One-Year Progress Summary Report:

Preliminary Modeling Results and High-Resolution Solar and Wind Data Sets

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Notice

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Introduction

The Puerto Rico Grid Resilience and Transitions to 100% Renewable Energy Study (PR100) is a 2-year study by the U.S. Department of Energy's (DOE's) Grid Deployment Office and six national laboratories to comprehensively analyze stakeholder-driven pathways to Puerto Rico's clean energy future.[1] In Year 1 of the study, the PR100 team rigorously modeled and analyzed scenarios that meet Puerto Rico's renewable energy targets and achieve short-term recovery goals and long-term energy resilience.

This report, which summarizes PR100 progress in Year 1, provides considerations that can inform potential funding and implementation decisions by key federal and local agencies and stakeholders. The summary report follows the publication in July 2022 of a PR100 *Six-Month Progress Update* (in English and Spanish), as well as public webinars in February 2022 to kick off the study and in July 2022 to present the 6-month update.[2] A final written report and web-based visuals will be published in late 2023. All publications and public events associated with the study will be available in Spanish and English.

Background

PR100 is funded primarily through an interagency agreement with the Federal Emergency Management Agency (FEMA), and the study is part of a larger portfolio of support for Puerto Rico energy planning, as articulated in a memorandum of understanding between DOE, the U.S. Department of Homeland Security, the U.S. Department of Housing and Urban Development (HUD), and the Commonwealth of Puerto Rico.

The PR100 study relies on extensive input to ensure the project team is providing effective and relevant technical assistance. DOE has convened a steering committee of federal recovery funders (e.g., FEMA, HUD) and local government implementers (e.g., Puerto Rico Electric Power Authority (PREPA), LUMA Energy, the Puerto Rico Energy Bureau (PREB), the Puerto Rico Department of Economic Development and Commerce (DDEC) Energy Policy Program, the Puerto Rico Department of Housing, and the Central Office for Recovery, Reconstruction, and Resiliency (COR3)) to help guide DOE's portfolio of technical assistance projects.

Additionally, PR100 involves an advisory group of nearly 100 individuals from 60 organizations representing the public, private, and nonprofit sectors, including academic, community-based, and environmental organizations; retail and manufacturing groups; and financial, legal, and other areas of expertise; see Appendix A for a list of Puerto Rico Energy Recovery and Resilience Advisory Group (Advisory Group) members and their affiliations. In this way, PR100 will reflect and respond to a breadth of stakeholder perspectives and priorities and will support progress toward energy justice for all Puerto Ricans.

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[1] The PR100 study is led by the National Renewable Energy Laboratory (NREL) with support from Argonne National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories.

[2] Access all project publications and past events from the Puerto Rico Energy Recovery and Resilience (DOE) and Multilab Energy Planning Support for Puerto Rico (NREL) web pages.

Summary of First-Year Progress

This Year 1 summary report provides initial modeling and analysis results and describes high-resolution wind and solar resource data sets for Puerto Rico, along with other publicly available data sets, developed in the first year of PR100.

A major accomplishment to date that will frame the remainder of the study is our development of feasible scenarios[3] for Puerto Rico to reach its goals of 100% renewable energy by 2050, with interim targets of 40% by 2025, 60% by 2040, the phaseout of coal-fired generation by 2028, and a 30% improvement in energy efficiency by 2040, as codified in the Puerto Rico Energy Public Policy Act of 2019 (Act 17).

We developed four initial scenarios for analysis following extensive engagement with Advisory Group members, who expressed interest in studying different levels and applications of distributed energy resource deployment, such as rooftop solar and batteries. Therefore, the primary distinctions between our four scenarios relate to the required amount and location of distributed energy deployment, as shown in Table 1. For all modeled scenarios, any remaining load not met by distributed resources will be met by the economic deployment of utility-scale resources.

Table 1. Four Initial Scenario Definitions

Scenario Number	Scenario Name	Description	Short Name (based on distributed energy resource adoption)
1	Economic adoption of distributed energy resources	Distributed energy resource adoption is based on financial savings to building owners.	Economic
2	Deployment of distributed energy resources for critical services	Installation of distributed energy resources is prioritized beyond Scenario 1 for critical services like hospitals, fire stations, and grocery stores.	Critical
3	Equitable deployment of distributed energy resources	Installation of distributed energy resources is prioritized beyond Scenario 2 for remote and low- and moderate-income households.	Equitable
4	Maximum (prescribed) deployment of distributed energy resources	Distributed energy resources are installed on all suitable rooftops.	Maximum

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[3] We use the term “feasible scenario” to mean a scenario for which there are no possible or known economic or engineering reasons for disqualifying the scenario from continued consideration.

For each of these scenarios, we varied parameters that might impact distributed energy deployment. We included two variations each for electrical load and land availability, resulting in a total of 16 possible model combinations (see Appendix B). Once we defined the scenarios, we conducted initial modeling of distributed energy resource adoption and system buildout through 2050.

All scenarios rely on a significant increase in rooftop solar photovoltaics (PV) and associated battery energy storage systems. Preliminary modeling shows that Scenario 1 requires a 6x increase in distributed solar and storage systems between 2022 and 2050, while Scenario 4 shows a 16x increase. This "maximum" scenario would be achieved by increasing the current rate of deployment by approximately 4x. Across all scenarios, distributed PV capacity would range from 3 GW to 7 GW.

Based on these results from our four initial scenario definitions, we identified three feasible scenarios for refined modeling and analysis in Year 2. We found that Scenarios 1 and 2 resulted in approximately the same level of distributed energy resource adoption because critical services are included in the approach that delivers maximum financial savings to building owners.[4] These two scenarios will be combined, as shown in Figure 1, in refined modeling and analysis of three feasible scenarios in Year 2.

Scenario 1 & 2. Economic & Critical

Distributed energy resource adoption is based on financial savings to building owners as well as critical services like hospitals, fire stations, and grocery stores.

Scenario 3. Equitable

Installation of distributed energy resources for remote and low- and moderate-income households, beyond the economic adoption seen in Scenario 1 & 2.

Scenario 4. Maximum

Distributed solar and storage is added to all suitable rooftops.

Figure 1.The three feasible scenarios for analysis in PR100. ***Graphics by NREL.***

Scenarios 1 and 2 are merged because the economic scenario is inclusive of the critical scenario.

Initial Findings

In this summary report, we present a selection of preliminary findings from study activities to date. In Year 2, we will continue to refine and iterate on these modeling activities, and we will perform additional analyses to understand how each scenario impacts transmission, distribution, emissions, energy justice, and resilience. Our analysis relies on a set of assumptions and uncertainties about Puerto Rico's energy landscape, which are described in Appendix C and will be refined in Year 2. Below we present and discuss high-level findings of Year 1.

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[4] Six types of critical facilities were included in this analysis and in transmission resilience modeling: seaports, water treatment plants, airports, hospitals, police and fire stations, and security shelters. Note that in Year 2, we intend to review and align definitions of critical facilities, and to consider the one used in the ongoing social burden analysis.

Renewable Energy Potential in Puerto Rico

One of the most important questions for reaching 100% renewable energy is whether Puerto Rico's renewable resource potential is sufficient—is there enough sun, wind, hydro, and other sources of renewable energy? To answer this question, we conducted assessments of the technical potential of a variety of renewable energy resources in Puerto Rico,[5] and we generated high-resolution, multiyear resource data sets for land-based wind, offshore wind, and solar, as well as wind and solar forecast data. We found that *the renewable technical resource in Puerto Rico significantly exceeds the current and projected total annual loads through 2050*.

We include in our modeling only generation technologies that meet the definition of renewable energy in the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act (Act 82 of 2010, as amended). Consistent with this policy, technologies considered in PR100 include solar energy, wind energy, hydropower, marine and hydrokinetic renewable energy, ocean thermal energy, and combustion of biofuel derived solely from renewable biomass.

The solar resource data from 1998–2021 are publicly available at https://nsrdb.nrel.gov, and the wind resource data from 2000–2021 are publicly available at https://www.nrel.gov/grid/wind-toolkit.html. Wind and solar resource forecast data generated during an earlier phase of the project are also available on request. Marine, hydropower, and pumped storage hydropower assessments are in progress, and data sets will be made publicly available once they are complete. Other resources will be considered (either for local production or the cost of import) as they emerge in the study.

Land Availability

Throughout discussions with the Advisory Group, one of many members' key priorities was to ensure the preservation of agricultural lands and other areas of environmental, historical, and social value. In response, we integrated this feedback into land exclusions for our land-based wind and utility-scale solar PV assessments. Land exclusions for both PV and wind energy projects include waterbodies, rivers, roads, buildings, habitat areas, protected areas, urban areas, and a contiguous area restriction.[6] Additionally, for utility-scale PV, the land must have less than a 5% slope, while for wind, the land must have less than a 13% slope. For the protected and agricultural areas, we used data from the Puerto Rico Planning Board (PRPB 2015).

Once all the exclusions are applied, the results show areas assumed to be suitable for utility-scale PV and wind energy development. Figure 2 shows land available for utility-scale solar PV development with agricultural lands excluded (left) and included (right); white space indicates excluded area and green is developable area.

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[5] The resource data are used to determine the renewable energy technical potential of a given technology to define its achievable energy generation given system performance, topographic, environmental, and land use constraints. Technical potential is the total amount of a resource that could be deployed; it is only limited by physical constraints (e.g., rooftop area, available land area, and technical efficiency). The benefit of assessing technical potential is that it establishes an upper boundary estimate of development potential (Lopez et al. 2012).

[6] We used a minimum contiguous area of 0.3 km^2 based on current land use assumptions.

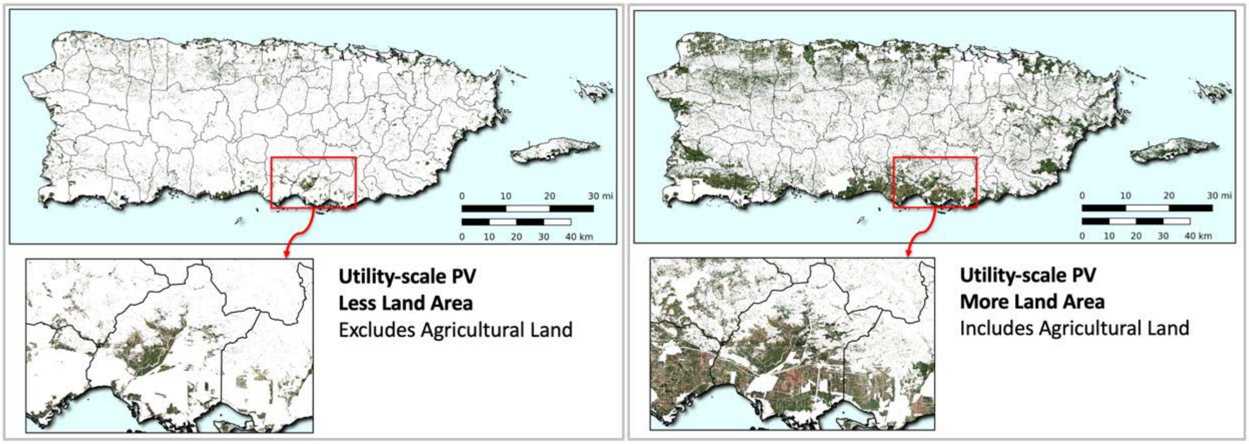

Figure 2. Land available for utility-scale solar PV development with agricultural lands excluded (left) and included (right), with detailed insets. ***Graphics by NREL.***

Legend: white = excluded area; green = developable area

We also developed exclusion maps for land-based wind deployment that are inclusive and exclusive of agricultural land (Figure 3), and we conducted analysis on marine exclusions for use with offshore wind technology. Excluded from consideration for offshore wind deployment are protected areas, danger zones and restricted areas, submarine cables, ocean disposal sites, and unexploded ordinance areas (Figure 4).

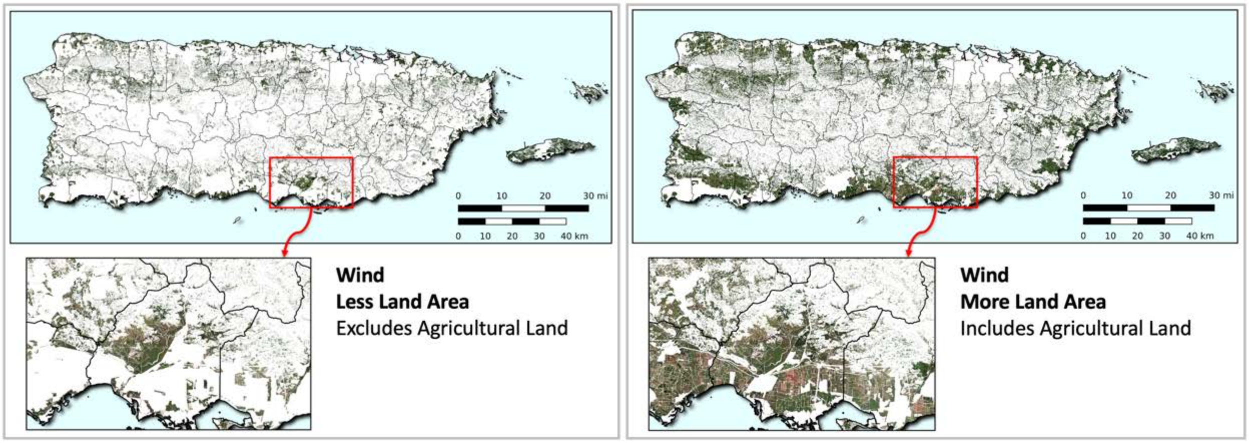

Figure 3. Land available for utility-scale, land-based wind development with agricultural lands excluded (left) and included (right), with detailed insets. ***Graphics by NREL.***

Legend: white = excluded area; green = developable area

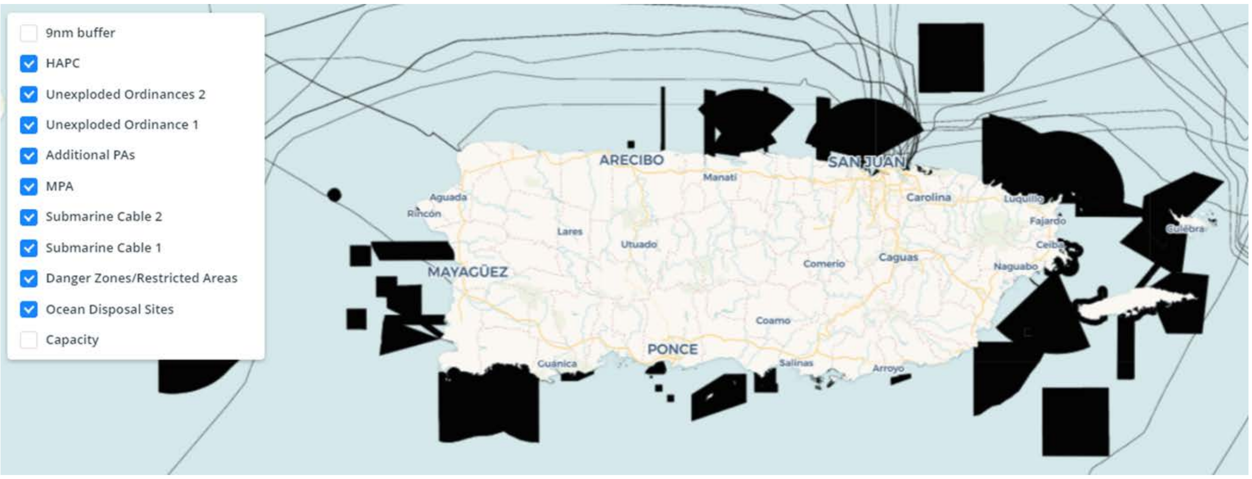

Figure 4. Exclusions for offshore wind technology. ***Graphic by NREL.***

HAPC = habitat area of particular concern; PA = protected area; MPA = marine protected area

Based on our initial modeling of renewable energy potential and available land area, one important finding is that *if only utility-scale solar and land-based wind resources were deployed, Puerto Rico could not meet its renewable capacity targets given the amount of land available when agricultural land is excluded*. Therefore, *identifying alternate system configurations for deployment on smaller specialized areas could increase developable area* for moderate- to large-scale renewable energy projects. For example, deploying community solar, floating PV, or agrivoltaics at locations such as airports, brownfields, or industrial areas could increase the amount of utility-scale potential.

Also, we estimated the levelized cost of electricity for locations that are suitable for renewable energy, which is a key driver of the economics of renewable energy options, and we found that *implementation of new utility-scale solar, land-based wind, and storage is more cost effective than maintaining existing generation*—based on operating costs alone, it is already more cost effective by 2025.

Electric Load

Another important consideration for Puerto Rico’s future power system is the electric load. We modeled projected changes in end-use load parameters such as population size, manufacturing employment, gross domestic product, and climate. Next, we considered load impacts from electric vehicle adoption and energy efficiency. We found that when these load factors are combined, the *net load, or combination of projected load increases and decreases, is likely to decline through 2050*. Additionally, we include a scenario variation in which load increases to explore a range of load uncertainty into the future. Subsequently, when distributed generation capacity is built out, the final energy requirement that the central grid system must meet decreases even further.

Adoption of Distributed Energy Resources

We modeled distributed energy resource adoption by considering a wide range of social, technological, geographical, and economic predictors. Our model accounts for customer demand

and adoption across demographic types, and for changing policies[7] and costs that affect that adoption. Our most pronounced finding is that *adoption of distributed solar and storage is projected to increase considerably in all scenarios*, with around 60% of residential customers adopting these technologies by 2050 in Scenario 1, which is a significant increase from current deployment.

Note that this model looks at the economics of electricity rates and payback periods for residential, commercial, and industrial customers, and their adoption is a reflection of those economics for Scenario 1. The model does not incorporate the distribution grid modifications needed to increase the hosting capacity of the grid to support those systems nor does it model other external factors that might limit deployment (e.g., supply chain issues, workforce limits, etc.). Analysis of the distribution system impacts relative to increased adoption of distributed energy resources, as well as implications for resilience, will be conducted in Year 2.

Capacity Expansion, Production Cost, and Resource Adequacy

We conducted capacity expansion modeling to find the lowest-cost system for each scenario while meeting load, legislative requirements like Puerto Rico's Act 17, and scheduled plans for resource procurement and retirement. We then checked the results of these optimizations for adequacy of system resources to sustain unplanned outages of generators consistent with North American Electric Reliability Corporation (NERC) standards or similar. With the current set of assumptions and uncertainties, which will continue to be refined in Year 2, we found that *significant additional generation capacity is needed immediately*—on the scale of hundreds of megawatts—to maintain reliability standards. Indeed, even if all six tranches of PREPA's Renewable Energy Generation and Energy Storage Resource Procurement Plan (PREB 2022) are successful, additional generation capacity would still be needed to meet NERC standards.

Bulk Power System Reliability and Resilience

Our resilience analyses of Puerto Rico's future power system expansions in Year 1 focused on simulations of hurricane-related infrastructure damage and simulation of system recovery. The locations and capacities of new renewable generation were determined from capacity expansion modeling described in the previous section.

Our analysis shows that the expanded scenario is more resilient and better able to restore 90% of the system load, according to a restoration metric simulated in 100 hurricane simulations. Under these simulations, which focused only on the bulk power system in Year 1 and will expand to the distribution grid in Year 2, we found that *the modeled future system with smaller renewable resources spread across the bulk electric grid tends to recover power faster than the current system*, which consists of fewer and larger power plants.

In all simulations, *the last loads recovered tend to be in mountainous regions* and where a hurricane makes landfall. We also simulated how advanced power inverters—which are

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[7] The impacts of incentives in the Inflation Reduction Act of 2022 will be considered in Year 2. See the Uncertainties section for additional discussion.

controllable components of distributed energy resources—can aid in recovery, finding that *black-start capabilities of inverters can significantly reduce recovery time*, by up to 3×.

Energy Justice

A key focus of the PR100 study is to chart possible pathways toward a renewable energy future for Puerto Rico that are grounded in principles and practices of energy justice. We partnered with the Hispanic Federation in Puerto Rico to involve an inclusive group of stakeholders, we adhered to just practices for energy planning, and we performed a literature review on key principles of energy justice. When we asked Advisory Group members about their visions for a just energy transition for Puerto Rico, themes that emerged were:

- Energy access, affordability, reliability, and resilience
- Community participation
- Economic and workforce development
- Siting and land use
- Environmental and health effects
- Public sector implementation.

In Year 2, we will continue to conduct a social burden analysis that measures the effort an individual expends to access critical services such as food, water, medication, and communications either during a grid outage, as is typical after a natural disaster or other emergency event, or normal day-to-day (blue-sky) operations. Findings from our initial analysis indicate Puerto Rico faces *inequitable access to critical services across geographic areas during normal grid operations*.

We are also performing a climate risk assessment, continuing in Year 2, to (1) evaluate the risks faced by communities and infrastructure that are vulnerable to the impacts of climate-driven hazards and (2) project how future climate conditions could result in or exacerbate inequities if these risks are not accounted for during infrastructure upgrades. We developed a data set of future climate conditions that could affect the operation of critical infrastructure. These climate projections illustrate the potential change by mid-century using the business-as-usual scenario of greenhouse gas emissions. *Initial climate risk assessment results illustrate a temperature increase of 1.5°–2.0°C, particularly over the coastal region and in metropolitan areas, and a precipitation decrease of up to 20% across the entire archipelago by 2055*.

In Year 2, we will leverage this downscaled climate data set to map the hazard landscape across Puerto Rico, including projected changes in temperature, precipitation, and sea-level rise. This hazard mapping will be used to identify and assess potential vulnerabilities to energy infrastructure and the communities they support, particularly those located along coastal areas.

Key Considerations

In the near term, as stakeholders are actively making plans and investment decisions to improve Puerto Rico's energy system, including the 2024 Integrated Resource Plan, we provide the following considerations derived from our work to date:

Accelerated Deployment

1. Due to the building-level resilience that rooftop PV and storage provides, accelerating deployment of rooftop PV and storage is likely to increase reliability and resilience locally.
2. Because aggregators and virtual power plants[8] allow a grid operator to dispatch battery storage to support the overall system, prioritizing the deployment of more virtual power plants would support greater reliability and provide resilience across the system.
3. Accelerated deployment of utility-scale solar and wind energy will reduce near-term system investment and operational costs because new utility-scale solar and wind energy is less costly to build than to operate existing fossil-fueled capacity, given current and projected fuel costs.
4. Deployment of solar and wind renewable energy technologies and storage has the potential to provide or contribute to economic, resource adequacy, system stability, and resilience benefits.

Investment Planning

5. Preliminary modeling results indicate rapid deployment of PV and storage projects approved in Tranche 1 of PREPA's 2019 integrated resource plan (IRP) procurement plan (PREB 2022) would begin to address, but not completely alleviate, the immediate need for additional capacity on the system. Additional capacity would be needed, but deployment of these specific projects are supported by our long-term modeling.
6. Preliminary modeling results indicate the planned tranches are insufficient to reach 40% renewable energy generation by 2025, assuming utility-scale PV or similar, so a review of the current procurement pipeline may be warranted. Assuming a typical capacity factor of 20% for one-axis tracking utility-scale PV (actual capacity factors will vary around Puerto Rico), the planned tranches reach about 36% of renewable energy generation; however, the bulk of the tranches would also need to be constructed within 3 years from the date of this report, which would be very rapid deployment.
7. Defining tranches in units of generation (MWh) rather than capacity (MW) would provide greater clarity in the procurement process. Capacity factors across renewable energy technologies in the tranches vary from 20% to 90%, illustrating that capacity does not clearly define the generation. Expressing proposals as both megawatts (MW) and megawatt-hours (MWh) is needed but setting the goal in MWh would be more technology agnostic.
8. Investment decisions informed by long-term system planning are critical because modeling indicates rapid deployment now of both fossil fuel and renewable technologies could lead to significant stranded assets if distributed generation is adopted more slowly but eventually dominates the energy supply.

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[8] Networks of distributed energy resources, often owned independently, that can be accessed and dispatched by a central entity.

Grid Upgrades and Storage

9. In the near term (next 5–15 years), the transmission system can accommodate the projected growth in renewables, but in the long term, transmission upgrades are needed to accommodate additional utility-scale generation resources on the bulk power system, especially for offshore wind.
10. Distribution feeder upgrades are needed to accommodate anticipated growth in distributed energy production, distributed storage, and electric vehicle adoption, and to enable increased power flow on certain lines, additional variable voltage profiles, and more complex control schemes.
11. Deployment of utility-scale battery energy storage in the very near term can support bulk power system resilience to extreme weather events, as well as day-to-day reliability, if properly sized and fitted with black-start capability.
12. Improved system protection would provide better stability during severe faults. Inverter controls, such as batteries with grid-forming inverters, could significantly improve system reliability immediately. Continued improvements to minimum technical requirements, particularly for grid-forming inverter requirements and black-start capabilities for energy storage, would be beneficial.

Grid Modernization

13. Implementation of real-time high-resolution grid measurement systems can facilitate model validation and improve reliability in the current system.
14. Enhancing the fidelity of generator governor models can help provide critical situational awareness and increase system stability.
15. High-fidelity models, such as those in electromagnetic simulations software, can help power grid planners gain confidence in simulating scenarios with inverter-based resources like renewables and battery energy storage systems.

Energy Justice

16. Energy justice involves prioritizing access to affordable, resilient electricity and high-quality energy sector jobs and economic opportunities for the most vulnerable utility customers, such as rural, remote, low-income, and people with disabilities.
17. An important way to work toward energy justice is by developing a process to ensure broad and meaningful stakeholder participation in the planning, decision-making, and implementation of the pathway to 100% renewable energy.

Next Steps

In Year 2, we will continue to analyze the impact of the modeled scenarios on the transmission system, including its resilience to future disruptions. We will study impacts to the distribution system from introducing high levels of distributed energy resources to the grid, and our work will include related considerations such as the use of microgrids for improved resilience. Results of these analyses will be fed back to capacity expansion and production cost models to iterate and refine investments and operational projections. Economic impact analyses will yield potential effects on retail rates, including energy justice metrics such as energy burden, which is the percentage of income that various income levels may pay for electricity under each scenario.

We have partnered with researchers at the University of Puerto Rico Mayagüez. In the next year, they will contribute to the study by (1) providing technical review and consultation on scenario definition, energy justice and resilience metrics and analyses, and (2) conducting a survey of existing residential PV systems to collect data and experiences. We will conduct a PR100 road show to engage with communities throughout Puerto Rico about the study and request input on considerations for implementers and energy justice priorities. Analysis results will be evaluated through an energy justice lens to understand benefits and burdens to various stakeholder groups across scenarios.

Glossary

Term	Definition
Act 17	The Puerto Rico Energy Public Policy Act (Act 17), passed in 2019, set a goal for the territory to transition away from imported fossil fuels and instead meet its electricity needs with 100% renewable energy by 2050, 60% by 2040, and 40% by 2025.
Capacity expansion modeling	“Capacity expansion modeling simulates and optimizes generation and transmission capacity costs given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation” (NREL n.d.).
Capacity factor	“The ratio of the electrical energy produced by a generating unit for the period of time considered to the electrical energy that could have been produced at continuous full power operation during the same period” (EIA n.d.).
Electric load	An end-use device or customer that receives power from the electric system.
Electricity demand	“The rate at which energy is delivered to loads and scheduling points by generation, transmission, and distribution facilities, measured in kilowatts (kW)” (EIA n.d.).
Feasible scenario	A scenario by which Puerto Rico can reach 100% renewable energy by 2050 that is helpful to the ongoing conversation about the future and for which economic or engineering reasons to discount the scenario are not possible or known.
Integrated resource plan	An assessment of the future electric needs and plan to meet those needs. Assesses demand side (e.g., conservation and energy efficiency) and supply side (e.g., generation/power plants and transmission lines) resources in recommending how best to meet future electric energy needs.
Levelized cost of electricity (or energy)	A measure of the average net present cost of electricity generation for a generator over its lifetime. It is used for investment planning and to compare different methods of electricity generation on a consistent basis.
Resilience	“The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions to the power sector through adaptable and holistic planning and technical solutions” (Resilient Energy Platform n.d.).

Term	**Definition**
Resource adequacy	A regulatory construct developed to ensure the power system has enough resources to meet electric demands under all reasonably likely conditions.
Tranche	A unit of measure for a portion of the total anticipated renewables requested to be deployed. Puerto Rico has six tranches of renewable procurement planned, and it just issued Tranche 2.

References

Denholm, Paul, Wesley Cole, A. Will Frazier, Kara Podkaminer, and Nate Blair. 2021. *The Challenge of Defining Long-Duration Energy Storage*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A40-80583. https://www.nrel.gov/docs/fy22osti/80583.pdf.

EIA (U.S. Energy Information Administration). n.d. "Glossary." Accessed December 9, 2022. https://www.eia.gov/tools/glossary/.

Gonzalez, Gloria. 2022. "Puerto Rico Grid Funding in Omnibus Falls Short of Biden, Legislator Requests." *Politico Pro*. Accessed January 12, 2023. https://subscriber.politicopro.com/article/2022/12/puerto-rico-grid-funding-in-omnibus-falls-short-of-biden-request-00074792

Lopez, Anthony, Billy Roberts, Donna Heimiller, Nate Blair, and Gian Porro. 2012. *U.S. Renewable Energy Technical Potentials: A GIS-Based Analysis*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-51946. https://www.nrel.gov/docs/fy12osti/51946.pdf.

NREL (National Renewable Energy Laboratory). n.d. "Engage Energy Modeling Tool." Accessed December 9, 2022. https://www.nrel.gov/state-local-tribal/engage-energy-modeling-tool.html.

PREB (Puerto Rico Energy Bureau). 2022. *NEPR-MI-2020-0012 Renewable Energy Generation and Energy Storage Resource Procurement Plan: First Tranche Projects for Phase III Contract Negotiation and Final Interconnection Plan Approvals*. https://energia.pr.gov/wp-content/uploads/sites/7/2022/09/20220901-MI20200012-Resolution-and-Order.pdf

PRPB (Puerto Rico Planning Board). 2015. *Puerto Rico Land Use Plan*. U.S. Geological Survey. https://www.sciencebase.gov/catalog/item/576bfe89e4b07657d1a26ee5.

Resilient Energy Platform. n.d. "Glossary." Accessed December 9, 2022. https://resilient-energy.org/about/glossary#power-sector-resilience.

Bibliography

Ascari, Matthew, Howard P. Hanson, Lynn Rauchenstein, James Van Zwieten, Desikan Bharathan, Donna Heimiller, et al. 2012. *Ocean Thermal Extractable Energy Visualization: Final Technical Report*. Lockheed Martin Mission Systems & Sensors (MS2). DE-EE0002664. https://www.energy.gov/sites/default/files/2013/12/f5/1055457.pdf.

Baker, Shalanda, Subin DeVar, and Shiva Prakash. 2019. *The Energy Justice Workbook.* Initiative for Energy Justice. https://iejusa.org/wp-content/uploads/2019/12/The-Energy-Justice-Workbook-2019-web.pdf.

Chestney, Nina. 2022. "High Gas Prices Spur Green Hydrogen Investment: Report." *Reuters*. October 20, 2022. https://www.reuters.com/business/energy/high-gas-prices-spur-green-hydrogen-investment-report-2022-10-19/.

DOE (U.S. Department of Energy). 2022. "DOE Selects First-Ever Director of Puerto Rico Grid Modernization and Recovery Team." U.S. Department of Energy. November 2, 2022. https://www.energy.gov/articles/doe-selects-first-ever-director-puerto-rico-grid-modernization-and-recovery-team.

Duffy, Patrick, Gabriel R. Zuckerman, Travis Williams, Alicia Key, Luis A. Martínez-Tossas, Owen Roberts, Nina Choquette, et al. 2022. *Wind Energy Costs in Puerto Rico Through 2035*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-83434. https://www.nrel.gov/docs/fy22osti/83434.pdf.

EIA (U.S. Energy Information Administration). 2022a. "Puerto Rico: Territory Profile and Energy Estimates." November 17, 2022. https://www.eia.gov/state/data.php?sid=RQ.

———. 2022b. "Hawaii State Profile and Energy Estimates." December 27, 2022. https://www.eia.gov/state/data.php?sid=HI#Prices.

Esmail, Laura, Emily Moore, and Alison Rein. 2015. "Evaluating Patient and Stakeholder Engagement in Research: Moving from Theory to Practice." *Journal of Comparative Effectiveness Research* 4(2): 133–145. https://doi.org/10.2217/cer.14.79.

Finley-Brook, Mary, and Erica L. Holloman. 2016. "Empowering Energy Justice." *International Journal of Environmental Research and Public Health* 13(9): 926. https://doi.org/10.3390/ijerph13090926.

FOMB (Financial and Oversight Management Board for Puerto Rico). 2022. 2022 Certified Fiscal Plan for the Puerto Rico Electric Power Authority. https://drive.google.com/file/d/1f6VcpY8sWmshvshWLNlJn52LFAvLABgk/view

———. 2022. 2022 Fiscal Plan for Puerto Rico: Restoring Growth and Prosperity. https://drive.google.com/file/d/1STrf0ksj1Sqc54UkABGcjyrbIZvc_Jem/view

Goodman, Melody S., Nicole Ackermann, Deborah J. Bowen, and Vetta Thompson. 2019. "Content Validation of a Quantitative Stakeholder Engagement Measure." *Journal of Community Psychology* 47(8): 1937–1951. https://doi.org/10.1002/jcop.22239.

Heffron, Raphael J., and Darren McCauley. 2017. "The Concept of Energy Justice Across the Disciplines." *Energy Policy* 105 (June): 658–67. https://doi.org/10.1016/j.enpol.2017.03.018.

Jeffers, Robert F., Michael J. Baca, Amanda M. Wachtel, Sean DeRosa, Andrea Staid, William Fogleman, Alexander Outkin, and Frank Currie. 2018. *Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico*. United States. https://doi.org/10.2172/1481633.

Jenkins, Kirsten, Darren McCauley, Raphael Heffron, Hannes Stephan, and Robert Rehner. 2016. "Energy Justice: A Conceptual Review." *Energy Research & Social Science* 11 (January): 174–82. https://doi.org/10.1016/j.erss.2015.10.004.

Kilcher, Levi, Michelle Fogarty, and Michael Lawson. 2021. *Marine Energy in the United States: An Overview of Opportunities*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5700-78773. https://www.nrel.gov/docs/fy21osti/78773.pdf.

Kishore, Nishant, Domingo Marqués, Ayesha Mahmud, Mathew V. Kiang, Irmary Rodriguez, Arlan Fuller, Peggy Ebner, Cecilia Sorensen, et al. 2018. "Mortality in Puerto Rico after Hurricane Maria." *The New England Journal of Medicine* 379:162–170. https://www.nejm.org/doi/full/10.1056/nejmsa1803972.

Lee, Joohee, and John Byrne. 2019. "Expanding the Conceptual and Analytical Basis of Energy Justice: Beyond the Three-Tenet Framework." *Frontiers in Energy Research* 7. https://www.frontiersin.org/articles/10.3389/fenrg.2019.00099 .

LUMA. 2022. Hurricane Fiona Response and Restoration Event Summary. December 9, 2022. https://lumapr.com/hurricane-fiona-response-and-restoration-event-summary/?lang=en.

———. 2022. *Generation Resource Adequacy Analysis*. San Juan, PR: LUMA Energy. https://energia.pr.gov/wp-content/uploads/sites/7/2022/09/Motion-to-Submit-Lumas-Resource-Adequacy-Study-NEPR-MI-2022-0002.pdf.

Mooney, Meghan, and Katy Waechter. 2020. *Puerto Rico Low-to-Moderate Income Rooftop PV and Solar Savings Potential*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy21osti/78756.pdf.

Piggot, Georgia. 2017. "The Influence of Social Movements on Policies that Constrain Fossil Fuel Supply." *Climate Policy* 18 (7): 942–954. https://doi.org/10.1080/14693062.2017.1394255.

PREB (Puerto Rico Energy Bureau). 2022. NEPR-MI-2020-0012. Puerto Rico Electric Power Authority Integrated Resource Plan and Subject: Submittal of Report on Resource Modified Action Plan Planning Process for Next IRP Cycle and Drat [sic] RFQ/RFP for IRP Consultant and Request for Confidential Treatment. https://energia.pr.gov/wp-content/uploads/sites/7/2022/04/20220422-MI20200012-Resolution-and-Order-Submittal.pdf.

———. n.d. Docket NEPR-MI-2020-0012 In Re: Implementation of the Puerto Rico Electric Power Authority Integrated Resource Plan and Modifies Action Plan. https://energia.pr.gov/en/dockets/?docket=nepr-mi-2020-0012

———. n.d. Docket NEPR-MI-2019-0016 In Re: Puerto Rico Electric Power Authority Interconnection Progress Reports. https://energia.pr.gov/numero_orden/nepr-mi-2019-0016/.

Puerto Rico Planning Board (PRPB). 2015. Land Classification Map, Puerto Rico Land Use Plan. https://jp.pr.gov/wp-content/uploads/2021/09/Mapa-PUT-Vigente.pdf.

Santos-Burgoa, Carlos, John Sandberg, Erick Suárez, Ann Goldman-Hawes, Scott Zeger, Alejandra Garcia-Meza, Cynthia M. Pérez, et al. 2018. "Differential and Persistent Risk of Excess Mortality from Hurricane Maria in Puerto Rico: A Time-Series Analysis." *The Lancet Planetary Health* 2 (11): e478–e488. https://doi.org/10.1016/S2542-5196(18)30209-2.

Sherman, Mya H., and James Ford. 2014. "Stakeholder Engagement in Adaptation Interventions: An Evaluation of Projects in Developing Nations." *Climate Policy* 14(3): 417–441. https://doi.org/10.1080/14693062.2014.859501.

Siemens (Siemens Industry). 2019. Puerto Rico Integrated Resource Plan 2018-2019, Draft for the Review of the Puerto Rico Energy Bureau, Prepared for Puerto Rico Electric Power Authority. https://aeepr.com/es-pr/QuienesSomos/Ley57/Plan%20Integrado%20de%20Recursos/IRP2019%20-%20Ex%201.00%20-%20Main%20Report%20%20REV2%2006072019.pdf

U.S. Congress. 2022. H.R.5376: Inflation Reduction Act of 2022. https://www.congress.gov/bill/117th-congress/house-bill/5376/text.

Appendix A. Advisory Group Members

We acknowledge the ongoing participation and valuable contributions to the PR100 study made by members of the Puerto Rico Energy Recovery and Resilience Advisory Group, which was convened by NREL to provide input into DOE's portfolio of Puerto Rico energy planning and resilience support. Members of the Advisory Group who have given us permission to publicly acknowledge their participation are listed below, along with their affiliations:

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Appendix B. Scenarios, Variations, and Combinations

Table B-1. Scenario Names and Descriptions

This table duplicate Table 1 (page 3).

Scenario Number	Scenario Name	Description	Short Name (based on distributed energy resource adoption level)
1	Economic adoption of distributed energy resources	Distributed energy resource adoption is based on financial savings to building owners.	Economic
2	Deployment of distributed energy resources for critical services	Installation of distributed energy resources is prioritized beyond Scenario 1 for critical services like hospitals, fire stations, and grocery stores.	Critical
3	Equitable deployment of distributed energy resources	Installation of distributed energy resources is prioritized beyond Scenario 2 for remote and low- and moderate-income households.	Equitable
4	Maximum deployment of distributed energy resources	Distributed energy resources are installed on all suitable rooftops.	Maximum

Table B-2. Sixteen Scenario Variations with Shortened Name, Available Land, and Load Cases

Scenario Number	Scenario Variation	Short Name	Available Land	Load Cases
1	A	Economic	Less	Mid
1	B	Economic	Less	Stress
1	C	Economic	More	Mid
1	D	Economic	More	Stress
2	A	Critical	Less	Mid
2	B	Critical	Less	Stress
2	C	Critical	More	Mid
2	D	Critical	More	Stress
3	A	Equitable	Less	Mid
3	B	Equitable	Less	Stress
3	C	Equitable	More	Mid
3	D	Equitable	More	Stress
4	A	Maximum	Less	Mid
4	B	Maximum	Less	Stress
4	C	Maximum	More	Mid
4	D	Maximum	More	Stress

Appendix C. Assumptions and Uncertainties

The following general assumptions and uncertainties underpin the PR100 study, and they are subject to revision in Year 2.

Assumptions

- All modeling and analysis in the PR100 study assumes compliance with Puerto Rico energy policy, including Act 17; definitions of renewable energy in the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act (Act 82 of 2010, as amended), and the Puerto Rico Climate Change Mitigation, Adaptation, and Resilience Act (Act 33 of 2019); and the Puerto Rico Electric Power Authority's (PREPA's) 2019 IRP (Siemens 2019).
- We include in the modeling only generation technologies that meet the definition of renewable energy in the aforementioned public policy. Consistent with Act 82 as amended, technologies considered in PR100 include solar energy, wind energy, hydropower, marine and hydrokinetic renewable energy, ocean thermal energy, and combustion of biofuel derived solely from renewable biomass. Of the other resources listed in Act 82, we are not currently including geothermal energy, renewable biomass combustion, or renewable biomass gas combustion.
- The retirement schedule for existing fossil fuel generation units will follow those established in the 2019 IRP. Revisions to existing retirement schedules will not be included in the models unless they are approved early enough in Year 2 to be incorporated within the study. Sensitivities to alternative retirement schedules can be performed. Note that PREPA has stated the planned retirements from the 2019 IRP are based on assumptions regarding renewable technology cost and electric load reductions and that the new renewable energy generation (with compliance with minimum technical requirements) is also assumed. Therefore, reasonable retirements might change as those assumptions are not maintained on schedule.
- With an historical commitment of federal recovery funds and statutory renewable energy targets to meet, several activities in Puerto Rico are happening in parallel with the PR100 study. Table C-1 summarizes these activities and how they relate to the study.

Table C-1. Federal Funding and Implementation Activities Related to PR100

Activity	Description	Relation to PR100
Renewable Energy and Energy Storage Procurement Process	PREPA and PREB are procuring 3,750 MW of renewable energy resources and 1,500 MW of energy storage resources—in six tranches over 3 years—toward implementation of the 2019 IRP (PREB n.d.a). PREPA is finalizing negotiations for proposals submitted in Tranche 1 (PREB 2022).	The project team is taking into account and using as a benchmark the capacity of renewable energy being procured as part of these six tranches.
FEMA Hurricane Maria Public Assistance and Hazard Mitigation Investments	FEMA authorized over $9.5 billion for Hurricane Maria recovery activities for the electric grid. Projects approved by FEMA to begin design and construction activities can be found at FEMA's Accelerated Awards Strategy (FAASt) website.	Projects funded by FEMA to upgrade Puerto Rico's electric generation, transmission, and distribution system will be included in modeling as relevant and available in time to be included in the analysis.

Activity	Description	Relation to PR100
FEMA Puerto Rico Power System Stabilization Task Force	In September 2022, after Hurricane Fiona left 950,000 Puerto Ricans without power, FEMA formed the Puerto Rico Power System Stabilization Task Force to perform repairs needed to stabilize the grid, including providing temporary generation to reach adequate capacities and reserves.	Projects identified by the Puerto Rico Power System Stabilization Task Force to be procured and deployed by the U.S. Army Corps of Engineers will be taken into consideration.
Puerto Rico Department of Housing (PRDOH): HUD Community Development Block Grant Disaster Recovery (CDBG-DR) and Community Development Block Grant Mitigation (CDBG-MIT) Programs	PRDOH is administering two relevant programs funded by HUD CDBG-DR and CDBG-MIT: the Energy Grid Rehabilitation and Reconstruction (ER1) Cost Share Program ($500 million) and the Electrical Power Reliability and Resilience (ER2) Program ($1.3 billion)	The objective of the ER2 program is to enhance electrical power system reliability, resilience, and affordability through the funding of projects that qualify as Electrical Power System Enhancements and Improvements. Most ER2 Program funds are anticipated to be used for distributed generation and microgrid projects. NREL is providing technical assistance to PRDOH to support program planning and design.
Green Energy Trust	Puerto Rico Governor Pierluisi announced the creation of a Green Energy Trust to manage $400 million in CDBG-MIT funding, including up to $30 million from PRDOH through HUD. Act 17 requires DDEC to create a Green Energy Trust.	The objective of the trust is to financially support projects that provide access to green energy to residents of low- and moderate-income (LMI) communities and to promote energy efficiency among other goals. NREL is providing technical assistance to support planning and design of a new financial institution to support Puerto Rico's clean energy transition.
2024 IRP Planning	LUMA is developing the next IRP for Puerto Rico, which will include a stakeholder engagement process to elicit input on the plan.	LUMA and the PR100 team are coordinating so that PR100 results inform the IRP development process as appropriate.

Activity	Description	Relation to PR100
FY23 Federal Spending Bill	The FY23 federal spending bill signed by President Biden at the end of 2022 includes $1 billion to improve the resilience of Puerto Rico's electric system, including grants to be administered by DOE's Grid Deployment Office for low- and moderate-income households and others to deploy distributed solar and storage (Gonzalez 2022).	The Grid Deployment Office and NREL lead the PR100 study.

Uncertainties

- This document is a report at the halfway point of a 2-year study: *all findings presented here are preliminary*. Results reported in the final PR100 report, slated for December 2023, may differ significantly from what is presented here.
- Impact modeling and analysis, including bulk power system analysis for enhanced resilience, distribution system analysis, and economic impact analysis, will be completed in Year 2, and final results will be provided in the final report.
- Modeling feedback loops among tasks involved, which have not yet been completed, will impact distributed generation adoption, utility-scale deployment, and necessary transmission and distribution upgrades, as well as downstream metrics.
- We continue to seek feedback from stakeholders and are working to refine inputs, such as current and future costs, system sizes and necessary storage for distributed systems, value of backup power, and geospatial constraints. Additionally, calculation of rate impacts will eventually be incorporated iteratively with the distributed rooftop adoption modeling. These improvements to the modeling are anticipated to accelerate rooftop PV and storage adoption as well as raise the total amount of PV and storage adopted by 2050.
- The impacts of incentives in the Inflation Reduction Act of 2022 (U.S. Congress 2022) are not currently represented, but they will be incorporated into the study as Puerto Rico's eligibility across provisions, such as the federal investment tax credit, is defined by the U.S. Department of Treasury. It is anticipated there will be eligibility for tax credit adders (e.g., for energy communities or disadvantaged communities) under the Inflation Reduction Act.
- In March 2022, Puerto Rico Governor Pedro Pierluisi signed Executive Order OE-2022-0022. It mandates that any agency of the Government of Puerto Rico that works directly or indirectly in the (1) generation, transmission, or distribution of electrical energy, (2) reconstruction and revitalization of the electrical system, or (3) regulation and supervision of the Energy Public Policy (Act 17), to consider hydrogen combustion as a source of renewable energy when evaluating any project. Hydrogen technologies are not included in this Year 1 progress report, but the project team may represent hydrogen resources in the models in Year 2.

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