The Future of Energy in Puerto Rico:
Current Challenges and Opportunities for a Resilient Power Grid

On Behalf of the U.S. Environmental Protection Agency, Region 2 Brownfields Program

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Introduction

Electricity is a fundamental component of nearly all aspects of modern life, powering everything from household appliances to life-saving medical equipment. The significance of reliable electricity was emphasized as the COVID-19 pandemic shifted a substantial portion of employees and students to remote work. It is a resource often taken for granted, but the combined aging of the United States' electrical infrastructure and increased extreme weather events has created an uptick in the number of outages seen nationwide.[i] These effects are felt more in the U.S. territory of Puerto Rico than anywhere else in the nation.

The Commonwealth of Puerto Rico is an archipelago of islands in the Caribbean, with residents living on the main island of Puerto Rico, and two smaller islands off its eastern coast—Culebra and Vieques. Puerto Rico has a long history of colonialism spanning from Christopher Columbus' second voyage to the Americas. Puerto Rico was a Spanish colony for nearly four centuries, until it was ceded to the United States under the Treaty of Paris following the Spanish-American War in 1899. Since then, Puerto Rico has remained an unincorporated territory of the U.S.

There are several reasons for Puerto Rico's history of frequent and lengthy power outages. Firstly, the generation fleet responsible for creating electricity in Puerto Rico is far older than systems in the rest of the United States. As of 2016, the territory's "median plant age is 44 years, compared to a U.S. industry average of 18 years."[ii] Additionally, these plants are heavily reliant on imported fossil fuels such as fuel oil and diesel, which are prone to price fluctuations that often translate to rate hikes on residents and businesses. Another contributing factor to the grid's lack of reliability is that much of the generation occurs in southern Puerto

Rico and travels to population centers in the north. These stretches of transmission lines traverse mountainous and densely vegetated terrain that make maintenance and vegetation management more difficult.[iii]

In addition to the struggling components of Puerto Rico's generation, transmission, and distribution, extreme weather events have caused significant and lasting damage to the power grid. Hurricane María made landfall in Puerto Rico in September of 2017 as one of the most destructive and deadly natural disasters to ever hit the United States. María's damage in the Caribbean also caused the longest electricity blackout in U.S. history. The average household had no access to electricity for 84 days, and residents in more remote areas waited even longer.[iv] The damage from the hurricane left 80% of the transmission and distribution system inoperable,[v] and much of the grid is still in need of repairs today.

While the rebuilding of power lines, transformers, and substations is essential, Puerto Rico must also undergo a massive shift in its sources of energy generation. Currently, Puerto Rico's grid is more reliant on fossil fuels than almost anywhere else in the country, with fewer than 3% of its energy generation coming from renewables.[vi] The Puerto Rican legislature and governor signed a bill into law in 2019, establishing a Renewable Portfolio Standard with an end goal of 100% of energy supplied to Puerto Rico's grid by 2050. This rapid deployment of renewable energy requires Puerto Rico to analyze its natural resources and the opportunities that best match the territory's needs for a renewable future.

One country that has achieved significant success in the transition to renewables for generating electricity is Costa Rica. Over seven years, Costa Rica has achieved a rate of clean energy sources greater than 98%.[vii] An abundance of natural resources within Costa Rica has greatly aided the integration and transition to renewables. Its sources of energy this year have been 73% hydropower, 14% geothermal sources, 12% wind, and under 1% biomass and solar. Costa Rica represents a model for other countries to sustainably source electric power, though it has a relatively unique concentration of rivers and volcanic activity, allowing for the majority of energy to come from hydro and geothermal power. However, its adoption of abundant, naturally occurring resources is exactly the model that should be emphasized. While Puerto Rico has little to no geothermal activity, there is more than enough potential in solar, wind, and water sources for Puerto Rico's electricity generation capacity to be met.

Puerto Rico is at a critical juncture for the future of its energy grid. The management and operation of Puerto Rico's power systems is undergoing major changes, including the privatization of its transmission and distribution system. With an antiquated generation fleet and lasting widespread damage from Hurricane María, essentially the entire grid system must be redesigned, modernized, and rebuilt. Historic federal investments from the Federal Emergency Management Agency (FEMA) and Department of Housing and Urban Development (HUD) to improve Puerto Rico's energy grid offer an opportunity to do just that, but there is much disagreement as to how it should be done.

Overview of Electrical Grid

The electrical grid is often referred to as the greatest engineering achievement of the 20th century. It is composed of a complex transmission and distribution (T&D) system of power lines that transport electricity from energy generators to consumers. Transmission refers to high-voltage lines used to transport energy long distances. Transmission uses high voltage because it minimizes the energy lost through the lines over greater distances. These transmission lines travel from generators to substations that use step-down transformers to reduce the voltage level for distribution. Distribution uses lower-voltage lines, operating at the appropriate voltage for consumption by homes and businesses, that travel a smaller distance from substations directly to consumers.

This form of centralized grid system is present across the country and around the globe. It is a delicate and constant balance of matching the supply and demand present in the grid. In the continental United States, the management of grid systems is spread into three large grid interconnections: the Eastern Interconnection, Western Interconnection, and Texas Interconnection. Within these interconnections are Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs). These are responsible for operating transmission systems, as well as creating procedures to manage transmission in an equitable manner—including the operation of energy and ancillary services markets for buyers and sellers to bid for or offer generation.[viii] From these large-scale transmission markets, local utilities procure energy to provide electricity to individual customers in the distribution system.

A substantial benefit of this method of large-scale, interconnected grid systems is reduced costs and increased reliability due to the scale of the systems in place, where precise matching of energy supply and demand is constantly maintained. The massive scale of the United States' grid system is able to provide relatively reliable service because outages of energy generators or power lines can typically be overcome through shifting energy supply from a myriad of alternative sources.

Puerto Rico's Current Grid System

Puerto Rico's energy system has operated in a vastly different manner than the contiguous U.S. due to the nature of being a remote island territory, as well as its utility's vertical integration of operations. For nearly seventy years, the generation, transmission, and distribution of electricity has been solely managed by the Puerto Rico Electric Power Authority (PREPA). Where communities in the continental United States receive energy from a local utility that procures energy from a wholesale market operated by an RTO or ISO within its interconnection, PREPA has been responsible for every aspect of Puerto Rico's energy grid. In terms of number of customers, it is the largest utility in the U.S.[ix] PREPA's management as a public monopoly has resulted in a higher frequency of power outages, longer duration of outages, and higher electricity rates than nearly all other utilities in the United States.[x] The frequent and lengthy disruptions in service pose dangerous risks to healthcare and economic development in Puerto Rico.

The price of electricity in Puerto Rico is one of the highest in the nation for residential, commercial, and industrial users that pay 23.26 cents/kWh, 25.94 cents/kWh, and 22.88 cents/kWh, respectively. The U.S. average for residential, industrial, and commercial users is 13.99 cents/kWh, 11.60 cents/kWh, and 7.65 cents/kWh, respectively.[xi] These remarkably higher prices are a hinderance to the economic growth in the territory, in addition to an unreasonable burden on low-to-moderate income residents. The median household in Puerto Rico earns approximately one-third of the U.S. average, while paying substantially higher rates, with some residents paying as much as 33% of their income for electricity.[xii]

Puerto Rico's mix of generation sources are shown in Figure 1[xiii] and is overwhelmingly dominated by fossil fuels. The age of generation plants is more than double the U.S. industry average, often leading to operating complications that increase the frequency of power outages. Additionally, the types of fuel used and the age of the equipment lead to lower efficiency levels of the plants' operation. The volatile nature of the oil & gas market has led to rate hikes for the residents and businesses in Puerto Rico. Furthermore, the Merchant Marine Act of 1920 requires ships carrying cargo between two U.S. ports to be built, owned, and crewed by an American majority. There are no tankers transporting liquid natural gas that meet these requirements, meaning Puerto Rico has no option for importing natural gas other than more expensive, foreign sources.[xiv]

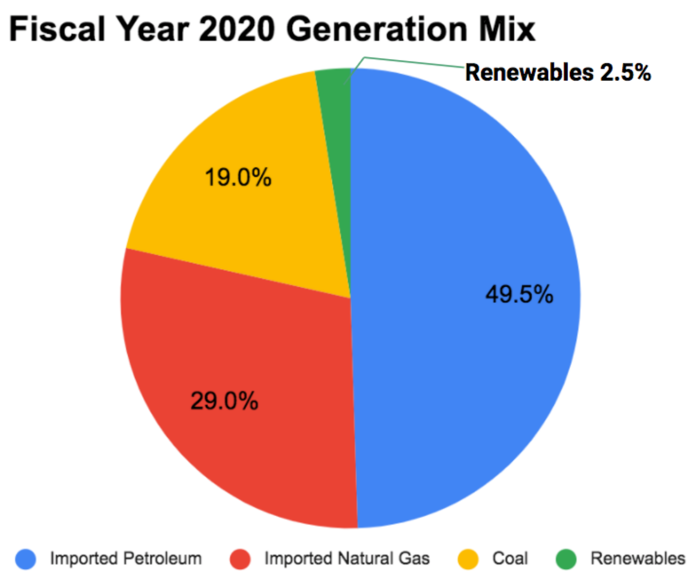

Figure 1

In addition to the numerous generation issues leading to higher prices and more outages, the unique and difficult to manage system of power lines in Puerto Rico contributes greatly to the high price and poor reliability of electricity. The transmission system is composed of 1,134 miles of transmission lines (230/115 kV) and 1,549 miles of sub-transmission lines (38 kV) that form three loops along the eastern, central, and western portions of the island. The sub-transmission lines diverge from the loops to reach more remote regions.[xv] Additionally, the islands of Vieques and Culebra are connected to the grid through an underwater cable running from the main island of Puerto Rico to Vieques to Culebra.

The topography of Puerto Rico's mountainous and densely vegetated main island makes the maintenance of transmission lines a difficult and costly enterprise. Approximately 70% of generation capacity occurs in the southern portion of the island and must be transported to the northern regions of the San Juan Metro Area and Humacao Industrial District that represent roughly 70% of the island's total load.[xvi] Difficult to reach stretches of transmission lines and poor vegetation management worsened and slowed the repair efforts following the impact of the hurricanes in 2017. Much of the T&D system in Puerto Rico remains in severe disrepair, causing continued problems with service disruptions and voltage fluctuations. "In 2019, the average duration of power outage (SAIDI) was over six times higher than the average peer utility, while the average frequency of outage (SAIFI) was over four times higher."[xvii] Voltage fluctuations and power surges from the damaged T&D system has caused destruction of appliances and even sparked a fire in a resident's home, causing thousands of dollars in damages.[xviii] The limited capacity of the damaged grid is also detrimental to the integration of new renewable energy.

Environmental and Health Concerns

The dependance on fossil fuels has negative effects on air quality, with increased CO2 levels, as well as SO2 levels not in compliance with the National Ambient Air Quality Standards.[xix] Sulfur dioxide causes inflammation and irritation of the respiratory system, damages trees and plants, and contributes to acid rain.[xx] These emissions harm the residents of Puerto Rico, its environment, and contribute to climate change.

Additionally, the use of coal ash at the AES plant in Guayama, Puerto Rico has contributed to respiratory illnesses in residents and polluted groundwater. A study from the

Graduate School of Public Health at the University of Puerto found that the rate of chronic bronchitis in the community surrounding the AES plant was five times higher than rates in communities in areas of Puerto Rico not in close proximity.[xxi] Additionally, research from the Puerto Rico Chemists Association revealed drinking water in communities nearby the AES plant contained arsenic, cadmium, lead, uranium, manganese, cobalt, chrome, molybdenum, nickel, strontium, and vanadium.[xxii] The levels of the chemicals found do not exceed national safety limits; however, even low-level exposure can harm human health and, furthermore, many are bio-accumulators that continue to build in the body over time and worsen the negative impacts on health.

The reliance of Puerto Rico's energy generation on fossil fuels has contributed to substantial negative health impacts that harm vulnerable communities. Puerto Rico has especially felt the effects of extreme weather events, but its continued use of inefficient and high-emissions fuel sources is contributing to climate change that will only exacerbate the strength and frequency of natural disasters.

PREPA, PREB, and LUMA

There are currently three entities responsible for the operation and regulation of Puerto Rico's grid system: the Puerto Rico Electric Power Authority (PREPA); Luma Energy, LLC; and the Puerto Rico Energy Bureau (PREB). The generation, transmission, and distribution of electricity in Puerto Rico was controlled by PREPA from 1941 until May 31, 2021. As the sole controller of the electric grid in Puerto Rico, PREPA acted as a public monopoly. Act 57-2014 established the Puerto Rico Energy Bureau (PREB) with "the responsibility to regulate, monitor and enforce the energy public policy of the Government of Puerto Rico." [xxiii] This established

PREB as the primary body to oversee and regulate PREPA's operations, including setting rates and approving all investments.

On June 1, 2021 the ownership and operation of Puerto Rico's transmission and distribution system was shifted from PREPA, to a private company, LUMA Energy, LLC. The transfer of T&D assets to LUMA was caused by a number of factors, including decades of poor management, high levels of debt from PREPA, and the desire for additional expertise to improve the grid system. LUMA is a joint venture between Quanta Services and Canadian Utilities Limited, which was selected for the transmission and distribution contract in Puerto Rico by the Puerto Rico Public-Private Partnerships Authority (P3). P3 reviewed proposals from five companies, ultimately selecting LUMA in June of 2020 for a 15-year, $1.5 billion contract. The transfer of PREPA's T&D assets and functions was authorized by Act 120-2018, "Puerto Rico Power System Transformation Act."

The privatization of Puerto Rico's T&D system has been met with much public frustration, as the understaffed new operator has struggled to repair service disruptions in a timely manner. In LUMA's first several months, the average duration of outages has been more than double the time during PREPA's operation last year.[xxiv] The weariness and suspicion from Puerto Rican residents is not unreasonable as there has been a lengthy history of mismanagement and corruption in Puerto Rico related to its power grid. In 2017, a small company, Whitefish Energy, was awarded a no-bid contract to repair the grid following the hurricanes before criticism led to the contract's cancellation; Cobra Energy was chosen as a replacement before two FEMA employees were charged with bribery and fraud for its selection.[xxv]

P3 has emphasized the transparency and robustness of LUMA's selection, but the components of its contract have been under scrutiny. This 336-page contract was approved by

PREPA in a meeting that lasted only 43 minutes.[xxvi] Many policymakers and industry experts find the performance benchmarks underwhelming and criticize the lack of investment required by LUMA in the system. Additionally, the agreement does not prohibit LUMA from hiring its parent companies for contracts. The CEO of Quanta Services even said on a call with Wall Street analysts that additional business in Puerto Rico could be gained due to the LUMA contract.[xxvii] Another point of contention has been the extent of LUMA's required transparency. LUMA refused to share documents with legislators, including salary information—ultimately resulting in the issuance of an arrest warrant of its CEO, Wayne Stensby. This warrant prompted LUMA to release the documents, resulting in the disclosure of salary information of top executives, including the CEO's total compensation of over $1.1 million per year.[xxviii] The 15-year contract has only just begun, but the Governor of Puerto Rico, Pedro Pierluisi, has remained committed to continuing with LUMA despite frequent protests and criticism.

Transition to Renewables

In the midst of the substantial changes in ownership and operation of the grid system, as well as the massive grid rebuilding and modernization projects required, Puerto Rico also has legislation enacting a rapid shift away from its fossil-fuel generation sources. Act 17, the Puerto Rico Energy Public Policy Act, was passed in 2019 to establish a cleaner and more resilient grid, including a Renewable Portfolio Standard "in order to achieve a minimum of forty percent (40%) on or before 2025; sixty percent (60%) on or before 2040; and one hundred percent (100%) on or before 2050."[xxix] The Renewable Portfolio Standard enacted is a substantial change from Puerto Rico's current portfolio of less than 3% of renewables. The current makeup of Puerto Rico's renewable energy is 147 MW of solar, 121 MW of wind, 34 MW of hydropower, and 5 MW from landfill gas.[xxx]

In order for PREPA to meet the required renewable energy generation levels, immense quantities of new solar, wind, hydropower, and/or other renewable developments must begin. Puerto Rico is an ideal candidate for solar energy, with many regions having a potential average daily output of 4.5 kilowatt hours (kWh) per installed kilowatt of capacity (kWp). The installation of solar is economically feasible in most regions of the island but would be especially cost-effective on or near the coasts. The map in Figure 2 demonstrates the photovoltaic power (PV) potential in Puerto Rico.[xxxi]

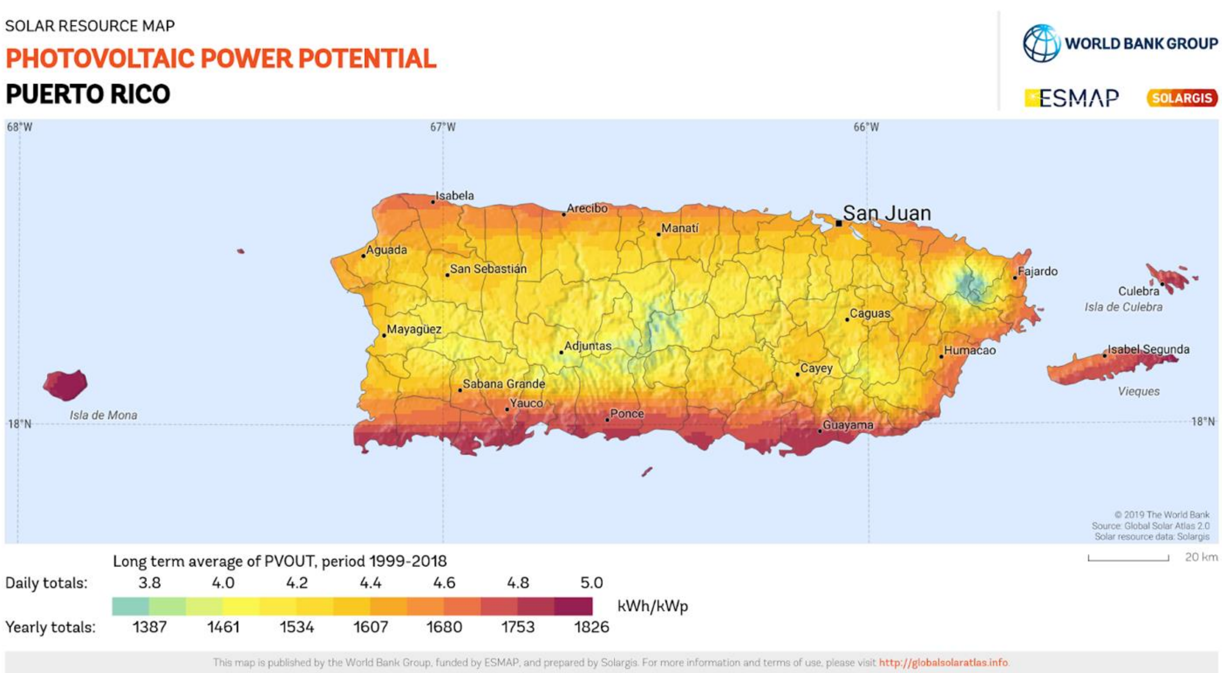

Figure 2

Solar PV generation is likely the greatest component for Puerto Rico's path to decarbonize its power grid. Due to economies of scale, large-scale solar generation plants are often less expensive to implement than rooftop solar, though there are several considerations regarding this tradeoff. Firstly, integration of utility-scale renewables into the grid is more difficult. Due to the design of a centralized grid system, there must be ample capacity in the T&D system for large-scale generation to be interconnected. In December of 2020, PREPA published a study indicating that Puerto Rico's current grid could only handle a maximum of 650MW of inverter-based renewable energy.[xxxii] Another issue with utility-scale generation was brought up in an interview for this report with Zolymar Luna, a Project Officer in Puerto Rico for the U.S. EPA Region 2 Brownfields Program. Ms. Luna remarked on the "very complicated, land-intensive" requirements for utility-scale solar. Finding suitable sites for solar, creating plans to interconnect them into the fragile grid system, and acquiring approval from the utilities can be a lengthy and frustrating process. The backlog of applications and the length of processing time to approve and connect renewable energy projects to the grid often derails projects that would otherwise have successful development.

Issues with this process were illustrated following a feasibility study with NREL and RE-Powering America to survey closed landfill sites in Puerto Rico. 21 landfills were visited and analyzed for solar generation viability and 20 were identified by the report as viable options.[xxxiii] Many of the municipalities where these landfills are located were excited at the opportunity and began sharing information with potential developers. However, a decade has passed since the feasibility study was conducted and none of the landfills have been used for solar. Slow adoption of solar energy in Puerto Rico has been a widespread issue, and the nature of PREPA's role as a monopoly in the generation, transmission, and distribution of electricity undoubtedly played a role for approving projects outside of its assets.

Another renewable energy technology that will almost certainly contribute to meeting the Renewable Portfolio Standard requirements is wind turbines. Puerto Rico has multiple wind plants in operation in the southern, eastern, and northern regions of the island. There is also good potential for offshore wind to be implemented, as demonstrated by Figure 3.[xxxiv]

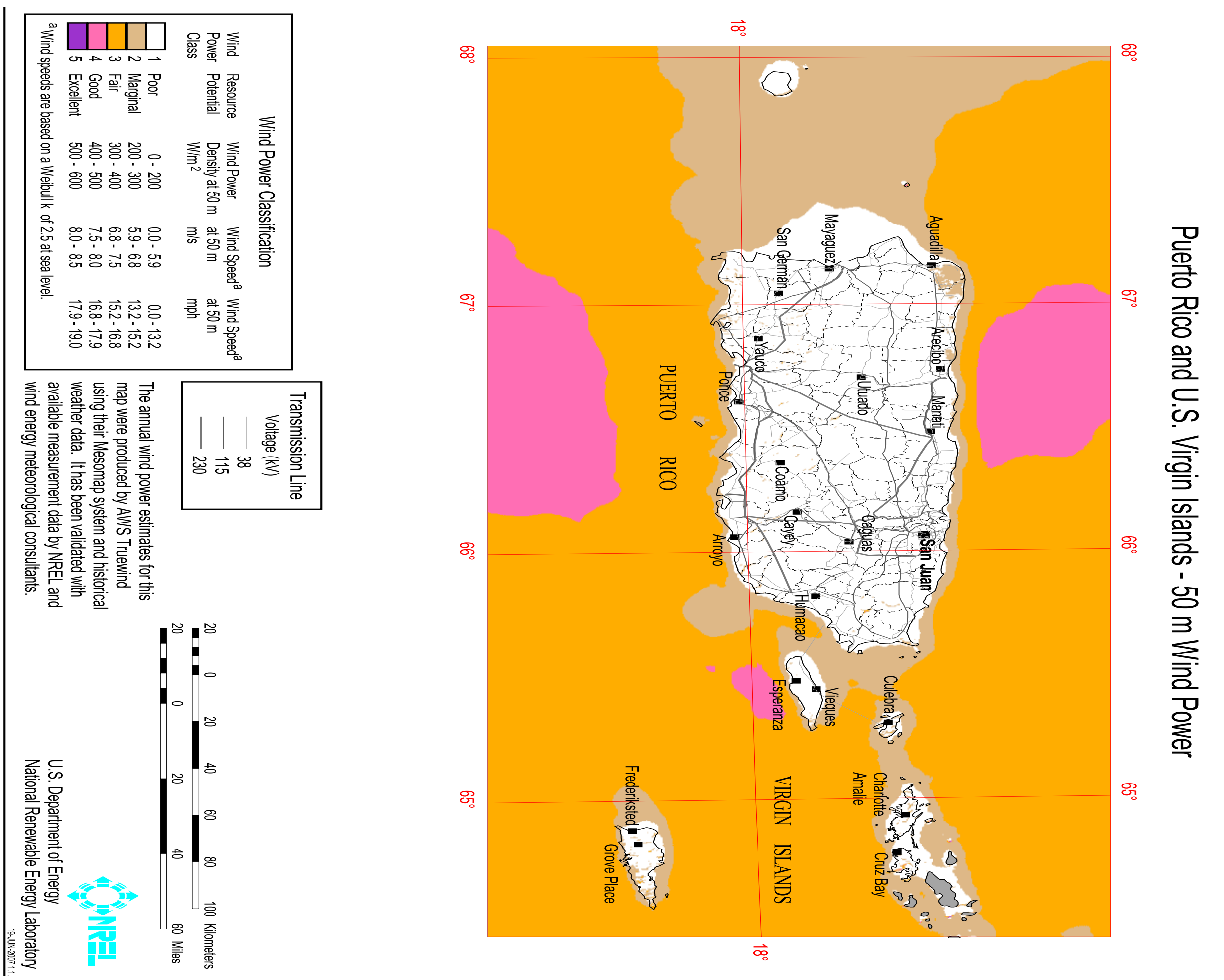

Figure 3

Hydropower is a third likely renewable energy generation source that will contribute to Puerto Rico's energy transition, though there are more substantial land requirements and environmental impacts associated with hydropower. Puerto Rico currently has 19 hydroelectric generating units that have received little to no use in recent years due to competing water uses for drinking and irrigation.[xxxv] Recently, there has been more interest in reestablishing some of these assets. A coalition of municipalities led by Villalba, the Mountain Energy Consortium, is creating a micro energy supply system using the Toro Negro Hydroelectric Power Plant combined with solar energy systems to self-supply electricity to the municipalities involved.[xxxvi]

For intermittent generation sources like solar and wind, energy storage becomes a critical element to ensure a consistent energy supply. Battery storage is the primary solution to aid with intermittency, though there are promising advancements in fuel cell technology that would allow for a longer duration of storage to aid the seasonality issues associated with renewable energy.

The beginning of this rapid shift to renewables is underway, as the most recent Integrated Resource Plan (IRP) from PREPA and approved by PREB established a substantial procurement process for new renewable energy development. The IRP created six procurement tranches to be released for requests for proposals (RFPs) every six months, with a minimum of 3750 MW of renewable energy online by 2025. Additionally, the procurement tranches will include 1500 MW of 4-hour battery storage. The approval process for the first round of RFPs is underway; however, it was substantially delayed and came with a series of challenges. PREB released a statement that the "process conducted by PREPA in connection with the Tranche 1 RFP suffers from numerous shortcomings and failed to comply with important directives and milestones established in the Approved Integrated Resource Plan."[xxxvii] Resultingly, PREB stripped PREPA of its oversight of Tranche 2 RFPs, and instead PREB will take its place.

While the beginning of this procurement process has had issues, the end targets will increase the renewable generation capacity of Puerto Rico more than ten-fold. The projects being proposed for these procurement tranches are mostly large, utility-scale plants. In addition to the flaws of grid capacity previously mentioned, utility-scale projects suffer the same issues with resiliency as the current generation systems in a centralized grid system.

Distributed Generation and Microgrids

One common argument for the modernization of Puerto Rico's grid is to shift away from the centralized model of large power plants supplying energy to the T&D system. Instead, a network of distributed generation could provide energy to consumers from a closer proximity. Distributed energy resources include technologies such as solar PV panels, wind turbines, fuel cells, batteries, and back-up generators. Depending on the capacity of the components, these resources can be designed for a single home or an entire community. "The only essential feature of a freestanding grid is that it lives within a continuous, highly precise supply-demand balance."[xxxviii]

In a centralized grid system, a disruption in large-scale generation or the T&D system leading to consumers causes a blackout. This happens due to electricity's inability to flow through power lines or a mismatch in supply and demand throwing the grid out of balance. A microgrid can be interconnected to the larger grid system, and during an outage is able to disconnect and self-regulate supply and demand. "So long as the physical and electrical integrity of your microgrid and your fuel supply remain undamaged, you have power service."[xxxix] This factor makes microgrids an appealing solution in terms of resiliency. This is especially true for more remote areas, in which repairs are more difficult to address.

A study from the Institute of Energy Economics and Financial Analysis (IEEFA) and CAMBIO modeled a distributed renewable generation scenario for Puerto Rico. Their analysis revealed that equipping every home in Puerto Rico with 2.7 kW solar PV systems and 12.6 kWh of battery storage, in addition to solar installations at commercial sites and parking lots, would yield renewable energy penetration of 75%.[xl] The study also concluded that this model of 75% distributed renewables generation would be "less expensive than the base case of PREPA's current grid."[xli] Another study from the Electrical Engineering Department of the University of Puerto Rico—Mayaguez concluded that "approximately 65% of residential roofs can provide the total electrical energy" generated in Puerto Rico.[xlii] These studies reveal that distributed generation from solar and battery technology represents an opportunity to produce both cleaner and more reliable energy across Puerto Rico.

One community that has been able to implement these systems with success is the municipality of Adjuntas. Casa Pueblo is a community center in Adjuntas that generates its own electricity with solar panels. While the town of Adjuntas was without power from the grid for six months following María, Casa Pueblo was able to continue operating off its own production.[xliii] Following the hurricane, Casa Pueblo designed and distributed solar lamps and solar-powered minifridges for medicine to the community, as well as "built 40 solar homes and five solar-powered markets to support recovery of both the community and the economy."[xliv] Since then, Casa Pueblo has teamed up with the Honnold Foundation and the Community Solar Energy Association of Adjuntas to install "approximately 1,000 solar panels to power 18 businesses in 13 buildings around the town's central plaza."[xlv] The second phase of this project will implement 1 MW of battery storage to allow businesses an off-grid capacity of up to 10 days.

Because distributed generation and microgrids are especially useful for remote areas, the islands of Culebra and Vieques are two areas that can greatly benefit from these types of projects. Culebra lost power following Hurricane María due to the failure of the underwater cable connecting it with Vieques. The island had no access to electricity for 3 months until diesel generators were supplied by the Army Corps of Engineers for critical loads.[xlvi] It took a year and a half before the island was interconnected back to the grid.[xlvii] Dulce María del Rio-Pineda, the founder of Mujeres de Islas—a non-profit based in Culebra with educational and community programs focused on sustainability—referred to a phrase to describe this experience on Culebra: "We're the tip of the tail of the dog." In other words, the very last of the last to be considered. The challenges following María left their organization and many community members with the goal of making Culebra the first solar island in America.

The process of establishing Culebra as a renewably powered and resilient community is underway through the work of multiple philanthropic organizations. For example, Mujeres de Islas offices are now solar powered thanks to donations from inverSOL. Some of the critical infrastructure of the island—fire and police stations, health clinic, child center, museum, and community kitchen—have been equipped with solar panels and battery storage. Two additional projects are attempting to bring distributed energy resources to businesses and homes in the community.

The Fundación Comunitaria de Puerto Rico received a grant from the Economic Development Administration to equip businesses in Culebra with solar panels and battery storage. The businesses involved will expand the resilient energy available to critical infrastructure and essential services, focusing on a support for immediate well-being of residents. The battery storage and solar PVs will be placed directly on the site in order to minimize the footprint of the technology. The environmental impacts and historic preservation studies are currently under review, and construction for these projects is hoped to begin early next year.

The Environmental Defense Fund is leading a project in Culebra for a microgrid solution for a low-to-moderate income households using rooftop solar and storage. The plan is to solarize 40-50 households, some of which have been without power since Hurricane Hugo in 1989. In order to include more houses, the plans focus on critical loads. The basic structural assessments have been completed and they hope to begin construction early next year. The intent is to install the systems before the next hurricane season.

The inspiration for many of these projects in Culebra stem from an Energy Resilience Assessment for Culebra, conducted by the National Renewable Energy Laboratory following the impacts from Hurricane María. This study demonstrated the technical and economic viability of establishing microgrid systems in Culebra to serve critical infrastructure.[xlviii] The goal of establishing Culebra as the first solar island in America is something that can be expanded to include Vieques and remote areas throughout the United States and the Caribbean.

The importance of microgrids was also established in PREPA's IRP. It proposed a system of 8 MiniGrids to create a more resilient T&D system on the main island of Puerto Rico, and the current IRP was modified by PREB "to focus on one or two adjacent MiniGrid Regions and optimize transmission needs."[xlix] This signals an understanding that the centralized generation and grid system is not a sustainable or practical method for transporting electricity throughout Puerto Rico.

Climate Resilient Renewable Energy

Integrating renewable energy on a large scale comes with a host of issues: grid capacity, intermittency of generation, and—for Puerto Rico in particular—the ability to withstand extreme weather events. Significant damage to both solar generation and wind power plants was experienced in Puerto Rico from Hurricane María. The worst destruction for PV plants occurred at Humacao, while every turbine at the Punta Lima wind farm experienced damage. The harm to these assets was largely in part to the insufficient design of the systems to handle hurricane-strength wind speeds. In 2020, magnitude 5.4 and 6.4 earthquakes on consecutive days in January caused damage to two of Puerto Rico's largest generation assets and left the majority of consumers without power.[l] In order for successful and resilient adoption of renewables in Puerto Rico, the specifications and installation of technology used needs to be appropriately designed to withstand substantial wind speeds and natural disasters.

The Department of Energy released a list of recommendations for solar PV systems following field examinations of hurricane-damaged systems.[li] In order to create climate-resilient solar generation systems the materials and design process must be thoroughly considered. The use of torqued and locked fasteners, such as wedge-lock washers, reduces the likelihood of fasteners loosening under vibrations from high wind speeds. Selecting modules with through-bolt systems instead of clamping fasteners adds substantial strength against forces during extreme weather. Additionally, the selection of solar modules with the highest wind resistance and debris strength ratings improves the likelihood of continued generation capability following a storm. A three-frame rail mounting system provides a stronger design than two-frame systems. The material selection and design of the frames and fasteners used also has a large impact on the success during extreme weather—the study recommends stainless steel fasteners and closed-form frame elements with low drag coefficients to minimize bending and twisting that can cause breakage. Wind-calming perimeter fencing can mitigate some of the intensity of wind speeds. In order to minimize damage from flooding, rubber-sealed enclosures can help keep water out of the path of the system and elevated pads for the modules can further protect them inside. There are a multitude of design considerations for building a hurricane-resistant solar system and incorporating storm hardening measures can increase the system cost as much as 51%.[lii] However, the inclusion of storm-resistant design in solar systems is necessary to establish a resilient energy system in hurricane-prone areas.

Additional protections for solar energy systems include removability and hurricane shutter systems. Designing the panels to be easily removed and stored in a protected area would allow owners to safely stow the systems when warned of an oncoming storm. Hurricane shutters are a barrier designed to protect against extreme wind and minimize damage from flying debris. These systems are usually intended to protect windows; however, shutter systems have been designed for the purpose of protecting solar panels in hurricane conditions.

In order to address issues experienced by wind turbines in hurricanes, NREL created a study for a Hurricane Resilient Wind Plant Concept.[liii] "This conceptual study shows that challenges posed by hurricanes to wind turbine survivability, operability, and cost effectiveness in the U.S. offshore environment can be successfully addressed using innovative research and development strategies." The results of this study demonstrated a 21.5% reduction in the levelized cost of energy for a hurricane-resilient wind plant in comparison with a baseline model of the same plant size. This was accomplished with a downwind turbine design that allows for the flexing of blades that reduces the potential of contact with the tower during high wind speeds. Additionally, the base uses a "twisted jacket" design that is similar to what was used on oilrigs that remained unscathed in the Gulf of Mexico during Hurricane Katrina. A conceptual drawing of the hurricane-resilient turbine is seen in Figure 4.

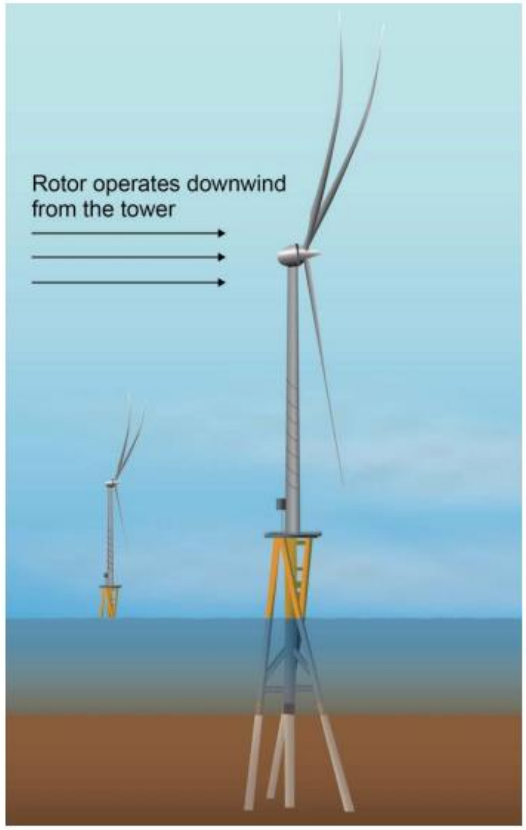

Figure 4

Financial Overview and Federal Funding

Puerto Rico is in the debt restructuring process of over $70 billion of public debt, approximately $9 billion of which belongs to PREPA. The overwhelming financial issues in Puerto Rico led to the passage of the Puerto Rico Oversight, Management and Economic Stability Act (PROMESA) in 2016. This law established an oversight board to restructure the debt and resolve disputes between the creditors and debtors.[liv]

The result of Puerto Rico's debt and the creation of the oversight board has been a constraint on the government of Puerto Rico and its municipalities in terms of funding and long-term planning. Both of these elements are crucial to the successful transformation of its grid system to renewable energy. However, federal funding from FEMA and HUD will serve as a starting point in the rebuilding and modernization of the grid to create a more resilient and sustainable energy system.

FEMA has set aside $9.4 billion for Puerto Rico's power grid, which is "the largest allocation of funds in FEMA's history."[lv] These funds will flow through the Central Office for Recovery, Reconstruction and Resiliency (COR3) to grid projects administered by PREPA and LUMA. PREB will be responsible for oversight of these investments, while FEMA and the Unified Federal Review Group will review and approve projects in compliance with federal, state, and local requirements. As of September 22, 2021, PREPA had not requested reimbursement of the funds to COR3, as PREPA must submit scopes of work detailing the proposed projects to repair and improve the grid.[lvi] With the privatization of T&D in Puerto Rico to LUMA, the monopolistic nature of Puerto Rico's utilities has been split into two: PREPA for energy generation and LUMA for T&D. This raises an issue for the use of FEMA funds to rebuild Puerto Rico's grid. There is little incentive for these entities to put forward projects that are aimed at distributed generation solutions that will ultimately hurt their bottom line as the amount of electricity required to be generated and transported is reduced. FEMA has oversight in the approval process, but the 10-year plan put forward "earmarks $0 of federal funds for renewable energy."[lvii] Instead, the plan focuses on rebuilding "essentially the same centralized grid that failed during Hurricane María."[lviii]

HUD has also put forward funding for disaster recovery and the power grid in Puerto Rico, separated into three grants: Community Development Block Grant–Disaster Recovery (CDBG-DR, $1.9 billion), Community Energy and Water Installations ($300 million), and City Revitalization Program ($1.29 billion). The CDBG-DR grant is intended for improvements to the power system and 70% of funds must "be used for activities that benefit low-and moderate-income persons."[lix] Additionally, 51% of low-and moderate-income residents must receive "a subsidized rate for electricity" or "measurably improve the reliability of the electrical power system in low-and moderate-income areas."[lx]

The HUD funding will be received by the Puerto Rico Department of Housing, Vivienda, and distributed to municipalities and organizations throughout Puerto Rico. It is intended to target issues with the power system that are left unaddressed by the FEMA funds, with an emphasis on benefitting lower income residents. The HUD funding represents a unique opportunity to promote distributed generation solutions for low-to-moderate income households because of the focus in demographic and the benchmarks for improvement. Distributed generation resources for lower income households, such as rooftop solar and battery storage, would allow for residents to gain access to energy technology and reliability that would otherwise not be economically feasible for them. Additionally, the HUD funding is not tied to the same conflicts of interest as the FEMA funds that restrict the likelihood of widespread, decentralized generation assets. An action plan for the use of HUD funds is due in January of 2022.

Lessons Learned

Puerto Rico has long struggled with an inept and financially burdensome power grid that has harmed the health, economics, and comfort of its residents and businesses. The mismanagement and lack of oversight of its utility has lasted for decades and has been compounded by a series of natural disasters in the past several years. The long-term planning and financial investment required for Puerto Rico to successfully rebuild, modernize, and transition its electricity sources to renewable energy is massive, and the financial oversight due to extreme debt is hindering these processes.

The funding from FEMA and HUD, as well as the progressive requirements set in the IRP, are components that will help to drive the success of this transition forward, but several considerations must be taken into account in the planning process. Firstly, it is critical that the generation system in Puerto Rico becomes decentralized. The current system of the majority of energy coming from the southern region of the island to the majority of consumption in the northern region is inefficient and certainly not resilient. Renewable energy generation is feasible throughout Puerto Rico, but utility-scale generation projects alone will continue to cause high levels of outages. This will occur because the T&D system will be unable to successfully handle disruptions caused by line failure from extreme weather and vegetation. Theoretically, this type of system could be more reliable with the majority of power lines underground; however, the construction costs of undergrounding lines is estimated to be approximately ten times that of overhead lines.[lxi] The use of distributed energy resources in conjunction with large-scale renewables is critical to improve the resiliency of Puerto Rico's energy system. This is especially true for the critical infrastructure throughout Puerto Rico and for more remote areas that have continuously struggled with disruptions in service. The director of Casa Pueblo in Adjuntas, Dr. Arturo Massol, summarized this point rather clearly: "We should not be rebuilding the same cables and the same infrastructure to be at the same position that we were before Hurricane María."[lxii]

In addition to decentralized generation and T&D, the review processes and incentives to integrate renewables in Puerto Rico must be improved. Lengthy periods of approval for interconnection diminish the investment interest to develop renewables. New York created the

Office of Renewable Energy Siting to streamline permitting and environmental review processes, enabling application completion within one year—and only six months for underutilized sites, such as brownfields and former landfills.[lxiii] This type of model and buy-in from LUMA and PREPA to hasten the integration of both small and large renewable projects would greatly assist Puerto Rico meeting the requirements of the Energy Public Policy Act.

Meanwhile, homeowners receive no tax incentives to install solar and battery systems. Distributed generation on homes throughout Puerto Rico would benefit the grid with reduced stress and lower capacity required, which in turn would aid large-scale integration of renewables. Conversely, it has been proposed that residents with solar panels would need to pay for the electricity they generate themselves, actively disincentivizing one of the most cost-effective, resilient energy solutions available.

As discussed previously, one of the most critical elements for establishing a resilient system is the design of climate-resilient renewable energy. Selecting technology and mounting systems with structural integrity able to withstand extreme windspeeds and weather events is of utmost importance to minimize the risk of widespread outages following a disaster.

The future of Puerto Rico's emissions-free energy grid will heavily depend on the implementation of solar panels and battery technology. The rapid deployment of these systems must also come with planning that considers the full lifecycle of these products. Solar panels have a lifespan of 20-30 years but should not simply be disposed of in landfills at the end of their lifecycle, as they can release toxins into the environment. The components of solar panels include metal, glass, and wiring that can all be recycled. Additionally, it is feasible for the silicon cells within the panels to be melted and repurposed. Lithium-ion batteries are the primary energy storage technology for grid applications. They contain critical minerals like cobalt, graphite, and lithium that have strategic importance to U.S. supply chains.[lxiv] The lifecycle considerations and reuse of these systems not only reduces waste and limits environmental impacts but has shown to be more cost effective.

Through discussions with federal and nonprofit employees working to improve the power system in Puerto Rico, one important theme arose: communication. The need for clear coordination and partnership between philanthropic projects, federal agencies, and the government of Puerto Rico is critical to effectively tackle issues. There are currently challenges in communication between these organizations that are detrimental to a more comprehensive improvement of the power system. The Puerto Rican government and its municipalities are lacking resources for an effective capacity, but non-governmental agencies can help to address these shortcomings through fostering relationships with municipalities, federal agencies, and communities. Above all else is the importance of communication, education, and partnership with communities to best understand their needs and reach a viable solution. Establishing a clear channel of communication between all of the stakeholders involved would greatly improve the understanding of the various needs of communities, the projects intended to address them, and the shortcomings of current plans in order to appropriately plan for the future.

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