GOBIERNO DE PUERTO RICO
JUNTA REGLAMENTADORA DE SERVICIO PÚBLICO
NEGOCIADO DE ENERGÍA DE PUERTO RICO

IN RE: ESTUDIO DE SISTEMAS DE ALMACENAMIENTO DE ENERGÍA	**CASO NÚM.:** NEPR-MI-2020-0002 **ASUNTO:** Publicación de Estudio de Sistemas de Almacenamiento de Energía.

RESOLUCIÓN

El Artículo 4.10 de la Ley 17-2019[1] requiere al Negociado de Energía de la Junta Reglamentadora de Servicio Público de Puerto Rico ("Negociado de Energía") "realizar un estudio para determinar las metas específicas de sistemas de almacenamiento de energía a todos los niveles, como mecanismo para facilitar la integración de fuentes de energía renovable sostenible y energía renovable alterna a la red y lograr el cumplimiento con la Cartera de Energía Renovable."[2] En cumplimiento con lo anterior, el 10 de enero de 2020, el Negociado de Energía presentó ante ambos Cuerpos de la Asamblea Legislativa el Informe sobre el Estudio de Sistemas de Almacenamiento de Energía ("Informe"). Dicho Informe se incluye como Anejo A de esta Resolución.

El Negociado de Energía deberá reevaluar las determinaciones esbozadas en el Informe por lo menos una vez cada tres (3) años y en acorde con el Plan Integrado de Recursos ("PIR"). Es importante señalar que el proceso de aprobación del PIR, bajo el Caso Núm. CEPR-AP-2018-0001,[3] no ha concluido aún. Una vez aprobado el PIR, el Informe será enmendado de acuerdo con los hallazgos que surjan de dicha aprobación.

Publíquese.

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[1] *Ley de Política Pública Energética de Puerto Rico.*

[2] Artículo 4.10, Ley 17-2019.

[3] In Re: Revisión del Plan Integrado de Recursos de la Autoridad de Energía Eléctrica.

Edison Avilés Deliz
Presidente

Ángel R. Rivera de la Cruz
Comisionado Asociado

Lillian Mateo Santos
Comisionada Asociada

Ferdinand A. Ramos Soegaard
Comisionado Asociado

CERTIFICACIÓN

Certifico que así lo acordó la mayoría de los miembros del Negociado de Energía de la Junta Reglamentadora de Servicio Público de Puerto Rico el 17 de enero de 2020. Además, certifico que en la misma fecha he procedido con el archivo en autos de la presente Resolución.

Para que así conste, firmo la presente en San Juan, Puerto Rico, hoy, 17 de enero de 2020.

Wanda I. Cordero Morales
Secretaria

NEGOCIADO DE ENERGÍA NEPR JUNTA REGLAMENTADORA DE SERVICIO PÚBLICO PUERTO RICO

10 de enero de 2020

Honorable Thomas Rivera Schatz
Presidente del Senado de Puerto Rico
El Capitolio, San Juan, Puerto Rico

Honorable Carlos Méndez Núñez
Presidente de la Cámara de Representantes
El Capitolio, San Juan Puerto Rico

Estudio de Sistemas de Almacenamiento de Energía
("Energy Storage Study")

Estimados Presidentes:

En cumplimiento con las disposiciones del Art. 4.10 de la Ley 17-2019, conocida como la Ley de Política Pública Energética de Puerto Rico y según solicitado en la carta del 19 de diciembre de 2019[1], le presentamos el Informe sobre el Estudio de Sistemas de Almacenamiento de Energía. [2]

El Negociado de Energía de la Junta Reglamentadora de Servicio Público deberá reevaluar las determinaciones del Estudio por lo menos una vez cada tres (3) años y en acorde con el Plan Integrado de Recursos (PIR). Es importante señalar que el proceso de aprobación del PIR no ha concluido aún, dicha aprobación debe culminar en los proximos meses. Una vez aprobado el PIR el Informe sobre el Estudio de Sistemas de Almacenamiento de Energía será enmendado con los hallazgos que surjan de dicha aprobación.

Reiteramos nuestro continuo compromiso con la fiscalización y regulación de la industria eléctrica en Puerto Rico. De estimarlo necesario, estamos a su disposición para discutir el contenido de este informe.

Cordialmente,

Edison Avilés Deliz
Presidente

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[1] Ver Anejo 1.
[2] Ver Anejo 2.

Anejo 1

19 de diciembre de 2019

Honorable Thomas Rivera Schatz
Presidente del Senado de Puerto Rico
El Capitolio, San Juan, Puerto Rico

Honorable Carlos Méndez Núñez
Presidente de la Cámara de Representantes
El Capitolio, San Juan Puerto Rico

Solicitud de Prórroga para presentar Informe sobre Sistemas de Almacenamiento de Energía ("Battery Energy Storage Study")

Estimados Presidentes:

La Ley de Política Pública Energética de Puerto Rico, Ley Núm. 17-2019, dispone en su Art. 4.10 que el Negociado de Energía de Puerto Rico de la Junta Reglamentadora de Servicio Público deberá presentar en o antes del 31 de diciembre de 2019 un Informe sobre el Estudio de Sistemas de Almacenamiento de Energía.

Nos encontramos en el proceso de elaboración del informe por lo que, respetuosamente, solicitamos una prórroga de veinte (20) días a vencer el 20 de enero de 2020.

Cordialmente,

Edison Avilés Deliz
Presidente

Anejo 2

Energy Storage Study

For a renewable and resilient island grid for Puerto Rico

Energy Bureau of the Puerto Rico Public Service Regulatory Board

(Energy Bureau)

December 19, 2019

CONTENTS

4

M

TABLE OF TABLES

TABLE OF FIGURES

M

Disclaimer:

Throughout this report there are conclusions based on the preliminary analysis by the Energy Bureau's IRP consultant team with respect to the treatment and potential of Energy Storage in Puerto Rico, pursuant to Article 2.12 of Act 82-2010, as amended, known as the *Puerto Rico Energy Transformation and RELIEF Act*. The Energy Bureau has included the information in this report in order to share with Legislature the most current knowledge and information available at this time. Any references to the proposed Integrated Resources Plan (IRP) or modeling done by Synapse reflect the views of the consultant team. Inclusion of this information at this time should not be construed in any way as a prejudgment of the outcome of the pending IRP proceeding. The Energy Bureau will consider these issues as they arise in the IRP proceeding in which it will make its determinations and issue a Resolution and Order based on the evidence included in the administrative record. Should the outcome of the IRP proceeding materially change the conclusions of this report, the Energy Bureau will, within ninety (90) days, submit an updated report to the Puerto Rico Legislature.

EXECUTIVE SUMMARY

Puerto Rico has joined a number of states and jurisdictions around the world in making a significant commitment to expand the use of renewable energy. In April 11, 2019 the former Governor of Puerto Rico, Ricardo Rosselló signed into law the Puerto Rico Energy Public Policy Act (Act 17-2019). Act 17-2019 increased Puerto Rico's Renewable Portfolio Standard (RPS) to 100 percent by 2050, with interim goals of achieving 40 percent renewables by 2025 and 60 percent by 2040. In addition, Act 17-2019 requires the Puerto Rico Energy Bureau to submit a report on energy storage to the legislature. This report was produced to meet this obligation.

Puerto Rico is vulnerable to a changing climate that is leading to more frequent and powerful storms as evidenced by the massive destruction caused by Hurricanes Maria and Irma in 2017. Given the realities of a changing climate, Puerto Rico is proactively planning to create a more sustainable and resilient grid to serve island residents in the coming decades. Transforming the electric grid in this way will take substantial investments. The Puerto Rico Energy Bureau is committed to an open and transparent process to determine the types and levels of investment that will achieve the desired outcome of a more sustainable and resilient energy system.

Energy storage is recognized as central to supporting a grid with the high levels of renewable generation envisioned in Puerto Rico. Key policy and regulatory decisions will influence how the energy storage industry develops in Puerto Rico. The purpose of this report is to provide the information necessary for stakeholders to discuss the role of energy storage in Puerto Rico's energy future so that those key decisions best support the beneficial growth of storage. Specifically, this report seeks to answer three fundamental questions facing Puerto Rico officials about the role of energy storage in Puerto Rico's energy future. These questions are:

1.	What role can energy storage play in supporting the Commonwealth's efforts to create a more sustainable and resilient electric grid?
2.	What role has battery energy storage historically played in Puerto Rico and what is the current vision about its future role in the Commonwealth?
3.	What are the primary barriers to energy storage in Puerto Rico and what policies and regulations are needed to realize the full value that energy storage can offer in transforming Puerto Rico's electric grid?

What role can energy storage play in supporting the Commonwealth's efforts to create a more sustainable and resilient electric grid?

Several factors contribute to the current growth of battery energy storage systems globally, sometimes referred to as BESS. These include decreasing battery costs, technological improvements, and increasing levels of variable generation resources such as solar and wind. According to Bloomberg New Energy Finance's latest forecast, global grid-connected battery storage deployments are poised to expand from 9 gigawatts (GW) as of 2018 to 1,095 GW by 2040. Bloomberg further projects that the anticipated 122-fold growth in battery system deployments over the next two decades will require $662 billion in new investment.[1]

Lithium-ion batteries are the dominant type of modern rechargeable batteries today because of their current cost and performance characteristics. Lithium-ion batteries account for over 80 percent of grid-scale battery systems in operation in the United States.[2] Battery storage systems are rated based on the power capacity (the rate at which they can provide electricity, expressed in kW or MW) and energy storage capacity (amount of energy they can hold expressed in kWh or MWh). The ratio of battery system energy capacity to energy power capacity dictates the storage duration of the storage system—the number of hours the system delivers energy before needing to be recharged.

Battery energy storage systems are being sited at different locations on the electric grid. This includes host customer-sited systems referred to as behind-the-meter systems. Grid-scale battery storage systems can occur within the distribution system and the transmission system and are commonly referred to as in-front-of-the-meter systems. Systems in front of the meter are typically much larger (measured in terms of MW/MWh) relative to behind-the-meter systems (measured in terms of kW/kWh). The siting of storage systems is driven by ownership and use of the

BATTERY SERVICES AND BENEFITS

Battery energy storage is best known for two key functions:

- enabling the integration of variable sources of generation such as solar onto the electric grid, and
- serving as a source of emergency power during a grid outage.

In addition, battery energy storage systems offer many lesser known benefits to the electric grid and host customers.

These services and benefits point to a large role for battery systems in transforming Puerto Rico's energy system to align with clean energy and resilience goals.

But first, stakeholder groups and decision-makers need a shared understanding of how battery storage can contribute to that clean and resilient electric grid.

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[1] Bloomberg New Energy Finance. July 2019. Energy Storage Investments Boom As Battery Costs Halve in the Next Decade. Available at https://about.bnef.com/blog/energy-storage-investments-boom-battery-costs-halve-next-decade/.

[2] EIA 2018 US Battery Storage Market Trends. 2018. Available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

asset to generate value for host customers, electric utilities, and within wholesale power markets.

Behind-the-meter storage systems paired with solar have been gaining popularity in Puerto Rico since the devastation caused by Hurricanes Maria and Irma. Interest in behind-the-meter solar + storage systems is driven by a desire for personal energy resilience. Companies including Tesla and Sunrun are finding a growing market for their innovative solar + storage product offerings. Although not yet used in Puerto Rico, aggregation of small-scale BESS could in the future allow individual host customer systems to be used collectively as a utility-scale resource.

Larger utility-scale systems sited within the distribution and transmissions systems offer several value streams. This includes providing reliability services required to operate a modern electric grid for the integration of variable sources of generation such as solar and wind. For example, battery systems can store energy during the times of day when solar generation is high and then release that energy back to the grid during the time of day when solar is not available. Given Puerto Rico's commitment to 100 percent renewable energy by 2050, which could be largely met with solar, battery systems could be instrumental in integrating solar into the Puerto Rico grid.

Energy storage will also provide critical support for achieving energy resilience goals. Battery systems integrated into minigrids and microgrids can serve critical loads such as hospitals and community centers during times when the broader island grid is not functioning. The amount of storage and its pairing with distributed sources of generation requires a complex analysis to determine how best to meet resilience goals at the least cost. Furthermore, it is difficult to assess the costs and benefits of storage relative to traditional utility investments. Although costs for battery systems have declined in recent years, reliance on a single value stream often is insufficient to justify investments in a new storage system. Puerto Rico can learn from other jurisdictions that are finding ways to "stack" the value of energy storage and thereby access multiple value streams that support cost-effective investments in battery energy storage systems.[3]

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3 RMI Battery Economics Study. Available at https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

What role has battery energy storage historically played in Puerto Rico and what is the current vision about its future role in the Commonwealth?

Today, there are relatively few battery energy storage systems in use in Puerto Rico. In 1994 the Puerto Rico Power Authority (PREPA) developed the Sabana Llana substation storage pilot project. This was a fully commercial battery system acquired for daily operation in a frequency control and spinning reserve mode.[4] However, once utility operations began in 1994, the battery was cycled more frequently than planned. This caused the battery to age more rapidly than expected. PREPA made the decision in 2001 to repower, or replace, the battery. After PREPA installed the new battery in mid-2004, several problems occurred, and the system was taken out of service. More recently, in June 2018 the Puerto Rican government (through PREPA) issued a request for qualifications (RFQ) to develop a utility-scale system. To date, the RFQ has not led to any projects.

Customer-sited solar and storage installations have been rapidly increasing in Puerto Rico. Following Hurricanes Maria and Irma, companies including Sunrun and Tesla arrived on the island—initially to provide aid. These companies have since found growing demand for the solar plus storage systems they design and sell. Unofficial reports indicate that thousands of customers in Puerto Rico have purchased solar plus storage systems in recent years to create personal energy resilience.

The Puerto Rico Electric Power Authority (PREPA) is required under Act 57 of 2014 to prepare an integrated resource plan (IRP) using a detailed and transparent planning process to evaluate all reasonable resources to meet the demand for electrical services over a 20-year planning horizon. Furthermore, considering the devastation caused by Hurricanes Maria and Irma in 2017, the IRP must consider resiliency, reliability, and stability of the power system, and be fully compliant with current and future environmental regulations. PREPA's draft IRP separates the Island into eight

BATTERY STORAGE IN PUERTO RICO

Few battery systems exist in Puerto Rico today. After an unsatisfactory pilot in the mid-1990s, little happened on the utility-scale storage front until Puerto Rico's utility issued a request for qualifications in 2018 to identify qualified contractors to develop a utility-scale project. This RFQ has yet to produce any projects.

In contrast, the residential and commercial market for solar plus energy storage systems has expanded rapidly since Hurricanes Maria and Irma in 2017.

Current electric utility planning envisions a central role for both solar and battery storage in Puerto Rico's future electric grid. PREPA's revised integrated resource plan calls for increasing solar capacity by nearly 1,400 MW and energy storage by 920 MW in the first four years of the plan's implementation.

Finding the best approach to meetings those targets will require more analysis—particularly into the role of minigrids and microgrids in meeting the Commonwealth's energy and resilience goals.

[4] The 1994 Sabana Llana substation battery energy storage system pilot project was taken out of service in 2004. The 2018 request for qualifications has not yet led to any new installed battery systems.

separate minigrids that include battery energy storage systems as well as some gas-fueled power plants.[5] A minigrid is a portion of the PREPA system that is able to operate as a separate electrical island in the event of severing of transmission ties across Puerto Rico. The minigrid construct reflects one form of resilient system design intended to retain reliable operations to some extent following a severe hurricane.

Overall, IRP modeling evaluates battery systems as one of several resource options that can be built to meet customer demand. PREPA uses industry-standard cost trajectories in the modeling. However, the utility also imposes constraints on the amount of new storage that can be added each year, which has the effect of potentially masking the amount of storage that might be cost-effective. In the early years, PREPA assumed that 300 MW of storage can be built annually, which doubles to 600 MW annually from 2022 onward.

As part of the storage study, Synapse explored different energy planning scenarios not addressed in the IRP. This additional modeling finds that the constraints within the IRP modeling have an impact on the amount of solar and storage selected in PREPA's modeling. Synapse also compared a microgrid strategy whereby distributed solar and battery systems satisfy critical and priority loads to the minigrid strategy identified in the IRP. Microgrids are likely to be less costly and produce greater value in most zones, if critical and priority loads make up 40 percent or less of the feeder loads[6].

Notwithstanding the above limitations, the IRP establishes aggressive targets for energy storage. However, more details and analysis may be needed to fully assess the best ways to use battery storage to maximize the value to Puerto Rico in support of achieving its clean energy and resilience goals. The two preferred plans put forth in the IRP both include large increases in battery energy storage system deployments. The IRP identifies these plans as the ESM and the S4S2 scenarios. They include the installation of 920 MW and 1,320 MW of storage in the first five years of the plan, respectively.[7] This represents considerable growth from the current situation in which PREPA's service territory has few storage systems deployed. The IRP, however, does not provide details on how the battery storage systems would be used and managed, nor does the plan present details of the costs and benefits of energy storage. Furthermore, the IRP offers no assessment of the relative size of behind-the-meter battery energy storage systems relative to the utility-scale in-front-of-the-meter storage selected in the IRP.

[5] Minigrids and microgrids allow segments of the larger grid to island and function without interruption when the larger grid is down. Minigrids typically refer to a larger area within the distribution system, whereas microgrids typically refer to a smaller geographically confined area including a single building or campus. Battery energy storage systems are considered an important component of minigrid or microgrid systems.

[6] A feeder is part of the electric grid that serves a geographically defined area within the distribution system that delivers electricity to homes and businesses.

[7] To put this into context, the peak demand for power in 2018 in Puerto Rico was 2,700 MW. The proposed levels of solar and storage represent a significant resource relative to the demand.

Puerto Rico needs to determine whether longer duration storage systems provide a viable alternative to the gas-fueled plants currently required as part of the IRP's minigrid construct. This will require a full analysis comparing the net present value of the costs and benefits of the minigrid transmission and generation infrastructure against the alternative microgrid strategies explored in this report. This should be done before minigrid transmission or generating resource investments are made.

What are the primary barriers to energy storage in Puerto Rico, and what policies and regulations can help capture the full value that energy storage can offer in transforming Puerto Rico's electric grid?

Energy storage holds much promise in helping move Puerto Rico's electricity grid into a least cost and highly resilient future. It is also clear that energy storage is a critical technology whose cost-effective deployment on the island can benefit PREPA's customers by:

- improving the reliability and the ability of the electric system to better withstand shocks and rebound;
- allowing for the greater integration of renewables;
- addressing peak demand with less overall generation capacity; and
- approximating a more "just and reasonable" cost.

Although falling costs are an important factor in the economic case for energy storage, the family of storage technologies has found it difficult under existing regulatory constructs to compete with traditional generation in providing electricity services. To date, the regulatory and policy framework has provided insufficient incentives and revenue opportunities for energy storage to garner material investment funding. It is therefore important to identify barriers faced by storage so that possible solutions can be instituted.

BARRIERS TO BATTERY STORAGE IN PUERTO RICO

The primary barrier to storage is economic. While the cost of battery energy storage systems has plummeted in recent years, it is still difficult to capture the full value that the systems provides to an electric grid due to the fragmented nature of the benefits. Battery systems provide value via different services to different entities (utilities, generators, and end-use customers) making it difficult to build a simple business case for storage.

Other jurisdictions use a variety of policies and regulations to support the growth of the energy storage sector.

Puerto Rico should consider the use of storage mandates or targets, demonstration projects, and other regulatory reforms to incent cost-effective investments in energy storage.

The report summarizes the primary barriers as:

Primary BESS barriers

- Valuation of storage so that multiple revenue streams (capacity, energy, ancillary, and distribution and transmission) can be realized
- Technology newness
- Classification of storage as a generation, transmission, and distribution asset
- Issues concerning treating storage as a market vs cost-of-service asset
- Interconnection queueing issues
- Lack of integrated distribution planning (lack of "non-wire" solutions")
- Financing issues and developing a stable revenue model
- Lack of federal and state incentives

The above listed barriers will be compounded by Puerto Rico's current fiscal crisis, utility bankruptcy, and the grid recovery effort after the devastation of Hurricane Maria. The latter conditions may:

Barriers specific to Puerto Rico

- Hamper Puerto Rico's government storage funding and incentives ability
- Increase storage project financing costs (given current uncertainty)
- Discourage major players, like storage aggregators, from engaging on the island

To the extent that federal financial assistance becomes available, it may help overcome the unique financial uncertainty that currently engulfs the island.

Storage policies and regulation that are supporting the growth of storage markets in the United States are divided in the report into grid-level policies and behind-the-meter policies.

Grid-level policies

Procurement mandates

- Seven states have adopted policies mandating utilities to procure storage
- Two states have adopted specific statewide storage targets
- Other states are in the process of defining state storage policies

Regulatory requirements

- Nine states have adopted grid-level storage policy requiring utility or commission action
- Three states have passed legislation directing utilities to consider energy storage in their resource planning process
- Two states have implemented additional planning processes for energy storage
- One state has provided an incentive rate of return on storage projects
- One state has moved up the timeline for cost recovery for storage projects
- At the federal level, the FERC through Order 841 has attempted to remove the valuation barrier in wholesale markets by requiring RTOs/ISOs to develop an energy storage model that will allow energy storage to provide all capacity, energy, and ancillary services it has the capability of providing

Demonstration programs

- Five states have adopted a policy driving energy storage demonstration programs

Behind-the-meter policies

Behind-the-meter strategies

- Several states (and Puerto Rico) have adopted policies governing the development of microgrids
- California has approved an order that authorizes customers with energy storage to receive credit for storage energy delivered to the grid
- Arizona and Massachusetts are seeking to increase both utility and customer distributed generation by modifying their Renewable Portfolio Standards to require an additional clean energy target for hours of peak demand (and thereby help reduce that demand)
- New York has developed a "bridge incentive" providing $130 million for retail storage projects: customer-sited systems below 5 MW, which are smaller and installed alone or paired with onsite generation such as solar

Some of these solutions to accelerate the development of storage capacity are transferable to Puerto Rico and should be considered.

1. INTRODUCTION

In May of 2019, the former Governor of Puerto Rico, Ricardo Rosselló signed into law the Mitigation, Adaptation and Resilience to Climate Change Act (Act 17-2019). This Act increased Puerto Rico's Renewable Portfolio Standard (RPS) to 100 percent by 2050, with interim goals of achieving 40 percent renewables by 2025 and 60 percent by 2040. Puerto Rico joins Hawaii and the District of Columbia with formal commitments to 100 percent renewables for electricity generation by 2050. In addition, several other states including New York, Maine, Oregon, Washington, Colorado, New Mexico, California, and New Jersey have passed aggressive renewable energy policies in recent years.

It is generally understood that the goal of 100 percent renewable energy generation requires the integration of energy storage systems strategically located within the electric power grid.[8] Without storage, energy demand must always be balanced in real time with energy production. Electricity has historically been a unique form of energy in that it must be produced and consumed at the same time because storage for later use has been costly and inefficient. As more and more variable sources of generation such as solar are connected to the grid, energy storage becomes an increasingly important technology helping to balance the production of energy with consumption.

Energy storage provides the ability to shift energy production from times when supply exceeds demand to times when demand exceeds supply. Storage can play a valuable role during a power outage by supplying energy to critical infrastructure and providing community resilience benefits. Puerto Rico Electric Power Authority's (PREPA) proposed Integrated Resource Plan (IRP) established the goal of a resilient system as one of the pillars for the transformation of Puerto Rico's electricity sector. Section 6.23 of Act 57 (Puerto Rico Energy Transformation and RELIEF Act) stipulated that the IRP "...satisfies in the short-, medium-, and long-term the present and future needs of the energy system both of Puerto Rico and of their customers at lowest cost possible."[9] Thus, investments intended to create a more resilient grid should be assessed based on the associated costs and benefits to determine the least cost options.

The purpose of this report is to provide the information necessary for stakeholders to engage in an informed discussion about the role of energy storage in Puerto Rico's energy future. This report begins by providing information on how battery energy storage systems work, the benefits of energy storage, and various applications. Section 0 of the report provides a review of PREPA's IRP results, with an emphasis on the amount of battery energy storage and solar found to be cost-effective given the different scenarios PREPA considered in its study.

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[8] U.S. Department of Energy. 2010. Electric Power Industry Needs for Grid-Scale Storage Applications. Available at https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Utility_12-30-10_FINAL_lowres.pdf

[9] Puerto Rico Act No. 57- 2014. Puerto Rico Energy Transformation and RELIEF Act. Page 132.

Section 0 of this report presents the results of Puerto Rico electric grid energy modeling using sensitivities not included in PREPA's IRP. The goal was to explore the impact that different modeling assumptions would have on the amount of solar and storage deemed to be cost-effective. In Section 4, we present a framework, along with some example results, to compare the use of microgrids to the minigrid approach used in the IRP to achieve the resilience goals of the IRP. The minigrid approach used in the IRP has a variety of fixed parameters that impact how Puerto Rico's resilience goals are met. The microgrid approach presented in Section 5 offers a different, and potentially less expensive, strategy to increase energy resilience in the Commonwealth. The report also includes, in Section 3, a discussion on various policy mechanisms used in different jurisdictions to accelerate battery energy storage system deployments and provides recommendations for Puerto Rico given the existing policy context within the Commonwealth.

1.1. Energy Storage Basics

Battery energy storage systems are ubiquitous in our modern digital world, from our cell phones to our laptop computers. As technologies improve and costs decline, battery storage systems have found new applications from power tools to electric vehicles. There is growing interest in the use of battery energy storage systems in grid-connected applications. Historically, there has been very little storage connected to the electric grid due to inefficiencies and high cost. With the increase in variable sources of generation such as solar and wind, along with technological improvements and cost reductions in batteries, energy storage is poised to play a central role in Puerto Rico's clean energy future. This section provides a brief introduction to how energy storage systems work, the benefits of energy storage, and the different types of applications that are common today.

Power Rating vs. Energy Rating

The power and energy ratings of a battery system are important characteristics that determine the appropriate application. The *energy rating* or battery storage capacity is the maximum energy that can be stored in the system. This is measured in kilowatt-hours (kWh) or megawatt hours (MWh).[10] The power rating, or *capacity*, is the amount of power in kilowatts (kW) or megawatts (MW) that can flow in or out of the battery at any given instant. These specifications are important and determine the localized energy need the storage system can serve.

The relationship between the system's power rating and energy rating is important. The power rating dictates how quickly the battery energy storage system can be charged or discharged. We can explain this relationship using a simple example. If a home battery system that can store 10 kWh of electricity and has a power rating of 1 kW, the battery system can be charged in 10 hours after a full discharge. The ratio of the energy to the power rating is referred to as the system's *duration* (typically measured in hours). For example, a 1 kW/10-kWh battery system with a 10-hour duration can provide 1 kWh

[10] 1 MWh = 1,000 kWh = 1,000,000 watts and 1 MW = 1,000 kW = 1,000,000 watts.

of electricity to a building each hour over a 10-hour period based on a constant 1 kW power draw.[11] The power rating is also the maximum amount of energy that can be discharged from the battery in a given time. When the battery is not discharging at the maximum power rating, it can discharge for a longer duration. For example, the same 1 kW/10 kWh system could discharge at 0.5 kW for 20 hours.

Energy Storage Types

There are five general categories of energy storage systems: mechanical; chemical; electrochemical; electric field; and thermal. Table 1 lists the types of energy storage systems in each of these five categories. Although pumped hydro storage has the most installed capacity in the United States at over 90 percent of the total installed energy storage,[12] there is limited potential for new pumped hydro due to environmental concerns and other barriers. In contrast, interest in small, modular battery-based energy storage systems is growing given the many benefits these systems provide. This report focuses on lithium-ion batteries as they are the fastest growing energy storage technology in the United States and currently represent 80 percent of the country's large-scale battery storage capacity.[13] Storage in the Commonwealth of Puerto Rico (Appendix B) provides descriptions of the other energy storage technologies listed in Table 1.

Table 1: Types of energy storage systems

Mechanical	Chemical	Electrochemical	Electric Field	Thermal
Pumped Hydro	Hydrogen	Lead Acid	Double-Layer Capacitor	Molten Salt
Compressed Air		Nickle Cadmium	Superconducting Magnetic Coil	
Flywheel		Lithium Ion		
		Sodium Sulfur		
		ZEBRA		
		Vanadium redox		
		Zinc Bromine		

Lithium-ion batteries consist of lithium combined with other active materials. Figure 1 shows how energy is stored using the active materials in the cathode in a lithium-ion battery. The chemical compositions of the anode and cathode vary. These materials have different costs, life spans, safety

[11] Note that it is not recommended to completely discharge a battery down to a zero state of charge and thus a 10 kWh battery system would typically have 8 kWh of usable energy assuming a standard 80 percent depth of discharge.

[12] The U.S. Department of Energy, Energy Information Administration, About Electricity Storage Available at https://www.epa.gov/energy/electricity-storage.

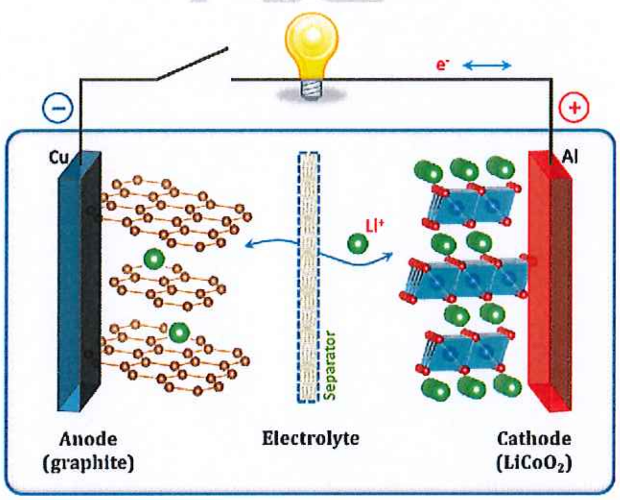
[13] Energy Information Agency (EIA). U.S. Battery Storage Market Trends. May 2018. Available at : https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

considerations, and energy densities.[14] Different chemistries are better suited for different applications. Scientists are continuing to research and develop improved chemistries with lower costs, longer life spans, and higher energy densities. The four most popular lithium-ion batteries on the market today are lithium nickel manganese cobalt oxide, lithium iron phosphate, lithium nickel cobalt aluminum oxide, and lithium titanate.[15]

Batteries with a high energy density can store more energy per volume and weight than other chemistries. Higher energy density allows for more compact and often lighter weight systems. Different battery chemistries can be charged and discharged a finite number of times, referred to as cycle life. The process of charging and discharging once is considered one cycle.

Safety is another important consideration for lithium-ion batteries. Each chemistry has a temperature ceiling to prevent the cells of a battery from overheating and causing thermal runaway.[16] Systems with higher energy densities tend to have a lower thermal runaway temperature and require additional safety considerations such as more restricted siting requirements, high tech cooling systems, or additional fire suppression technology.

Figure 1: Schematic of a lithium-ion battery



Source 1:Goodenough, J. B. and K. Park, "The Li-ion rechargeable battery: a perspective" Journal of the American Chemical Society, 2013. Accessed via https://www.semanticscholar.org/paper/The-Li-ion-rechargeable-battery%3Aa-perspective.-Goodenough-Park/42e965ce9.

[14] Energy density is a measure of power or energy per unit of volume or weight. Higher energy density batteries can store more energy per unit of weight or volume. This is particularly important for certain applications such as EVs as lighter, more energy dense batteries provide longer range.

[15] Battery University, Lesson 205: Types of Lithium-Ion, Updated July 2019. Available at: https://batteryuniversity.com/learn/article/types_of_lithium_ion.

[16] Thermal runaway is when one cell overheats to a point where it begins to overheat surrounding cells, causing the entire system to fail and potentially cause fire and other safety concerns like the release of toxic gas and electrode.

Off-Grid vs. Grid-Connected Energy Storage Systems

Historically, batteries have played a key role in meeting the energy demands for applications in remote locations far from the electric power grid. This includes providing energy to remote villages in the developing world to powering communications and signaling devices far from the electric grid. This continues to be an important market for battery energy systems today. However, the market for battery systems connected to the electric grid is growing rapidly to address a variety of challenges and to meet the increasingly important goal of energy resilience.

Grid-connected battery systems are directly connected to a building or the utility-controlled transmission and distribution infrastructure. Grid-connected battery storage systems can either be installed in front of the meter (utility side) or behind the meter (customer side). Battery storage systems provide different services depending on which side of the meter they are connected to—front of the meter or behind the meter (BTM). Storage installed in front of the meter is typically monitored and controlled by the utility company, which can manage the charging and discharging of the battery depending on the needs of the grid. Utility-controlled storage systems are often large-scale batteries in front of the meter or aggregated BTM small-scale batteries[17] that allow the utility to respond to the conditions on the electric grid in a way that provides economic and reliability benefits.

As the price for energy storage drops, the popularity of BTM storage is increasing for both commercial and residential application. BTM energy storage systems are often used to reduce a building's peak demand for power to avoid costly demand charges.[18] Customers on time-of-use (TOU) rates can use BTM energy storage to charge during low-cost periods to avoid energy use during the higher cost periods. For both commercial and residential customers, energy storage systems provide a source of emergency back- up power during an outage. In addition, storage is increasingly paired with solar to allow host customers to self-consume more of the solar-generated electricity than they would without storage. Paired resources also allow sharing the costs of inverters and other power electronics between the solar and storage, thereby reducing overall costs.

Amount of Utility Storage

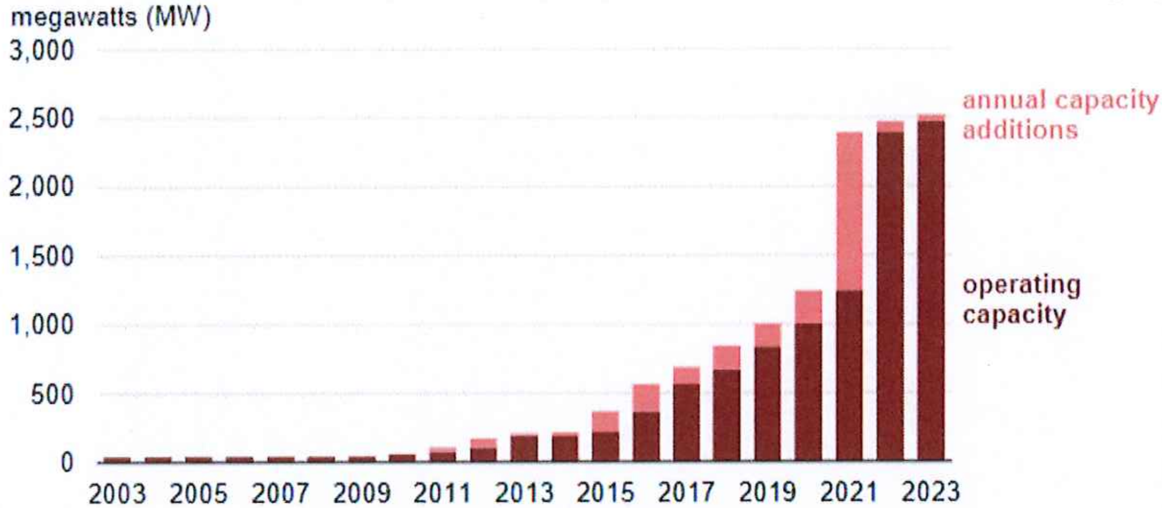
Utility-scale battery storage units (units of one MW or greater power capacity) are a newer electric power resource, and their use has been growing in recent years. As shown in Figure 2, operating utility-scale battery storage power capacity in the United States has more than quadrupled from the end of 2014 (214 MW) through March 2019 (899 MW). Assuming currently planned additions are

[17] A utility company can aggregate behind-the-meter batteries and manage them based on contractual agreements with the owners. Green Mountain Power in Vermont has a program based on this model.

[18] Utility rates often include a demand charge for commercial and industrial customers, which is applied to the peak energy use of the building. Battery energy systems are used to reduce the peak demand for energy and thus reduce overall electric bills.

completed, and no current operating capacity is retired, utility-scale battery storage power capacity could exceed 2,500 MW by 2023 in the United States.[19]

Figure 2: U.S. utility-scale battery storage capacity projection through 2023



Source: U.S. Energy Information Administration, Annual Electric Generator Report and the Preliminary Monthly Electric Generator Inventory (March 2019).

Growth in utility-scale battery installations is the result of supportive state-level energy storage policies and the Federal Energy Regulatory Commission's Order 841 directing power system operators to allow utility-scale battery systems to participate in wholesale energy, capacity, and ancillary services[20] markets. In addition, pairing utility-scale battery storage with intermittent renewable resources, such as wind and solar, has become increasingly competitive compared with traditional generation options.

Conventionally, merchant generation and storage plants have been large scale—usually dozens or hundreds of megawatts. An increasingly viable and attractive alternative is aggregation of distributed energy resources including distributed storage, distributed generation, and geographically targeted demand response. The storage, generation, and demand response capacity is aggregated into a "block" of electric power that is operated like a much larger scale merchant plant. This is sometimes referred to as a "virtual" power plant.[21]

19 U.S. Energy Information Administration (EIA). 2019. *Today in Energy*. Available at: https://www.eia.gov/todayinenergy/detail.php?id=40072.

20 The ancillary services include operational reserves, voltage regulation, voltage support, regulation services, and frequency response.

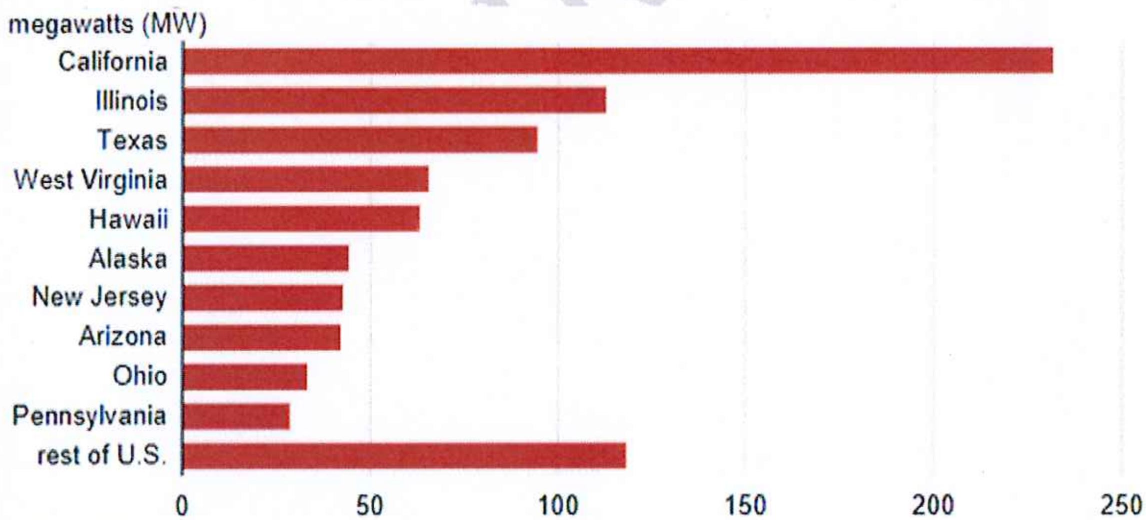
21 Energy Storage Association (ESA). January 2013. "Merchant Electricity Storage." *The Energy Storage Association Blog*. Available at: https://energystorage.org/merchant-electricity-storage/.

1.2. The Benefits of Battery Energy Storage Systems

Declining costs and increased scalability of lithium-ion batteries—along with recognition of the numerous benefits they offer—have expanded the market for grid-connected battery storage systems. That said, the market for battery storage systems is still evolving because the benefits they provide are sometimes difficult to monetize. For example, energy market rules may not accommodate battery energy systems and thus battery energy systems are unable to participate. In other cases, battery energy system owners may not be able to capture the full value due to the fragmented nature of energy markets. As the role of battery energy storage systems in meeting clean energy goals becomes more broadly understood, efforts are underway in numerous jurisdictions to address the barriers to cost-effective investments in energy storage systems.

Figure 3 illustrates the top 10 states by installed energy storage capacity. These states have taken steps to address the barriers to energy storage, and several states have adopted specific energy storage targets. In 2010, California's Assembly Bill Number 2514 established an aggressive energy storage mandate for the state's three largest electric utilities to contract for an additional 1.3 GW of energy storage power generation by 2020.[22] Section 5 provides detailed coverage of the various state and federal policies and regulations used to promote investments in energy storage.

Figure 3: U.S. large-scale battery storage capacity by state (top 10 2019)



Source: U.S. Energy Information Administration. July 2019. "U.S. utility-scale battery storage power capacity to grow substantially by 2023: Annual Electric Generator Report and the Preliminary Monthly Electric Generator Inventory (March 2019)." Today in Energy. *Available at https://www.eia.gov/todayinenergy/detail.php?id=40072.*

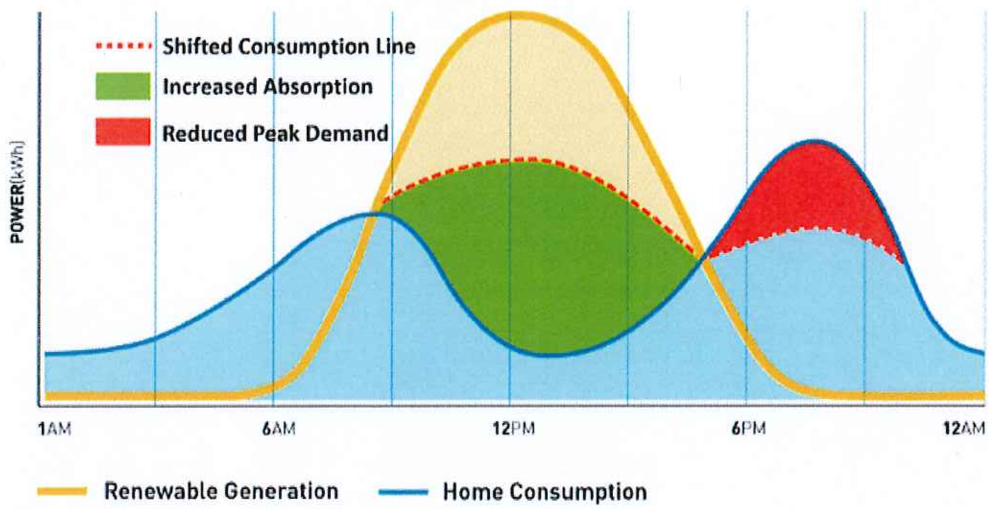
[22] California Legislative Information. AB 2514. Available at http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200920100AB2514.

Integration of Variable Renewable Resources

Renewable energy generation is often generated by time-varying fuel sources. While these fuel sources have the benefit of being ultimately free, they have a disadvantage in that their availability does not always coincide with the energy demands of consumers. The goal of supplying consumers with 100 percent renewable energy means the grid will transition away from generators with on-demand generation times to generators with less controllable generation times.

Figure 4 illustrates how a host customer can use energy storage to shift renewable energy production to meet demand throughout the day. Here, the host customer can store some of the excess generation during the day (green shade) and then discharge the energy during the evening hours (red shade) when solar is no longer available. The example customer in Figure 4 is able to net meter, which allows them to receive a credit for supplying excess solar-generated electricity to the grid (yellow shade) such that increased self-consumption of the solar energy is made possible using battery storage.[23] On a larger scale, energy storage allows grid operators to absorb energy when renewable generation exceeds demand and then later dispatch that same energy when demand exceeds supply to meet the energy requirements for large groups of customers. For Puerto Rico, this will be an important role that energy storage can play in supporting the goal to achieve 100 percent renewable energy by 2050.

Figure 4: Using storage to shift energy from solar energy production to the evening hours



Source: Cooney, S. November 2019. "Utility Adds 2.5 MW of Demand Response Capabilities With Very Unusual Batteries." Cleantechnica.com. https://cleantechnica.com/2019/11/02/utility-adds-2-5-mw-of-demand-response-capabilities-with-very-unusual-batteries/.

Storage Used as a Generation Resource

Utility-scale energy storage connected to the power grid can be dispatched as a generation resource to meet system demand. These are front-of-the-meter systems controllable by the utility or balancing

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23

authority. Grid operators often use pumped hydro for this purpose, but they are increasingly turning to large-scale or aggregated small-scale electrochemical batteries as a generation resource. Small-scale systems can generally be controlled by a single aggregator and appear to the utility or balancing authority as one system providing energy and capacity to the power grid. Large-scale battery storage systems can be relied upon to replace peaking capacity generators as they retire. The National Renewable Energy Laboratory (NREL) found long duration battery storage to be a sufficient replacement to fossil fuel-powered peaking plants.[24] The proposed IRP for Puerto Rico's energy grid includes peaking plants installed for each minigrid. However, long duration energy storage systems coupled with a renewable generator such as solar photovoltaic (PV) systems could be a viable supplement or alternative to the proposed peaking plants.

Ancillary Services

Grid operators use the ancillary services provided by generators to ensure the grid operates reliably.[25] Ancillary services include voltage support, frequency regulation, contingency reserves, and black start services.

Table 2 describes the different types of ancillary services a system operator needs. Independent system operators (ISO) and regional transmission organizations (RTO) are tasked with controlling and operating the electric power system for their region. Most RTOs and ISOs created markets for these services, thus creating the opportunity for generators to sell these services to load-serving entities.[26] Non-RTO regions require essentially the same set of ancillary services, but cost-based rather than market-based compensation predominates in these areas. These services ensure that the grid has enough reserve capacity to provide adequate reserves if a generator fails and also ensure that the system stays in balance. Ancillary services are vital to a safe and reliable grid. To assist in providing a reliable grid to their region, ISOs and RTOs require market participants to purchase ancillary services from generators. Lithium-ion energy storage systems are well suited to provide ancillary services and increasingly provide these services to the ISO or RTO as a primary source of revenue. Frequency regulation in particular has been one of the main revenue streams available to large-scale batteries due to their quick response time and ability to be sized according to grid needs.[27] Currently PREPA operates Puerto Rico's electric grid and is responsible for obtaining these ancillary services to meet electric reliability standards. This is poised to change as the operation of the Puerto Rico grid transitions to a new system operator.

[24] Denholm, Paul, Jacob Nunemaker, Pieter Gagnon, and Wesley Cole. 2019. *The Potential for Battery Energy Storage to Provide Peaking Capacity in the United States.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-74184. https://www.nrel.gov/docs/fy19osti/74184.pdf.

[25] Introduction to Electricity Markets – Lesson 9. Seth Blumsack. Pennsylvania State University College of Earth and Mineral Sciences. Available at: https://www.e-education.psu.edu/ebf483/node/694.

[26] Load serving entities purchase energy and ancillary services on behalf their customers.

[27] IRENA (2019), Innovation landscape brief: Utility-scale batteries, International Renewable Energy Agency, Abu Dhabi.

Table 2: Ancillary services

Service	Description
Reactive Power/Voltage Support	Power the grid operators need from generators to bring the grid back into phase. In some markets, generators will be compensated for the lost real power opportunities during the time the generator supplies the grid with reactive power.
Frequency Regulation	Service provided to maintain a steady grid frequency by generators that are able to respond immediately to grid needs.
Contingency Reserves	Reserves that are meant to be a constantly available source of energy to the balancing authority. These reserves often represent a small percent of average load and/or peak load. Reserves are either considered spinning or non-spinning. Spinning reserves constantly maintain the same frequency as the grid but are not necessarily producing energy. Alternatively, non-spinning reserves represents the capacity of generators that have not started but can be up and running within a predictable amount of time.
Black Start	Generators that are able to start up with no assistance from the grid, assisting the grid in returning to normal operation after an outage event.

Transmission and Distribution Infrastructure Deferral

Load growth and increased installation of distributed generation can contribute to the need for grid infrastructure upgrades. However, these upgrades can be deferred or substituted with the strategic application of battery storage systems based on grid needs.[28] Installing battery storage systems means that the battery can absorb energy that would otherwise overload a line, or it can provide for local supply closer to the site or load growth to take pressure off a distribution line.

Component of Demand Response Programs

Many utilities are implementing demand response programs within their service territories. A number of utilities already have access to hundreds of megawatts of demand response resources through various programs designed to encourage flexible load. Over 1,300 MW of demand response in New York and 9,700 MW in PJM is available to the grid operator to meet peak load requirements.[29,30] Demand response resources take many forms, from controlling smart thermostats to turning off production lines in factories. Utility customers with onsite energy storage systems can contribute to demand response programs by discharging their systems in order to reduce their load or feed power back to the grid during peak hours. These programs provide program participants with

[28] Nexight Group. December 2010. Electric Power Industry Needs for Grid-Scale Storage Applications. Available at: https://www.energy.gov/sites/prod/files/oeprod/DocumentsandMedia/Utility_12-30-10_FINAL_lowres.pdf.

[29] PJM is the regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

[30] 2018 State of the Market Report for the New York ISO Markets. Potomac Economics, May 2019. Available at: https://www.nyiso.com/documents/20142/2223763/2018-State-of-the-Market-Report.pdf/b5bd2213-9fe2-b0e7-a422-d4071b3d014b and https://learn.pjm.com/-/media/about-pjm/newsroom/fact-sheets/demand-response-fact-sheet.ashx.

a financial incentive to participate in these programs that produce valuable reliability benefits to the grid.

Emergency Backup Power and Energy Resilience

Battery storage can support critical facilities through any sort of grid disturbance. Battery storage and on-site generation can be engineered to serve the needs of a critical facility from a few hours up to a few days depending on the configuration. Providing this backup power allows for grid operators to strategically respond to outages in emergency events. Installing energy storage at critical facilities can also be a short-term solution that can turn into an important part of a long-term resilience strategy. Solar and battery storage systems provide longer term resilience solutions. This may be particularly important in Puerto Rico where a major storm can cause sustained grid outages and road conditions that can prevent fuel deliveries needed to keep backup diesel generators running.[31]

1.3. Battery Energy Storage Applications

Lithium-ion battery storage systems are increasingly popular given the wide range of applications. The energy density of lithium-ion batteries allows them to be useful in a wide range of applications, including electric vehicles, and their scalability allows them to provide benefits in large utility-scale applications.

Households

Household systems can serve the needs of both the homeowner and grid operators. For the homeowner, residential battery storage allows the owner more control over their energy usage and provides a source of emergency back-up power during outages. Depending on the homeowner's electricity rate structure and the system configuration, battery storage can provide several economic benefits for the owner. Storage can help a residential consumer reduce load during peak pricing under a time-of-use (TOU) rate structure or other critical peak rates. Furthermore, storage can allow a household with solar to use locally produced energy during the times of household demand, which is often not coincident with peak solar production. If the homeowner enrolls in a program that allows utility control of their home energy storage system, residential energy storage can provide the grid with all of the benefits that utility scale storage can provide from numerous aggregated smaller energy storage systems. These systems generally require metering, communication, and control systems that provide grid operators the ability to manage the storage resources.

[31] Valuing the Resilience Provided by Solar and Battery Energy Storage Systems. National Renewable Energy Laboratory (NREL). January 2018. Available at: nrel.gov/docs/fy18osti/70679.pdf

The box to the right describes current BTM storage plus solar use in Puerto Rico.[32]

Commercial and Industrial

Commercial and industrial rates often include a demand charge in $/kW, applied to each facility's peak demand. Storage allows these facilities to reduce their peak energy demand resulting in substantial electric bill savings. Commercial and industrial facilities can also participate in energy arbitrage, where the facility charges the battery storage system when the cost of energy is low, displacing higher cost energy from the grid during other times of the day. Many larger commercial and industrial facilities maintain a backup generator to provide emergency backup power in the event of an outage. Battery storage systems are a viable alternative and can provide even longer duration resiliency benefits when coupled with on-site solar.

Off-Grid Remote

Battery storage can play an important role for off-grid renewable energy solutions. Storage allows sites located in remote areas to use solar or other renewable resources to meet local energy needs. Otherwise, these remote sites would often rely on generators that require a supply of fuel, which may be costly and difficult to obtain on a regular basis.

Minigrids and Microgrids for Energy Resiliency

The terms minigrid and microgrid are often used interchangeably. The U.S. Department of Energy defines microgrids as "a group of interconnected loads and distributed energy

SOLAR PLUS STORAGE IN PUERTO RICO

In Puerto Rico, behind-the-meter solar and storage installations have been rapidly increasing. This new installed capacity will help provide the benefits discussed here to both the homeowners and the grid operators. Sunrun has one of the largest market shares in Puerto Rico for behind-the-meter solar plus storage, likely because it was one of the first companies to send aid after the storm. The initial installations were in partnership with nonprofits to help restore energy to emergency facilities but have since expanded to residences as well. Tesla is another large contributor to the storage market and claims to have 11,000 energy storage projects underway on the island. While solar installations were popular and growing on the island prior to the hurricanes, the coupling of solar and storage has dramatically increased since the hurricanes, according to Gabriel Rivera from Verdifica. He notes that his customers are electing to self-consume their solar energy using energy storage so they can be less reliant on the grid. Solar plus storage systems have nearly doubled on the island of Puerto Rico since September 2017 and demand for these systems has increased faster than battery production has been able to supply new systems. Behind-the-meter solar plus storage installations will dramatically decrease demand on the greater electric grid and will be important to consider in future resource planning.

[32] Rodriguez, Ricardo. August 2018. *Battery Storage Accelerates Puerto Rico's Transition to a Distributed Energy Grid.* Navigant Research. Available at: https://www.navigantresearch.com/news-and-views/battery-storage-accelerates-puerto-ricos-transition-to-a-distributed-energy-grid.

resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected and island-mode."[33,34] For purposes of this report we adopt the definition of minigrids used in PREPA's IRP: "...zones of resiliency into which the system can be segregated during and after a major weather event ensuring that the load can be served using local resources."[35] In contrast, a microgrid serves a single building or campus aggregated through a facility's distribution service. See Figure 5 for illustration of a generic microgrid. PREPA's IRP considers the role of minigrids in meeting the resilience goals established for Puerto Rico's energy future and to a lesser degree microgrids. Both types of systems are capable of seamlessly connecting to a larger regional grid and islanding to become self-sufficient in the event of a disruption to the regional grid.

Battery storage systems are key to the implementation of self-reliant minigrids and microgrid systems. Minigrids and microgrids relying completely on renewable resources[36] require battery storage to reliably meet customers' energy demand over an extended period during a regional power outage.[37] Minigrid and microgrid strategies often include the use of the battery storage systems during normal operations as well to provide value and generate revenue or energy bill savings as discussed above. However, some amount of energy must be reserved in the batteries for use in the event of a regional grid outage. Keeping energy in reserve allows energy demand to be met locally during emergency events. This amount of reserve energy can vary depending on regional weather forecasts and the likelihood of severe weather leading to a regional grid outage. The storage system can be sized to provide energy from a few hours to a few days, depending on the amount of energy needed to meet critical loads.

33 The U.S Department of Energy's Microgrid Initiative. Department of Energy (DOE). 2012. Available at: https://www.energy.gov/sites/prod/files/2016/06/f32/The%20US%20Department%20of%20Energy's%20Microgrid%20Initiative.pdf

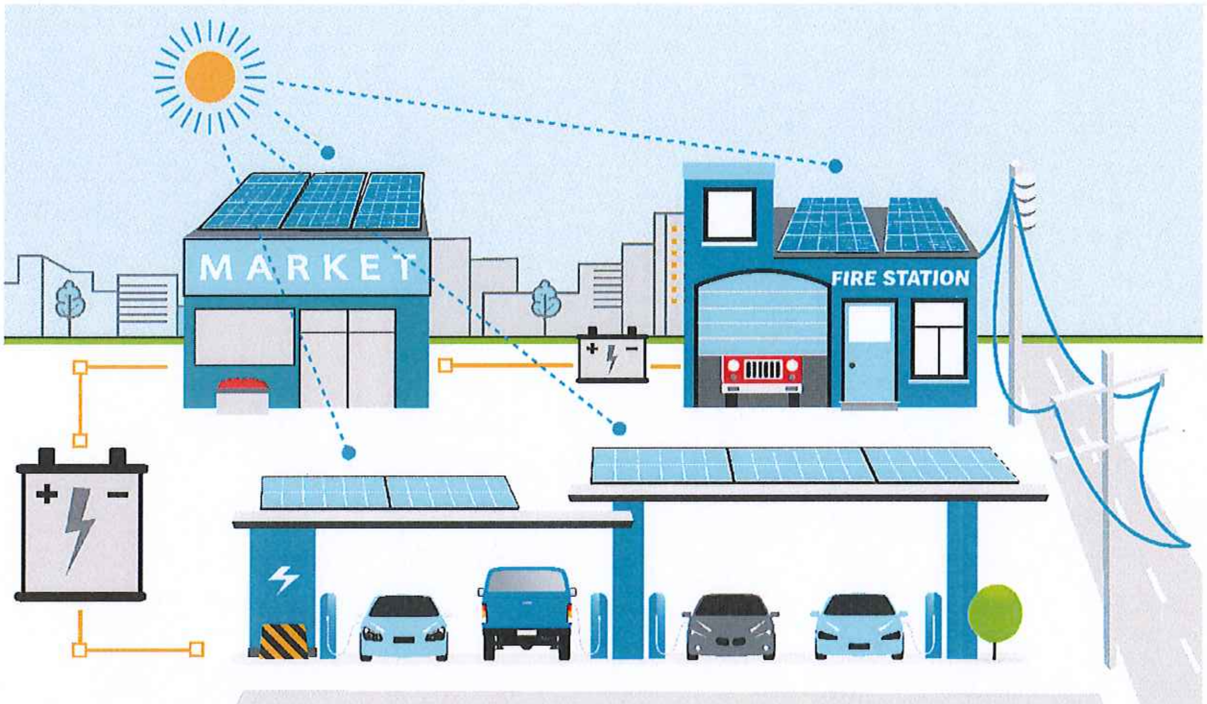
34 This is consistent with the definition that the Energy Bureau adopted in the microgrid rules. See Section 1.08(B)(20), Regulation on the Microgrid Development of the Puerto Rico Energy Commission.

35 PREPA IRP, page 1-2.

36 Note that the minigrid concept adopted in PREPA's IRP includes both renewable and thermal or fuel-based sources of generation.

37 Note that Puerto Rico's microgrid rules mirrors fairly closely the PURPA standards for a Qualifying Facility such that the bulk of the output from the facility must be renewable energy or employ a combined heat and power technology. Regulation on Microgrid Development of the Puerto Rico Energy Commission, Article 3.

Figure 5: Illustrative microgrid with renewable energy generation



Source: Synapse Energy Economics, Inc.

Minigrids are engineered to supply power during an outage to a defined geographic region. PREPA's IRP proposes establishing eight minigrids that encompass the entire island. As discussed in Section 0 below, PREPA includes minigrids as an important strategy in its IRP analysis.

Microgrids are focused on serving a single building or campus during a prolonged outage. Figure 5 illustrates some of the loads and assets considered in a generic microgrid. Implementing microgrids at critical facilities can ensure that power remains uninterrupted for those facilities in the event of a grid outage. For example, a hospital consisting of a few buildings with critical load can install a microgrid system consisting of battery storage, solar PV, and other generating assets. Once installed, the hospital campus will be able to seamlessly transition to island mode in the event of a grid outage and continue providing services to the public regardless of the state of the regional electric grid.[38,39]

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[38] The current microgrid rules in Puerto Rico are applicable to islanded microgrids only; however, rulemaking on interconnection standards for microgrids is currently in progress. Once interconnection rules are adopted, this will be possible.

[39] Note that island mode refers to the operation of a facility, campus, or discrete geographic region when the larger grid is down. Island mode allows energy to flow within the minigrid and microgrid when the larger grid is out and seamlessly reconnects when the larger grid is restored.

1.4. Battery Storage System Case Studies

While battery storage is still a fairly new technology, there are many examples of storage meeting grid needs in various applications. The use cases below highlight ways in which storage has been used to provide critical services to facilities and utilities that could be replicated in Puerto Rico.

Emergency Response Preparedness

Table 3: National Grid's application of storage for emergency preparedness

Project Specifications	
Company	National Grid
Location	Nantucket, MA
System Location	Distribution Level
Technology	Lithium Ion
System Size	6 MW/48 MWh

The geographic island of Nantucket receives energy by underwater lines in National Grid territory. To equip the island with power supply in a total outage event, National Grid installed a 6 MW/8-hour duration lithium-ion battery.[40] In addition to providing emergency response services, the battery will defer the need for line upgrades to the highly expensive underwater lines for up to 20 years. This system is particularly large to meet the increased summer demand of the island. In other seasons, it provides the island with longer duration power supply in the event of an outage, which is critical given the difficulty of line repair.

Renewable Energy Shift

Table 4: NextEra application of storage for renewable energy shift

Project Specifications	
Company	NextEra Energy Resources
Location	Pinal, AZ
System Location	Transmission Level

[40] Edison Electric Institute. October 2018. U.S. Electric Company Investment and Innovation in Energy Storage. Available at: https://www.eei.org/issuesandpolicy/Energy%20Storage/Energy_Storage_Case_Studies.pdf.

Technology	Lithium Ion paired with solar
System Size	10 MW/40 MWh

This transmission level energy storage system installed by NextEra Energy Resources is paired with 20 MW of PV to enable the Salt River Project to shift the solar energy to better align with customer demands.[41] The energy storage system's sole purpose is to help integrate the solar installation as a reliable grid resource. The storage is sized to be able to absorb excess solar produced while the sun is shining, and then dispatch that renewable generation for a longer duration to meet customer demand after the sun has set and the solar has ramped down.

The usefulness of the 20 MW PV installation to the grid operator is increased with the addition of the 10 MW/40MWh energy storage installation. The energy storage allows the PV to be a more reliable resource for grid operators and allows for a high penetration of renewable energy into the grid.

Puerto Rico's renewable energy goals will require increased installation of solar resources. Coupling these oncoming resources with energy storage will allow the grid operator to comply with Puerto Rico's renewable energy goals to meet the customer demand that does not always align with solar generation. This coupling will further prevent the need to over size and curtail solar installation on the island, because energy storage will be able to ensure all of the solar can be used.

Islanding Solar and Storage Microgrid

Table 5: Alabama Power's application of storage for storage and solar microgrid

Project Specifications	
Company	Alabama Power
Location	Hoover, AL
System Location	Customer Sited
Technology	Lithium-ion batteries paired with PV and natural gas backup
System Size	300 kW/680 kWh

This smart neighborhood microgrid installed in Hoover, Alabama aims to provide Alabama Power with a variety of services including renewable integration, energy storage integration, solar smoothing, load following, backup generation, seamless islanding/reconnect, ancillary services such as voltage and frequency regulation, and integration of customer-side loads.[42] This smart neighborhood is designed to measure the load of high demand components, such as HVAC and water heaters, and then coordinate the assets within the microgrid to dispatch in tandem with those loads.

[41] *Ibid.*

[42] Edison Electric Institute, 2018.

The benefits of the smart neighborhood microgrid includes the ability for the smart technology to enable the generation assets in the microgrid to closely follow the load of the houses, allowing the assets to function as efficiently as possible. The microgrid can also respond to grid needs and be accessed as a generation resource for the grid if local demand is already being met. The project has the capability to serve local customers, the grid, as well as provide resiliency benefits in an outage.

As mentioned previously, islanding from the electric grid is when a location is powered by distributed generation in the event of a grid outage. For a location to safely island, the assets or microgrid must be configured to prevent any unwanted backflow of energy into the larger grid. This precaution is to prevent line workers from being electrocuted when repairing any damaged lines that may have caused the greater outage.

The functions this smart microgrid aims to serve are well suited to meet grid needs in Puerto Rico. Resiliency considerations are now being included in transmission and distribution planning since the major storms that have debilitated the electric grid in Puerto Rico have accentuated this vulnerability. Smart microgrid solutions can allow Puerto Rico to provide customers a resilient grid that functions as efficiently as the currently market technologies allow.

Frequency Regulation

Table 6: NextEra's application of storage for frequency regulation

Project Specifications	
Company	NextEra Energy Resources
Location	Tucson, AZ
System Location	Distribution Level
Technology	Lithium Ion
System Size	10 MW/2.5 MWh

NextEra Energy Resources' energy storage installation provides many high-power services to the Tucson Electric energy grid.[43] The system's main use is to provide Tucson Electric with frequency regulation services. The system is used secondarily for voltage support, reserve capacity, and peak shaving. Both NextEra and Tucson Electric have the capability to dispatch the system. The duration of this system is 15 minutes at maximum power. The system can dispatch for a longer duration at a lower power, but systems sized for frequency regulation are generally sized to be high power and low duration to respond to short duration high power needs of frequency regulation.

Frequency regulation needs vary based on grid configuration and grid operator needs. Lithium-ion batteries can be a great resource for frequency response regulation as discussed earlier in this section. If the grid operators assess the frequency regulation needs of their assets and size a battery

[43] Edison Electric Institute, 2018.

accordingly, the battery system can provide the desired frequency response regulation needs, with additional capabilities if needed.

PREPA, like other balancing authorities, needs support for frequency regulation. Fossil fuel generators are often used for this purpose; however, energy storage has the capability to provide this service as shown by NextEra in Tucson, AZ. Unlike fossil fuel generators, energy storage can be charged locally by renewable generators and help reduce the demand of imported fuels needed for fossil fuel generators.

1.5. Battery Energy Storage System Economics

The cost of battery energy storage systems is driven by two key technical characteristics: power capacity and energy storage capacity of the system.[44] The ratio of the nameplate energy storage capacity to the nameplate power capacity determines the nameplate storage duration, which is the amount of discharge time at the system's power capacity before depleting its energy capacity. For example, a battery with 5 MW of power capacity and 10 MWh of usable energy capacity has a storage duration of two hours. Note, the system could discharge at a lower power rating. For instance, the same battery discharging at 2.5 MW would have a 4-hour storage duration.

The battery energy storage system nameplate storage duration generally falls into one of three main categories:[45]

Short-duration battery storage systems	• systems with less than 0.5 hours of nameplate duration
Medium-duration battery storage systems	• systems with nameplate durations ranging between 0.5 hours and 2.0 hours
Long-duration battery storage systems	• all systems with more than 2.0 hours of nameplate duration

The application being served dictates the storage duration need. For example, grid-scale batteries engineered to provide frequency response regulation are designed with a low nameplate storage duration. These systems are discharged and charged in short intervals to balance the instantaneous mismatch between the supply and demand for electricity to maintain the system frequency within

[44] The cost of BESS includes the battery pack plus the balance of system components, including the inverter and other components for interconnection and site preparation.

[45] U.S. Department of Energy, Energy Information Administration. 2018 Battery Storage Trends. Available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

an acceptable range. Longer nameplate duration battery systems are needed to store excess renewable energy generation and dispatch the energy over several hours when the renewable resource is unavailable. All things remaining equal, short storage duration batteries cost less on a unit cost per power capacity ($/kW) basis but cost more on a unit cost per energy capacity ($/kWh) basis relative to longer energy duration systems.[46]

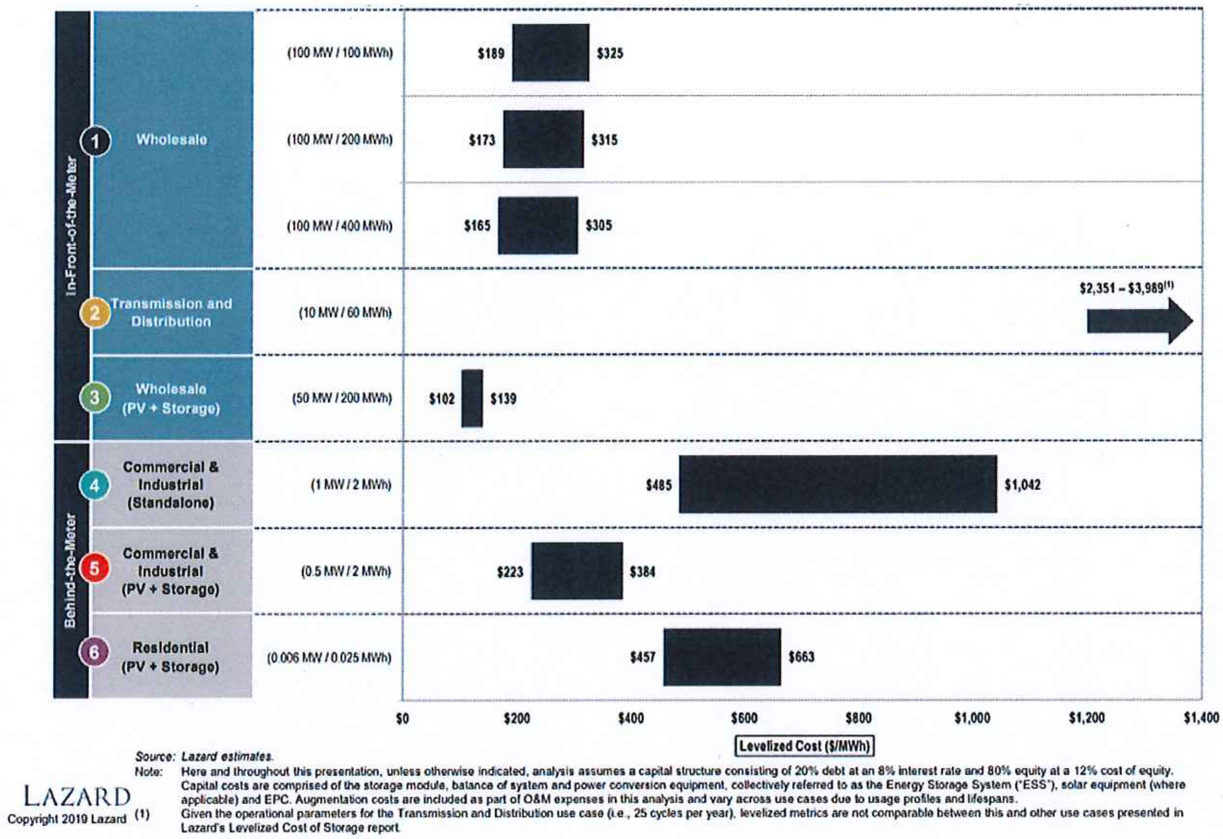
Another approach to evaluating battery energy storage system costs is to use the levelized cost of storage (LCOS). LCOS is stated in $/MWh ($/kWh) and is defined as the total lifetime battery energy storage system cost including capital costs and ongoing operations and maintenance costs over the system life divided by the total energy discharged over the life of the system.[47,48] The LCOS is calculated for each specific application and can thus be used to compare the cost of BESS relative to other energy technologies that serve the same application. Figure 6 provides Lazard's most recent LCOS estimates for 2019. The LCOS varies considerably between the different applications, with the lowest LCOS serving wholesale solar + storage applications, a particularly important application within the context of Puerto Rico's evolving electric grid.

[46] *Ibid.*

[47] Note that operations costs include the cost of the energy used to charge the battery, accounting for round-trip losses.

[48] Ilja Pawel. 2014. "The Cost of Storage – How to Calculate the Levelized Cost of Stored Energy (LCOE) and Applications to Renewable Energy Generation." 8th International Renewable Energy Storage Conference and Exhibition, IRES 2013. Available at https://www.researchgate.net/publication/260043756_The_Cost_of_Storage_-_How_to_Calculate_the_Levelized_Cost_of_Stored_Energy_LCOE_and_Applications_to_Renewable_Energy_Generation.

Figure 6: Unsubsidized levelized cost of storage, Lazard's 2019 estimates



Source: Lazard's Levelized Cost of Storage Analysis – Version 5.0. Lazard. November 2019. Available at https://www.lazard.com/media/451087/lazards-levelized-cost-of-storage-version-50-vf.pdf.

As discussed above, battery energy storage systems provide multiple benefits in a variety of applications. However, battery systems are unique relative to other generation and electric grid assets and thus it can be difficult to analyze battery system investments relative to traditional utility investments.[49] Given the fragmentation of value between stakeholders (ISO/RTO, utilities, host customers) and the fact that the functional requirements of storage to serve various applications are not well defined under existing market rules and other policies, it is difficult today to develop a sustainable business model. This is beginning to change, however, as the technology matures, policies and regulations evolve, and industry participants in several regions gain more experience financing, procuring, and operating battery energy storage installations.[50]

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49 U.S. EIA. 2018. Battery Storage Trends. Available at https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf.

50 *Ibid.*

The value that a battery system creates serving a single application is often insufficient to justify the initial investments and ongoing operation and maintenance costs.[51] Thus, the concept of battery energy storage system value stacking is gaining acceptance. Value stacking refers to assessing and capturing the multiple value streams that a single system can create. This could include providing a primary service such as backup power while simultaneously providing another valuable service such as participation in a utility program as a demand response resource. These "stacked benefits" of battery storage require detailed analysis of both the operational characteristics of the battery system and the requirements of the multiple value streams it seeks to captures.[52] Stacking battery energy storage values can tip the economics in favor of battery system investments.[53]

51 Rocky Mountain Institute (RMI). 2018. The Economics of Battery Energy Storage. Available at https://rmi.org/wp-content/uploads/2017/03/RMI-TheEconomicsOfBatteryEnergyStorage-FullReport-FINAL.pdf.

52 Brattle Group. 2017. Stacked Benefits. Available at http://files.brattle.com/files/7208_stacked_benefits_-_final_report.pdf

53 RMI, 2018, Battery Report.

2. Solar and Battery Energy Storage in PREPA's 2019 Integrated Resource Plan

PREPA is required under Act 57 of 2014 to prepare an IRP using a detailed and transparent planning process to evaluate all reasonable resources to meet the demand for electrical services over a 20-year planning horizon. Furthermore, considering the devastation caused by Hurricanes Maria and Irma in 2017, the IRP must consider resiliency, reliability, and stability of the power system, and be fully compliant with current and future environmental regulations.

PREPA retained Siemens Power Technology, Inc. (Siemens) to prepare its 2019 IRP, which includes extensive modeling to evaluate different scenarios and strategies. PREPA submitted the initial IRP on February 13, 2019, but the IRP was subsequently judged to be noncompliant with Puerto Rico's IRP regulations and previous Puerto Rico Energy Bureau (PREB) orders. PREPA submitted a revised IRP on June 7, 2019. The revised IRP was judged to be compliant with requirements in Regulation 9021 by PREB in an order dated July 3, 2019. As of the writing of this report, PREB is currently reviewing the IRP and has not yet made a determination about specific plans or recommendations offered in the IRP report.

This section of the energy storage study provides a high-level overview of the IRP process with a focus on the modeling assumptions and results for solar and storage over the 20-year planning horizon.

2.1. Overview of the PREPA IRP Process

The 2019 PREPA IRP is unique given the existing planning environment within the Commonwealth. This includes projections of declining load due to anticipated population emigration and the pursuit of aggressive energy efficiency goals. Furthermore, the IRP recommendations were developed to align with five key pillars adopted by the PREPA Governing Board in its *Vision for the Future of Power in Puerto Rico*. These include the following as stated in the IRP:[54]

[54] Siemens Industry Inc. June 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, Page 1-1 and 1-2.

Customer-Centric

- The IRP includes customer participation via energy efficiency, customer-side energy resources and demand response with a predominant role in the supply and consumption matrix of Puerto Rico, and empowering customers to participate and take ownership on their energy security and affordability.

Financial Viability

- Within the requirements of resiliency and reliability, the plan minimizes the cost of supply and drastically reduces the dependence on imported fuels and the associated volatility—thus, supporting affordable rates that promote financial viability at both sides of the meter.

Reliable and Resilient

- The IRP is centered on the concept of minigrids, defined as zones of resiliency into which the system can be segregated during and after a major weather event ensuring that the load can be served using local resources. In addition, minigrids must support effectively preparing, managing, and timely recovery from such event.

Model of Sustainability

- The IRP's implementation will transition the Puerto Rico electric system from one centered on fossil fuels to one in which renewable resources play a central, if not, predominant role. The IRP's implementation will drastically reduce emissions, increase the penetration of renewable generation, achieve compliance with all current regulations, and position Puerto Rico for future regulations.

Economic Growth Engine

- The distributed nature of the new generation resources that will have to be developed, the high levels of customer participation on the energy production, and the overall reduction in the system cost are expected to result in employment opportunities and economic growth for Puerto Rico. The IRP will support a reliable and economic system that will attract economic development in Puerto Rico.

As with any forward-looking analysis, uncertainties and risks exist that must be addressed. PREPA's IRP investigates a range of alternative scenarios, strategies, and sensitivity analyses intended to support determination of the best "no-regrets" decisions today leading to a least-cost preferred plan that provides specific guidance on both short-term and long-term investments.

PREPA'S IRP models five different scenarios that capture, "...a combination of system requirements needed to serve load, commodity prices, capital costs, and risks that influence the choice of resources serving PREPA's future load."[55] Within each scenario different cases were considered and different assumptions included about load growth, fuel prices, and the capital cost of renewable energy systems. The five scenarios were evaluated within each of three different strategies that characterize the grid from a centralized architecture (Strategy 1) to a more distributed architecture (Strategy 2). A more distributed grid relies on flexible generation closer to the customer, which is through a minigrid construct adopted in the IRP. Strategy 3 evaluated a hybrid architecture that attempts to capture the benefits of both a centralized grid with those of a more distributed grid.

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[55] Siemens Industry Inc. June 2019. Puerto Rico Integrated Resource Plan 2018-2019: Draft. Page 5-4.

The IRP initially modeled nine different sensitivities to isolate the impacts of certain important variables while holding other assumptions constant. These sensitivities ranged from deeper cost reductions than currently projected for solar and storage systems to different assumptions about natural gas prices and the retirement of existing generating stations. PREPA is in the process of modeling additional sensitivities as a result of further considerations concerning carbon emissions, LNG costs, contract amendments, and energy efficiency options. The key sensitivities for storage are Sensitivity 1, Sensitivity 6, and Sensitivity 8. These different sensitivities alter a variety of parameters including solar costs, storage costs, energy efficiency penetration, and retirement/addition of specific units. In summary, the IRP evaluated a large number of factors that impact Puerto Rico's energy future.

IRP and the Renewable Portfolio Standard

As noted above, Puerto Rico recently updated its RPS with the goal of meeting 100 percent of electricity demand with renewable forms of energy by 2050 and interim goals of achieving 40 percent by 2025 and 60 percent by 2040. The IRP modeling included a requirement that the RPS goals are met, including an earlier goal of 15 percent renewables by 2021. The lowest level of renewable contribution to energy supply from all the IRP modeling runs was 53 percent in 2038. The highest level modeled was 87 percent in the same year.[56] It should be noted that PREPA modeled the RPS goals with utility-scale renewables only, though with the expectation that PREPA would or could eventually purchase renewable energy credits from owners of distributed renewable energy systems. The system load used in the IRP modeling was adjusted assuming customers installed solar reducing their need for grid energy.

2.2. Minigrid Construct as Proposed in the IRP analysis

Under IRP Strategies,[57] PREPA models the Puerto Rico Electric system as a series of minigrids. A minigrid is a portion of the PREPA system that is able to operate as a separate electrical island in the event of severing of transmission ties across Puerto Rico. The minigrid construct reflects one form of resilient system design because a minigrid can retain reliable operations to some extent following a severe hurricane. Minigrid regions would contain a greater share of locally sited and distributed resources such as storage than if Puerto Rico remained fully dependent on large central station generation. The minigrid construct envisions significant investment in 115 kV and 38 kV transmission infrastructure—$5.9 billion total—[58] and additional distribution system investment.

Each minigrid region (see Figure 7) would contain sufficient capacity and energy resources to meet most of the local demand within the region prior to full restoration and reconnection to the rest of

[56] PREPA 2018 / 2019 IRP. Exhibit 8-3: Summary of Results by Scenario, Strategy and Load Growth, Page 8-8.

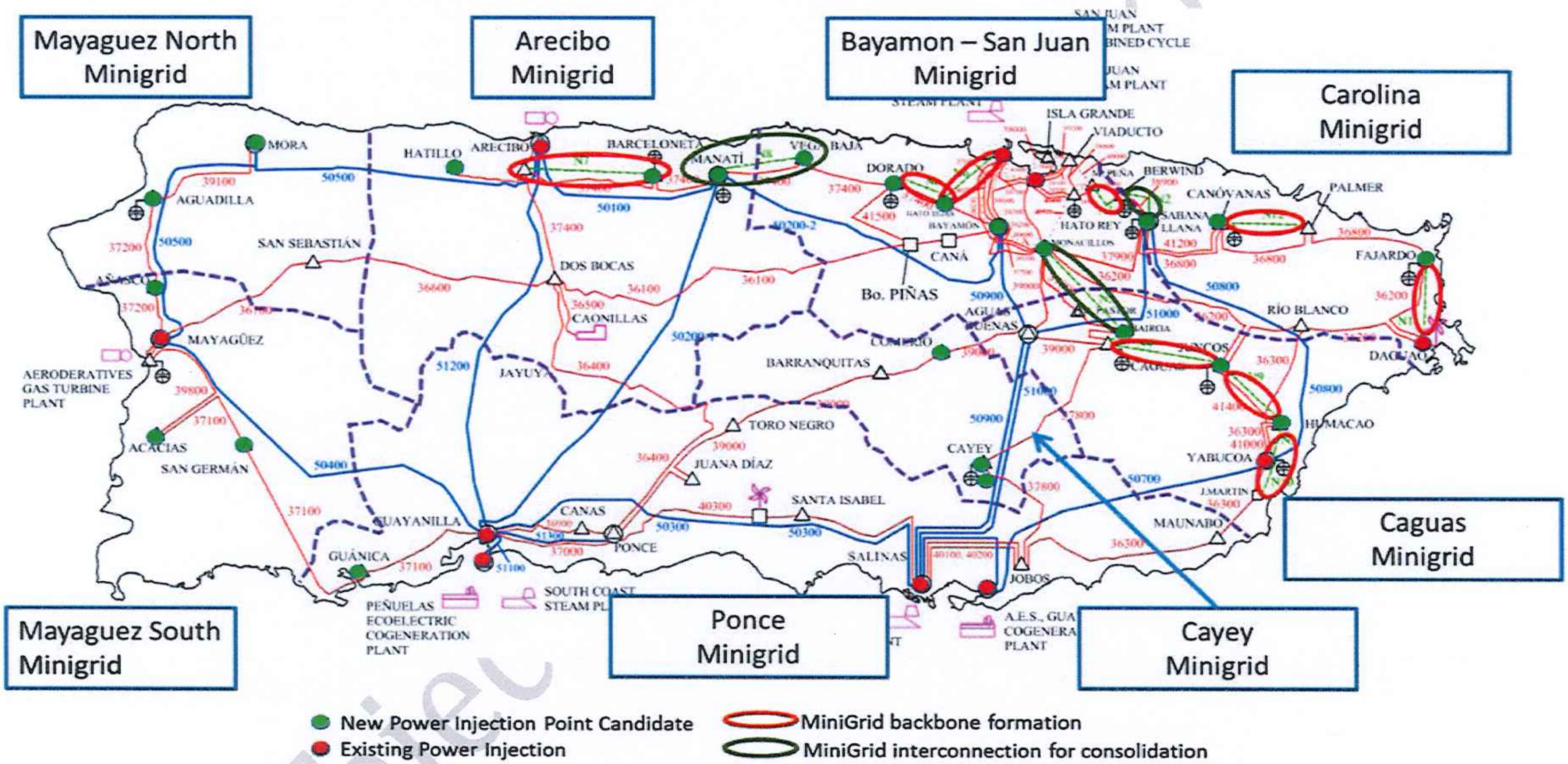
[57] Minigrid information in the IRP is primarily contained in the IRP Main Report (REV2, filing 6/7/2019), Appendix 1, and associated workpapers. While some information is confidential, discussion in this section is based on publicly available documents, including the redacted version of Appendix 1 (IRP2019 EX 1.01C Appendix 1_Section2_Redacted).

[58] 2019 IRP, Appendix 1, Exhibit 2-93.

the transmission grid. During normal operation, the minigrids would be interconnected with the rest of the electric power system via transmission lines. In the event of a hurricane, the minigrids would be able to operate independently for an extended period of time prior to complete system recovery.

The minigrids are designed to ensure continued supply to "critical" load feeders (circuits containing loads most necessary for the safety and health of residents) and provide timely recovery of the remaining loads, categorized by PREPA as "priority" and "balance" loads.

Figure 7: PREPA transmission system map with proposed 115 kV investments



Source: IRP2019 EX 1.01C Appendix 1_Section2_Redacted.

2.3. Solar and Battery Energy Storage Assumptions

Price and Costs

The solar and battery energy storage system costs are based on the National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) 2018. NREL ATB anticipates utility solar capital cost will fall at a compound rate of 1.5–3 percent from 2018–2050. Solar and solar paired with energy storage such as lithium-ion batteries were modeled as part of the IRP. Lithium-ion batteries are expected to be the mainstream technology for energy storage within the IRP time horizon. The capital costs for battery systems consist of the battery cell, the power conversion system costs, EPC (engineering, procurement, and construction) costs, storage module, and balance of system costs. Table 7, below, provides the capital costs and operating costs for lithium-ion batteries of different durations. Note that one of the sensitivities analyzed in the IRP considers deeper cost reductions for solar and storage than anticipated in the NREL 2018 ATB.

Table 7: Projected energy storage capital and operating costs

Construction Year	All-in Capital Costs			Operating Costs	
	2-hour Li-ion Battery Storage	4-hour Li-ion Battery Storage	6-hour Li-ion Battery Storage	Fixed Operating Costs	Variable Operating Costs
2018	832	1,392	1,953	9.09	2.67
2019	734	1,218	1,703	8.96	2.60
2020	674	1,110	1,546	8.95	2.58
2021	635	1,041	1,447	8.81	2.51
2022	596	972	1,349	8.67	2.43
2023	576	936	1,296	8.54	2.36
2024	556	899	1,243	8.41	2.29
2025	534	861	1,188	8.40	2.28
2026	523	843	1,163	8.26	2.20
2027	512	825	1,138	8.12	2.13
2028	496	800	1,104	7.99	2.06
2029	485	782	1,079	7.86	1.99
2030	474	764	1,054	7.85	1.97
2031	462	746	1,031	7.71	1.90
2032	450	728	1,007	7.57	1.82
2033	443	717	992	7.44	1.75
2034	431	700	969	7.31	1.69
2035	419	682	945	7.30	1.67
2036	407	664	922	7.19	1.64
2037	395	647	898	7.08	1.62
2038	383	629	875	6.97	1.59

Source: Siemens, NREL.

Limitations Placed on Solar and Storage Deployments

The IRP assumes an accelerated timeline for solar projects, assuming 12 months for the development period from RFP through financing and 12 months for construction. Limitations on annual PV and BESS additions were placed on most of the scenarios analyzed. These limitations are based on perceived constraints to planning, designing and procuring the required renewable resources and BESS. These constraints are in the form of annual installed MW limits based on the scenario under consideration, which are presented below in Table 8 and Note: These constraints did not apply to Scenario 3.

Table 9. In some of the modeling runs, these constraints were relaxed.[59]In conclusion, most scenarios restricted the solar and BESS build out based on the values in Table 4 except for Scenario 3. The Energy System Modernization scenario had more stringent limitations placed on the build out of solar and BESS.

Table 8: Solar and BESS annual installation limit/constraints for Scenarios 1, 4, 5, and 6

	2019	2020	2021	2022-2038
Solar PV Annual Installation Limit	0	300	300	600
BESS Annual Installation Limit	60-180	300	300	600

Note: These constraints did not apply to Scenario 3.

Table 9: Solar and BESS annual installation limit/constraints for energy system modernization (ESM)

Year of Completion	2019	2020	2021	2022	2023	2024
Photovoltaic Resources (PV)						
Annual Increment (MW)	-	-	240	480	480	300
Cumulative Total (MW)			240	720	1200	1500
Battery Energy Storage Systems (BESS)						
Annual Increment (MW)	20	100	160	160	160	150
Cumulative Total (MW)	20	120	280	440	600	750

While there might be limits to the amount of solar and BESS that can be installed in any given year, a more inclusive discussion with industry stakeholders may be necessary to estimate what those limits might be for Puerto Rico.

[59] This was reflected in the IRP's Scenario 3, which did not restrict the annual buildout of solar and BESS, resulting in the most aggressive deployments of solar and BESS relative to the other scenarios modeled.

Demand-Side Resources

Distributed Generation (DG) in Puerto Rico consists of DG resources connected to the distribution system and DG resources connected to the transmission system. Both of these categories of DG consist of rooftop solar and some limited combined heat and power systems. At the time of the IRP, there were 130 MW of distribution DG and 42.75 MW of transmission DG. PREPA based its projection of distribution level DG on EIA, Annual Energy Outlook (AEO), and residential sector equipment stock forecasts. There was no attempt to determine current levels of behind-the-meter storage, nor did the IRP project future adoption of behind-the-meter storage systems. PREPA indicated that the modeling of utility-scale battery resources does not imply an intentional limitation on potential behind-the-meter systems—though "downstream" benefits of such systems (e.g., system-loss savings) were not captured in the IRP results.

Siemens reviewed scenarios in which the customer decides to self-supply their entire electrical consumption and completely disconnect from the grid. This is often referred to as grid defection. Siemens calculated the total cost for a grid defection alternative. The costs for this scenario were based on the rooftop PV costs estimates and NREL 2018 ATB's estimates for a 6-hour lithium-ion storage system. Based on the results, the total costs to the end customer of grid defection alternatives are estimated to be $216/MWh in 2019, $179/MWh in 2025, $150/MWh in 2030, and $129/MWh in 2038. Electric customers typically choose grid defection when they find it cheaper to produce their own electricity and no longer rely on the grid to supply their home. The IRP, however, did not include grid defection in the load forecast or any of the modeled scenarios.

2.4. Summary and Conclusions

The IRP analysis included modeling various combinations of scenarios, strategies, and sensitivities discussed above. PREPA narrowed the initial 76 runs to a set of 35 cases to explore in greater detail within the IRP. Ultimately, based upon their interpretations of the IRP modeling results, PREPA identified two resource plans as both low cost and practicable: The Energy System Modernization (ESM) and Scenario 4 Strategy 2 (S4S2). Notably, PREPA has not, to date, indicated a preference for the more extensive solar PV and battery storage buildout described by other IRP scenarios, even though under some assumption sets those scenarios cost less than PREPA's currently indicated preferences. Again, no determination has been made about the proposals set forth in the IRP. The information presented here is to illustrate the results of planning and modeling contained in the draft 2019 IRP.

Based on these findings, the filed IRP puts forth an action plan based on the ESM and a set of near-term steps to begin the transformation of Puerto Rico's energy system. This includes the installation of 1,380 MW of solar and 920 MW of storage in the first four years of the plan. Notably, alternative Scenario 3 (S3S2) and Scenario 4 (S4S2) include the installation of 1,320 MW of battery storage by 2025—400 MW more than the ESM plan. Table 10 below shows the storage and solar capacity buildout across several select scenarios.

ESM and S4S2 result in a similar storage buildout by the end of the study period in 2038. A key difference between the two plans is the location of where the new large 302 MW CCGT additions are added and conversion of the existing Mayagüez peaking units to natural gas. Based on these differences, the S4S2 results in a higher addition of solar over the timeframe of the IRP compared to the ESM.

Scenario 3, Strategy 2 results in the highest buildout of solar and storage across the timeframe of the IRP due to the assumption of lower costs for renewables and higher availability of renewable resources. Based on the IRP results, it also results in the lower production costs compared to ESM and Scenario 4. The higher renewable penetration from this scenario results in a high buildout of storage in order to meet the peak demand on the system.

Scenario 5 results in the lowest buildout of storage across the timeframe of the IRP due to the full permitting and regulatory approval of the Aguirre Offshore Gas Port (AOGP) moving forward. This scenario is also based on Strategy 1 which is a traditional and centralized energy program and has minimum generation requirements to meet peak demand on a regional basis.

PREFERRED SCENARIOS

Draft IRP Excerpts

ENERGY SYSTEM MODERNIZATION (ESM)

This is a variation of Scenario 4 advanced by PREPA...that includes a set of pre-defined investments decisions that considers procurement options presented by the Public Private Partnership Authority, pricing structures necessary to retain existing natural-gas fired generation in the south, and locational alternatives for new large scale CCGTs."

SCENARIO 4 STRATEGY 2 (S4S2)

"Scenario 4-- Gas to Yabucoa (east) and to Mayagüez (west) through ship-based LNG and gas to the north is supplied through land-based LNG at San Juan. The land-based LNG at San Juan is assumed to acquire the required permitting approval. The Scenario uses the base case assumption of solar and storage costs and availability."

"Strategy 2 - Reflects a distributed system of flexible generation, and micro or mini-grids and hardening of existing infrastructure around Puerto Rico, which emphasizes resiliency and closeness to the customer. In this strategy, most of the load is supplied from local supply resources that can be isolated from the remainder of island during a major event but still supply all or a portion of the nearby load. It is defined in terms of a minimum level of the load to be supplied by local resources (e.g., 80%)."

Table 10. Storage and solar capacity (in MW) buildout by scenario for milestone years

	2020	2025	2028	2035	2038
ESM Additions					
Battery_2hr	-	240	280	400	520
Battery_4hr	240	640	760	800	800
Battery_6hr	-	40	80	320	320
Total Battery	240	920	1,120	1,520	1,640
Solar	300	2,400	2,580	2,580	2,580
S4S2B Additions					
Battery_2hr	-	200	280	440	440
Battery_4hr	120	720	720	720	720
Battery_6hr	120	400	400	480	480
Total Battery	240	1,320	1,400	1,640	1,640
Solar	300	2,220	2,820	2,820	2,820
S3S2B Additions					
Battery_4hr	240	840	1,200	1,680	1,760
Battery_6hr	-	560	720	960	1,280
Total Battery	240	1,400	1,920	2,640	3,040
Solar	300	2,820	4,140	4,140	4,140
S1S2B Additions					
Battery_2hr	-	480	480	480	480
Battery_4hr	240	760	760	840	880
Battery_6hr	-	40	40	240	360
Total Battery	240	1,280	1,280	1,560	1,720
Solar	300	2,580	2,700	2,700	2,700
S5S1B Additions					
Battery_2hr	-	560	560	560	560
Battery_4hr	240	640	640	720	720
Battery_6hr	-	-	-	80	200
Total Battery	240	1,200	1,200	1,360	1,480
Solar	300	2,580	2,580	2,580	2,580

3. Additional Scenario Analysis of Solar and Battery Energy Storage

The deployment of storage across Puerto Rico will depend on multiple factors. The key drivers are the cost of the resources, demand, fuel prices, policy requirements such as the RPS, and transmission flow constraints across regions. The results presented by Siemens as part of the IRP are based on specific scenarios and constraints to deployment of both solar and storage as discussed in the previous section of the report. Synapse conducted additional modeling in order to assess the deployment of utility-scale storage under a wider range of sensitivities and to quantify the impact of the various drivers. As part of the results, we present the relative buildout of storage and solar and the percentage of generation from each of these resources based on the sensitivity to various factors.

The Synapse modeling analysis involves building a base case influenced by the modeling assumptions provided in the IRP. The base case is used as a baseline in order to understand the impact of the different scenarios we evaluate relative to the IRP in terms of the build out of utility scale solar and BESS. Synapse utilized the EnCompass capacity expansion and production cost model, licensed from Anchor Power Solutions, to conduct the analysis.

Synapse modeled one baseline scenario[60] and three additional scenarios not considered in the IRP. (Please see Appendix A: System Modeling Methodology and Results for a more complete discussion of the scenarios Synapse evaluated.):

Base Case	•This scenario creates the baseline and was designed to represent as closely as possible the two preferred plans identified in the IRP.
No Import Constraints	•The no import constraints scenario removed the constraint that limits the transfer of electricity between the eight minigrids proposed in the IRP.
Unlimited Renewables	•The unlimited renewables scenario removed the annual installation constraints on solar and storage discussed in the section above.
Reduced Gas Peaker Builds	•This scenario removes one of the fixed decisions in the IRP, specifically the requirement that the minigrids are served with gas-fueled power plants to meet the energy demands when the larger Island grid is down.

[60] Note that this does not represent an endorsement of the preferred plans identified in the IRP it was simply a basis to establish a baseline for use to explore additional energy planning scenarios not covered in the IRP.

As discussed above, PREPA's IRP analyzed a variety of parameters that impact the Island's energy system. Several constraints were included throughout the analysis, including the requirement that gas-fired plants serve the critical load within the microgrids and that there are limits on the amount of solar and storage that can be built each year in Puerto Rico. Synapse found the following in its analysis of the additional scenarios:

- Constraining the import limits between the proposed eight minigrids impacts the types of resources that are selected in the modeling, most notably in the reduced selection of more distributed resources.
- When the annual constraints on the amount of solar and battery energy storage systems are removed, the model selects more of these resources to meet the Island's energy needs.
- The requirement that gas-fired generation be used to meet the critical and priority loads within each of the eight microgrids is a significant constraint that limits the amount of solar and battery energy storage selected.

3.1. Solar and Storage Capacity by Scenario

Figure 8 and Figure 9 below show the capacity of storage and solar that is built in each of the additional scenarios Synapse ran. The trends observed in both the storage and solar builds are very similar. Based on the results, the scenario with the highest buildout of storage and solar capacity is the Reduced Gas Peaker Build scenario. This scenario places no constraints on the amount of solar that can be deployed across the Island and no longer provides the gas-fueled peaking plants as fixed decisions to the model. The scenario with the lowest buildout of storage and solar capacity is the No Import Constraints scenario. However, this scenario still meets the RPS requirements. This implies that the creation of minigrids with requirements to meet local generation and peak demand at a regional level may be drivers to the buildout of solar in the eight regions. Removing these constraints allows for unlimited transfer between the regions and thus greater reliance on larger power plants and less need for distributed solar and battery storage.

The Reduced Gas Peaker Build scenario eliminates the requirement that the minigrids must be served by gas-fueled plants, but rather lets the model choose between the gas peaking units, solar, and batteries. All annual constraints on the solar and storage builds are removed in this scenario. This scenario results in the highest buildout of solar and storage. The Unlimited Renewables scenario also results in a slightly higher buildout of solar and storage relative to the base case. Although the gas peaking units continue to be fixed decisions to the model, all annual constraints on solar and storage are removed in this scenario. The assumption that critical and priority loads be met by thermal resources remains a significant constraint on buildout of both solar and storage resources in the IRP. All scenarios continue to meet the RPS requirements of 60 percent renewable generation by 2040.

Figure 8: Storage capacity by scenario from 2019 to 2038

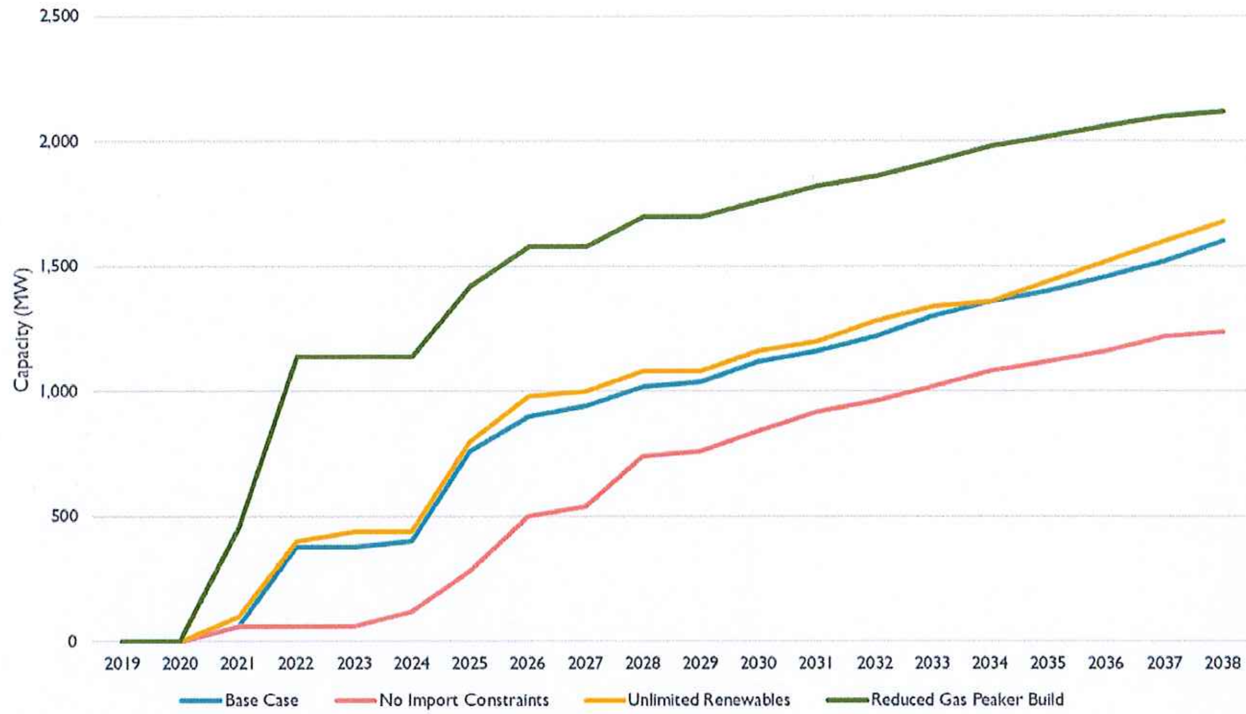
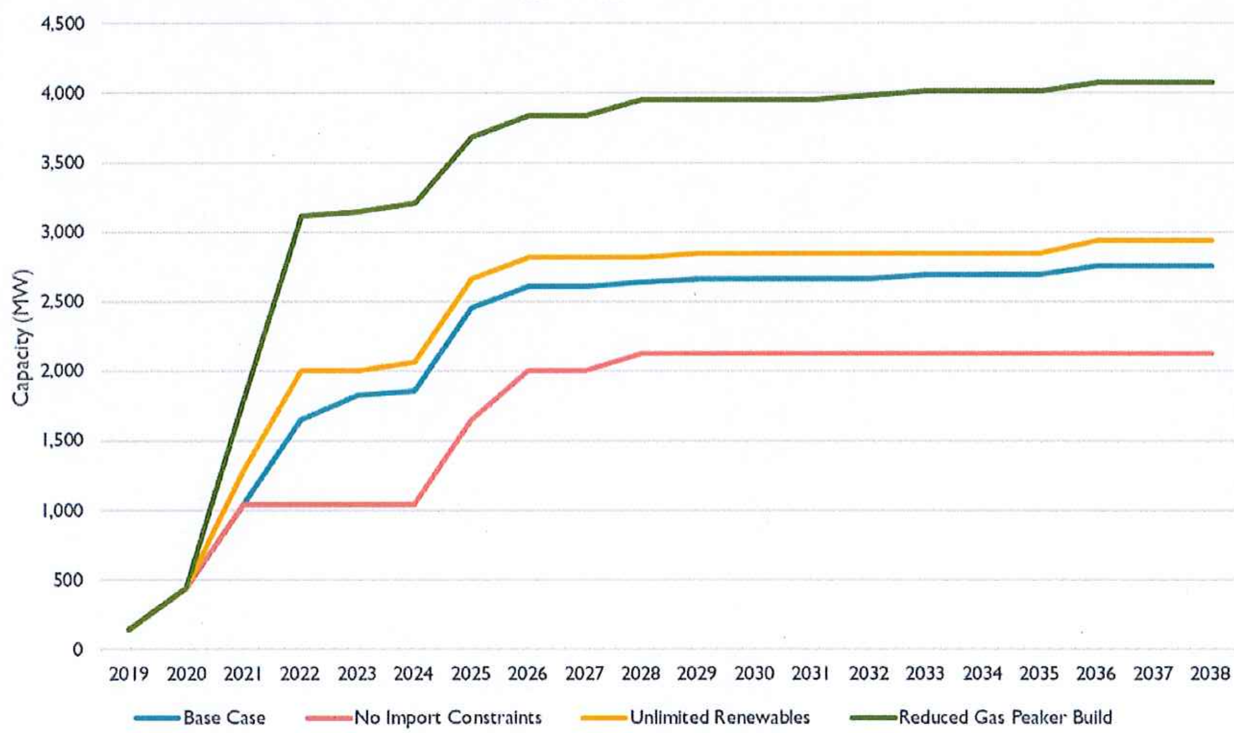


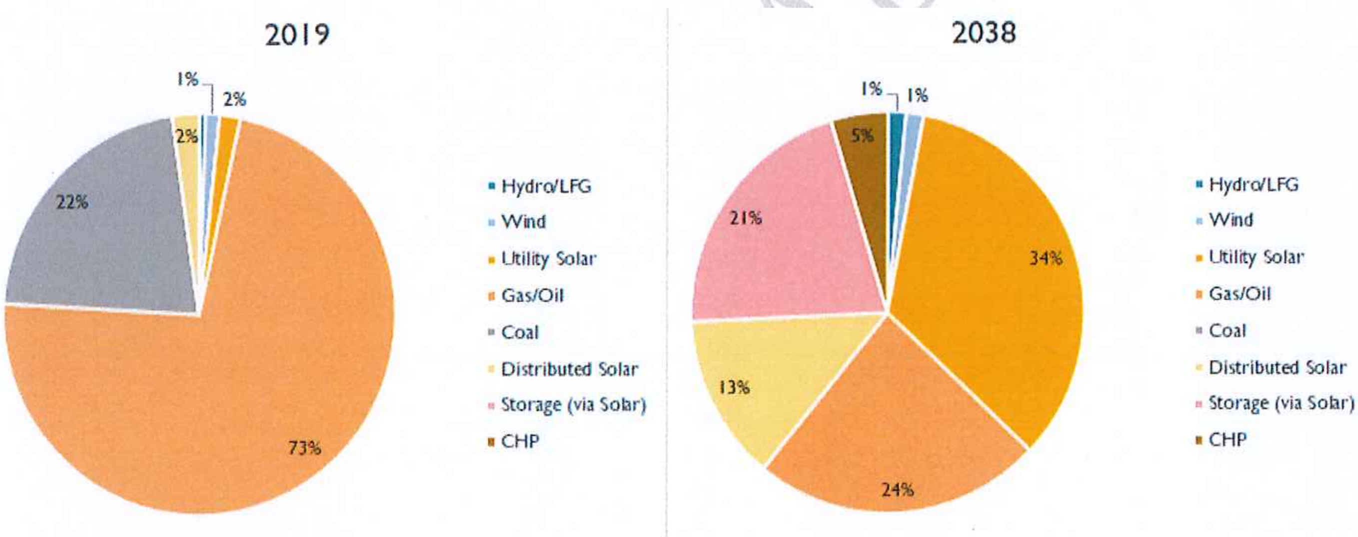
Figure 9: Solar capacity by scenario from 2019 to 2038



3.2. Energy Generation by Scenario

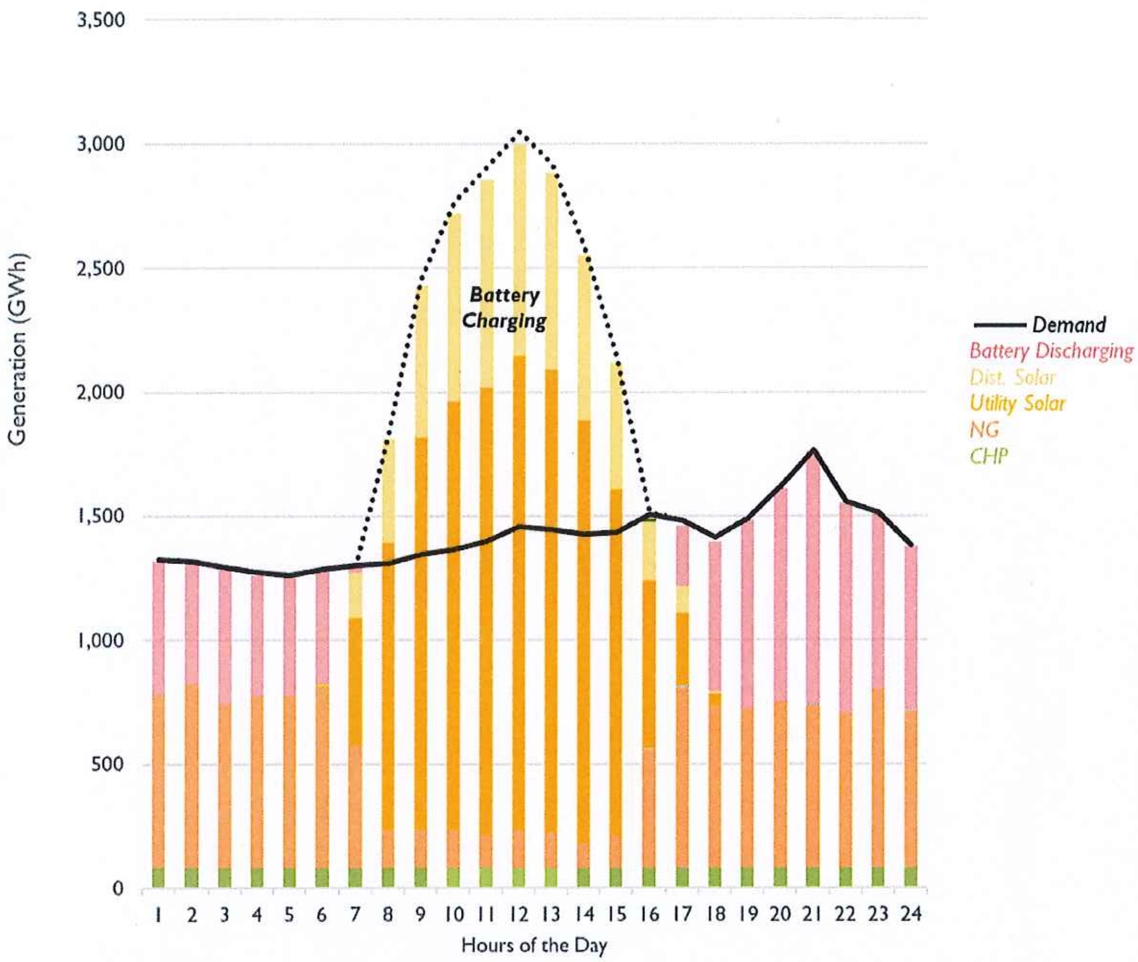
Base Case: Figure 10 shows the base case generation portfolio in 2019 and 2038. The Base Case generation in 2019 mostly consists of coal, oil, and gas generation. The total demand in 2019 is 17,637 GWh across the entire island. In 2038, the demand has decreased to 11,000 GWh due to aggressive energy efficiency measures. In addition, the IRP outlines distributed generation consisting of distributed solar and Combined Heat and Power. These resources have been modeled as supply-side resources to meet the demand. Fossil fuel generation has decreased due to the AES coal plant retirement and the additional gas retirements. The total generation for utility-scale solar is 34 percent of the portfolio, distributed solar is 13 percent, and battery storage (primarily charged through solar) is 21 percent of the portfolio. Hydro, landfill gas, and wind are a small component of the generation portfolio. However, they are also contributors to meeting the RPS requirement of 60 percent by 2040. The Base Case scenario exceeds the RPS requirements with the total percentage of renewables closer to 70 percent of the entire portfolio by 2038.

Figure 10: Base Case generation in 2019 and 2038



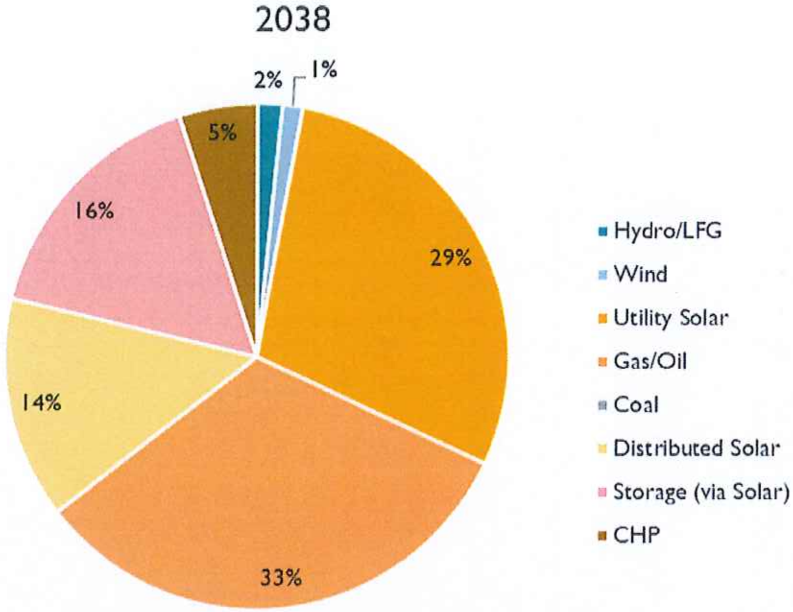
Storage and solar follow similar trends in buildout across each of the scenarios. This is due to the fact that solar production primarily occurs during off-peak hours of the day. As can be seen below in Figure 11., on a typical day in August the peak end-use demand occurs between the hours of 8 pm – 10 pm, whereas the majority of the solar production occurs between 7 am and 4 pm. It is during these hours that the batteries are charging. The ability to charge the batteries through solar reduces curtailment of these resources and allows the peak demand to be met by batteries that are charged primarily through solar and a small percentage of gas and combined heat and power units.

Figure 11. Base Case, hourly generation for typical day in August 2038



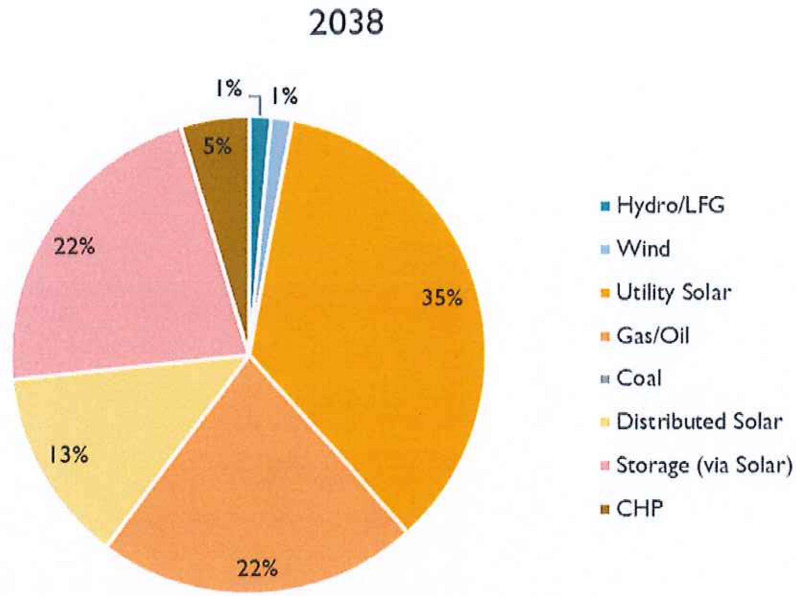
No Import Constraints: For this scenario, the 2019 generation portfolio is similar to the Base Case, however the generation in 2038 has significantly less solar and storage deployment compared with the Base Case 2038 generation profile. As discussed above, this is due to the unlimited imports that are allowed between the regions that then no longer require additional resources to meet the peak demand and generation locally. The thermal resources required by the minigrids to meet critical and priority load have been provided to the model as fixed decisions and continue to be limiting more solar and storage builds across the regions. Figure 12 below shows solar generation dropping to 29 percent of the total generation, and battery storage generation—which occurs primarily through solar—is reduced to 16 percent. Distributed solar generation is 14 percent. Other renewables such as wind, hydro, and landfill gas comprise approximately 3 percent of the total generation portfolio. The scenario is RPS compliant, with approximately 60 percent of the generation in 2038 coming from renewables.

Figure 12: No Imports Constraints generation in 2038



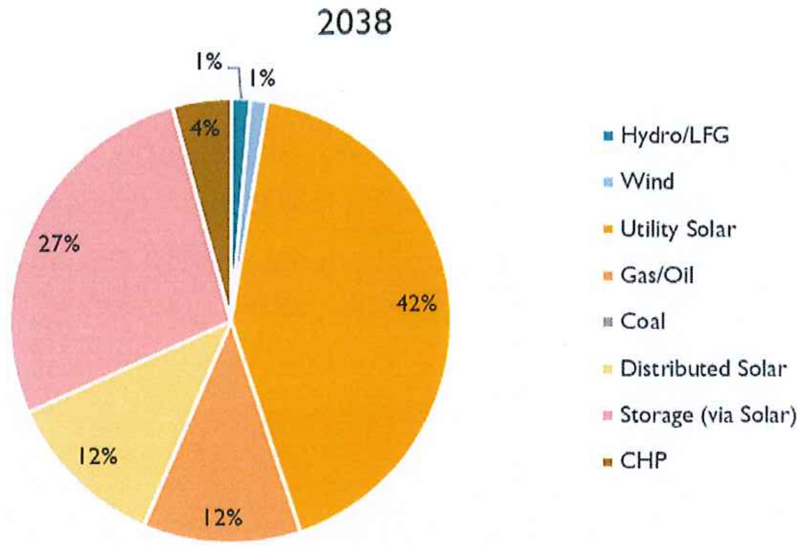
Unlimited Renewables: For this scenario, the 2019 generation portfolio is similar to the Base Case. The generation in 2038 is incrementally higher than solar and storage deployment compared with the Base Case 2038 generation profile. Post 2020, the constraints on renewables are removed, allowing the system to build incremental solar and storage capacity to meet the remaining generation. Again, the thermal resources—embedded in the model as fixed decisions—continue to limit solar and storage builds across the regions. Compared with the Base Case, as shown in Figure 13, the percentage of solar generation has gone up to 35 percent and battery generation is 22 percent of the total generation. This scenario exceeds the RPS requirement, with close to 70 percent of the generation coming from renewables in 2038.

Figure 13: Unlimited Renewables generation in 2038



Reduced Gas Peaker Build: For this scenario, the 2019 generation portfolio is similar to the Base Case. However, the generation in 2038 has significantly higher solar and storage deployment compared with the Base Case 2038 generation profile. This increase is to meet the reduced generation from the gas peaker plant builds compared with the Base Case, since the model is no longer forced to choose the peaker plants as fixed decisions. Compared with the Base Case, as shown in Figure 14, there is a considerable increase in generation of both solar and storage: The percentage of solar generation goes up to 42 percent and battery generation becomes 27 percent of the total generation. The gas generation is 12 percent of the total generation portfolio, substantially reduced from the Base Case.

Figure 14: Reduced Gas Peaker Build generation in 2038



3.3. Conclusions and Next Steps

Storage and solar deployment across the island depend on various drivers. These include the cost of the resources, RPS requirements, fuel prices, the requirement to meet critical and priority loads within a minigrid area, and others. The IRP analysis conducted by Siemens using the Aurora model includes several of these factors.

The RPS targets in Puerto Rico are 20 percent renewable penetration by 2022, 40 percent by 2025 and 60 percent by 2040. Although battery energy storage systems cannot count towards the RPS, they are crucial in meeting the RPS requirement. This is primarily because utility-scale and distributed solar, which are intermittent resources, are the key contributors to meeting the RPS requirement. Since the peak use of energy on the Island is in the evening and most solar production occurs during the daytime between the hours of 7:00 am and 5:00 pm, storage provides the ability to meet the evening peak demand by charging during the peak solar production times. This prevents curtailment of the solar production with the result that the combination of solar and storage to meet the peak demand can be done in a more clean and cost-effective manner than gas peaking units.

Based on Siemens' results for preferred scenarios, the gas-fueled plants required to meet critical and priority load were embedded in the model as fixed decisions in the Base Case. In other words, for the Base Case scenario the model was forced to choose fossil fuel thermal resources for meeting critical loads rather than seeking out the most cost-effective options. This had the result of limiting the amount of solar and storage built across the regions. The result has been substantiated through the Reduced Gas Peaker Build scenario, which builds considerably more storage and solar after removing the annual constraints on storage and solar as well as allowing the model to optimize between solar, storage and gas peaking units. The model chooses a higher buildout of solar in conjunction with storage in lieu of the gas peaking units to meet the critical and priority loads. The No Imports Constraints scenario provides additional evidence that allowing for unlimited imports between the regions while still forcing the model to choose thermal resources results in a lower storage and solar buildout since there is no longer a need for additional resources to meet the peak demand and generation locally. All generation is being met by the thermal resources provided as fixed decisions. The buildout of solar and storage in this scenario is being driven by the RPS requirements and not by whether or not they are cost-effective relative to the cost of gas-fired peaking units.

For the Unlimited Renewables scenario, the model has fewer constraints on solar and storage builds. The reduced constraints increase the deployment of solar and storage resources over the timeframe of the IRP but only incrementally. This indicates the current IRP constraints may be too stringent and there is a potential that any arbitrary constraints would limit a higher potential for cleaner resources to meet the demand requirements. Thus, it may be reasonable to revisit the reasonableness of the annual constraints based on solar and battery storage. However, as discussed above, the key constraint continues to be the assumption that thermal resources, i.e., gas peaking units, are required to meet the critical and priority loads. This may undermine the ability of storage paired with solar to meet these loads in a more cost-effective manner while still contributing to the RPS requirements and maintaining the reliability of the system on the Island.

The results provided are preliminary results and are not meant to recreate the IRP. Rather they are meant to inform the storage study. The Base Case has been closely calibrated to the IRP. It is not expected to be a true representation or validation of any specific scenario although it is loosely based on assumptions in PREPA's currently preferred scenario. The analysis is meant to provide only an evaluation of the impact on storage (in conjunction with solar) deployment across the Island based on some key sensitivities. The next steps in the analysis require a more in-depth calibration to the specific scenario results within the IRP with the purpose of evaluating the most cost-effective portfolio that would meet both Puerto Rico's resiliency and RPS goals.

4. Minigrid and Microgrid Analysis for Resilience

This section presents an alternative to the minigrid construct modeled in PREPA's IRP. The analysis by Synapse offers—for illustrative purposes—a calculation by zone of the potential cost and generating capacities of infrastructure for a microgrid strategy using only solar PV and battery systems to meet the critical and priority loads. First, we discuss underlying assumptions of the IRP's minigrid construct, because these are an important reference for the microgrid analysis. Next, we present a microgrid strategy as a potential option for achieving a more resilient electrical system.

4.1. Assumptions in the IRP Minigrid Analysis

The IRP's stated intent of creating a more resilient electrical system with more distributed and flexible generation is sensible, given the risk of future hurricanes causing island-wide power grid outages. Nonetheless, to reduce the burden on ratepayers, the IRP's approach should be evaluated closely to minimize the capital expenditures needed to achieve the intended goals .[61] In particular, the IRP does not fully consider the role that battery storage could play in supporting a least-cost resilient system—that is, an optimal resiliency solution may better leverage battery capabilities. Three underlying assumptions of the IRP minigrid strategy which warrant further review include:

Infrastructure sizing based on "deemed" critical loads	•The "deemed" critical loads are based on serving a distribution feeder and not targeted critical facilities. This could result in an overestimate of the load that must be served to meet the overall resilience goal.
Assumption that the critical loads can only be served by thermal resources	•As discussed in Section 4 above, the minigrid construct is based upon the fixed decision within the IRP that the critical loads within the minigrid must be met with oil- or gas-fired plants (thermal resources) in the event of an Island-wide power outage. The IRP does not consider how distributed energy resources, including battery storage, could be designed and sized to provide reliable power to critical loads during such an event.
Assumption that substantial new transmission infrastructure is needed to ensure availability of power	•The IRP Microgrid strategy prioritizes hardened transmission infrastructure capable of delivering power to customers, resulting in significant expense to ratepayers.

For a more detailed discussion of these assumptions, please see Appendix 3: Technical Data and Results.

[61] In particular, Act 17-2019 directly indicates the importance of limiting overall rates to PREPA customers.

4.2. Microgrid Modeling Assumptions and Scenarios

Table 11 provides a summary of the modeling assumptions used to estimate the cost and capacities of equipment needed to provide reliable power to critical loads—for the IRP Minigrid Strategy as well as a Microgrid Strategy. The analysis draws on information presented in Section 2.2, Minigrid Construct as Proposed in the IRP analysis and additional resources as identified below.

Because PREPA may have included critical and priority loads that were too high, Synapse modeled a microgrid scenario in which PV and battery storage are deployed in sufficient capacity to provide reliable power to loads equal to 30 percent of the deemed critical and priority loads assumed in the IRP. The 30 percent level would be consistent with the microgrid estimate of Sandia National Laboratory for Puerto Rico,[62] and Synapse includes a plausible range of 20 percent to 40 percent to allow for uncertainty and differing requirements in the level of load for each zone.

Table 11: Microgrid analysis modeling assumptions

Parameter		IRP Minigrid Strategy[a]	Microgrid Strategy[b]
Microgrid peaker cost[c]	*2018$/kW*	2,197	NA
Microgrid solar cost[d]	*2018$/kW*	1,867	1,867
Minigrid solar cost[e]	*2018$/kW*	1,231	NA
Battery storage cost[f]	*2018$/kW*	251	560
	2018$/kWh	209	233
PV to load ratio[g]	*unitless*	3.2	3.2
BESS to load ratio[g]	*unitless*	1.2	1.2
Storage duration[h]	*hours*	6	18
Ratio of critical and priority loads to feeder load	*unitless*	1.00	0.30 ± 0.10
Fraction of new central generation attributed to critical and priority loads	*unitless*	See note[i]	0

IRP parameters are modeled according to S4S2base.

[a] *IRP Strategy 2: Hardened minigrid with thermal generation and feeder-level resiliency*

[b] *Microgrid Strategy: Distributed photovoltaic generation and batteries with partial feeder-, campus-, or site-level resiliency*

[c] *Based on 1MW distributed peaker (AEO 2019) with Puerto Rico adder (IRP).*

[d] *Mid-case distributed commercial cost in year 2021 (ATB 2019) with Puerto Rico adder (IRP).*

[e] *Mid-case utility-scale cost in year 2021 (ATB 2019) with Puerto Rico adder (IRP).*

[f] *Mid-case cost in year 2023 (IRP) with Puerto Rico adder (IRP). Microgrid strategy includes markup for commercial- & industrial-scale vs. utility-scale: 124% on the cost per kW and 12% on the cost per kWh (Lazard 2019).*

[g] *Based upon IRP assumptions.*

[h] *IRP strategy systems sized for IRP assumptions. Microgrid strategy systems sized for 100% load coverage.*

[i] *Computed as: (Deemed critical + deemed priority load) ÷ zone total load*

[62] Jeffers, R.F., A. Staid, M.J. Baca, F.M. Currie, W.E. Fogleman, S. DeRosa, A. Wachtel, A.V. Outkin. 2018. *Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico.* No. SAND2018-11145. Sandia National Lab.(SNL-NM), Albuquerque, NM.

The minigrid strategy as modeled in the IRP requires the development of 646 MW of thermal generation, 538 MW of solar PV, and 266 MW/1,064 MWh of battery energy storage in order to meet critical and priority loads.[63] However, the capacity buildout of PV resources in the IRP exceeds what is required to serve critical or priority loads in the minigrids. To apportion the cost and capacity of new generation resources to each minigrid, Synapse modeled the capacity of new central generation used per minigrid zone in the IRP as the ratio of the deemed critical and deemed priority load to the zone total load. PREPA's IRP modeling also included thermal, solar, and battery resources for microgrids where grid hardening was not an option to connect a remote but critical load to the minigrid backbone. As modeled, many of these microgrids would not meet the requirements of a microgrid under PREB's Regulation 9028 on microgrids because they are designed to use thermal resources to meet more than 25 percent of the participants' load.

Under Synapse's microgrid scenario, solar and battery systems are sized to ensure 100 percent availability of critical resources through a major grid outage under "worst-case" solar resource availability during tropical storms and hurricane seasons.[64] These scenarios do not use thermal generation to meet critical or priority loads. Instead, long duration battery storage is used to achieve full availability of critical resources. PV and battery storage would need to be coupled and designed for the battery system to provide black start power to the PV systems. Hardened PV racking systems to avoid damage during hurricane-force winds would be needed to prevent system losses. These renewable microgrids would meet the requirements of Regulation 9028.

4.3. Microgrid Scenario Results

Based on Synapse analysis, Figure 15 below illustrates that the costs of a microgrid strategy vary by region and by the percentage of the load covered by microgrids.[65] Figure 16 below presents the capacities of generating units needed under each scenario, based on Synapse analysis.[66] Note that results are meant to be illustrative and vary considerably by zone due to the differing local generation, transmission, and distribution resources as well as end load types. As the zone with the greatest population density, the San Juan region shows microgrids as less cost-effective than other regions. Buildout of microgrids could achieve 596 MW/10,735 MWh of battery storage (30 percent load case), or 65 percent of the 920 MW battery storage target in the IRP and 300 percent of the associated 3,600 MWh energy capacity. Similarly, it could achieve 1,590 MW of solar PV (30 percent load case), or 115 percent of the 1,380 MW solar PV target over the first four years of the IRP. This

[63] In the IRP, PREPA assumes that critical loads can only be met with thermal resources, but solar PV and battery storage can be used to meet priority loads.

[64] This analysis evaluates the production of a solar PV system in each of the eight minigrid zones during months with average storm and hurricanes frequency of 1 or greater (July to October). Storm data source: Landsea, Chris. "Total and Average Number of Tropical Cyclones by Month (1851-2017)". National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory. Archived from the original on September 1, 2018.

[65] See also Table 18 in Minigrid and Microgrid Analysis: Technical Data and Additional Results for detailed tabular information.

[66] See also Table 19 in Minigrid and Microgrid Analysis: Technical Data and Additional Results for detailed tabular information.

level of distributed solar generation would exceed the current projections for distributed generation in the IRP, which include 381 MW of total DG by year 2021, which rises to 1,092 MW by 2038.[67]

[67] Total distributed generation (DG) in the IRP includes transmission-level solar DG, distribution-level DG, and combined heat & power DG.

Figure 15: Microgrid strategy - Capital expenditure by zone and assumed load fraction

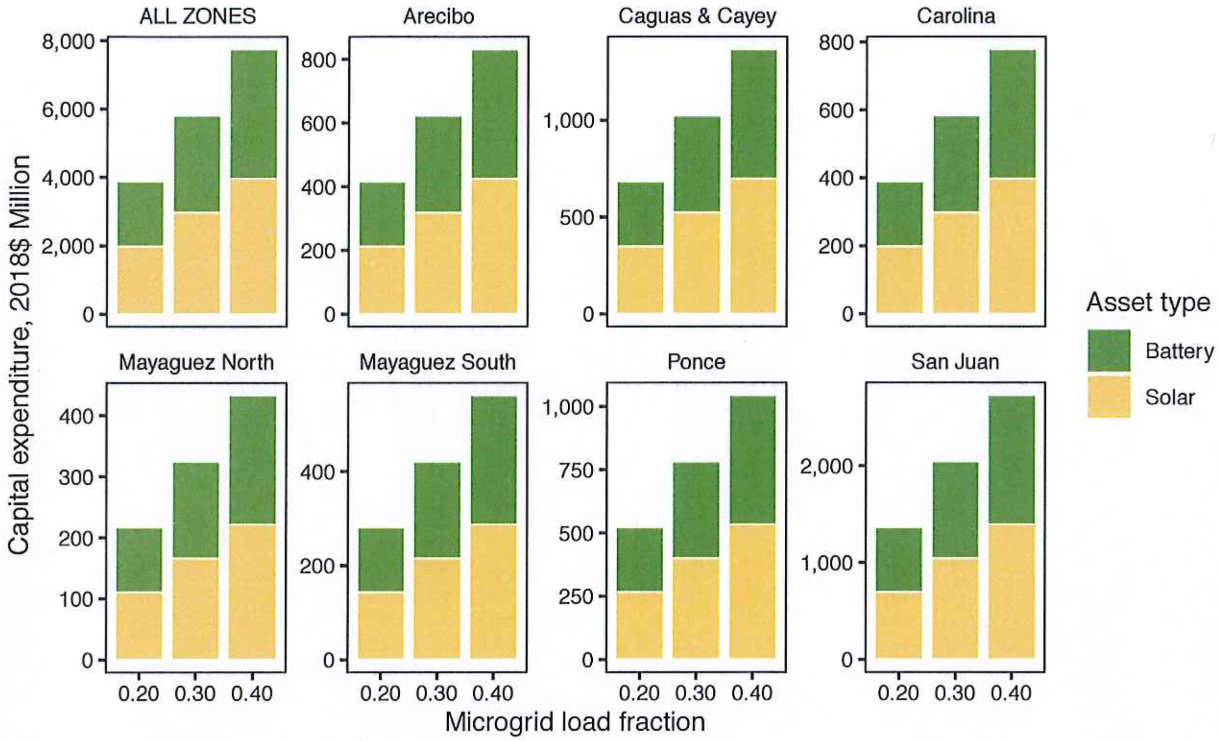
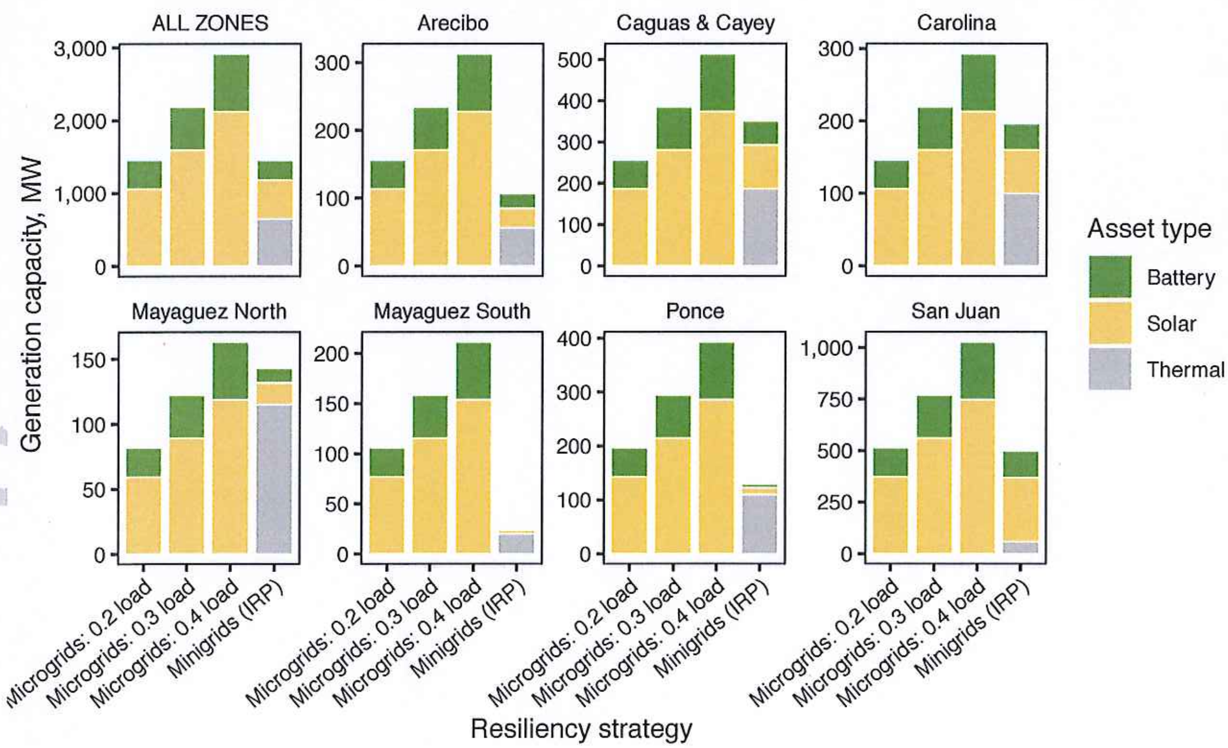


Figure 16: Microgrid strategy – generating capacity comparison



This analysis does not include a valuation of the ongoing costs and benefits of the transmission and generation infrastructure.[68] It is worth noting, however, that solar PV and battery systems offer substantial value during "blue sky" conditions, which are likely to pay off the cost of the infrastructure over its useful life. Conversely, transmission investments offer minimal marginal value over the existing transmission infrastructure during normal operating conditions.[69]

4.4. Conclusions

A microgrid strategy whereby critical and priority loads are met with distributed solar and battery systems offers a viable approach to resilience of critical and priority loads. This approach has different costs and benefits from the minigrid strategy identified in the IRP. In most zones, if critical and priority loads are 40 percent of the feeder loads or less, microgrid capital costs may be less than the costs associated with the IRP's minigrid approach to meeting the Commonwealth's resilience goals. The San Juan area minigrid is the primary exception to this. Before a minigrid or microgrid approach is selected for any given area, more detailed analysis than included in this report or in the IRP would be required. If critical and priority loads are 30 percent of feeder loads, as research by Sandia National Laboratory estimates,[70] avoided capital expenditures could be even less relative to the minigrid strategy. If a microgrid strategy is deemed to be appropriate, projects should focus on critical facilities before priority facilities.

A microgrid-based approach to resilience could be used to deploy the battery storage and solar PV assets identified in the IRP. Currently, the IRP does not fully explore how the solar and batteries selected as part of the scenario modeling would be deployed. With the approach described here, these resources can serve Puerto Rico's energy needs during normal operating conditions in addition to meeting critical and priority loads during an emergency event. This strategy could leverage planned investment in battery storage and solar PV systems, without incurring significant new costs[71] and would avoid substantial investments in minigrid-related transmission and new thermal generation. Under the 30 percent load case, microgrids would achieve 65 percent of the 920 MW battery storage target in the IRP and 115 percent of the 1,380 MW solar PV target over the first four years of the IRP. Further, it would exceed the forecast of distributed generation in the IRP.

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[68] Costs include fixed operating and maintenance, variable operating and maintenance, and fuel. Benefits include customer services (e.g. peak shaving, emergency back-up power, power quality enhancement, demand response) and grid services (e.g. resource adequacy, frequency regulation, reserve, voltage support, black start, renewable energy shift, transmission & distribution investment deferral, and energy arbitrage).

[69] These values are mean to be illustrative and should not be used for decision-making. The results suggest that more site-specific data should be acquired and used to compare the IRP's minigrid construct to an alternative and potentially less costly minigrid construct.

[70] Jeffers, Robert Fredric, Andrea Staid, Michael J. Baca, Frank M. Currie, William Ernest Fogleman, Sean DeRosa, Amanda Wachtel, and Alexander V. Outkin. *Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico*. No. SAND2018-11145. Sandia National Lab. (SNL-NM), Albuquerque, NM (United States), 2018.

[71] Some cost increase for deploying microgrid battery storage and solar PV is expected, as the projects will occur at a smaller scale, missing some economy of scale benefits.

Thermal resources are not required to prevent loss of critical loads. Solar PV can meet this need, although it must be paired with long duration battery storage to ensure availability in the periods of low solar resources experienced during the hurricane and tropical storm season.

This analysis suggests that before making minigrid transmission or generating resource investments, PREPA should conduct a full analysis identifying the net present value (NPV) of the costs and benefits of the minigrid transmission and generation infrastructure compared against alternative microgrid strategies. Costs should include fixed operating and maintenance, variable operating and maintenance, and fuel. Benefits should include customer services (e.g. peak shaving, emergency back-up power, power quality enhancement, demand response) and grid services (e.g. resource adequacy, frequency regulation, reserve, voltage support, black start, renewable energy shift, transmission and distribution investment deferral, and energy arbitrage) provided by the generation and storage assets. PREPA and PREB might also consider economic development outcomes such as losses to the economy from fuel imports for thermal resources.

5. Survey of Battery Energy Storage Policies

In this section, we explore the range of policies that can be used to support the growth of energy storage markets. This includes policies to promote grid-level storage and behind-the-meter storage systems.

5.1. Grid-Level Storage Policies

According to the Pacific Northwest National Laboratory's (PNNL) database on energy storage policies in the United States,[72] 15 states have adopted at least one storage policy. Discussed below are those policies relevant to a consideration of projects involving utility investment in grid-level storage, as opposed to customer investments in behind-the-meter storage. Unless otherwise noted, all information below is available at PNNL's online database.

Procurement Mandates

Seven states have adopted a policy mandating some or all utilities to procure storage capacity. The form of the policy and direction provided by the state vary significantly. Two states have adopted specific statewide targets: Massachusetts aims for 200 MW by 2020 and 2,000 MW by 2025, while New Jersey aims for 600 MW by 2021 and 2,000 MW by 2030. Two other states have adopted targets only for certain utilities: California's three investor-owned utilities must together procure 1,325 MW

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[72] Pacific Northwest National Laboratory, Energy Storage Policy Database, last updated January 2019, , https://energystorage.pnnl.gov/regulatoryactivities.asp; see also Twitchell, J. (2019, June), A Review of State-Level Policies on Electrical Energy Storage, *Current Sustainable/Renewable Energy Reports* 6(2), pp. 35-41, retrieved from https://link.springer.com/article/10.1007/s40518-019-00128-1.

(plus 500 MW of behind-the-meter storage) by 2020, while Oregon's two large investor-owned utilities must each procure at least 5 MWh but no more than 1 percent of 2014 peak load by 2020. The remaining two states have not announced a targeted amount but have directed the regulatory commission to act. In New York, the commission was tasked with establishing a target: In December 2018, the commission adopted a goal of 1,500 MW by 2025 and an "aspirational" goal of 3,000 MW by 2030.[73] In Nevada, the regulatory commission was tasked with evaluating if a specific storage target should be established.[74] On November 26, the commission filed a proposal to the State Legislative Counsel Bureau that would create biennial targets, beginning with 100 MW by the end of 2020 and then ramping up to 400 MW and 800 MW by 2024 and 2028, respectively.[75] Finally, in Colorado, the regulatory commission must establish mechanisms for utilities to procure energy storage systems. The state has incorporated storage into planning processes but did not adopt a specific numerical target.[76]

Regulatory Requirements

Nine states have adopted a grid-level storage policy requiring utility or commission action. Three states—New Jersey, Oregon, and Vermont—directed their regulatory commissions to develop a report or other guidance on storage. Three other states—California, New Mexico, and Washington—passed legislation directing utilities to consider energy storage in their resource planning processes. Two states have implemented additional planning processes for energy storage: Massachusetts requires companies to identify locations with critical needs for energy storage investments, and Virginia requires its utilities to submit annual project plans including investments in energy storage. Virginia provides an incentive rate of return for these projects. Hawaii similarly modified rate recovery for storage projects by moving up the timeline for rate recovery.

At the federal level, the FERC through Order 841[77] has attempted to remove the valuation barrier by requiring RTOs/ISOs to develop an energy storage model that will allow energy storage compensation for all capacity, energy, and ancillary services the technology can provide. FERC has also recognized that energy storage can provide electrical services to multiple markets (organized markets, transmission and distribution utilities) including both cost-based and market-based services.

[73] New York Public Service Commission, Case 18-E-0130, Order on December 13, 2018, p. 12, retrieved from http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={FDE2C318-277F-4701-B7D6-C70FCE0C6266}.

[74] Nevada Public Utility Commission, Case 17-07014, document listing, retrieved from http://pucweb1.state.nv.us/PUC2/DktDetail.aspx (accessed November 12, 2019).

[75] Kavya Balaraman,"Nevada PUC floats proposal for 1,000 MW storage target by 2030," Utility Dive, December 3, 2019.

[76] Colorado Public Utilities Commission, Proceeding No. 18R-0623E, Decision on December 12, 2018, retrieved from https://www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=896764.

[77] See David Schmitt and Glen M. Sanford, "Energy Storage: Can we Get It Right?" The Energy Bar Association, 11/14/18 for an insightful discussion of the valuation and other regulatory legal issues tackled by the FERC.

Demonstration Programs

Five states have adopted a policy driving demonstration program(s) that explores the new technology options and capabilities. Massachusetts' Advancing Commonwealth Energy Storage program has so far committed $20 million to storage demonstration projects, which range in scale from behind-the-meter programs to utility-scale programs.[78] New York's Reforming the Energy Vision initiative has an open call for demonstration programs, including those with storage technologies. Utah's legislature passed a law authorizing utility pilot programs in storage. Legislation passed in Virginia authorized its utilities to invest in pilot programs involving either up to 10 MW or up to 30 MW of storage (depending on the utility). Finally, in Washington, the state's Washington Clean Energy Fund provides utilities with matching funds and has so far supported four utility-scale energy storage projects.

5.2. Behind-the-Meter Policies

Microgrids

Several states have adopted policies governing the development of microgrids. Because the definition of a microgrid may vary, the Puerto Rico legislature adopted the following definition:

> A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.[79]

As a distributed energy resource, storage may be a part of a microgrid. Given the relevance of microgrid policies for storage deployment, therefore, it is necessary to recognize the landscape of microgrid policies as relevant to the future of energy storage.

A 2018 report by NREL provides a survey of state policies affecting microgrid development.[80] The most common policy type—with 11 identified policies across seven states—relates to financing support for microgrids, whether through grants, loans, or another approach.[81] The second most common policy type relates to the development of "microgrid roadmaps" which may provide recommendations on future deployment efforts.[82] Less common policies include "energy market reforms" (in four states) and "resiliency retrofits" (only in Texas) that may result in enabling

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78 Massachusetts Clean Energy Center, *Advancing Commonwealth Energy Storage (ACES)* [webpage], retrieved from https://www.masscec.com/advancing-commonwealth-energy-storage-aces.

79 Act 133-2016, as amended.

80 Cook, J.J.; Volpi, C.; Nobler, E., and Flanegin, K. (2018, November). Check the Stack: An Enabling Framework for Resilient Microgrids. Golden, CO: National Renewable Energy Laboratory. Technical Report NREL/TP-6A20-71594. Retrieved from https://www.nrel.gov/docs/fy19osti/71594.pdf.

81 Id. at 10-11.

82 Ibid.

microgrid deployment.[83] Finally, one state (Connecticut) has adopted a policy explicitly exempting municipal microgrids from utility regulation.[84] As NREL notes, microgrid policies are comparatively few, and the lack of support in policy and regulation is a recognized barrier to microgrid deployment.[85]

Other Behind-the-Meter State Policies and Regulations

This section summarizes several state policies or programs that support distributed storage, most commonly in the context of distributed generation. Together, these policies and programs illustrate the importance of supportive policies and regulations to promote energy storage deployment.

The California Public Utilities Commission (CPUC) Approves Energy Storage Net Metering

The CPUC in 2019 approved an Order[86] that authorizes customers with energy storage systems to receive credits for storage energy that is delivered to the grid, contingent on the storage system charging entirely from solar. Most recently, customers were only allowed to receive credits from the excess energy produced by a solar system exported to the grid. The key provisions of the Order are:[87]

- The battery must charge 100 percent from solar to receive the net metering credits from storage energy exported to the grid;
- Metering requirements: For storage systems >10 kW that meet certification requirements, a net generation output meter (NGOM) is no longer required;
- Elimination of "retail netting" or "banking" of excess generation;
- Existing NM customers are allowed to keep original rates for 20 years from interconnection—new customers will be on the new lower export rate for 10 years;
- Solar customers join a separate rate class (to address any customer subsidization issues);
- Indicated Value of Solar (VOS) should be considered;
- Value of solar defined: VOS= avoided generation cost + deferred T&D + avoided line loses, environmental attributes (on 5-year basis);
- Grid security, societal, and economic benefits such as fuel hedging were excluded; and

83 Cook, J.J. et al., 2018, November, Check the Stack.

84 Ibid.

85 Ibid.

86 https://www.energytoolbase.com/newsroom/PolicyUpdates/cpuc-approves-energy-storage-net-metering.

87 The CPUC Order can be obtained at: https://static1.squarespace.com/static/54c1a3f9e4b04884b35cfef6/t/5c5a02ff104c7b5f073745dc/1549402881064/STORAGE+DEVICES+PAIRED+WITH+NET+ENERGY+METERING+GENERATING+FACILITIES.PDF.

- To qualify, storage equipment must be certified under a new standard, the UL Power Control Systems Certification Requirements Decision.

The decision to eliminate the restrictions on the operation of energy storage systems will allow for the capture of the full net metering value spurred on by an adequate price signal to export. Moreover, previous NGOM metering requirements were expensive and time-consuming, so the new metering rules will reduce the cost and remove some hurdles for systems greater than 10 kW.

To complement the commission order, the California electric utilities are offering customers time-of-use (TOU) rates with much later evening peak periods, making storage more economically viable.[88]

New York State Energy Plan (SEIA)

New York State has an energy plan that seeks to generate 100 percent carbon-free electricity by 2040.[89] The 100 percent target will require substantially more storage capacity. In order to spur that growth, the state has developed new funding known as a "bridge incentive." "The New York State Energy Research and Development Authority's (NYSERDA) Market Acceleration Bridge Incentive Program[90] will help the project economics of approximately two-thirds of the State's 1,500-MW target of energy storage by 2025, supporting a transition to a self-sustaining market within the state. Funding is available in two categories:

- $150 million for bulk storage projects: systems over 5 MW that primarily provide wholesale market energy or distribution services; and,
- $130 million for retail storage projects: customer-sited systems below 5 MW, which are smaller and installed alone or paired with onsite generation such as solar."[91]

New York has also initiated several projects specifically on energy-constrained Long Island, including a $55 million storage investment and program that rewards customers for deploying their batteries to reduce demand during key times.[92]

[88] The CPUC Order can be obtained at: https://static1.squarespace.com/static/54c1a3f9e4b04884b35cfef6/t/5c5a02ff104c7b5f073745dc/1549402881064/STORAGE+DEVICES+PAIRED+WITH+NET+ENERGY+METERING+GENERATING+FACILITIES.PDF.

[89] https://energyplan.ny.gov/Plans/2015.

[90] https://www.nyserda.ny.gov/All-Programs/Programs/Energy-Storage.

[91] https://www.nyserda.ny.gov/About/Newsroom/2019-Announcements/2019-04-25-Governor-Cuomo-Announces-280-Million-Available-for-Energy-Storage-Projects-to-Combat-Climate-Change.

[92] Id.

Arizona "Clean Peak" RPS Idea to encourage storage

Similar to the Massachusetts effort mentioned below, Arizona is seeking to increase both utility and DG customer-sited storage by modifying its existing RPS.[93] An RPS requires utilities to meet a certain percentage of their annual electrical production from renewable sources. An RPS generally provides a signal to construct the cheapest renewables regardless of the time of day when those renewable assets generate electricity. At high renewable energy penetrations, an RPS can modify utility system load shapes creating a challenge to meet peak load, requiring construction of more flexible fossil fuel plants or other measures.[94] Arizona now supplements the general renewables requirement with an additional clean energy target for hours of peak demand. Prior to the modified RPS, incorporating energy storage into a solar project simply added cost to the project without helping to satisfy the RPS. Under the new model, the storage makes it possible for that solar installation to satisfy the clean peak standard. The modified RPS would send a clear signal of value for storage not just to enable delivery of clean energy at times of greatest need, but also to simultaneously avoid other investments in peaking capacity.[95] This type of upgrade to RPS policies could make them more effective at encouraging investment in storage systems to better balance the electric utility grid. The Arizona plan includes an 80 percent clean energy target by 2050 coupled with a 3,000 MW energy storage procurement target for 2030.[96]

Massachusetts

In 2018, the Massachusetts Department of Energy Resources launched the Solar Massachusetts Renewable Target (SMART) program. SMART provides $130 million for retail storage projects: customer-sited systems below 5 MW, which are smaller and installed alone or paired with onsite generation such as solar.[97] The program already includes 130 MW of storage and small systems. Massachusetts also set a target to achieve 200 MWh of storage by January 1, 2020 through its Energy Storage Initiative.[98]

Massachusetts is also finalizing a Clean Peak Standard, which ensures a larger percentage of peak-hour electricity comes from clean energy sources. Under this regulation, customers are rewarded for use of battery storage when either coupled with renewable energy generators (contractually or physically) or used during predetermined highly renewable hours.[99] The Massachusetts Department

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93 https://www.greentechmedia.com/articles/read/arizona-regulator-proposes-sweeping-clean-energy-plan#gs.9bbknx.

94 See Lazar, Jim, Teaching the 'Duck' to Fly, Second Edition, Regulatory Assistance Project, Feb. 2016, available at: http://www.raponline.org/ document/download/id/7956 (accessed Mar. 19, 2017) (hereinafter Teaching the 'Duck to Fly', Second Edition).

95 See https://www.greentechmedia.com/articles/read/upgrade-renewable-portfolio-standards-peak-capacity-arizona#gs.9b34er.

96 See Arizona Corporation Commission Docket No. E-00000Q-16-0289.

97 https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program.

98 https://www.mass.gov/energy-storage-initiative.

99 https://www.seia.org/blog/spi-sneak-preview-solar-storage-lessons-two-states.

of Energy Resources rolled out a rough proposal in April 2019 and clarified and provided generational valuation figures on August 7, 2019. These included different hourly and seasonal peaks, and an actual system peak multiplier of 15. Storage resources that increase energy resilience to outages are subject to a 1.5 multiplier.[100]

Oregon

HB 2618, signed into law by Oregon Governor Brown in September 2019, created a new rebate program for solar electric systems and paired solar and storage systems installed for residential customers and low-income service providers. The Oregon Department of Energy has $2 million allocated for rebates and program administration. For residential projects, the maximum rebate is $5,000 for a solar electric system and $2,500 for an energy storage system. For low-income service providers, the caps are $30,000 for solar electric and $15,000 for an energy storage system. [101] The anticipated launch date for the program is January 1, 2020.

In this section, we explore the range of policies that can be used to support the growth of energy storage markets. This includes policies to promote grid-level storage and behind-the-meter storage systems.

5.3. Grid-Level Storage Policies

According to the Pacific Northwest National Laboratory's (PNNL) database on energy storage policies in the United States,[102] 15 states have adopted at least one storage policy. Discussed below are those policies relevant to a consideration of projects involving utility investment in grid-level storage, as opposed to customer investments in behind-the-meter storage. Unless otherwise noted, all information below is available at the PNNL's database.

Procurement Mandates

Seven states have adopted a policy mandating some or all utilities to procure storage capacity. The form of the policy and direction provided by the state vary significantly. Two states have adopted specific statewide targets: Massachusetts aims for 200 MW by 2020 and 2,000 MW by 2025, while New Jersey aims for 600 MW by 2021 and 2,000 MW by 2030. Two other states have adopted targets only for certain utilities: California's three investor-owned utilities must together procure 1,325 MW (plus 500 MW of behind-the-meter storage) by 2020, while Oregon's two large investor-owned utilities must each procure at least 5 MWh, but no more than 1 percent of 2014 peak load by 2020.

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[100] https://pv-magazine-usa.com/2019/08/07/massachusetts-zeroes-in-on-shaving-the-peak/.

[101] Oregon Solar + Storage Rebate Program. Oregon Office of Energy (ODOE). 2019. Available at: https://www.oregon.gov/energy/Incentives/Pages/Solar-Storage-Rebate-Program.aspx.

[102] Pacific Northwest National Laboratory, Energy Storage Policy Database, last updated January 2019, , https://energystorage.pnnl.gov/regulatoryactivities.asp; see also Twitchell, J. (2019, June), A Review of State-Level Policies on Electrical Energy Storage, *Current Sustainable/Renewable Energy Reports* 6(2), pp. 35-41, retrieved from https://link.springer.com/article/10.1007/s40518-019-00128-1

The remaining two states have not spoken on the targeted amount but have directed the regulatory commission to act. In New York, the commission was tasked with establishing a target; in December 2018, the commission adopted a goal of 1,500 MW by 2025 and an "aspirational" goal of 3,000 MW by 2030.[103] In Nevada, the regulatory commission was tasked with evaluating if a specific storage target should be established.[104] On November 26, the Commission filed a proposal to the State Legislative Counsel Bureau that would create biennial targets, beginning with 100 MW by the end of 2020 and then ramping up to 400 MW and 800 MW by 2024 and 2028, respectively.[105] Finally, in Colorado, the regulatory commission must establish mechanisms for utilities to procure energy storage systems; it has incorporated storage into planning processes but did not adopt a specific numerical target.[106]

Regulatory Requirements

Nine states have adopted a grid-level storage policy requiring utility or commission action. Three states—New Jersey, Oregon, and Vermont—directed their regulatory commissions to develop a report or other guidance on storage. Three other states—California, New Mexico, and Washington—passed legislation directing utilities to consider energy storage in their resource planning processes. Two states have implemented additional planning processes for energy storage: Massachusetts requires companies to identify locations with critical needs for energy storage investments, and Virginia requires its utilities to submit annual project plans including investments in energy storage. Virginia provides an incentive rate of return for these projects; Hawaii similarly modified rate recovery for storage projects by moving up the timeline for rate recovery.

At the federal level, the FERC through Order 841[107] has attempted to remove the valuation barrier by requiring RTOs/ISOs to develop an energy storage model that will allow energy storage to provide all capacity, energy, and ancillary services can provide. FERC has also recognized that energy storage can provide electrical services to multiple markets (organized markets, transmission and distribution utilities) including both cost-based and market-based services.

103 New York Public Service Commission, Case 18-E-0130, Order on December 13, 2018, p. 12, retrieved from http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={FDE2C318-277F-4701-B7D6-C70FCE0C6266}

104 Nevada Public Utility Commission, Case 17-07014, document listing, retrieved from http://pucweb1.state.nv.us/PUC2/DktDetail.aspx (accessed November 12, 2019)

105 Kavya Balaraman, "Nevada PUC floats proposal for 1,000 MW storage target by 2030," Utility Dive, December 3, 2019.

106 Colorado Public Utilities Commission, Proceeding No. 18R-0623E, Decision on December 12, 2018, retrieved from https://www.dora.state.co.us/pls/efi/efi_p2_v2_demo.show_document?p_dms_document_id=896764

107 See David Schmitt and Glen M. Sanford, "Energy Storage: Can we Get It Right?" The Energy Bar Association, 11/14/18 for an insightful discussion of the valuation and other regulatory legal issues tackled by the FERC.

Demonstration Programs

Five states have adopted a policy driving demonstration program(s) that explores the new technology options and capabilities. Massachusetts' Advancing Commonwealth Energy Storage program has so far committed $20 million to storage demonstration projects, which range in scale from behind-the-meter programs to utility-scale programs.[108] New York's Reforming the Energy Vision initiative has an open call for demonstration programs, including those with storage technologies. Utah's legislature passed a law authorizing utility pilot programs in storage. Legislation passed in Virginia authorized its utilities to invest in pilot programs involving either up to 10 MW or up to 30 MW of storage (depending on the utility). Finally, in Washington, the state's Washington Clean Energy Fund provides utilities with matching funds and has so far supported four utility-scale energy storage projects.

5.4. Behind-the-Meter Policies

Microgrids

Several states have adopted policies governing the development of microgrids. The definition of a microgrid may vary; the Puerto Rico legislature has adopted the following definition:

> A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.[109]

A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.[110] As a distributed energy resource, storage may be a part of a microgrid. Given the relevance of microgrid policies for storage deployment, therefore, it is necessary to recognize the landscape of microgrid policies as relevant to the future of energy storage.

A 2018 report by the National Renewable Energy Laboratory (NREL) conducted a survey of state policies affecting microgrid development.[111] The most common policy type—with eleven identified policies across seven states—relates to financing support for microgrids, whether through grants,

108 Massachusetts Clean Energy Center, *Advancing Commonwealth Energy Storage (ACES)* [webpage], retrieved from https://www.masscec.com/advancing-commonwealth-energy-storage-aces

109 Act 133-2016, as amended.

110 Act 133-2016, as amended.

111 Cook, J.J.; Volpi, C.; Nobler, E., and Flanegin, K. (2018, November). Check the Stack: An Enabling Framework for Resilient Microgrids. Golden, CO: National Renewable Energy Laboratory. Technical Report NREL/TP-6A20-71594. Retrieved from https://www.nrel.gov/docs/fy19osti/71594.pdf

loans, or another approach.[112] The second most common policy type relates to the development of "microgrid roadmaps" which may provide recommendations on future deployment efforts.[113] Less common policies include "energy market reforms" (in four states) and "resiliency retrofits" (only in Texas) that may result in enabling microgrid deployment.[114] Finally, one state (Connecticut) has adopted a policy explicitly exempting municipal microgrids from utility regulation.[115] As NREL notes, microgrid policies are comparatively few, and the lack of support in policy and regulation has been recognized as a barrier to microgrid deployment.[116]

Other Behind-the-Meter State Policies and Regulations

This section summarizes several state policies or programs that support distributed storage, most commonly in the context of distributed generation. Together, these policies and programs illustrate the importance of supportive policies and regulations to promote energy storage deployment.

The California Public Utilities Commission (CPUC) Approves Energy Storage Net Metering

The CPUC in 2019 approved an Order[117] that authorizes customers with energy storage systems to receive credits for storage energy that is delivered to the grid, contingent on the storage system charging entirely from solar. Most recently, customers were only allowed to receive credits from the excess energy produced by a solar system exported to the grid. The key provisions of the Order are:[118]

- The battery must charge 100% from solar in order to receive the net metering credits from storage energy exported to the grid;
- Metering requirements. For storage systems >10 kW that meet certification requirements, a net generation output meter (NGOM) is no longer required;
- Eliminated "retail netting" or "banking" of excess generation;
- Allowed existing NM customers to keep original rates for 20 years from interconnection. New customers will be on the new lower export rate for 10 years;
- Made solar customers a separate rate class (to address any customer subsidization issues);

112 Id. at 10-11.

113 Id.

114 Id.

115 Id.

116 Id.

117 https://www.energytoolbase.com/newsroom/PolicyUpdates/cpuc-approves-energy-storage-net-metering.

118 The CPUC Order can be obtained at: https://static1.squarespace.com/static/54c1a3f9e4b04884b35cfef6/t/5c5a02ff104c7b5f073745dc/1549402881064/STORAGE+DEVICES+PAIRED+WITH+NET+ENERGY+METERING+GENERATING+FACILITIES.PDF

- Indicated Value of Solar (VOS) should be taken into account;
- VOS= avoided generation cost + deferred T&D + avoided line loses, environmental attributes (on 5-year basis);
- Grid security, societal and economic benefits such as fuel hedging was excluded; and
- To qualify, storage equipment must be certified under a new standard, the UL Power Control Systems Certification Requirements Decision.

The decision to eliminate the restrictions on how Energy Storage Systems can operate will allow for the capture of the full NM value spurred on by an adequate price signal to export. Moreover, NGOM metering requirements have been expensive and time-consuming, so the new metering rules will reduce the cost and remove some resistance for systems greater than 10 kW.

To complement the CPUC Order, the California electric utilities are offering customers time-of-use (TOU) rates which have much later evening peak periods making storage more economically viable.[119]

New York State Energy Plan (SEIA)

New York State has an energy plan that seeks to generate 100 percent carbon-free electricity by 2040.[120] The 100 percent target will require significantly more storage capacity. In order to spur that growth, new funding known as a 'bridge incentive' has been developed. "The New York State Energy Research and Development Authority's (NYSERDA) Market Acceleration Bridge Incentive Program[121] will help the project economics of approximately two-thirds of the State's 1,500-megawatt target of energy storage by 2025, supporting a transition to a self-sustaining market for the State. Funding is available in two categories:

- $150 million for bulk storage projects: systems over five megawatts that primarily provide wholesale market energy or distribution services; and,
- $130 million for retail storage projects: customer-sited systems below five megawatts, which are smaller and installed alone or paired with onsite generation such as solar."[122]

119 Id.

120 https://energyplan.ny.gov/Plans/2015.

121 https://www.nyserda.ny.gov/All-Programs/Programs/Energy-Storage.

122 https://www.nyserda.ny.gov/About/Newsroom/2019-Announcements/2019-04-25-Governor-Cuomo-Announces-280-Million-Available-for-Energy-Storage-Projects-to-Combat-Climate-Change.

New York has also initiated several projects specifically on Long Island, including a $55 million storage investment and program that rewards customers for deploying their batteries to reduce demand during key times.[123]

Arizona "Clean Peak" RPS Idea to encourage storage

Similar to the Massachusetts effort mentioned below, Arizona is seeking to increase both utility and DG customer sited storage by modifying their existing renewable portfolio standard (RPS).[124] An RPS requires utilities to meet a certain percentage of their annual electrical production from renewable sources. An RPS generally provides a signal to construct the cheapest renewables regardless of the time of day when those renewable assets generate electricity. At high renewable energy penetrations, an RPS can modify utility system load shapes creating a challenge to meet peak load, requiring construction of more flexible fossil fuel plants or other measures.[125] Arizona now supplements the general renewables requirement with an additional clean energy target for hours of peak demand. Prior to the modified RPS, incorporating energy storage into a solar project simply added cost to the project without helping to satisfy the RPS. Under the new model, the storage makes it possible for that solar plant to satisfy the clean peak standard. The modified RPS would send a clear signal of value for storage not just to enable delivery of clean energy at times of greatest need, but also to simultaneously avoid other investments in peaking capacity.[126] This type of upgrade to the RPS could make them a more effective at encouraging investment in storage systems to better balance the electric utility grid. The Arizona plan includes an 80 percent clean energy target by 2050 coupled with a 3,000-megawatt energy storage procurement target for 2030.[127]

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[123] Id.

[124] https://www.greentechmedia.com/articles/read/arizona-regulator-proposes-sweeping-clean-energy-plan#gs.9bbknx.

[125] See Lazar, Jim, Teaching the 'Duck' to Fly, Second Edition, Regulatory Assistance Project, Feb. 2016, available at: http://www.raponline.org/ document/download/id/7956 (accessed Mar. 19, 2017) (hereinafter Teaching the 'Duck to Fly', Second Edition).

[126] See https://www.greentechmedia.com/articles/read/upgrade-renewable-portfolio-standards-peak-capacity-arizona#gs.9b34er.

[127] See Arizona Corporation Commission Docket No. E-00000Q-16-0289.

[128] https://www.mass.gov/info-details/solar-massachusetts-renewable-target-smart-program.

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6. Conclusions and Recommendations for Commonwealth

6.1. Conclusions from IRP and Independent Resource Modeling

Puerto Rico is currently planning the transformation of its electric grid to achieve several important goals, including 100 percent renewables and a resilient grid. Modeling conducted by Siemens for PREPA, and by Synapse for PREB, shows that Puerto Rico will benefit from a comprehensive and well-developed program to encourage energy storage deployments. These storage resources can be deployed as utility-scale resources, as modeled in the IRP, or in part as distributed resources that are under utility control. In either case, storage shifts daytime solar PV generation to meet evening and overnight loads. Storage resources can also provide the Island with increased resilience when used

[129] https://www.mass.gov/energy-storage-initiative.

[130] https://www.seia.org/blog/spi-sneak-preview-solar-storage-lessons-two-states.

[131] https://pv-magazine-usa.com/2019/08/07/massachusetts-zeroes-in-on-shaving-the-peak/.

[132] Oregon Solar + Storage Rebate Program. Oregon Office of Energy (ODOE). 2019. Available at: https://www.oregon.gov/energy/Incentives/Pages/Solar-Storage-Rebate-Program.aspx.

in minigrids and/or microgrids, particularly when coupled with generation resources. Furthermore, energy storage can help improve the reliability of the Island grid by providing needed ancillary services such as regulation and frequency response, operating reserves, voltage support, and black start ancillary services.

The IRP involved modeling a variety of planning scenarios, with sensitivities to input assumptions. One of the key elements of the plan is the development of eight minigrids designed to meet critical loads in the event of a large catastrophic power outage. Energy storage is identified as an important technology to enable high penetration of solar energy in Puerto Rico. The ESM and Scenario 4 Strategy 2 (S4S2) emerged as PREPA's preferred plans based on the IRP modeling. Based on these findings, the IRP puts forth an action plan and a set of near-term steps to begin the transformation of Puerto Rico's energy system. This includes the installation of 1,380 MW of solar and 1,080 MW of storage in the first four years of the plan. These plans are still being evaluated and no determination of the IRP has been made at the time this report was issued.

The modeling conducted by Synapse for this study provides additional insights on the IRP results and the role that energy storage can play in the transformation of Puerto Rico's grid.

Synapse's modeling initially finds that the constraints within the IRP modeling have a significant impact on the amount of solar and storage that is built. The analysis finds that the gas-fired plants (thermal resources) required by PREPA's minigrids approach to meet critical and priority load impact the buildout of solar and storage. Because the model is forced to include thermal resources, it cannot add as much solar and storage as it would if it were allowed to seek out the most cost-effective options for meeting demand. The remaining Synapse scenarios the constraints removed increase the amount of solar and storage that is being built. This indicates the constraints are stringent and may be hindering higher builds of solar and storage.

Synapse's preliminary analysis suggests that the approach identified in the IRP to create a more resilient electrical system with more distributed and flexible generation may result in greater capital expenditures than is necessary to achieve the intended goals. Synapse also finds that it is possible to create such a system utilizing more distributed and flexible generation at a lower cost. This report discusses three limitations to the IRP minigrid strategy: (1) infrastructure sizing is based on "deemed" critical loads, (2) the IRP strategy assumes that the critical loads can only be served by thermal resources, and (3) the assumption that substantial new transmission infrastructure is needed to ensure availability of power.

Synapse developed a microgrid strategy whereby critical and priority loads are met with distributed solar and battery systems, which is a different approach from the minigrid strategy identified in the IRP. Microgrids are likely to be less costly in most zones if critical and priority loads are 40 percent of the feeder loads or less, and if not required to provide resilient power to lower-priority loads on the feeders with critical and priority loads. If critical and priority loads are 30 percent of feeder loads, avoided capital expenditures could be significant. Further, Synapse finds that thermal resources are not required to prevent loss of critical loads, but long duration battery storage will be needed to ensure availability during periods of low solar resources experienced during the hurricane and tropical storm season. It is recommended that before making minigrid transmission or generating resource investments, PREPA conduct a full analysis identifying the net present value (NPV) of the costs and benefits of the minigrid transmission and generation infrastructure compared against alternative microgrid strategies.

6.2. Policy Recommendations

Identification and Removal of Barriers to Energy Storage

Energy storage, for the many reasons stated in this report, has been identified as a critical technology ripe for innovation and deployment. While falling costs are an important factor in the economic case for energy storage, regulatory barriers and market structures may be tipping the cost-benefit scale against realizing the full potential of energy storage as a solution for today's grid problems.[133] It is therefore important to identify the barriers faced by storage so that possible solutions can be instituted.

Table 12 outlines some of the potential barriers encountered by energy storage applications that do not apply to traditional generation resources and possible solutions.

Table 12: Potential barriers to battery storage systems

Barrier	Description	Potential Solution
Valuation	Storage provides value via different services to different entities (utilities, generators, and end customers) but it is difficult to build a simple business case for storage.	Allow storage projects to stack the value of multiple streams of revenue (capacity, energy, ancillary services, and transmission related benefits). The FERC through Order 841[134] has attempted to remove the valuation barrier in wholesale markets by requiring RTOs/ISOs to develop an energy storage model that will allow energy storage to provide all capacity, energy, and ancillary services it can provide.
Technology Newness	Besides pumped hydro storage, other forms of storage have not been extensively deployed on the electric grid. Grid operators may not be familiar with the physical and operating characteristics of the new technologies, thereby presenting numerous challenges.	Simulation models that are robust enough to model the complexities of energy storage or its ability to deliver multiple services simultaneously need to be developed and refined. A more sophisticated form of tariff schedule has to evolve to cover the different storage technologies and circumstances.

[133] The DOE recognizes four key challenges to the widespread deployment of electric energy storage. They are 1) Performance and Safety, 2) Regulatory Environment 3) Cost-competitive systems and 4) Industry Acceptance. "Solving Challenges in Energy Storage," July 2019.

[134] David Schmitt and Glen M. Sanford, "Energy Storage: Can we Get It Right?" The Energy Bar Association, 11/14/18.

Barrier	Description	Potential Solution
Classification	Unlike traditional generation and transmission and distribution assets, energy storage can perform all three functions so they cannot be reduced to a single functional definition.	Laws and regulations must be promulgated to allow for a storage system to be valued for generation, transmission, distribution, and ancillary services.
Market vs Cost of Service	There are questions about the role of utilities in building and owning storage projects. For example, are energy storage projects to be built and owned by a regulated utility or by competitive storage providers?	Puerto Rico's intention to use public-private partnerships to develop new resources can simultaneously ensure ratepayers do not overpay while resources are secured at lowest cost through competitive procurement practices. However, oversight of procurement details is critical to ensure ratepayers capture economics of scale and scope associated with a transformed resource development landscape.
Interconnection Barriers	Length of time[135] and testing required for grid interconnection deters investors and customers.	Interconnection queues tend to be "first in time" where the first project to file is given preference over projects that file later. Although this process may appear "fair," energy storage projects usually have shorter lead times and would be better served by a "first ready, first served" approach that rewards projects that come on line quicker.
Distribution and Behind-the-Meter Storage	Behind-the-meter storage can provide a "non-wire" solution in distribution planning, but the regulations and programs to do this are not yet developed.	Laws and regulations requiring integrated distribution planning are practiced in states like California and New York.[136] The lack of customer-friendly time-of-day and dynamic pricing in state electric utility tariff books (and the unavailability of advanced metering systems) provide little incentive for customers to install behind-the-meter storage due to the lack of arbitrage revenues. TOU and dynamic pricing rate designs need to be implemented across the country.

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[135] At ERCOT, the minimum interconnection time is 225 days but it can take several years depending on the project. http://www.ercot.com/services/rq/re/reg/GUIDE_TO_THE_INTERCONNECTION_PROCESS_v1_0.pdf. Page 8. For a general description to the interconnection process see: https://irecusa.org/2017/04/irec-releases-energy-storage-guide-for-policymakers/. See page 19. Also, http://www.windustry.org/community_wind_toolbox_14_interconnection.

[135] https://www.cpuc.ca.gov/General.aspx?id=5071.

[136] https://www.cpuc.ca.gov/General.aspx?id=5071.

Barrier	Description	Potential Solution
Financing Projects	Getting banks and other financial institution to loan funds to storage projects is challenging due to the uncertainty around long-term revenue and performance of the storage energy system.[137]	A contracted model where revenues are spelled out under a long-term contractual arrangement with a creditworthy counter party is favored over a merchant model where the market determines revenues and is subject to the vagaries of the market such as volatility and regulatory risk.[138] A revenue model that combines both a long-term contractual arrangement and some market revenues can also be useful.
Federal and State Incentives	Funding and tax credits for energy storage projects improve the economics of storage projects.	Bills have been introduced in Congress to provide ITC and other benefits to storage projects.[139] At the state level, "at least 20 states (nine of which are restructured), regulatory and legislative bodies are considering strategies to spur growth in energy storage."[140]

As demonstrated above, various impediments exist that will constrain the full cost-effective deployment of energy storage systems in the United States and elsewhere. While this situation is not altogether unique for new energy technologies, the dynamic and all-encompassing nature of energy storage technologies adds an extra layer of complexity. Federal and State legislation and storage policies have started addressing many of the barriers outlined above. Only time and experimentation with storage devices will allow for policymakers and grid monitors to better understand how to optimally integrate them into the evolving electric system.

Minimum Storage Goals

Act 82-2010[141] calls upon PREB, with the assistance of the Energy Public Policy Program of the Puerto Rico Department of Economic Development and Commerce, to "prescribe by regulations the specific goals to be reached by regulated entities regarding minimum energy storage and compliance schedule."[142] Act 82-2010 notes that the Bureau "may consider incentive programs that promote the

[137] See https://www.projectfinance.law/publications/2017/june/financing-energy-storage-projects-assessing-risks/.

[138] "Moody's puts a merchant project on the other end of the risk profile and cites the projects that were built in the PJM Interconnection after the RTO changed its rules for frequency regulation. Many of those projects were built on a merchant basis, using the sponsors' balance sheets. The market collapsed, however, when PJM put a cap on fast responding frequency regulation, imperiling the income streams for many of the projects." https://www.utilitydive.com/news/project-finance-getting-more-viable-for-energy-storage-moodys-says/519701/.

[139] hr2096-116. For an introduction to the ITC see: https://www.seia.org/initiatives/solar-investment-tax-credit-itc.

[140] Maryland Storage Study, pp. 12-15.

[141] Known as the Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act, as amended.

[142] Public Policy on Energy Diversification by Means of Sustainable and Alternative Renewable Energy in Puerto Rico Act, as amended, at Section 2.12.

profitable development of energy storage systems to comply with the Renewable portfolio standard." Further, Act 82-2010 calls for the Bureau to "evaluate these determinations at least once every three years and as part of the Integrated Resource Plan."[143]

The Bureau hereby notifies the Legislature of its intent to prescribe goals, compliance schedules, and performance incentives, if any, through regulations, including the Regulation on Integrated Resource Plan for the Puerto Rico Electric Power Authority.

Compliance Schedules

The Energy Bureau shall establish in the year 2020, a schedule for the development of regulations on energy storage to address compensation and barriers and shall "prescribe by regulations the specific goals to be reached by regulated entities regarding minimum energy storage and compliance schedule."[144]

Performance Incentives

The Energy Bureau currently has a proceeding opened to address performance incentive metrics for PREPA. As part of this proceeding the Energy Bureau will consider appropriate metrics regarding energy storage, on which PREPA will be required to report. As part of the proceeding, the Energy Bureau may also consider the establishment of performance incentives that encourage the development of storage capacity.

Work with Energy Office on Education about Storage

Based on the results of this study, the Puerto Rico Energy Bureau finds that the emergence of storage technologies may depend significantly upon consumer awareness and education regarding the potential for storage to further the energy public policy of Puerto Rico. The recent consumer reaction to the Bureau's energy efficiency rider that has led the Bureau to implement multiple workshops reaffirms the importance of education. The Energy Bureau therefore recommends that education around storage be promoted by the Energy Office.

Compensation Issues

There have been numerous examples put forth for the compensation of storage to remove economic barriers to their implementation. The Energy Bureau shall commence a proceeding within the next year or through a rate case filed by PREPA, to consider mechanism to appropriately compensate energy storage providers based on the value they provide to the grid.

[143] Id.

[144] Id.

6.3. Next steps

PREB recommends the formation of an Energy Storage Working Group (ESWG) to consider the analysis and recommendations contained in this report. The ESWG should be comprised of stakeholders from all the relevant interests with the goal to:

- develop education initiatives and information on the role of energy storage in meeting the Commonwealth's clean energy and resilience goals;
- evaluate and recommend policies and regulations to promote opportunities for cost-effective investments in BESS; and
- monitor progress as the BESS industry evolves in Puerto Rico and report to PREB on a regular basis.

7. GLOSSARY OF TERMS

Ancillary Services: Ancillary services are services provided by generators that grid operators require to ensure that the grid operates reliably. Ancillary services typically include voltage support, frequency regulation, contingency reserves, and black start services

Battery Energy Storage System (BESS): BESS consists of the battery cell, the power conversion system costs and EPC (engineering, procurement, and construction) costs, storage module and balance of system costs.

Behind the meter: Behind-the-meter resources are generation resources that are installed behind the meter and are often used to reduce a building's peak demand for power to avoid costly demand charges. Typically, these include storage and rooftop solar.

Black start: A black start is the process of restoring an electric power station or a part of an electric grid to operation without relying on the external electric power transmission network to recover from a total or partial shutdown

Capacity: Capacity is the output of a generating unit at any point in time and is generally expressed in kilowatts (kW) or megawatts (MW).For batteries, the power rating, or capacity, is the amount of power in kilowatts (kW) or mega-watts (MW) that can flow in or out of the battery at any given instant.

Cost of Service Asset: A cost of service approach is used to determine a fair price for electric service, by which the aggregate costs for providing each class of service (residential, commercial, and industrial) are determined. Prices are set to recover those costs, plus a reasonable return on the invested capital portion of those costs and allocated based on the sales made to each class.

Critical Loads: Critical loads include basic resources that should either ride through the storm or must be available shortly after. These loads are considered crucial for the restoration effort.

Cycle Life: Cycle life refers to the finite number of times that a battery can be charged and discharged. The process of charging and discharging once is considered one cycle.

Demand Response: Demand response is ability of customers to respond to either a reliability concern or increased prices from their utility system operator, load-serving entity, regional transmission organization/independent system operator (RTO/ISO), or other demand response provider by lowering their power consumption.

Distributed Energy Resources: (DERs), refers to electricity and gas resources that are installed on customers' premises (behind the meter). These include EE, demand response, distributed generation, storage, plug-in electric vehicles, and more

Distribution: The delivery of electricity to end-users via low-voltage electric power lines (usually 34 kV and lower)

Duration of Battery: The battery duration is the number of hours the system can be used to deliver energy before needing to be recharged. It is calculated as the ratio of the battery energy rating to power ratings.

Energy: The energy rating or battery storage capacity is the maximum energy that can be stored in the system. This is measured in kilowatt-hours (kWh) or megawatt hours (MWh) .

Energy Density: Energy density is a measure of power or energy per unit of volume or weight. Higher energy density batteries can store more energy per unit of weight or volume.

Energy Efficiency: Energy efficiency is the deployment of end-use appliances that achieve the same or greater end-use value while reducing the energy required to achieve that result.

Frequency Regulation: Frequency regulation (or just "regulation" for short) is a tool employed by power grid operators to maintain system frequency within a specified range.

Independent system Operator (ISO): A non-utility that has multi-utility or regional responsibility for ensuring an orderly wholesale power market, the management of transmission lines, and the dispatch of power resources to meet utility and non-utility needs. An ISO controls and operates the transmission system independently of the local utilities that serve customers. This usually includes control of the dispatch of generating units and calls on demand-side resources over the course of a day or year.

Integrated Resource Plan: An integrated resource plan is a long-term plan prepared by a utility to guide future energy efficiency, generation, transmission, and distribution investments.

Levelized cost of storage (LCOS): LCOS is stated in $/MWh ($/kWh) and is defined as the total lifetime BESS cost including capital costs and on-going operations and maintenance costs over the system life divided by the total energy discharged over the life of the system.

Microgrids: A Microgrid serves a single building or campus aggregated through a facilities distribution service, In comparison with minigrids, Microgrids typically refer to a smaller geographically confined area including single building or campus

Minigrids: Minigrids are zones of resiliency into which the system can be segregated during and after a major weather event ensuring that the load can be served using local resources

Net Meter: Net metering allows customers with behind-the-meter distributed energy resources to receive a credit for supplying excess energy generated electricity to the grid. A rate design that allows a customer who has distributed generation, typically solar photovoltaic systems, to receive a bill credit at the full retail rate for energy injected into the electric system.

Net Present Value (NPV): Net Present Value (NPV) is The value in the present of a sum of money, in contrast to some future value it will have when it has been invested at compound interest.

Non-Wires Solutions: Non-wires solutions are electric utility system investments and operating practices that can defer or replace the need for specific transmission and/or distribution projects, at lower total resource cost, by reliably reducing transmission congestion or distribution system constraints at times of maximum demand in specific grid areas. These solutions may include demand response, distributed generation (DG), energy efficiency, electricity and thermal storage, load management, and rate design.

Peak Demand: The maximum demand by a single customer, a group of customers located on a particular portion of the electric system, or all of the customers in a class or all of a utility's customers during a specific period of time – hour, day, month, season, or year.

Priority Loads: Priority loads include those necessary to restore normalcy to each of the localities.These loads must be reconnected shortly after the Critical Loads with the objective to achieve full reconnection no more than 10 days after event.

Regional Transmission Organization (RTO): An independent regional transmission operator and service provider established by FERC or that meets FERC's RTO criteria, including those related to independence and market size. RTOs control and manage the high-voltage flow of electricity over an area generally larger than the typical power company's service territory. Most RTOs also operate day-ahead, real-time, ancillary services and capacity markets, and conduct system planning. RTOs include PJM, ISO-New England (ISO-NE), the Midwest Independent System Operator (MISO), the Southwest Power Pool (SPP), the New York ISO (NYISO), and the California ISO (CAISO).

Renewable Portfolio Standards: A Renewable Portfolio Standard (RPS) is a standard that requires utilities to meet a certain percentage of their annual electrical production from renewable sources.

Reserves: The amount of capacity that a system must be able to supply, beyond what is required to meet demand, in order to assure reliability when one or more generating units or transmission lines are out of service. Traditionally a 15- to 20-percent reserve capacity was thought to be needed for good reliability. In recent years, the accepted value in some areas has declined to ten percent or even lower.

Solar-plus-storage: A solar-plus-storage system is a battery system that is charged by a connected solar system

Spinning Reserves: Any energy resource that can be called upon within a designated period of time and that system operators may use to balance loads and resources. Spinning reserves may be in the form of generators, energy storage, or demand response. Spinning reserves may be designated by how quickly they can be made available, from instantaneously up to some short period of time.

Time of Use (TOU): Time-of-use is a rate plan in which rates vary according to the time of day, type of day or season. Typically, higher rates are charged during the peak demand hours and lower rates during off-peak (low) demand hours. Rates that vary by time of day and day of the week. TOU rates are intended to reflect differences underlying costs incurred to provide service at different times of the day or week.

Transmission/Transmission System: That portion of the electric system designed to carry energy in bulk. The transmission system is operated at the highest voltage of any portion of the system. It is usually designed to either connect remote generation to local distribution facilities or to interconnect two or more utility systems to facilitate exchanges of energy between systems.

Utility Scale Storage: Storage systems that are installed in front of the meter and are typically monitored and controlled by the utility company with the ability to manage the charging and discharging of the battery depending on the needs of the grid.

Value stacking: Value stacking refers to assessing and capturing the multiple value streams that a resource can create.

Voltage Support: An ancillary service in which the provider's equipment is used to maintain system voltage within a specified range.

Appendix A. SYNAPSE MODELING METHODOLOGY AND RESULTS

Appendix A is a supplement to the modeling conducted by Synapse to explore alternative energy planning scenarios to those contained in PREPA's draft 2019 IRP.

A.1 Base Case Modeling Assumptions

The following section outlines the modeling assumptions for building the base case.

Base Case: The base case scenario was modeled leveraging the preferred generation portfolio outlined in the IRP. Synapse provided specific generation resources to the model as fixed decisions based on the modeling results conducted by Siemens in Aurora for the preferred plans. The fixed decisions included 18 new mobile unit GT's (LM2500 SAC), all of which are to come online by 2021 and two F-Class CCGTs – at Caguas and Palo Seco. In addition, AES was assumed to retire in 2027, San Juan Units 5 & 6 were converted to gas in June 2019 and Ecoelectrica was renegotiated to continue production past 2022. The base case model was then optimized for the quantity of solar and storage that would be required to meet the peak demand and generation needs.

The load forecast used as input to the model is the Base Case Load Forecast. To simulate the minigrids based on Appendix 1 of the IRP, Synapse configured eight separate demand regions similar to the IRP but with two differences. The Mayaguez North and South were established under one region (minigrid) and San Juan and Bayamon regions (which are expected to form one minigrid) were separated into two separate regions for the purpose of the modeling analysis. Following the formation of the minigrid areas, we established transmission limits between each of the regions – although theoretically transmission may be unlimited, for the purpose of the analysis we assumed that each region would need to build sufficient local generation in order to support the localized critical and priority loads to support the minigrid approach as outlined in the IRP. The difference between the peak demand of the region and the total peak load that would need to be supported (critical and priority load) was set as the limit to the maximum amount of energy imports allowed into the area.

The renewables were modeled based on inputs from the IRP. The modeling reflects the Act 17-2019 RPS targets of 20% by 2022, 40% by 2025 and 60% renewable penetration by 2040 and the renewable costs are based on NREL ATB 2019, reference case assumptions. The BESS modeled were lithium-ion batteries only. For the baseline scenario, new PV installations are limited to 300 MW in 2020 and 600 MW annually thereafter. Storage installations are limited to 40 MW in 2019, 200 MW in 2020 and 600 MW annually thereafter. The energy efficiency and demand response programs have been established with the objective of reducing demand by approximately 2% per year.

A.2 Modeling Approach and Scenarios

In addition to the base case scenario designed to represent the preferred plans identified in the IRP, the following four scenarios were modeled using the base case assumptions outlined above as the reference.

No Import constraints: The import constraints for the base case scenario were based on the requirement that critical and priority loads had to be met by local generation resources in the specific region. However, the "No Imports constraints" scenario assumes that there are no requirements to meet local generation and demand and the entire island is connected by transmission lines with no import or export constraints between the regions.

Unlimited Renewables: For the base case scenario, new PV installations are limited to 300 MW in 2020 and 600 MW annually thereafter. Storage installations are limited to 40 MW in 2019, 200 MW in 2020 and 600 MW annually thereafter. The unlimited renewables scenario removes all annual/cumulative constraints on solar and BESS builds after 2020. The constraints for limited builds prior to 2020 continued to be constraining factors due to the limited time available in procuring and building these resources.

Reduced Gas Peaker Build: The base case scenario builds 18 mobile peaking units in 2021. These mobile peaking units are provided as fixed decisions to the model to compensate for the reduced generation from retirement of the Aguirre Steam units. In this scenario, the mobile peaking units are no longer fixed decisions provided to the model. Instead the model is provided the three resource options to meet the overall generation requirements: mobile gas peaking units, solar or lithium-ion batteries. This scenario presents the impact of reducing the gas peaker builds on the deployment of solar and storage resources by no longer providing these units as fixed decisions to the model but rather allowing the model to optimize between these three resources.

Each of the scenarios above is optimized for the quantity of solar and storage between 2019 and 2038 and compared with the base case optimization to understand the impact of the constraints on build out of the solar and storage and compare the generation of each of these scenarios with the base case.

Appendix B. Storage in the Commonwealth of Puerto Rico

Appendix B contains supplemental information

B.1 State of Storage in Puerto Rico

Current Storage Projects in Puerto Rico

Sabana Llana substation pilot project (1994)

PREPA's Sabana Llana substation pilot project was a fully commercial battery system that was acquired for daily operation in a frequency control and spinning reserve mode. The Puerto Rican grid had ongoing stability issues, and routinely had frequency and voltage excursions that could only be controlled by aggressive load-shedding, unless new generation was added to provide regulation and stability. The choices for new generation included fast-acting combustion turbines or battery energy storage. PREPA's analysis showed that battery energy storage systems offered superior operational benefits due to their faster reaction times, both for frequency regulation and spinning reserve requirements. The comparable slower response times of combustion turbines required more installed capacity, whereas the faster reaction time of a battery system meant that a much smaller battery could offer the same functionality as larger sizes of combustion turbines. Typically, battery systems can reach full operating power in less than 1 second, whereas mechanical systems such as combustion turbines need several seconds to minutes to reach their full power output. The seemingly small difference in reaction times translates into very large consequences for the stability of the electric grid, where events that lead to outages propagate within cycles, and a difference of 1 min translates to a complete blackout under some conditions. Therefore, it was shown that battery systems were a more cost-effective option compared to combustion turbines because a smaller battery could outperform a much larger block of combustion turbines. The PREPA battery was patterned after the BEWAG battery[145] in application as well as battery type. Valve-regulated lead-acid (VRLA) batteries were commercially available by the time the PREPA battery project was started, but PREPA chose a flooded, flat-plate cell because it had a proven track record at BEWAG. However, once utility operations began in 1994, the battery was cycled more frequently than planned, which caused the battery to age more rapidly than expected. This use led to positive-plate growth, which caused cell / jar cracks, leaks, short circuits, and ultimately early battery failure. PREPA made the decision in 2001 to repower, or replace, the battery. A tubular positive plate, flooded

[145] Berliner Kraft und Licht (A German utility project closes in design to Puerto Rican project). https://www.sandia.gov/ess-ssl/publications/ESHB%201001834%20reduced%20size.pdf, see pages 6-28 and 6-30.

battery was selected, and the new battery was installed in mid-2004. Several problems occurred, however, and the system was taken out of service.[146]

Storage Projects in Puerto Rico

The Puerto Rican government (through the Puerto Rico Electric Power Authority (PREPA)), issued a request for qualifications (RFQ) to develop a utility scale battery electric storage systems (BESS) on June 2018.[147] The 10 BESS projects will be interconnected to a 115 kV switchyard owned by PREPA. The 20.0 MW/20.0 MWh BESS system should have the flexibility and modularity to expand to a 40 MW/160 MWh BESS Facility. The design, layout configuration, physical dimensions, spacing and electrical clearances of the equipment, components, structures, containers and buildings to be installed as part of this initial BESS shall clearly consider the future expansion of the facility.[148] The projects are large enough to supply 5% of the US commonwealth's peak electricity demand and are expected to come in at a cost of $3.8 million each. Energy analysts expect net savings of from $8 to $12 million per substation when compared to the cost of diesel.[149]

Battery Storage in Action Plan

PREPA's revised IRP considers several metrics such as resiliency, a shift to decentralized generation resources, and a central role for renewables in compliance with the Puerto Rico Energy Public Policy Act. Most notably, the revised IRP calls for increasing solar capacity by nearly 1,400 MW and energy storage by 920 MW in the first four years of the plan's implementation. These metrics are proposed to help reach the 100% renewable energy goal.[150]

B.2 Available Technologies

Mechanical Energy Storage Systems

There are several types of mechanical energy storage systems on the market today. The most known of these are pumped hydro, flywheels, and compressed air energy storage systems. These systems work by using energy to mechanically store that same energy by doing things like pumping water

146 (https://www.energystorageexchange.org/%E2%80%8Cprojects/752). Summary provided by Sandia National Laboratories. For greater detail see: https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/1999/992232.pdfhttps://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/1999/992232.pdf).

147 Request for Qualifications for the Puerto Rico Electric Power Authority Utility Scale Energy Storage System Project. Puerto Rico Public Private Partnerships Authority. June 2018. Available at: http://www.p3.pr.gov/assets/rfq-energy-project-june-2018.pdf. Statements of qualifications were to be filled by August 3, with a notice of shortlisted respondents due out on August 17.

148 Id at 12.

149 Coren, Michael. *Puerto Rico just asked for enough batteries to supply 5% of its peak electricity demand.* Quartz. June 2018. Available at: https://qz.com/1315352/puerto-rico-just-asked-for-enough-batteries-to-supply-5-of-its-peak-electricity/.

150 PR IRP Plan, page 10-3.

uphill (pumped hydro), spinning a rotor (flywheel), or compressing air underground (compressed air). Once the energy is needed, the opposite mechanical process is applied to release that energy for use. Each of the technologies are useful for various response times, store times, and storage size need. The benefits of mechanical storage include the high storage capacity for systems like pumped hydro and compressed air that help the utility meet the constantly changing demand for energy over long periods of time. However, these systems have low energy density[151] and are not very popular for energy storage outside of large pumped hydro systems. Flywheels are not frequently used for bulk energy storage and instead are mostly useful for instantaneous discharge of power.

Chemical Energy Storage Systems

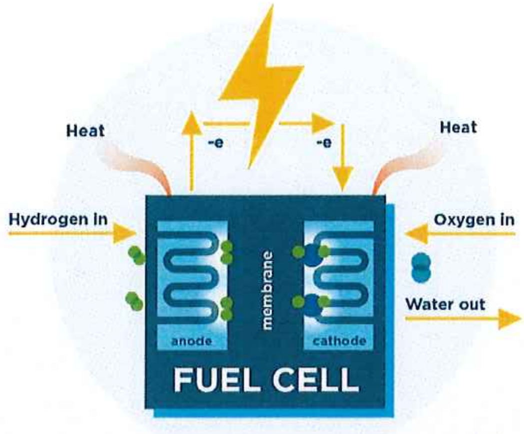
One of the only types of chemical storage on the market today is hydrogen storage. Hydrogen can generally be stored physically as a liquid at -253 degrees C or a gas in a high-pressure tank. Hydrogen storage is attractive because of the high energy density of this material. Hydrogen fuel can be created through various processes. The ones used today include natural gas reforming (gasification), electrolysis, renewable liquid reforming, and fermentation.[152] All these processes require the use of electricity except for the fermentation, to create the hydrogen fuel. Energy is stored in the creation of the hydrogen fuel and released in a fuel cell by combining the hydrogen with oxygen to create a water by-product. Figure 17 shows how electricity is created during this process. Most of the interest in hydrogen storage is for its applications to the transportation sector. However, the temperature and pressure requirements of storing hydrogen have limited this form of energy storage from being broadly adopted. [153]

[151] Energy density is the amount of energy stored in any material per unit volume.

[152] *Hydrogen Production and Distribution*. Alternative Fuels Data Center. Department of Energy (DOE). Available at: https://afdc.energy.gov/fuels/hydrogen_production.html

[153]Hydrogen Basics – Storage. Florida Solar Energy Center. Available at: http://www.fchea.org/fuelcells#:~:targetText=A%20fuel%20cell%20works%20by,and%20oxygen%20through%20the%20cathode.&targetText=At%20the%20cathode%2C%20the%20protons,%2C%20excess%20heat%2C%20and%20water.http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/storage.htm

Figure 17: Hydrogen Fuel Cell[154]



Electrochemical Energy Storage Systems

Electrochemical energy storage systems are defined as batteries due to their use of chemicals to store energy. Electrochemical batteries encompass a large range of different types of batteries. These battery systems generally use chemical energy in its materials to store and discharge electric energy. The subcategories of electrochemical batteries are: standard batteries; modern batteries; flow batteries; and high temperature batteries.[155]

Standard batteries include lead acid batteries and Ni-Cd batteries. Lead acid batteries are generally low in price because of the availability of lead, reliability, high voltage, and have a high cycle life. However, they are now not good for repetitive cycles and often corrode. Ni-Cd batteries have the benefits of long-life cycle, overcharge capabilities, high rates of charge and discharge, almost constant discharge voltage, and can operate at low temperatures. However, the market for Cadmium is unstable and it is expensive. Ni-Cd batteries also subject to a high rate of self-discharge at high temperatures

Modern batteries consist of Ni-MH and Li-ion batteries. Ni-MH batteries are frequently used for smaller cases like hybrid vehicles, mobile phones, toothbrushes, cameras, etc Ni-MH batteries can be cycled around 1,000 times, but they are subject to the "memory effect" causing capacity loss that cannot be changed if the battery is not charged and discharged properly. Alternatively, Li-ion batteries are very popular for their high energy density and the good conductive power of lithium. Li-ion batters offer high voltage, around 500 or more cycles, rapid charging and discharging, and are not subject to the "memory effect." The materials in Li-ion batteries are lighter, allowing for larger scale application and is the preferred chemistry for electric vehicles and other transportation applications. Additionally, Li-ion batteries are suited for multiple applications, including electric

154 Fuel Cell Basics. Fuel Cell and Hydrogen Energy Association (FCHEA).

155 Electrochemical Energy Storage. Petr Krivik and Petr Baca. Intech. January 23, 2013. Available at: http://cdn.intechopen.com/pdfs/42271/InTech-Electrochemical_energy_storage.pdf

vehicles. Storage used in electric vehicles is mostly used for mobility but is currently being explored as an energy storage resource as well.[156]

Flow batteries use reversible electrochemical reactions in two different liquids to store and discharge energy. The energy capacity of these type of batteries is scalable through the increase or decrease in the amount of the solution in the battery's electrolyte tanks. Flow batteries can be fully discharged, experience almost no loss when cycling, and are subject to low self-discharge. However, they have low energy density and specific energy[157]. Furthermore, flow batteries still have low commercial maturity and often require high operation costs since the systems require a certain amount of energy to remain active to the grid.

Thermal energy storage (TES) entails heating or cooling storage materials with highly specific heat capacities and then using power generation to discharge the storage. The least cost form of TES is sensible heat storage. Sensible heat storage stores thermal energy by heating or cooling some material (e.g. salts, water, sand, molten, rocks). Water is the least expensive option; however, all sensible heat storage requires a lot of space because if the low energy density of all of the storage materials. TES systems require specific designs to properly maintain and discharge energy at the right temperature and rate. These systems can be used centrally or distributed. Centralized systems can be used as part of a district heating or cooling system, at industrial locations, combination heat and power plants, or for storage of renewable energy. Distributed applications often use concentrating solar power (CSP) for space and water heating and cooling. [158]

B.3 Regulatory Environment

Current Commonwealth Regulations/ Dockets Impacting Energy Storage

Puerto Rico's current legal and regulatory environment is likely to impact any future development of energy storage systems in the Commonwealth. Of particular relevance is the public policy as stated most recently in Act 17-2019[159]; the Integrated Resource Planning process; the regulation on microgrids; and various dockets regarding distributed generation.

[156] *Vehicle-to-Grid Application Puts Businesses in Drivers Seat of EV Revolution.* John Parnell. Greentech Media. September 2019. Available at: https://www.greentechmedia.com/articles/read/vehicle-to-grid-technology-puts-businesses-in-drivers-seat-of-ev-revolution

[157] Specific energy is the amount of energy per unit mass. It is measured in Joules per kilogram (J/kg).

[158] Thermal Energy Storage: Technology Brief. International Renewable Energy Agency (IRENA). January 2013. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-ETSAP-Tech-Brief-E17-Thermal-Energy-Storage.pdf

[159] Known as the *Puerto Rico Energy Public Policy Act.*

Act 17-2019

Act 17-2019 declares that the public policy of the Government of Puerto Rico includes, among other things:

> To guarantee that the cost of the electric power service in Puerto Rico be affordable, just, reasonable, and nondiscriminatory for all consumers in Puerto Rico . . .
>
> To reduce our reliance on energy sources derived from fossil fuels . . .
>
> To ensure the integration of renewable energy into the Electrical System in a safe and reliable manner and at a reasonable cost . . . [; and]
>
> To design the infrastructure of the Electrical System to be more robust and resistant to weather events and other disasters . . .[160]

Energy storage may aid in the achievement of a system that is modern, sustainable, reliable, efficient, cost-effective, and resilient. For this reason, Act 17-2019 called upon the Puerto Rico Energy Bureau to complete the study to which this Appendix is attached.[161] Further, Act 17-2019 states as that one objective of the public policy is:

To encourage the use of energy storage technology for consumers at all levels to facilitate and accelerate the integration of renewable energy sources and capitalize on their capacity as a distributed generation mechanism.[162]

This use of energy storage technology may occur at many levels, both centralized and decentralized. Act 17-2019 further clarifies the process laid out in Act 120-2018[163] for the sale or concession of the assets of the Puerto Rico Electric Power Authority (PREPA) to private entities. The vision of a transformed power system in Puerto Rico necessarily includes the participation and engagement of additional entities besides PREPA, and it is within that context that energy storage technologies may emerge.

Integrated Resource Plan

Pursuant to Act 83-1941, as amended,[164] the Puerto Rico Electric Power Authority must develop and maintain an integrated resource plan that "considers all reasonable resources to satisfy the demand of electric power services during a specific period of time, including those related to the offering of electric power, whether existing, traditional and/or new resources, and those related to energy demand, such as energy conservation and efficiency or demand response and localized energy

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[160] Id. at Section 1.5(1)(a), (5)(a), (8)(a), and (9)(b).

[161] Id. at Section 4.10 (amending Act 82-2010); see also id. at Section 1.5(8)(e).

[162] Id. at Section 1.6(9).

[163] Known as the *Puerto Rico Electric Power System Transformation Act.*

[164] Known as the *Puerto Rico Electric Power Authority Act.*

generation by the customer."[165] Energy storage is one possible resource that PREPA must consider in its integrated resource planning process. The consideration of energy storage in the integrated resource plan is likely to have a significant impact on whether and how PREPA or its successor invests in energy storage technologies.

Microgrid

Energy storage technologies may emerge as components of microgrids. The regulatory environment governing microgrids is therefore likely to impact the development of energy storage systems in Puerto Rico. The Puerto Rico Energy Bureau has issued its Regulation on Microgrid Development in order "to promote and encourage the development of microgrid systems in Puerto Rico," among other goals.[166] The Bureau acknowledges that this regulation will impact the development of energy storage technologies as energy storage can be a useful companion to the microgrid.

Distributed generation

Energy storage technologies may emerge in conjunction with distributed generation. The regulatory environment governing distributed generation is therefore likely to impact the development of energy storage systems in Puerto Rico. For instance, the ongoing proceeding regarding distribution system planning[167] is likely to impact how distributed storage is valued and pursued. Storage will enable distributed generators to lean less on the system for supplemental or back-up power. Moreover, regulations will be needed to determine the value of the services to be offered by the storage unit to the grid. The level of compensation should be set forth in a utility tariff.

Regulations from other Jurisdictions

Identified barriers to energy storage

Many of the general barriers to energy storage and their potential solutions discussed in this report apply to Puerto Rico. As more of the Puerto Rican grid is opened to competitive and market forces over time, capacity, energy and ancillary markets may allow for full value stacking of energy storage projects.

Other barriers will be exacerbated by Puerto Rico's current fiscal crisis, utility bankruptcy and the grid recovery effort after the devastation of Hurricane Maria.

With an estimated $59 million consolidated and financing gap between fiscal years 2017 and 2026, Congress enacted the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA), which was signed into law on June 30, 2016:

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165 Id. at Section 2(k).

166 See CEPR-MI-2018-0001, Resolution on May 16, 2018, Adoption of Proposed Regulation on Microgrid Development.

167 Puerto Rico Energy Bureau, Case No. NEPR-MI-2019-0011, Process for the Adoption of Regulation for Distribution Resource Planning.

"PROMESA provides a series of mechanisms to achieve fiscal and budgetary balance and capital markets access to spur infrastructure revitalization in Puerto Rico. Among its main provisions, PROMESA established the Financial Oversight and Management Board for Puerto Rico (Oversight Board), provided a framework to restructure Puerto Rico's public debt, called for the approval of long-term fiscal plans and budgets, mandated balanced budgets and established a specific chapter (Title V) to identify and pursue critical infrastructure projects through an accelerated local permitting process and a prioritized federal review procedure to ensure the prompt and effective revitalization of Puerto Rico's critical infrastructure."[168]

Furthermore, storage equipment and supplies shipped to the island will incur higher than normal costs because of the legal requirement that only US shippers can carry cargo to Puerto Rico.[169]

With all the uncertainty surrounding the Puerto Rican economy, there is an expectation that any major project will be assessed a sizeable risk premium by the financial community, that will negatively impact project economics. Will storage aggregators be enticed to bid on projects and set-up shop in Puerto Rico? Since the dire financial situation of Puerto Rico will limit the government's financial incentives and tax breaks for storage projects, federal funding will be needed to fill this gap. To the extent that federal financial assistance becomes available, it may help overcome the unique financial uncertainty that currently engulfs the island.

Mechanisms to remove barriers

As demonstrated in the report's battery energy storage policies section, several state commissions have held proceedings and issued Orders supporting energy storage. These vary widely and can be summarized as follows:

- Allow storage projects to stack the value of multiple streams of revenue to improve their cost-effectiveness;
- Require that energy storage be considered as part of an IRP;

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168 Government of Puerto Rico, "Request for Qualifications for the Puerto Rico Electric Power Authority Utility Scale Energy Storage System Project," June 22, 2018, Pages 2-3. "ROMESA requires the Puerto Rico Energy Commission (PREC) to make two findings: first, whether the project "affects" an approved Integrated Resource Plan and, second, whether it will "adversely affect" an approved Integrated Resource Plan (IRP). For PREC to determine a project has no adverse effect on an IRP, such project must be consistent with the IRP by: (i) being specified in an approved IRP; (ii) being a reasonable substitute for a project specified in an approved IRP; or (iii) satisfying a legitimate need, as determined by the PREC, regardless of whether such need is identified in an existing approved IRP. Furthermore, to avoid a determination of adverse effect, projects not specified in an approved IRP must also demonstrate cost-effectiveness, which may be achieved by demonstrating having been selected through a competitive bidding process or that its costs are no greater than necessary to satisfy the project's stated purpose."

169 Under the Jones Act, any vessel **can** enter **Puerto Rico**. In fact, many **foreign vessels** enter **Puerto Rico** regularly, importing goods from countries around the world. However, transportation of goods between two U.S. ports must be carried out by a vessel that was built in the U.S. and operated primarily by Americans. https://www.pbs.org/newshour/nation/jones-act-explained-waiving-means-puerto-rico.

- Require that energy storage be considered as a "non-wires" solution to integrated distribution planning;
- Require that the utility to report on its energy storage activity and develop relevant metrics;
- Require that utilities implement pilot energy storage programs;
- Modify existing RPS to consider a "clean peak period" requirement;
- Adopt a "first in time" rather than "first project to file" in the energy storage interconnection process;
- Develop time-differentiated and critical peak pricing tariffs to incent the arbitrage opportunities for behind-the-meter storage;
- Upgrade net-metering regulations to incent combined solar and storage systems;
- Monitor that no anti-competitive behavior is taking place in markets that have competitive and cost-based storage providers;
- Provide performance-based incentives for utilities that are able to successfully promote energy storage in their service territories; and
- Encourage aggregated storage providers to bid projects that are cost-effective.

These are all options that Puerto Rico can consider to advance the development of battery storage on the island.

Appendix C. MINIGRID AND MICROGRID ANALYSIS: TECHNICAL DATA AND ADDITIONAL RESULTS

Appendix C provides supplemental information on the minigrid versus microgrid analysis conducted by Synapse for this report.

C.1 IRP Minigrid Limitations

Infrastructure sizing based on "deemed" critical loads

The IRP assumes power supply to critical and priority loads within each minigrid region via power distribution feeders. Within the modeling construct, PREPA does not attempt to isolate critical and priority loads from other loads that are also connected to the same feeder. As such, PREPA has sized the minigrid zone resources (thermal, solar PV, and batteries) to meet the peak load of the entire feeder, as opposed to the actual peak load of critical and priority end uses.

This approach is crucially imprecise and may result in overbuilding of infrastructure, as the "deemed" critical and priority loads are larger, and may be substantially larger, than the actual loads. The "deemed" critical and priority loads (1,177 MW and 480 MW, respectively) total to 1,657 MW or 62% of the total island peak load. See **Error! Reference source not found.** below for minigrid load details by zone and Table 15 in Minigrid and Microgrid Analysis: Technical Data and Results of this study for detail by minigrid zone.

While the actual critical and priority loads are not disclosed in the IRP, a recent benchmark analysis is available. A report by Sandia National Laboratory estimates critical and non-critical loads for consideration of a microgrid infrastructure solution for resiliency in Puerto Rico.[170] The study identifies 159 potential microgrids to serve the critical infrastructure throughout the island with an estimated 343 MW of critical loads and 399 MW of non-critical loads. Compared to this result, the deemed critical loads used in the IRP are more than 3 times larger than what might be considered as actual critical loads.

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[170] Jeffers, Robert Fredric, Andrea Staid, Michael J. Baca, Frank M. Currie, William Ernest Fogleman, Sean DeRosa, Amanda Wachtel, and Alexander V. Outkin. *Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico*. No. SAND2018-11145. Sandia National Lab. (SNL-NM), Albuquerque, NM (United States), 2018.

Table 13: Minigrid Load Breakdown

Exhibit 2-2: 2019 Deemed Critical/Priority/Balance Load

Source: IRP2019 EX 1.01C Appendix 1_Section2_Redacted.pdf – page 2-6

2019 Critical/Priority/Balance Night Peak Load, MW

Minigrid	Total Load	Critical	Priority	Balance	% Critical	% Priority	% Balance
Arecibo	234.2	117.2	60.6	56.4	50%	26%	24%
Caguas	306.7	128.2	74.4	104.1	42%	24%	34%
Carolina	310.8	132.9	33.7	144.2	43%	11%	46%
Cayey	101.1	59.7	29.9	11.5	59%	30%	11%
Mayaguez North	163.5	85.1	7.5	70.9	52%	5%	43%
Mayaguez South	161.7	110.4	9.7	41.6	68%	6%	26%
Ponce	332.3	144.2	79.2	108.9	43%	24%	33%
San Juan	1,050.7	399.0	185.0	466.7	38%	18%	44%
Total	**2,660.9**	**1,176.7**	**480.0**	**1,004.2**	**44%**	**18%**	**38%**

The IRP presents deemed critical and priority loads based on feeder-level data for both minigrids and microgrids. However, microgrids could be built such that not all feeder level loads are served, including the installation of distributed energy resources like solar PV and BESS at the level of partial feeders (part of a distribution-level power line), on campuses, or behind the meter of individual buildings. Further, switches to shed non-critical loads could be installed on feeders or partial feeders to avoid oversizing infrastructure.

Assumption that the critical loads can only be served by thermal resources

The IRP requires that thermal resources be used to ensure full availability of critical services immediately following an event. It is possible for critical loads to be served by non-thermal resources if properly sized and protected to ensure availability throughout a grid outage during a storm or other event. An alternative strategy using microgrids with site-level resiliency could ensure provision of critical services across Puerto Rico using distributed energy resources.[171] Further, investment in such resources can provide additional benefits such as community ownership, economic development, reduced reliance on imported fuels, reduced line losses, and additional services to the end-user and the electric grid during non-event operations.

The Rocky Mountain Institute recently performed initial analysis of the capability of distributed solar and energy storage to meet the electricity demand of over 20,000 critical facilities across the island,

[171] See expert testimony of Ronny Sandoval, Puerto Rico Energy Bureau, CEPR-AP-2018-0001, p12.

powering loads during a grid failure.[172] Results of this review suggest that 650-700 MW of solar generation and 900-1,000 MWh of battery storage would be adequate to ensure resiliency. The identified portfolio of alternate resources would have the potential to offset substantial costs to PREPA ratepayers.

Assumption that substantial new transmission infrastructure is needed to ensure availability of power

The IRP Microgrid strategy prioritizes hardened transmission infrastructure capable of delivering power to customers across eight wide-ranging areas of the island. Proposed work includes installing minigrid controllers, hardening or reconstructing transmission lines and switchyards, underground construction, and adding new transmission lines. The total cost of the proposed work is $5,862 Million (2018$), with investment varying considerably by region, as shown in **Error! Reference source not found.**.

Table 14: Minigrid Transmission Costs by Region

Exhibit 2-93: Total Minigrid Transmission Investment, $ million									
Source:	IRP2019 EX 1.01C Appendix 1_Section2_Redacted.pdf – page 2-105								
	Arecibo	**Bayamón**	**Caguas**	**Carolina**	**Isla**	**Mayaguez**	**Ponce**	**San Juan**	**Total**
115 kV	295	308	481	426	87	311	419	480	2,808
38 kV	253	220	526	231	17	603	773	424	3,047
Controller	1.4	0.4	1.2	0.3	1.2	1.2	0.5	0.5	7
Total	**549**	**528**	**1,009**	**657**	**105**	**915**	**1,193**	**905**	**5,862**

The 2018 report by Sandia National Laboratories[173] identifies a portfolio of 159 microgrids capable of meeting the power needs across Puerto Rico for critical facilities. The report suggests four approaches to the microgrid portfolio, costing in the range of $218-$917M. The economic burden to PREPA ratepayers to achieve resiliency using a minigrid strategy is many times greater, as shown in Section 0:

[172] Amicus Brief filing of Rocky Mountain Institute; September 20, 2019.

[173] Jeffers, Robert Fredric, Andrea Staid, Michael J. Baca, Frank M. Currie, William Ernest Fogleman, Sean DeRosa, Amanda Wachtel, and Alexander V. Outkin. *Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico*. No. SAND2018-11145. Sandia National Lab. (SNL-NM), Albuquerque, NM (United States), 2018.

Minigrid and Microgrid Analysis for Resilience.

Puerto Rico has seen significant adoption of distributed solar PV and battery systems, with additional growth expected in the use of these technologies, addressed in Appendix 4 of the IRP. Such investments by households and local organizations reduce the need for both central generation and transmission-level infrastructure. Recent third-party expert testimony suggests a potential of 6.6 GW solar PV and 12.4 GWh of battery energy storage at residential properties across Puerto Rico[174] (substantial additional potential exists if commercial, industrial, and institutional facilities are considered). This potential for distributed energy resources is of comparable magnitude to the utility-scale solar and battery systems considered in the IRP.

C.2 Data and Inputs

Table 15: Microgrid Deemed Load and Planned Generation Capacity Categorized by minigrid Region

Exhibit 2-4: Microgrid Deemed Critical and Priority Loads in 2019 Night Peak Case, MW
Source: IRP2019 EX 1.01C Appendix 1_Section2_Redacted.pdf – page 2-10 and sections 2.5 to 2.5

Minigrid	Microgrid Name	Critical *MW*	Priority *MW*	Balance *MW*	Thermal *MW*	PV *MW*	BESS *MW*
Arecibo	CAGUANA	2.0	0.0	0.7	3	0	0
Arecibo	CHARCO HONDO	3.6	0.0	0.0	4	0	0
Arecibo	CIALES	4.8	0.0	0.0	6	0	0
Arecibo	DOMINGUITO	3.2	0.0	4.8	4	0	0
Arecibo	DOS BOCAS	0.8	0.0	0.0	1	0	0
Arecibo	FLORIDA	4.1	0.0	2.0	5	0	0
Arecibo	JAYUYA	7.1	2.1	0.0	8	6.4	3.2
Arecibo	GUAJATACA	0.4	0.0	2.3	1	0	0
Arecibo	ADJUNTAS	3.3	0.0	0.8	4	0	0
Arecibo	YAHUECAS	1.1	0.0	0.0	2	0	0
Arecibo	MOROVIS	8.8	0.0	0.0	10	0	0
Arecibo	UTUADO	6.6	0.6	3.7	8	3.2	1.6
Caguas	AGUAS BUENAS	6.4	0.0	0.0	8	0	0
Caguas	PUEBLITO RIO	4.5	0.0	0.0	5	0	0
Caguas	SAN LORENZO	9.1	0.6	6.4	11	0	0
Caguas	YABUCOA	4.2	0.0	3.9	5	0	0
Caguas	NAGUABO	2.0	0.6	0.1	3	0	0
Caguas	RIO BLANCO	2.9	0.0	0.0	4	0	0
Carolina	CULEBRA	2.9	0.0	0.0	0	0	0
Carolina	VIEQUES	5.7	0.0	0.0	7	0	0
Cayey	ABANICO	4.5	0.0	0.0	6	0	0

[174] See expert testimony of Christopher Rauscher, Puerto Rico Energy Bureau, NEPR 10-23-2019, p14.

Exhibit 2-4: Microgrid Deemed Critical and Priority Loads in 2019 Night Peak Case, MW

Source: IRP2019 EX 1.01C Appendix 1_Section2_Redacted.pdf – page 2-10 and sections 2.5 to 2.5

Minigrid	Microgrid Name	Critical *MW*	Priority *MW*	Balance *MW*	Thermal *MW*	PV *MW*	BESS *MW*
Cayey	AIBONITO	9.8	3.4	1.4	11	12.8	6.4
Cayey	BARRANQUITAS	9.2	0.0	0.0	11	0	0
Cayey	COMERIO	6.1	0.0	1.7	7	0	0
Cayey	OROCOVIS	5.0	0.0	0.1	0	0	0
Mayaguez North	LARES	6.4	0.2	4.0	8	0	0
Mayaguez North	SAN SEBASTIAN	12.1	0.0	9.5	14	0	0
Mayaguez South	BOQUERON	1.6	0.3	4.0	2	3.2	1.6
Mayaguez South	COMBATE	4.5	0.0	1.3	6	0	0
Mayaguez South	CROEM	0.8	0.0	1.7	1	0	0
Mayaguez South	LAS MARIAS	3.2	0.0	0.0	4	0	0
Mayaguez South	LAS VEGAS	0.7	0.0	0.0	1	0	0
Mayaguez South	MARICAO	2.3	0.0	0.6	3	0	0
Mayaguez South	BARTOLO	0.6	0.0	0.0	1	0	0
Mayaguez South	INDIERA	0.4	0.0	0.2	1	0	0
Mayaguez South	MONTE DEL ESTADO	0.6	0.0	0.0	1	0	0
Ponce	ARROYO	2.4	2.1	4.9	3	6.4	3.2
Ponce	MAUNABO	2.8	0.0	0.7	4	0	0
Ponce	PATILLAS	4.6	0.2	3.7	6	0	0
Ponce	PENUELAS	2.3	0.0	4.5	3	0	0
Ponce	VILLALBA	7.4	1.9	1.9	9	6.4	3.2
Ponce	PORTUGUES	0.4	0.0	0.3	1	0	0
San Juan	CARRAIZO	1.8	0.0	10.7	3	0	0
San Juan	NARANJITO	6.6	0.2	6.1	8	0	0
San Juan	PINAS	4.4	0.0	11.6	5	0	0
San Juan	UNIBON	0.0	3.2	5.3	0	12.8	6.4
San Juan	VILLA BETINA	3.9	7.0	15.2	5	22.4	11.2
San Juan	QUEBRADA NEGRITO	0.0	0.0	4.5	0	0	0
San Juan	COROZAL	6.0	2.7	0.0	0	0	0
Total		**193.8**	**24.9**	**118.6**	**223**	**73.6**	**36.8**

Source: Thermal, solar, and battery capacities are derived from sections 2.5 to 2.11 of Appendix 1.

Table 16: PV Capital Costs

PV System Overnight Capital Cost

Source: 2019-ATB-data.xlsm Available at https://atb.nrel.gov/electricity/data.html				
Year	Utility-scale		Distributed commercial	
	Low-case	Mid-case	Low-case	Mid-case
	2017$/kW	*2017$/kW*	*2017$/kW*	*2017$/kW*
2017	1,096	1,096	1,832	1,832
2018	1,100	1,100	1,786	1,786
2019	949	1,080	1,315	1,699
2020	890	1,060	1,231	1,601
2021	857	1,040	1,108	1,578
2022	823	1,019	1,070	1,542
2023	790	998	1,032	1,505
2024	757	977	995	1,469
2025	724	956	957	1,432
2026	690	934	920	1,396
2027	657	913	882	1,359
2028	624	892	844	1,323
2029	590	871	807	1,286
2030	557	850	769	1,250
2031	541	841	750	1,238
2032	525	831	732	1,226
2033	509	822	713	1,215
2034	493	812	694	1,203
2035	477	803	675	1,191
2036	465	793	656	1,179
2037	453	784	638	1,168
2038	441	775	619	1,156

Source: NREL (National Renewable Energy Laboratory). 2019. 2019 Annual Technology Baseline. Golden, CO: National Renewable Energy Laboratory

Table 17: Lithium-Ion Capital Costs

Exhibit 6-39. Li-Ion Battery System All-in Capital Costs – Base Case *Source:* IRP2019 – Main Report REV2 06072019.pdf					
Construction year	4-hour Li-ion Battery Storage	2-hour Li-ion Battery Storage	6-hour Li-ion Battery Storage	Power-related costs	Energy-related costs
	2018$/KW	*2018$/KW*	*2018$/KW*	*2018$/kW*	*2018$/kWh*
2018	1392	832	1953	272	280
2019	1218	734	1703	250	242
2020	1110	674	1546	238	218
2021	1041	635	1447	229	203
2022	972	596	1349	220	188
2023	936	576	1296	216	180
2024	899	556	1243	213	172
2025	861	534	1188	207	164
2026	843	523	1163	203	160
2027	825	512	1138	199	157
2028	800	496	1104	192	152
2029	782	485	1079	188	149
2030	764	474	1054	184	145
2031	746	462	1031	178	142
2032	728	450	1007	172	139
2033	717	443	992	169	137

Exhibit 6-39. Li-Ion Battery System All-in Capital Costs – Base Case					
Source:	IRP2019 – Main Report REV2 06072019.pdf				
Construction year	4-hour Li-ion Battery Storage	2-hour Li-ion Battery Storage	6-hour Li-ion Battery Storage	Power-related costs	Energy-related costs
	2018$/KW	*2018$/KW*	*2018$/KW*	*2018$/kW*	*2018$/kWh*
2034	700	431	969	162	135
2035	682	419	945	156	132
2036	664	407	922	150	129
2037	647	395	898	143	126
2038	629	383	875	137	123

Data in blue are computed by Synapse based on information in the IRP.

C.3 Results

Table 18: Capital investment costs to meet critical and priority loads, 2018$ Million

		Arecibo	Caguas & Cayey	Carolina	Mayaguez North	Mayaguez South	Ponce	San Juan	**Total**
IRP Strategy 2: Hardened microgrid with thermal generation and feeder-level resiliency[a]									
Minigrid transmission[b]		561	1,027	668	404	524	1,208	1,470	**5,862**
Minigrid thermal[c]		0	122	83	156	0	107	41	**509**
Minigrid PV[d]		30	142	92	26	0	0	422	**712**
Minigrid BESS[e]		18	63	37	10	0	0	116	**244**
Microgrid thermal[f]		123	156	15	48	44	57	46	**490**
Microgrid PV[g]		18	24	0	0	6	24	66	**137**
Microgrid BESS[h]		7	10	0	0	2	10	26	**55**
Total		**757**	**1,544**	**895**	**644**	**577**	**1,405**	**2,187**	**8,008**
Microgrid Strategy: Distributed PV generation & batteries with local resiliency[i]									
0.4 load	Microgrid PV[j]	425	698	398	221	287	534	1,396	**3,960**
0.4 load	Microgrid BESS[k]	342	562	321	178	231	430	1,124	**3,188**
0.4 load	**Total**	**767**	**1,261**	**719**	**400**	**518**	**964**	**2,520**	**7,148**
0.3 load	Microgrid PV[j]	319	524	299	166	215	400	1,047	**2,970**
0.3 load	Microgrid BESS[k]	257	422	240	134	173	322	843	**2,391**
0.3 load	**Total**	**575**	**946**	**539**	**300**	**389**	**723**	**1,890**	**5,361**
0.2 load	Microgrid PV[j]	212	349	199	111	144	267	698	**1,980**
0.2 load	Microgrid BESS[k]	171	281	160	89	116	215	562	**1,594**
0.2 load	**Total**	**383**	**630**	**359**	**200**	**259**	**482**	**1,260**	**3,574**

IRP parameters are modeled according to S4S2base.
Distribution-level investments will be required for each strategy and are excluded from this analysis.
[a] *Resources sized based on feeder loads with critical and priority uses.*
[b] *Transmission work identified in IRP: controllers, hardening/reconstruction of lines & switchyards, underground construction, new lines.*
[c] *Gas peakers, diesel peakers, and CCGT as identified in IRP. Central CCGT is attributed as described in assumptions.*
[d] *Central solar PV as identified in the IRP, attributed as described in assumptions. Modeled as utility-scale systems.*
[e] *Central BESS as identified in the IRP, attributed as described in modeling assumptions.*
[f] *Distributed thermal resources as identified in IRP.*
[g] *Distributed solar PV as identified in IRP. Modeled as commercial-scale systems.*
[h] *Distributed BESS with 6 hours storage as identified in IRP.*
[i] *Resources sized based on fractional levels of feeder loads.*
[j] *Modeled as commercial-scale systems, assuming distributed solar PV interconnected at site.*
[k] *Distributed BESS with storage capacity as identified in modeling assumptions.*

Table 19: Generating capacity to meet critical and priority loads, MW

		Arecibo	Caguas & Cayey	Carolina	Mayague z North	Mayague z South	Ponce	San Juan	**Total**
IRP Strategy 2: Hardened microgrid with thermal generation and feeder-level resiliency[a]									
	Minigrid transmission[b]	---	---	---	---	---	---	---	---
	Minigrid thermal[c]	0	116	93	93	0	84	38	**423**
	Minigrid PV[d]	19	93	60	17	0	0	275	**464**
	Minigrid BESS[e]	17	52	36	11	0	0	113	**229**
	Microgrid thermal[f]	56	71	7	22	20	26	21	**223**
	Microgrid PV[g]	10	13	0	0	3	13	35	**74**
	Microgrid BESS[h]	5	6	0	0	2	6	18	**37**
	Total	**107**	**351**	**196**	**143**	**25**	**129**	**499**	**1,450**
Microgrid Strategy: Distributed PV generation & batteries with local resiliency[i]									
0.4 load	Microgrid PV[j]	228	374	213	119	154	286	748	**2,121**
0.4 load	Microgrid BESS[k]	85	140	80	44	58	107	280	**795**
0.4 load	**Total**	**313**	**514**	**293**	**163**	**211**	**393**	**1,028**	**2,916**
0.3 load	Microgrid PV[j]	171	281	160	89	115	214	561	**1,590**
0.3 load	Microgrid BESS[k]	64	105	60	33	43	80	210	**596**
0.3 load	**Total**	**235**	**386**	**220**	**122**	**159**	**295**	**771**	**2,187**
0.2 load	Microgrid PV[j]	114	187	107	59	77	143	374	**1,060**
0.2 load	Microgrid BESS[k]	43	70	40	22	29	54	140	**398**
0.2 load	**Total**	**156**	**257**	**147**	**82**	**106**	**197**	**514**	**1,458**

IRP parameters are modeled according to S4S2base.
Distribution-level investments will be required for each strategy and are excluded from this analysis.
[a] *Resources sized based on feeder loads with critical and priority uses.*
[b] *Generation capacity is not applicable to transmission.*
[c] *Gas peakers, diesel peakers, and CCGT as identified in IRP. Central CCGT is attributed as described in assumptions.*
[d] *Central solar PV as identified in the IRP, attributed as described in assumptions. Modeled as utility-scale systems.*
[e] *Central BESS as identified in the IRP, attributed as described in modeling assumptions.*
[f] *Distributed thermal resources as identified in IRP.*
[g] *Distributed solar PV as identified in IRP. Modeled as commercial-scale systems.*
[h] *Distributed BESS with 6 hours storage as identified in IRP.*
[i] *Resources sized based on fractional levels of feeder loads.*
[j] *Modeled as commercial-scale systems, assuming distributed solar PV interconnected at site.*
[k] *Distributed BESS with storage capacity as identified in modeling assumptions.*