditions, storm recovery and community support can be enhanced through these community-based microgrids in more remote areas of the Commonwealth. In addition, while further analysis is required before developing specific recommendations, microgrid investment has the potential to be more cost effective than alternative system upgrades to harden the system for improved function and reliability.

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[31] For example, a stand-alone DER such as solar, wind, CHP, or energy storage, without a controller or islanding capability would not meet this definition; it must be a larger set of loads and resources combined with controls that operate as a system. IEEE p2030.7 Standard for the Specification of Microgrid Controllers and the language of IEEE p1547-REV and IEEE 1547.4 for islanded systems should be followed.

The services that microgrids can provide vary greatly to support different applications, such as critical infrastructure availability, industrial site reliability, and basic service in remote areas. Microgrids can facilitate the integration of distributed energy resources, which will help to place generation assets close to loads and diversify fuels, as recommended in Section C2 (Generation) of this report. In addition, microgrids may be able to offer benefits to the PREPA grid (like power and ancillary services). In order to maximize the benefits of each microgrid, it will need to be designed for its specific site, use, and suite of benefits and should be at least as resilient as the grid.

Increasing Reliability of Industrial Infrastructure in Louisville

Oak Ridge National Laboratory (ORNL), in partnership with Sandia National Laboratories (SNL) and UPS, assessed microgrid capabilities at the UPS WorldPort facility in Louisville, Kentucky - the most technically advanced facility of its kind in the world. UPS is very interested in the development of an industrial microgrid to serve their 50MW peak WorldPort facility to increase reliability and strengthen the surrounding grid through advanced microgrid control schemes. At the WorldPort facility, even short outages can cost millions of dollars; a microgrid system will help to eliminate this risk. In addition, the microgrid assets will provide benefits during "blue-sky days" such as demand reduction and utility services. ORNL, SNL, and UPS are investigating the risks, costs, and benefits of a microgrid at the UPS WorldPort and Centennial Hub facilities. The "Industrial Microgrid Analysis and Design for Energy Security and Resiliency" project provides a roadmap for UPS and other industries interested in microgrid technologies by laying out the technical, institutional, and regulatory challenges associated with developing an industrial microgrid. It will also highlight the interaction between an industrial customer interested in pursuing a microgrid and the customer's utility.

The physical and economic interaction between microgrids and the main grid need to be examined. These applications need to be identified in the context of the overall system, whether critical loads and/or areas least able to withstand disruptions or remote end-of-line areas. Modeling and power-flow analysis from the transmission substation to the microgrid or local customer may assist in prioritizing projects. PREC and PREPA should allocate interconnection costs and risks, as well as tariffs that recognize beneficial ancillary services provided by customer owned microgrids.

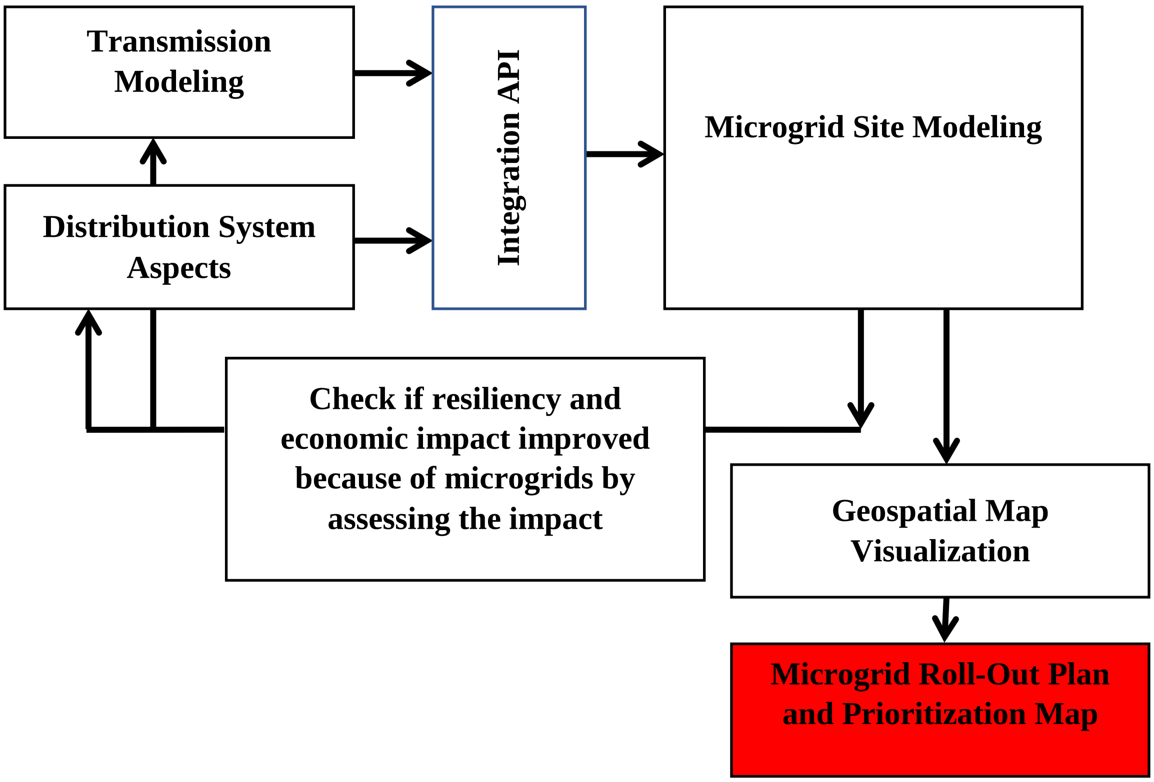

Figure 10: Potential Approach for Microgrid Deployment (Source: ANL)

Modeling and analysis will contribute to the identification of the most advantageous potential microgrid locations. Three main applications of microgrid technology have been discussed that would be beneficial for Puerto Rico. These applications include essential services/critical infrastructure in urban areas; unique needs of certain customers, such as large or clustered industrial customers; and remote locations and the islands of Vieques and Culebra.[32]

When considering locational issues, the microgrid system needs to provide a certain load serving capability over a given duration of time without fuel supplies from outside the microgrid boundary. This requires the analysis of load to serve critical infrastructure. The Microgrid Design Tool (MDT),[33] DER-CAM,[34] and OpenDSS can be employed to assist with this analysis (See Appendix D).

As more DERs and microgrids are deployed, PREC should consider adopting standards relevant to the Puerto Rico network, ensuring that project developers have a clear and unambiguous

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[32] In April 2018, PREPA announced a request for proposal seeking providers of power solutions for the electrical system of the island municipalities of Vieques and Culebra.
[33] http://energy.sandia.gov/download-sandias-microgrid-design-toolkit-mdt/.
[34] https://building-microgrid.lbl.gov/projects/der-cam.

understanding of the requirements needed for compliant projects. The electric power industry has adopted and continues to refine standards for distributed energy and microgrid systems. The Institute of Electrical and Electronics Engineers (IEEE) has developed IEEE 1547 and 2030 Standards for Distributed Energy Resources (DER) Interconnection and Interoperability with the Electricity Grid (including IEEE 2030.7-2017: Approved Draft Standard for the Specification of Microgrid Controllers, and 2030.8: Draft Standard for the Testing of Microgrid Controllers). The North American Electric Reliability Corporation (NERC) also has developed industrial standards for the interconnection of DER and microgrids.

Strengthening Community Resilience in New Orleans

Since the devastation of Hurricane Katrina, resilience has been a renewed focus for New Orleans. Through the Grid Modernization Initiative, the U.S. Department of Energy worked with researchers from Sandia and Los Alamos National Laboratories and city officials to strengthen New Orleans' resilience to natural disasters. The "Grid Analysis and Design for Energy and Infrastructure Resiliency for New Orleans" project in 2015-16 developed a set of cost-effective options for enhancing resilience. Their recommendations focused on advanced microgrids, automated reclosers and automated fault location, isolation, system recovery (FLISR) software, as well as localized backup generation. The team identified clusters of high-impact infrastructure, like emergency medical services and fuel stations and fleets, assets could be best served by microgrids during a blackout or other disruption. By ensuring a reliable "Plan B" for such critical infrastructure, services could be returned to citizens much faster than if they are dependent on power being restored to the larger grid network.

Prior to the more detailed engineering studies, the DOE's Energy Transition Initiative and National Labs delivered recommendations in the form of conceptual designs for New Orleans officials, Entergy, and state and federal agencies to rank energy infrastructure improvement options and set improvement implementation and funding priorities. The project produced approaches and lessons learned that can be applied to other cities across the nation including Puerto Rico and the U.S. Virgin Islands.

C4. System Operations, Management, and Planning

RECOMMENDATIONS

1. 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.
2. 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.

3. 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.
4. 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.
5. 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.
6. 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.
7. 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.

C4A. Context for Planning Improvement Recommendations

C4A1. Integrated Resource Planning

Puerto Rico became the first U.S. territory required to conduct forward-looking planning with the *Act for the Transformation and Energy Relief of Puerto Rico*, 2014 (Act 57) including comprehensive oversight of the process by a local regulatory body.[35] PREC approved the first Integrated Resource Plan (IRP) for Puerto Rico on February 10, 2017.[36] Both Act 57 and the PREC regulation on the IRP process, "Regulation on the Integrated Resource Plan for the Puerto Rico Electric Power Authority" (May 22, 2015), require specific items to be addressed in the IRP.

The process began with Act 57, which requires that the utility periodically develop and submit to the PREC for review, an integrated resource plan. Section 6.23 of Act 57 states:

> (a) PREPA…shall submit to the Commission an Integrated Resource Plan (IRP) describing the combination of energy supply and conservation resources that satisfies in the short-, medium-, and long-term the present and future needs of the energy system

[35] Act 57-2014, Act for the Transformation and Energy Relief of Puerto Rico, May 2014 (Act 57), http://www.oslpr.org/download/en/2014/A-057-2014.pdf.

[36] *Resolution on the Verified Motion for Reconsideration of the Puerto Rico Electric Power Authority*, CEPR-AP-0002-15.

> both of Puerto Rico and of their customers at lowest cost possible. . .. (d) After the approval of the integrated resource plans, the Commission shall supervise and oversee compliance therewith. Every three (3) years, the Commission shall carry out another review process, and if applicable, modify such plans, as well as issue and post on its website, a detailed report showing compliance with integrated resource plans and the modifications made thereto after the review process.

The *IRP Order* and *Rate Review Order*, issued by the PREC, identified the many ways PREPA's energy infrastructure can be improved. Puerto Rico law also provides for contractual arrangement with outside parties with the expertise needed to modernize PREPA's infrastructure and improve its performance. Attracting outside expertise may result in novel, reliable, lower cost solutions to meet the energy needs of Puerto Rico.

C4A1a. The Key Role of the Puerto Rico Energy Commission

The energy regulatory authority in Puerto Rico, equivalent to a state Public Utilities Commission, was created by Act 57. At the time of passage, several states regulated aspects of rate setting or other behaviors of publicly-owned electric utilities.[37] While there is often variance between the scope of state-level regulation of municipal utilities and investor-owned utilities, one example that may prove to be of particular relevance to Puerto Rico is the change to the Long Island Power Authority's (LIPA) autonomy in 2013, whose debt restructuring plans have resulted in investment-grade ratings by both S&P and Moody's.[38]

Similar to the legislative reforms of LIPA, Act 57 subjected PREPA to a state-level regulatory authority, the PREC. Beyond the reforms in New York, Act 57 made several other strides in creating an energy system governance structure that is standard in the fifty states. These included: 1) establish the PREC; 2) establish a consumer advocate; 3) establish a long-term planning process, called the "Integrated Resource Plan" ("IRP"); 4) ensure certain levels of efficiency in the generation fleet; 5) promote end-use efficiency, including in the public sector; 6) promote diversity and reliability in the fuel portfolio; 7) focus the efforts of the state energy office; 8) enable the functional separation of generation and grid services; and 9) reform certain long-standing consumption subsidies, including those paid to municipal governments.[39]

Stepping into this environment of policy modernization, the newly-established PREC was empowered with regulatory authority to implement many of the reforms described in Act 57, as well as less comprehensive but still significant reform efforts from the preceding years.[40] With

[37] American Public Power Association, "References for State Rate Regulation of Public Power Utilities" (June 19, 2014), http://appanet.files.cms-plus.com/Resources/Rate_reg_of_PP_by_PUC_-_Statutes_6_19_2014_update.pdf.
[38] https://www.lipower.org/wp-content/uploads/2016/09/SP-Global-Ratings-Report-LIPA-20171122.pdf; https://www.lipower.org/wp-content/uploads/2016/09/LIPA-Report-Moodys-2017-2.pdf.
[39] The full, 165-page Act 57 is here: http://www.oslpr.org/download/en/2014/A-057-2014.pdf. A more detailed summary is available from a Puerto Rico law firm: http://www.mcvpr.com/media/publication/273_Act%2057.pdf.
[40] Of note, Acts 82 and 83 of 2010, enabling wheeling of electricity and setting a Renewable Portfolio Standard, among other changes.

further refinements in the Electric Power Authority Revitalization Act, 2016 (Act 4), the PREC began operations with the scope and power typical of any state PUC.[41]

Among them, the PREC was created with explicit jurisdiction over planning as part of landmark energy reform designed to bring Puerto Rico's energy system governance in line with state best practices, as well as increase the fuel diversity, efficiency, and overall performance of the energy system in Puerto Rico. As the PREC has noted, "the center-stage of the energy reform [is] turning back years of fiscal and operational mismanagement."[42]

PROMESA 503(b)(1)(D) also calls for reliance on the PREC's IRP process. This deference to the local process was reaffirmed by the Congressional Task Force on Economic Growth in Puerto Rico in 2016. It stated: "There are certain challenges in Puerto Rico—such as an outdated energy system, a troubled K-12 public education system, and inefficiencies in various other sectors—that must be tackled first and foremost by the government of Puerto Rico and the private sector."[43]

In May 2015, the PREC finalized a 41-page order, the *Regulation on Integrated Resource Plan for the Puerto Rico Energy Power Authority*, which included, among other points, specific requirements as to information and analytic requirements, and performance metric targets.[44]

PREPA submitted its IRP in July 2015, which was rejected by PREC, who requested a modified IRP. PREPA submitted its modified IRP in February 2017, but after review, the PREC found the plan insufficient, stating:

> The IRP provided by PREPA was insufficient in terms of the process and mechanisms chosen for achieving the results contained therein. Therefore, the Commission is unable to rely upon the IRP filed by PREPA. If the IRP cannot be used for its intended purposes, then it is noncompliant.[45]

The above timeline is not unusual, but PREC was highly critical of PREPA's plan, and the utility's responsiveness. And given the significant changes resulting from the September 2017 hurricanes and restoration efforts, the PREC has revised the timeline for future submissions:

> The Commission finds that a review of PREPA's existing IRP (the February 2017 Modified IRP) prior to the three-year term established in The Puerto Rico Electric Power

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[41] http://www.oslpr.org/download/en/2016/A-004-2016.pdf.

[42] *Final Order on PREPA's Motion for Reconsideration*, p. 9 (Mar. 7, 2017), http://energia.pr.gov/wp-content/uploads/2017/03/8-marzo-2017-Final-Resolution-PREPAs-Reconsideration-CEPR-AP-2015-0001.pdf.

[43] Congressional Task Force on Economic Growth in Puerto Rico, "Report to the House and Senate", p. 8 (Dec. 2016).

[44] Commonwealth of Puerto Rico, "Regulation on Integrated Resource Plan for the Puerto Rico Energy Power Authority," Puerto Rico Energy Commission, May 22, 2015, http://cepr.cloudapp.net/wp-content/uploads/2015/09/RE-8594-EN.pdf.

[45] PREPA's first IRP was disapproved by PREC in September 2016. PREC allowed for a revised IRP. PREC statement from: Commonwealth of Puerto Rico, "IRP for PREPA: Resolution on the Verified Motion for Reconsideration of the Puerto Rico Electric Power Authority," Puerto Rico Energy Commission, Case No. CEPR-AP-2015-0002, February 10, 2017, http://energia.pr.gov/wp-content/uploads/2017/02/10-feb-2017-Resolution-Ruling-on-PREPAs-Verified-Motion-for-Reconsideration.pdf.

> Authority Act, 1941 (Act 83) and Act 57 is warranted in order to determine the effects hurricanes Irma and Maria may have had on Puerto Rico's resource needs and determine whether any proposed update, revision or modification is necessary to mitigate "substantial changes in demand or group of resources….The Commission authorizes PREPA to file an updated IRP on or about October 2018.[46]

C4A1b. The Role of the PREPA Governing Board

Under its original act (Act 83), as amended, PREPA's internal controls are overseen by a Governing Board. Until Act 57, six of nine members were appointed by the Governor with the advice and consent of the Senate, and a seventh served ex officio, by virtue of appointment to an executive branch position by the governor. No qualifications were explicitly required, and no conflict of interest restrictions on service were made explicit.

Act 4 further refined the responsibilities of PREPA's Governing Board. It eliminated the ex officio positions and returned the Governor's appointments to six of nine, with the key distinctions that those individuals must: 1) be selected from a list compiled by an executive search firm "based on objective criteria" including expertise, and 2) meet the criteria of independence set by the New York Stock Exchange Corporate Governance Standards. Also, Act 57 restricted on service for persons with "substantial economic interest" in PREPA's business decisions, similar to the standard practice of ensuring diversity and independence for Boards of Directors in privately-owned corporations. Nonetheless, Act 3-2017 provides that every member of a governing board or body of a public corporation, like PREPA, shall enjoy the trust of the Governor of Puerto Rico. The Governor may remove a member who is believed to have failed to implement his public policy or who has lost his trust to carry out the fiscal plan to be submitted to the Financial Oversight and Management Board. The statute provides that the Chief of Staff and cabinet members in a committee shall make recommendations to the Governor as to who should be removed for such reasons.[47]

PREPA's governing body was further reformed by Act 37-2017 to a full composition of seven (7) members. The Governor shall appoint three (3) of the seven (7) members from a list of candidates with educational and professional background in fields such as: electrical engineering, business administration, economics and finance, or law, and no less than ten (10) years of experience in the field. Also, they shall have expertise in energy affairs and shall not be public employees, except for being professors at the University of Puerto Rico. The independent members and the elected member shall be subject to the independence requirements under the NYSE Corporate Governance Standards. The statute also calls for review of the Board's compliance with industry's governance standards every three (3) years by a recognized consultant with expertise and experience in providing advice to boards of directors of similar entities.[48]

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[46] Government of Puerto Rico Energy Commission, March 15, 2018, CEPR-AP-2018-0001, "Commencement of Review Proceeding and Order Establishing Initial Submission Timeline," http://energia.pr.gov/wp-content/uploads/2018/03/Resolution-and-Order-IRP-CEPR-AP-2018-0001.pdf.
[47] http://www.oslpr.org/download/en/2017/A-003-2017.pdf.
[48] http://www.oslpr.org/download/en/2017/A-037-2017.pdf.

As of March 2018, the PREPA Board approved the issuance of a Request for Proposals (RFP) for the development of a new IRP.[49]

C4A1c. The Role of the PREPA Executive Director

Act 4 also refined the role and responsibilities of PREPA's Executive Director, giving the Board discretion to dismiss the person serving, rather than requiring cause. This change is another incorporation of standard practice in private industry to help ensure effective and efficient management.

C4A2. Energy Assurance Planning and Mutual Aid

Another critical form of planning in the energy sector is energy assurance planning. Energy infrastructure and delivery systems are increasingly vulnerable to severe weather, system, and infrastructure failures, and deliberate physical or cyber-attacks. Planning for energy sector disruptions—termed energy assurance planning, and often led by a Governor's energy office—is essential to safeguarding energy system reliability and resilience. Energy assurance planning can help to achieve a robust, secure and reliable energy infrastructure that is also able to restore services rapidly in the event of any disaster.[50]

Energy providers can respond quickly to limited disruptions. Spikes in energy demand during peak energy use, unanticipated power plant or refinery outages, transmission congestion, or natural disasters can cause disruptions that extend over a broad area or last more than several hours. These energy emergencies often require intervention by government emergency responders and a more collaborative public-private response to ensure public health and safety.

Government officials can coordinate across governments (federal, state and territory, local) and government agencies and with utilities and other energy providers, businesses, and the public to reduce consequences and provide for rapid recovery. Governments should be in ongoing contact with industry, always seeking ways to reduce risk and vulnerabilities to critical energy infrastructure to reduce the effects of future disruptions.

Nearly all state and territory governments and select local governments have an energy assurance plan, which serves as a foundation for action when an energy disruption threatens public welfare or when the energy industry requests help. These plans address energy supply risks and vulnerabilities and enable a quick recovery and restoration. Combined with training and exercises for personnel and stakeholders, energy assurance plans enhance response and recovery efforts and support resiliency investments.

DOE has provided support for states and local governments to develop and refine energy assurance plans, build in-house expertise on infrastructure interdependencies (i.e., other critical infrastructure systems' reliance on electricity for operations) and vulnerabilities, and integrate renewable energy portfolios and new applications such as cyber and smart grid technologies. The energy assurance plan that DOE has on file for Puerto Rico is from 2011.

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[49] https://www.aeepr.com/docs/irp%20rfp%2020180310%20.pdf.

[50] NASEO, Energy Assurance Planning, http://www.naseo.org/energyassurance.

As demonstrated by post-Hurricane restoration efforts in Puerto Rico, a lack of replacement parts and back-up equipment can delay restoration efforts. Energy assurance plans ensure that state officials, in collaboration with industry, consider the development of an inventory and identify the proper placement of essential components and back-up equipment to operate the energy system. Given Puerto Rico's geography and the delays associated with shipping resources to the island, this aspect of an energy assurance plan should be an important and early focus.

Under the direction of the DOE's Office of Electricity (OE), the National Association of State Energy Officials (NASEO) and the National Association of Regulatory Utility Commissioners (NARUC) created guidelines[51] for states and territories to use in the development of energy assurance plans. The guidelines integrate lessons learned from prior energy emergencies and energy emergency exercises of government and industry officials. The National Emergency Management Association (NEMA) also offers a helpful and related resource on current state and promising practices for energy assurance planning.[52]

Puerto Rico is a member of the Emergency Management Assistance Compact (EMAC), a national interstate mutual aid agreement that enables states to share resources during times of disaster. (EMAC is administered by NEMA, the National Emergency Management Association.) The thirteen articles of the Compact set the foundation for sharing resources from state to state.[53]

In the response to Hurricane Maria, the six-week delay in requesting mutual aid assistance hampered recovery efforts and raised questions as to Puerto Rico authorities' overall management of the recovery effort. While no regulatory changes are needed, a complete review of the procedures for invoking a call for mutual aid assistance should be undertaken to ensure future situations are handled effectively.

To prepare for the future calling for mutual aid assistance, the utility, along with appropriate Commonwealth government agencies, should undertake a review of their emergency response management procedures and develop an updated Incident Command System (ICS). In general, ICSs are part of the National Incident Management System (NIMS) under federal Department of Homeland Security authority.

An ICS establishes a command hierarchy to coordinate emergency response and identifies the Incident Management Team (IMT) and procedures for communications, use of emergency equipment (and pre-positioning), and command operations.

Many U.S. East Coast utilities adopted or upgraded their ICS procedures in 2012 following Superstorm Sandy. PREPA and appropriate Puerto Rico authorities can expedite their ICS update by working with utilities (such as members of the Southern States Energy Board) and with utility organizations, such as the American Public Power Association (APPA). Beyond

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[51] NASEO, Guidelines, http://www.naseo.org/eaguidelines.
[52] NEMA's Energy Assurance Planning: Current State and Promising Practices, https://www.nemaweb.org/index.php/docman/resources/long-term-power-outage/919-nema-energy-resilience-report-oct-2017/file?force-download=1.
[53] Emergency Management Assistance Compact, at https://www.emacweb.org/index.php.

developing plans and an organization structure, it is important that PREPA and appropriate Puerto Rico authorities conduct periodic training exercises based on their ICS.

C4B. Human Resources and Training

Consistent with the overall economic decline in Puerto Rico and the resulting outmigration, the grid-related workforce has shrunk by over 30% over the past decade.[54] Thus, DOE agrees with the recommendations of the NYPA report that future re-building efforts should provide opportunities for the retention of on-island skilled labor and development of new high-quality jobs. And that highly skilled (or re-trained) technicians will be needed to operate future systems—e.g., control centers enabling active monitoring and control of distributed generation and microgrids; enhanced outage management functionality, integrated with an Advanced Distribution Management Systems (ADMS) and Distributed Energy Resource Management Systems (DERMS); and integrated cyber and physical asset security in all systems.[55] Furthermore, training staff to comply with ISO certification could help ensure resources are allocated to capture the full value of the initial capital expenditures.

In 2015, the University of Puerto Rico created an interdisciplinary program called the Institute for Island Energy Sustainability (INESI). As one of its first major projects, INESI received a National Science Foundation grant to study the technical and social barriers to a highly distributed energy future in Puerto Rico. In conjunction with federal recovery and mitigation efforts, INESI could provide the foundation on which to firmly establish Puerto Rico as a Center of Excellence on distributed grid operations, and could provide both the supply of interdisciplinary engineers and policymakers Puerto Rico will need and the expertise other island and remote grid systems will need in their transition to a distributed, resilient electricity sector.

DOE recommends that the PREC be properly staffed, with a sufficient number of professionals skilled in the appropriate technical areas, so that the review of plans—e.g., IRPs, EAPs—is as effective and efficient as possible. Periodic training for PREC staff would help ensure that they are kept abreast of industry best practices.

C4C. Standards, Regulatory and Legislative Actions to Enhance Long-term Recovery

A number of the recommendations presented earlier in this report may require regulatory or legislative changes to be implemented effectively. DOE identifies those changes in this section.

Earlier recommendations called for all transmission and distribution towers and poles to be designed and installed to withstand 150 mph wind speed standard, and for critical grid assets to be located at least 3 feet above (in elevation) the line demarcated by the revised FEMA FIRMs. Legislative and/or regulatory action will be needed to ensure these standards are adhered to and effectively implemented. NERC reliability standards may guide similar standard setting tailored

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[54] 2,343 PREPA employee retirements since 2012, 1,018 were from T&D operations and 630 were from generation operations. *PREPA Draft Fiscal Plan 04 2*-18 and *Rate Review Order*, pp. 37 and 51-52.

[55] NY Power Authority, et al., *Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico*, December 2017.

to Puerto Rico, and provide for penalty provisions for non-compliance to be enforced by the Commonwealth.[56] This may require legislative action.

In Section C4B, DOE discussed the need for comprehensive Energy Assurance Planning (EAP) in conjunction with mutual assistance projects. A comprehensive plan that addressed technical issues as well as logistical issues, such as the lodging of external technicians, should be periodically updated and practiced using live-action drills. Legislative action may be necessary to affect an annual review of the Energy Assurance Plan and mutual assistance agreements, as well as resources to practice those plans in drills. The plans and exercises should engage large energy customers in the Commonwealth to ensure the adequacy of the EAP. DOE, as well as the National Association of State Energy Officials, can provide assistance in the development of EAP activities.

[56] The North American Electric Reliability Corporation (NERC) is a not-for-profit entity set up to ensure the reliability of the electricity system in North America. NERC sets mandatory and enforceable industry standards under the authority delegated by the Federal Energy Regulatory Commission (FERC). This authority allows NERC to assess penalties on electric utilities and service providers that fall out of compliance with relevant standards.

D. Conclusion

The analysis needed to provide the system-wide understanding for resilience investment is being undertaken with all due haste.

The fundamental question that modeling and analysis must answer, in collaboration with the Government of Puerto Rico and PREPA, is which design options will provide the people of Puerto Rico with the resilience they need and the downward pressure on rates critical to the Commonwealth's economic revitalization. The insights gathered from these efforts will allow articulation of firm recommendations on a variety of investment decisions that will confront the Commonwealth.

The recommendations included here are intended to inform recovery plans pursuant to section 21210 of P.L. 115-123. DOE observed that, generally, PREPA designed the electricity system well, as evidenced by the uncompromised power stations and effective "dead end" structures. It became clear that the system was weakened over time to the point of catastrophic failure, in the face of the second most powerful hurricane to hit the Commonwealth in recorded history.

The recommendations focus on what considerations should be incorporated into the recovery plan required by Section 21210 of P.L. 115-123. The recommendations focus on three main areas:

1. Ensuring that investments will result in modern, intelligent infrastructure systems that are affordable, reliable, and resilient, while fully complying will all local and federal law;
2. Undertaking the analysis and planning necessary to de-risk those investments and identify an effective mix of centralized and distributed energy resources of different fuel types; and
3. Providing for adequate training and capacity building to offset human capital out-migration and transitioning system operations.

In addition, as soon as practicable, DOE recommends that:

1. The Governor and PREPA should immediately ensure that updated, effective mutual aid agreements and Incident Command System are primed to quickly provide support during the next event.
2. 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.
3. Electricity transmission towers installed specifically for temporary emergency restoration should be considered for prioritized replacement, potentially by monopoles. Many round monopole structures withstood the storm effectively.
4. The PREC, in coordination with PREPA, should implement microgrid regulations in line with accepted industry standards and practices; and establish effective, efficient, and reasonable interconnection requirements and wheeling regulations. These regulations will allow customers to design their systems in a manner that supports the reliability and resilience of the broader electricity grid.

5. The Puerto Rican State Office of Energy Policy or its successor, in coordination with other appropriate Commonwealth agencies and instrumentalities, should immediately commence drafting of an updated Energy Assurance Plan. This plan should provide for, among other things, the use of the Incident Command System including the immediate establishment of a standing Incident Management Team.

Even before the storm, there was “consensus that the high cost and low reliability of electric power in Puerto Rico is one of the most serious challenges confronting households and businesses, and a significant obstacle to economic growth on the island.”[57] The recommendations and analysis identified in this report should guide any recovery plans for energy infrastructure in Puerto Rico toward creating a modern, intelligent energy sector that can be the engine for Puerto Rico’s revitalization.

[57] Bipartisan Congressional Task Force on Economic Growth in Puerto Rico, p. 37 https://www.finance.senate.gov/imo/media/doc/Bipartisan%20Congressional%20Task%20Force%20on%20Economic%20Growth%20in%20Puerto%20Rico%20Releases%20Final%20Report.pdf.

Appendix A: Scenarios

	MATS Waiver	2025 Compliance	2035 Compliance
LCOE in 2035, Relative to BAU[58] assuming $1bn Grid Investment	Baseline	-16.0%	-10.9%
Relative LCOE for $5bn Grid Investment	+7.1%	-8.5%	-3.5%
Total Portfolio Cost $1bn Grid Investment	Baseline	-21.5%	-17.3%
Total Portfolio Cost High Grid	+7%	-14.4%	-10.4%
Fuel Saved	Baseline	$11,234,097,575.73	$9,014,097,706.74
Consumer Energy Efficiency	N/A	5,149,461MWh Saved through 2035	5,149,461MWh Saved through 2035

Costs and capacity factors came primarily from the most recent publicly-available figures from the Energy Information Administration. More relevant capacity factors for Puerto Rico power plants were taken from the Fortieth Engineer's report for existing power plants. NREL and LBNL offer more granular cost and capacity factor information for solar PV and wind, respectively, enabling a broader range of inputs to reflect the size of projects in Puerto Rico relative to the U.S. mainland. These figures were held constant across each scenario to provide a basis for comparing difference in the overall cost of the different systems through 2035.

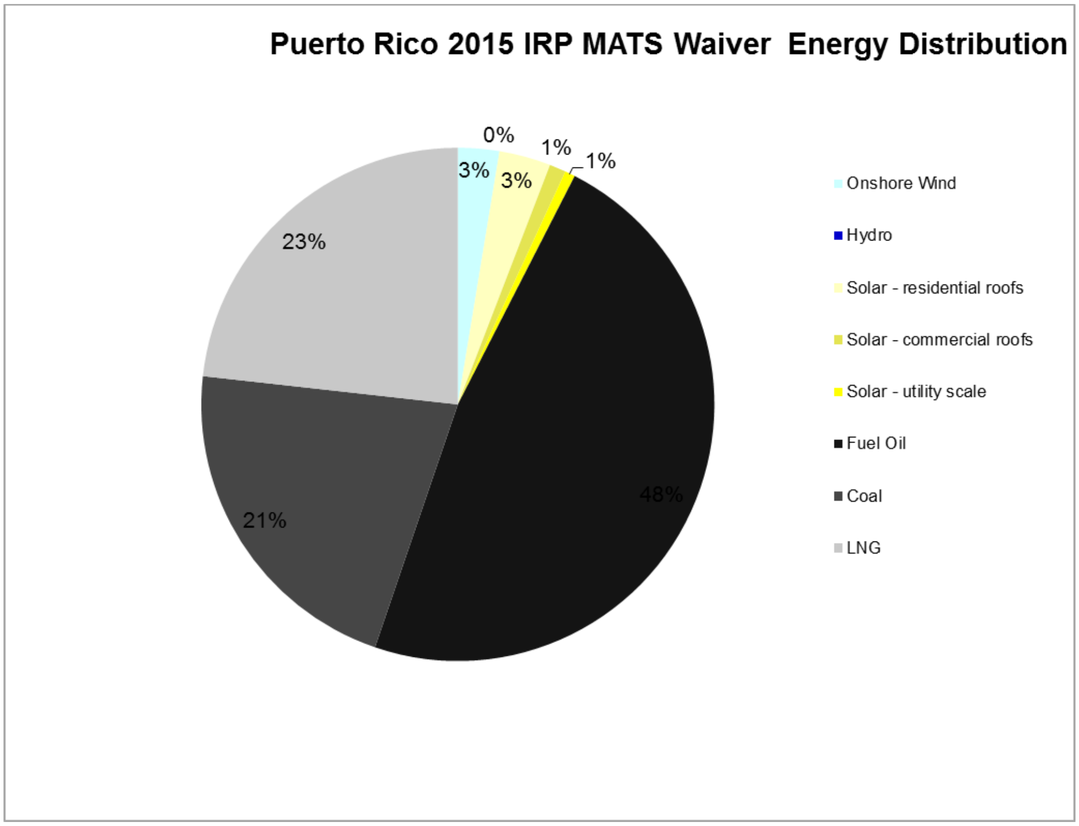
The Business-as-Usual (BAU) Scenario assumes Puerto Rico continues operating its heavy fuel oil units subject to MATS as currently applied for existing generation, pre-storm renewable energy is restored, and distributed generation reaches 322MW by 2035.

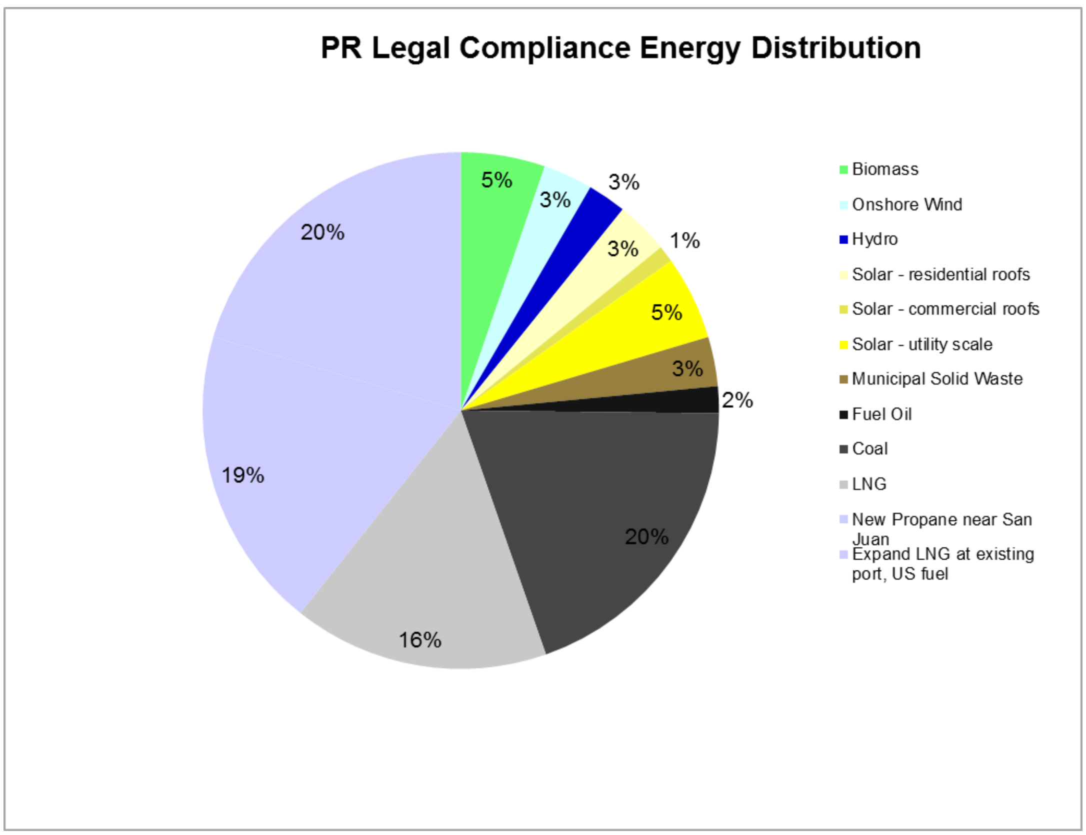
The 2025 Compliance Scenario and 2035 Compliance Scenarios assume that the electricity system meets all relevant legal requirements by 2025 and 2035, respectively, including:

- Mercury and Air Toxics Standards and Act 57 High Efficiency Generation requirements met by --
  - Re-firing Palo Seco with propane,
  - Maintaining the LNG-fired EcoEléctrica and Costa Sur,

[58] This chart sets the LCOE for the BAU $1bn Grid Investment scenario as equal to 1, so that the LCOE for other scenarios is shown as a percentage change away from BAU and low grid investment.

    - Expanding LNG import capacity at EcoEléctrica to supply a completed southern pipeline that fires 500-600MW of new combined cycle gas turbines at Aguirre or Roosevelt Roads,
    - Co-firing biomass at AES;
- Energy efficiency equal to 1.5% of retail electricity sales annually, as a result of requirements regarding:
    - Building energy codes,
    - Energy Savings Performance Contracts in government-owned buildings,
    - Streetlight retrofits to Light Emitting Diodes (LEDs),
    - Ratepayer-funded consumer end use efficiency program,
    - Reductions in technical and non-technical losses;
- Renewable energy sufficient to meet the existing RPS, met by –
    - Restoring pre-storm utility-scale projects,
    - Each project currently before the Revitalization Coordinator,
    - 322MW of distributed solar, per PREPA's estimate,
    - 100MW of existing hydro facilities that need refurbishment,
    - 150MW of biomass,
    - 150MW of solar,
    - 25MW of wind.


Puerto Rico 2015 IRP MATS Waiver Energy Distribution
0%
1%
1%
3%
3%
23%
48%
21%
Onshore Wind
Hydro
Solar - residential roofs
Solar - commercial roofs
Solar - utility scale
Fuel Oil
Coal
LNG


PR Legal Compliance Energy Distribution
5%
3%
3%
3%
1%
5%
3%
2%
20%
19%
16%
20%
Biomass
Onshore Wind
Hydro
Solar - residential roofs
Solar - commercial roofs
Solar - utility scale
Municipal Solid Waste
Fuel Oil
Coal
LNG
New Propane near San Juan
Expand LNG at existing port, US fuel

Appendix B: Consolidated Recommendations from Long-term Plans

All plans issued to date, explicitly mentioned the need for transmission and distribution infrastructure improvements. Plans consistently recommended hardening transmission and distribution systems for increased storm resilience, with recommendations ranging from Rocky Mountain Institute's (RMI) specific proposed step of updating grid ties to New York Power Authority's (NYPA) wide-scale recommendation to relocate substations and upgrade relay protection to enable DER and microgrid integration. DOE proposed repairing where needed and replacing to hardened specifications. NYPA, Congressional Research Service (CRS), and FEMA all recommended relocating lines or reducing distribution line lengths to reduce their risk from weather events.

Financial Oversight and Management Board (FOMB), PREPA, DOE, NYPA, and CRS all recommended increasing the grid's "smart" capabilities, including automation and scalability. These plans also recommended updating the control systems used across the grid, noting the importance of this step, in light of each plan's suggestion to add renewable generation sources that introduce variability into energy supply. NYPA specifically recommended two-way communication systems such as ADMS and DERMS, which they noted are key for demand matching. DOE, CRS, and FOMB suggested adding more robust sensing and control capabilities to better locate and respond to issues when they arise. DOE specifically called out the need for these new communication and controls systems to be cybersecure, as well as the need to identify and mitigate other risks inherent to information and communications technologies.

Multiple plans made recommendations for the overall Puerto Rican electricity system to be designed and operated for enhanced resilience through the incorporation of new technologies, including behind-the-meter distributed generation and other energy resources as well as technologies that could reduce or adjust loads such as energy efficiency. The PREPA, FOMB, and RMI plans also recommended re-thinking system architecture, including moving generation assets to be closer to load as well as building regionalized grids. The DOE, NYPA, and CRS plans all discussed the incorporation of microgrids and energy storage and the strategic use of DERs to help balance loads. DOE also proposed additional interconnection arrangements between municipalities to enhance community resilience, while CRS proposed the potential development of interconnections with the U.S. Virgin Islands and other Caribbean islands for load balancing and to reduce the need for back-up power. Multiple plans recommended the adoption of best practices for system operations, including sound long-term planning (PREPA), practicing storm readiness (CRS), and modernizing control center facilities and adding mobile backup control centers (NYPA).

Not all plans specifically addressed the institutional or market elements of Puerto Rico's power grid, but those that did all called for some type of reform. Proposed reforms varied, but a common theme was overhauling managerial and financial arrangements to increase transparency and rationalize annual operating costs and rate structures. Federalization was recommended in the DOE and CRS reports as a means of governance, though alternatives such as municipality ownership, co-ops, and public-private partnerships were also considered. The DOE, CRS, and

RMI plans promoted strengthening the role of the independent regulator to ensure transparent, accountable, and enforceable regulation, while both the PREPA and FOMB plans promoted privatization to drive investment. The PREPA plan highlighted five key pillars that needed to be upheld by any governing structure: customer-centricity, financial viability, reliability and resilience, sustainability, and service as an economic growth engine for Puerto Rico.

Most plans recommended consumer engagement through the implementation of energy efficiency programs, the promotion of energy efficiency practices, or by providing choices for behind-the-meter efficiency. The DOE and NYPA plans also emphasized the importance of enforcing building energy codes, especially for new buildings constructed post-hurricane.

A majority of plans touched on environmental concerns, with DOE, RMI, and PREPA reports in particular noting the reduction in emissions and air pollution associated with diverse energy resources and renewable generation; the RMI plan also specifically called out the consumer benefits of lowered air pollution and CO_2 emissions. In order to be fully prepared for future events, the CRS plan recommended robust hardening of areas likely to be most impacted by worsening climate change.

Most plans proposed long-term timelines for recovery and modernization, with each of DOE, NYPA, and CRS outlining a 9-10-year schedule. The RMI and PREPA plans focused on slightly more near-term actions, while the FEMA plan prioritized immediate, disaster-response activities.

Comparison and Characterization of PR Recovery Plans as of April 30 2018							
	DOE[59]	**NYPA**[60]	**CRS**[61]	**RMI**[62]	**FEMA**[63]	**PROMESA**[64]	**PREPA**[65]
Electricity Sector Approach	Ensure standard management and oversight practices are enforced	Restoration, upgrade to best practices, harden, grid modernization	Harden infrastructure, modernize power system	Reinvestment strategy to support a more resilient, cost-effective, and sustainable grid	Restore critical, restore general population, harden, modernize	Transparent management, incentivize private investment, and develop “bias for action” to begin integrating various resources towards broad end-state	Privatization with a model for power generation and delivery that sets a global example for cost, resilience, sustainability, and customer engagement and empowerment.
Generation		Modify the size and technology of fleet, potentially reduce reserve margin for PREPA		Update location and technology of generating assets			
Fuel Mix	Move away from fuel oil and towards U.S. natural gas and renewable energy resources (wind, solar, hydro, biomass, and waste-to-energy)	Revisit the 2015 IRP to incorporate shift to natural gas, increased DERs, and hardening of existing assets	More renewable energy integration, though wind and solar potential limited. Need to consider alternatives, including hydro, fuel cells, and storage	Increase share of generation capacity from "fuel-free energy resources" (RE, EE)	Diesel generators used immediately	Less volatile mix (divest diesel, bunker and coal), 50% renewables by 2040	Less carbon intensive, increasingly take advantage of renewable power generation alternatives and integrate emerging technologies

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[59] B. Parks et al., Catalyzing an Innovative, Resilient, and Secure Electric Sector for Puerto Rico, U.S. Department of Energy, November 2017.

[60] New York Power Authority, et al., Build Back Better: Reimagining and Strengthening the Power Grid of Puerto Rico, December 2017, New York Power Authority, https://www.governor.ny.gov/sites/governor.ny.gov/files/atoms/files/PRERWG_Report_PR_Grid_Resiliency_Report.pdf.

[61] Richard J Campbell, Corrie E. Clark, and D. Andrew Austin, Repair or Rebuild: Options for Electric Power in Puerto Rico, Congressional Research Service, November 16, 2017, https://fas.org/sgp/crs/row/R45023.pdf.

[62] Isaac Toussi and Mark Dyson, The Role of Renewable and Distributed Energy in a Resilient and Cost-Effective Energy Future, Rocky Mountain Institute, December 2017, https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2017/12/Insight_Brief_Puerto_Rico_Resilient_CostEffective_Energy.pdf.

[63] “Power Restoration Project,” Presentation, Federal Emergency Management Agency, December 2017.

[64] Noel Zamot, “Puerto Rico’s Future Energy Utility,” Presentation, Federal Oversight and Management Board for Puerto Rico, December 2017.

[65] Governor of Puerto Rico, “PREPA's Governing Board Adopts a New Vision for the Transformation Announced by the Governor of Puerto Rico,” Press release, Puerto Rico Electric Power Authority, February 1, 2018.

Comparison and Characterization of PR Recovery Plans as of April 30 2018							
	DOE[59]	**NYPA**[60]	**CRS**[61]	**RMI**[62]	**FEMA**[63]	**PROMESA**[64]	**PREPA**[65]
DERs	Distributed generation from renewable resources, diesel generators, energy storage technologies, and demand response	DERs for resiliency (microgrids); DERs for cost savings (energy efficiency, demand response)	Existing wind and solar integration goals, require grid modernization. Potential interconnection with USVI/other Caribbean for balancing		Utilized for hardening operations, improving resiliency	Generation closer to demand; Grid to serve as an energy platform that allows entry of innovative technology and solutions	Customers empowered to allow behind-the-meter distributed generation; grid designed to take advantage of distributed energy resources
T&D		"Build Back Better": modernize via smart grid investments, including increased automation				Scalable grid architecture (future proofing)	
Transmission Infrastructure	Repair where needed, replace to hardened specifications at minimum, consider and pursue grid modernization alternatives where possible	Harden T&D infrastructure for greater storm resiliency, including relocation of substations and upgrading relay protection to enable DER/microgrid integration	Harden and modernize where feasible	Update grid ties	Harden generation assets;	New Energy Grid Infrastructure (Smart Grid, Micro Grids, etc.)	
Distribution Infrastructure		Relocate lines and upgrade for more automation	Relocate/construct new lines; elevate substations		Reduce distribution line lengths		

Comparison and Characterization of PR Recovery Plans as of April 30 2018							
	DOE[59]	**NYPA[60]**	**CRS[61]**	**RMI[62]**	**FEMA[63]**	**PROMESA[64]**	**PREPA[65]**
Communications & Controls	Deploy novel "sensor-enabled" monitoring and control systems; identify and mitigate cybersecurity risks inherent to advanced ICT	Upgrade to modern control systems (ADMS, DERMS, two-way communications)	Integrate smart sensors and control technology to locate problems rapidly			Advanced control systems (demand matching, etc.)	
System Design	Strategic use of local DERs, managed through microgrids or other interconnection arrangements, to help reduce the severity of power outage impacts and enhance community resilience	Incorporate hazard resilience, including RE and DER including energy storage and microgrids to improve resilience	Incorporate energy storage to help with RE demand balancing, improving resilience	Opportunity to move generation assets closer to load (e.g., diesel/solar, PV/storage) and improve reliability and resilience		Generation closer to demand, including in the north; regional / municipal minigrids, including interconnected municipal mini-grids to allow wheeling between municipalities; an energy platform that allows entry of innovative technology and solutions	Architecture (distributed vs regionalized vs centralized) is intentionally made to balance reliability/resilience and cost objectives
System Operations		Modernize control center facilities (hardware and software), add mobile backup control center	Practice storm-readiness (planning, training, fuel level maintenance)	Remote system deployment faster than transmission line extensions			Operational excellence and sound long-term planning reduce cost to serve.

Comparison and Characterization of PR Recovery Plans as of April 30 2018							
	DOE[59]	**NYPA**[60]	**CRS**[61]	**RMI**[62]	**FEMA**[63]	**PROMESA**[64]	**PREPA**[65]
Governance	Federalization, new management and financial structures, and a new independent grid operator		Consider alternative governance such as municipals, co-ops, public private partnership, or federalization	Strengthen the role of the independent regulator		Transparent, accountable and enforceable regulation via independent regulatory agency	5 key pillars: customer-centric; financial viability; reliable and resilient; model of sustainability; economic growth engine for Puerto Rico
Market Structure	Defined consumer interactions and inputs, including transparent rates structures and the requirement that municipalities pay for electricity		Dependent on governance structure	Update load growth forecasts and accounting for services provided by DERs for new capital investments		Privatization (From projects to IPPs to IOUs) to drive significant private investment	Privatization
End-Use Efficiency	Right-size the capital investment needed for grid modernization by updating and enforcing building energy codes and implementing other energy efficiency programs	Rebuilt buildings meet or exceed code (IECC 2009) or above	Promote energy efficiency to consumers	RE and EE lower local air pollution and reduce carbon dioxide emissions			Provide consumer choice for behind-the-meter efficiency

Comparison and Characterization of PR Recovery Plans as of April 30 2018							
	DOE[59]	**NYPA[60]**	**CRS[61]**	**RMI[62]**	**FEMA[63]**	**PROMESA[64]**	**PREPA[65]**
Environment	Environmental law requirements limit cost-effectiveness of existing fossil-fuel generation assets, reinforcing attractiveness of renewable generation and DERs		Climate change requiring more robust hardening efforts for future preparedness	RE and EE lower local air pollution and reduce carbon dioxide emissions, potential opportunity for cost-avoidance compared to existing operating existing assets			Diversify energy resources and reduce carbon intensity of power sector (primary and backup generation)
Timeline	10 years	9 years	10 years	Near and long term	Immediate		Short-, medium-, and long-term

Appendix C: DOE Recommended Actions

These recommendations are provided for the purpose of informing the Governor's recovery plan. The Governor should identify the appropriate actor or agency responsible for implementation. DOE will continue to consult with relevant Federal agencies and Commonwealth stakeholders on implementing these recommendations as appropriate.

Transmission and Distribution

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.

Generation

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.

Microgrids

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.

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.

Appendix D: Microgrid Tools

Distributed Energy Resources - Customer Adoption Model (DER-CAM)

The Distributed Energy Resources Customer Adoption Model (DER-CAM) is a comprehensive decision support tool for microgrid projects. It is the most widely used model in the U.S. for determining the optimal distributed energy resource (DER) investments in the context of either buildings or multi-energy microgrids.

DER-CAM answers several important questions for decisions related to microgrids:

- ✓ What is the optimal portfolio of DER that meet the specific needs of this microgrid?
- ✓ What is the ideal installed capacity of these technologies to minimize costs?
- ✓ How should the installed capacity be operated so as to minimize the total customer energy bill?
- ✓ Where in the microgrid should distributed energy resources be installed and how should they be operated to ensure voltage stability?
- ✓ What is the optimal DER solution that minimizes costs while ensuring resiliency targets?

- ✓ 1,572 verifiable registered users.
- ✓ 2,992 projects created by users, and 9,272 recorded sessions accessing the website.
- ✓ 10,899 job requests communicated direct to the "middleman" server.
- ✓ Based on these assumptions, a fair estimate would be that the outside world has tried to run DER-CAM about 15,000 times.

Example Applications:

• Develop feasibility studies for the majority of the 83 studies for the New York Prize Microgrid Program (the largest in the United States)

• Optimize the Stone Edge Farm Microgrid (SEM). The SEM is a mile-long power line that connects a network of electrical services and integrates various forms of distributed energy generation and storage with real time monitoring and control.

• The DOD Environmental Security Technology Certification Program (ESTCP) which involves a microgrid at Ft. Hunter Liggett.

Microgrid Design Toolkit (MDT)

Microgrid Design Toolkit (MDT) is a decision support software toolkit that aids designers in creating optimal microgrids.

Employing powerful algorithms and simulation capabilities, MDT searches the trade space of alternative microgrid designs based on user-defined objectives (e.g., cost, performance, and reliability) and produces a set of efficient microgrid solutions. MDT allows designers to investigate the simultaneous impacts of several design decisions and gain a quantitative understanding of the relationships between design objectives and trade-offs associated with alternative technological design decisions. MDT can account for grid-connected and islanded performance, power and component reliability in islanded mode, and dozens of parameters as part of the trade space search, and presents designers with an entire trade space of information from which to base final design decisions.

Without MDT, designers rely on engineering judgment and perhaps a quantitative analysis of relatively few candidate designs. MDT allows designers to explore a larger field of options and provides defensible, quantitative evidence for design decisions.

Technological Benefits:

- ✓ Provides ability to perform topology optimization
- ✓ Illuminates large trade space of design alternatives
- ✓ Provides a variety of performance, reliability, and cost-related insights for candidate microgrid designs
- ✓ Provides microgrid designers a full understanding of trade-offs associated with certain design decisions
- ✓ Provides many result views and graphs to help interpret results

Example Applications:

•The Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program

•The City of Hoboken, NJ backup power system

•The U.S. Marine Corps for Expeditionary Units & Brigades