Technical Appendix

RESILIENT SOUTHEAST

Exploring Opportunities for Solar+Storage in Five Cities

CleanEnergyGroup
Innovation in Finance, Technology & Policy

greenlink

ABOUT THIS REPORT

Resilient Southeast—Technical Appendix includes detailed supplementary information about the inputs, assumptions, and methodologies supporting the analysis results presented in the Resilient Southeast report series, which explores the obstacles and opportunities for solar PV and battery storage (solar+storage) to strengthen the resilience of communities throughout the Southeast. The series contains individual reports for five cities: Atlanta, GA; Charleston, SC; Miami, FL; New Orleans, LA; and Wilmington, NC. The Technical Appendix includes descriptions of economic modeling methodologies used in the analyses; the methodologies used to determine avoided outage costs; and the details relevant modeling inputs and assumptions. It presents detailed analysis results of evaluations for the potential economic opportunities resulting from the installations of solar alone or solar+storage systems at four types of facilities that could provide services during a disaster. The economic analysis was performed by The Greenlink Group

ABOUT THIS REPORT SERIES

Resilient Southeast is a collection of reports that evaluates the current policy landscape and economic potential for solar and battery storage to provide clean, reliable backup power to critical facilities in five cities: Atlanta, GA; Charleston, SC; Miami, FL; New Orleans, LA; and Wilmington, NC. These reports are produced under the Resilient Power Project (*www.resilient-power.org*), a joint project of Clean Energy Group and Meridian Institute. The Resilient Power Project works to provide clean energy technology solutions in affordable housing and critical community facilities, to address climate change and resiliency challenges in disadvantaged communities. The Resilient Power Project is supported by The JPB Foundation, Surdna Foundation, The Kresge Foundation, Nathan Cummings Foundation, The New York Community Trust, Barr Foundation, and The Robert Wood Johnson Foundation.

The full report series, including a *Series Overview*, is available online at *www.cleanegroup.org/ceg-resources/resource/resilient-southeast*.

ACKNOWLEDGEMENTS

The authors would like to thank Bryan Jacob at Southern Alliance for Clean Energy and Maria Blais Costello, Samantha Donalds, Meghan Monohan, and Lewis Milford at Clean Energy Group for their valuable input and review of this report. Much appreciation also for the generous support of the foundations and organizations funding this work, in particular, The New York Community Trust for their support of Clean Energy Group's targeted work in the Southeast. The views and opinions expressed in this report are solely those of the authors.

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CLEAN ENERGY GROUP

Clean Energy Group (CEG) is a leading national, nonprofit advocacy organization working on innovative policy, technology, and finance strategies in the areas of clean energy and climate change. CEG promotes effective clean energy policies, develops new finance tools, and fosters public-private partnerships to advance clean energy markets that will benefit all sectors of society for a just transition. CEG created and manages The Resilient Power Project (*www.resilient-power.org*) to support new public policies and funding tools, connect public officials with private industry, and work with state and local officials to support greater investment in power resiliency, with a focus of bringing the benefits of clean energy to low-income communities. *www.cleanegroup.org*

THE GREENLINK GROUP

Greenlink is an Atlanta-based energy research and consulting firm equipped with sophisticated analytical technologies and deep industry knowledge in the clean energy space, receiving accolades from MIT and Georgia Tech, among others. Greenlink provides the evidence and expert analysis needed to evaluate the most pressing issues faced by today's energy market, namely the integration of a wide range of clean energy options, such as energy efficiency in buildings, demand side management, and centralized and distributed renewable resources. *www.thegreenlinkgroup.com*

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Apollo Elementary School in Titusville, FL lost power during Hurricane Irma and used a solar+storage system to power emergency lights and charge cell phones. This installation is part of the SunSmart Emergency Shelters Program.
Nick Waters, Florida Solar Energy Center

REPORT DESIGN & PRODUCTION:
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Introduction

Resilient Southeast is a series of reports designed to explore the obstacles and opportunities for solar photovoltaic (PV) and battery storage to strengthen the resilience of communities throughout the Southeast.

As natural disasters continue to increase in occurrence and severity, the impacts are becoming progressively more severe, and recovery is taking longer. The last two hurricane seasons, with Harvey, Irma, and Maria battering the Southeast in 2017 and Florence and Michael in 2018, have heightened awareness of the fragility of the centralized power grid and the need for more local energy resilience. Major hurricanes left hundreds of thousands of homes, businesses, and community facilities without power across the coastal Southeast.

Vulnerable populations are disproportionately impacted and face increased risk as prolonged power outages become the norm post disaster. Community facilities such as schools, nursing homes, fire stations, and multifamily housing are increasingly turned to for emergency services and shelter. Ensuring that these facilities can provide critical services, including access to electricity, in the event of an emergency will require investments in energy resilience.

The combination of solar PV and battery storage (solar+storage) offers an innovative alternative to traditional backup generators. While diesel generators are often considered the default solution for energy resilience, they do not necessarily represent the most reliable solution—requiring regular maintenance to avoid failure and subject to disruptions in fuel supply—and they produce negative externalities such as excessive noise and pollution. Solar+storage can deliver reliable backup power during outages and savings throughout the year, leading building owners to increasingly consider and implement the technologies in resilient power solutions.

Research Objectives

The purpose of this report series is to evaluate the opportunity for solar+storage to provide clean, reliable, onsite backup power to critical facilities located across hurricane-prone areas of the Southeast. To accomplish this, Clean Energy Group partnered with The Greenlink Group, an Atlanta-based energy research and consulting firm, as well as local and regional partners to assess the economic, policy, and regulatory landscape for solar+storage for multiple facility types in five cities: Atlanta, GA; Charleston, SC; Miami, FL; New Orleans, LA; and Wilmington, NC. The analysis was applied to four building types: a secondary school, a nursing home, a fire station, and a multifamily housing property. The analysis and landscape review have three primary objectives:

1. Evaluate specific economic opportunities for deployment of customer-sited solar PV and battery storage under current market conditions.
2. Identify local and regional market, policy, and regulatory opportunities and barriers impacting solar+storage deployment.
3. Propose potential solutions to enable greater deployment of solar+storage to enhance energy resilience throughout the Southeast.

Economic Modeling Methodology

Two scenarios were explored to evaluate the economic opportunity for customer-sited solar and battery storage systems in four building types across the five Southeastern cities:

1. **ECONOMIC SCENARIO:** The economic scenario evaluates the most cost-effective system configuration based on available electric bill savings opportunities and incentives.

   The goal of the **Economic Scenario** is to maximize the net present value of the evaluated systems over a 25-year period.[1] The 25-year period is assumed to be the viable useful life of an installed solar+storage system, assuming battery and inverter replacement after year 15. In cases where a solar or battery storage system installation would not result in a positive net present value (NPV), the most economic scenario is assumed to be the business-as-usual case where no solar or storage system is installed.

2. **RESILIENT SCENARIO:** The resilient scenario evaluates solar+storage system configurations capable of providing onsite backup power to critical loads for a significant period of time.

   The goal of the **Resilient Scenario** is to model a system capable of providing at least several hours of backup power to keep critical services at a facility operational during a grid power outage. The scenario requires that both solar PV and battery storage are installed regardless of the economics of the system. In some cases, the resilient scenario may recommend systems with a negative NPV, indicating that the lifetime cost of the system would outweigh savings realized over time.

   In addition to electric bill savings and available incentives, the resilient scenario also explores the economics of the solar+storage system by factoring in a value for *avoided outage costs*. The value of avoided outage costs is only considered in evaluating the economic potential of a solar+storage system. The value is not factored into the cost-optimal sizing of components, so a **Resilient Scenario** with avoided outage costs included will have the same size solar and battery storage components as the resilient scenario without avoided outage costs factored in. These avoided outage costs, or improved resilience benefits, are discussed in more detail in the next section.

   It is important to note that the **Resilient Scenario** does not account for any of the additional costs associated with making a solar+storage system able to disconnect from the grid and operate independently during a grid disruption, a process known as islanding. Added expenses vary depending on the project and may include additional hardware components, such as a transfer switch or critical load panel; software components; electrical design complexity, such as isolating critical loads; and permitting costs. These factors must all be considered when determining the full cost of a solar+storage system designed to deliver backup power.

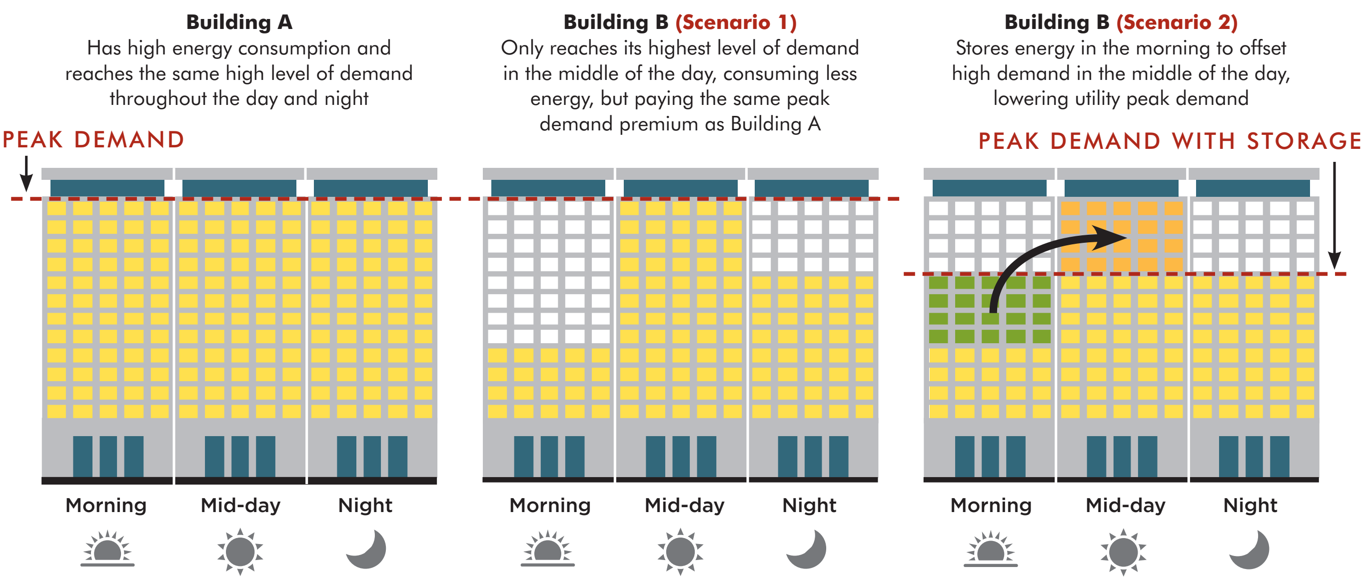
The two scenarios were applied to four building types: a secondary school, a nursing home, a multifamily housing property, and a fire station. The four building types were selected as a representative proxy for facilities providing critical community services in a disaster, with schools representing emergency shelters, fire stations representing disaster response, nursing homes representing health care services, and multifamily housing representing residential community shelter-in-place facilities.

To understand the economic viability of solar+storage for these facilities, the costs of the systems were evaluated against modeled electric bill savings over time. To accomplish this, hourly electricity usage load profiles were generated for each building (see the *Economic Modeling Inputs and Assumptions* section for detailed information on how this was done). These load profiles were then modeled against utility electric rate tariffs to determine energy and demand charge savings that could be realized throughout the projected life of the systems.[2] **Figure 1** illustrates the difference between energy and demand charges and how battery storage can be dispatched to reduce a building's demand.

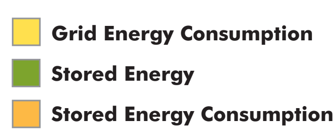
FIGURE 1
How Demand Charge Affect Project Economics

How Energy Storage Can Reduce Demand Charges

Demand is the total amount of electric load required by the customer's electric equipment operating at any given time. Utilities assess demand charges based on the highest average demand, (i.e. Peak Demand) that occurs over any interval (usually 15-minutes) during each billing period, and it is measured in kilowatts. Utilities assess energy consumption charges based on the total amount of electricity consumed over any period, and it is measured in kilowatt-hours.



In **Scenario 1**, Building A and Building B will incur the same peak demand charges over the course of the day, even though Building A will have consumed considerably more energy during that time. In **Scenario 2**, Building B can use energy storage to reduce its mid-day grid energy consumption by meeting some of its demand with on-site stored energy. **This could reduce its overall peak demand** for the period, resulting in a lower utility bill.



Avoided Outage Costs

Avoided outage-related costs account for the value of unmet electricity needs during grid outages. In other words, they represent the aggregated value of losses that would be incurred if a facility were to experience a power outage. For a business, this could include lost workforce productivity, losses due to interruption of sales or services, and expenses related to resuming production. For a critical community service provider, outage-related costs could also include difficult to monetize losses ranging from lost communications due to lack of cell phone charging or loss of wireless connections to loss of life due to failure of electricity-dependent medical devices, lack of refrigeration for mediations, or disrupted disaster response services.

When an onsite solar+storage system is configured to deliver power to local electric loads during a grid outage, some or all of these outage-related costs can be avoided. While it is difficult to put a value on these avoided costs and even more difficult to monetize the benefits, particularly for public services, there is irrefutable value in keeping critical services powered during an emergency.

AVOIDED OUTAGE COST METHODOLOGY

A variety of methodologies have been devised to assign a monetary value to outage-related costs. The analyses performed for this report series use the Department of Energy's Interruption Cost Estimate (ICE) Calculator, developed by Lawrence Berkeley National Laboratory and Nexant, Inc., to estimate these costs.[3]

The calculator approximates the value of unserved energy consumption (kilowatt-hours) and average unserved power (kilowatts) during a grid outage for various customer types. These outage-related cost valuations are based on two reliability indicators annually reported by utilities to the U.S. Energy Information Administration: System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). SAIDI is a measurement of the average length of outages in minutes experienced by customers of the reporting utility. SAIFI is a measurement of how often those power interruptions occur.

As shown in **Table 1**, the customers served by the five utilities evaluated in this report series experienced, on average, about two power outages in 2017, except for those served by Duke Energy Progress, which reported a lower outage frequency. Those outages lasted about three to five hours except for customers in Florida and Georgia. Georgia Power reported an average outage duration of 18 hours, while Florida Power & Light customers experienced an average outage of more than 60 hours.[4]

These longer outage durations are likely due to the extreme 2017 hurricane season, which resulted in extended outages throughout the coastal Southeast, particularly in Florida. Based on outages occurring between 2015 and 2017, Miami utility customers average 25 hours in outages per year; Atlanta and Charleston customers average 10 hours per year; Wilmington customers average 9 hours per year; and New Orleans customers average 4 hours per year. While 2017 may have been on the more extreme end of the spectrum for grid outages for some southeastern utilities, outages due to severe weather are expected to increase as global temperatures continue to rise.

TABLE 1
Utility Power Outage Duration and Frequency Indexes

City	Utility	SAIDI (minutes)	SAIFI
Atlanta, GA	Georgia Power	1101	2.19
Charleston, SC	South Carolina Electric & Gas	330	1.85
Miami, FL	Florida Power & Light Company	3962	2.00
New Orleans, LA	Entergy New Orleans	298	1.85
Wilmington, NC	Duke Energy Progress	204	1.39

2017 System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) values filed through U.S. Energy Information Administration Form 861 by the five utilities included in the economic modeling analyses. Higher SAIDI values indicate longer duration outages. Higher SAIFI numbers indicate more frequent outages. These values include major event days, the occurrence of sustained disruptions affecting at least 10 percent of customers over a 24-hour period.

Utility reported SAIDI and SAIFI values were input into the ICE Calculator to determine a monetary amount to assign to losses that could be incurred or avoided by the facilities evaluated. One of the limitations of this valuation methodology is that the calculator only returns values for three broad customer segments: Residential, Small Commercial & Industrial, and Medium and Large Commercial & Industrial. Because of this, the resulting outage cost values are only generic proxies for the actual costs an individual building would incur due to a grid outage. These values do not include considerations for the types of critical—in some cases potentially life-saving—services provided by the four building types analyzed. The value society would place on the delivery of critical community and health services would likely be much higher than those of typical commercial customers. As a result, the avoided outage costs used in this report series represent a conservative estimation of true societal value.

As shown in **Table 2**, the ICE Calculator assigns two cost components to value the losses related to a grid outage: the cost of average unserved power (Cost per Average Kilowatt) and the cost of unserved energy (Cost per Unserved Kilowatt-hour). The buildings evaluated fall into either the Medium and Large Commercial & Industrial customer segment or the Small Commercial & Industrial customer segment depending on the modeled building size (see the section on *Economic Modeling Inputs and Assumptions—Building Characteristics*). Higher interruption index SAIDI values for the utilities serving Miami and Atlanta are reflected in the ICE Calculator results through higher Cost per Average Kilowatt dollar amounts. It is worth noting that the calculator assigns significantly higher outage cost components to buildings within the Small Commercial & Industrial customer segment.

The ICE Calculator outage cost components allow for a methodology to approximate losses incurred during an outage, but applying these values to future scenarios is challenging. While SAIDI and SAIFI values give a snapshot of outages in any given year, there is no publicly available source of historical data with the actual timing and duration of outages that occurred at the utility level; and forecasting future outages is no more than a guessing game.

To simplify the valuation of avoided outage costs, the analysis assumes that, in each year of operation, a customer-sited solar+storage will deliver backup power to defined critical loads during a single extended outage event. The months of September and October, typically the height of the hurricane season in the Southeast, were selected as the most likely timing of an extended outage event in the cities evaluated. The value of powering critical loads for the maximum sustained duration possible during one event in this period is used as a proxy for the cumulative value of avoided outage costs in any given year.

TABLE 2

Interruption Cost Estimator Calculator Outage Cost Components

City	Customer Segment	Building Types	Cost per Average Kilowatt ($/kW)	Cost per Unserved Kilowatt-hour ($/kWh)
Atlanta, GA	Medium & Large Commercial & Industrial	• Fire station • Multifamily housing • Nursing home • Secondary school	280.45	33.47
Charleston, SC	Medium & Large Commercial & Industrial	• Fire station • Multifamily housing • Nursing home • Secondary school	50.08	16.86
Miami, FL	Medium & Large Commercial & Industrial	• Fire station • Multifamily housing • Nursing home • Secondary school	740.69	46.29
New Orleans, LA	Small Commercial & Industrial	• Fire station • Multifamily housing	185.76	68.97
	Medium and Large Commercial & Industrial	• Nursing home • Secondary school	103.93	38.59
Wilmington, NC	Small Commercial & Industrial	• Fire station • Multifamily housing	410.36	167.72
	Medium & Large Commercial & Industrial	• Nursing home • Secondary school	61.63	25.19

Estimated grid interruption costs generated by the Department of Energy's Interruption Cost Estimator Calculator for different customer segments in the five cities included in the economic modeling analysis. There are two components to the cost valuation: the cost of average unserved power (Cost per Average Kilowatt) and the cost of unserved energy (Cost per Unserved Kilowatt-hour).

The following formula was used to determine the value of avoided outage costs:

$$\textit{Avoided Outage Cost} = kWh_O \times Cost_{kWh} + kW_O \times Cost_{kW}$$

Where:

kWh_O is the electricity consumption of defined critical loads during the longest sustained September/October period that the solar+storage system could deliver backup power in kilowatt-hours [kWh].

$Cost_{kWh}$ is the ICE Calculator cost of unserved consumption during an outage in dollars per kilowatt-hour [$/kWh].

kW_O is the average power demand of defined critical loads during the longest sustained September/October period that the solar+storage system could deliver backup power in kilowatts [kW].

$Cost_{kW}$ is the ICE Calculator cost of average unserved power during an outage in dollars per kilowatt [$/kW].

For example: If a large commercial building in Atlanta had a solar+storage system that was capable of powering 1,000 kilowatt-hours of critical loads at an average power of 100 kilowatts throughout a 10-hour power outage, the avoided outage cost would be calculated as:

Avoided Outage Cost = (1,000 kWh) x ($33.47/kWh) + (100 kW) x ($280.45/kW) = ***$61,515***

If same outage scenario had occurred in Charleston, the avoided outage cost would be:

Avoided Outage Cost = (1,000 kWh) x ($16.86/kWh) + (100 kW) x ($50.08/kW) = ***$21,868***

The difference in avoided outage costs between the two cities is due to differences in the cost of unserved consumption and cost of average unserved power (see **Table 2**), which are higher for Atlanta than Charleston.

While longer-duration extended outages may not always be an annual occurrence, outage costs would be similar, if not higher, for the same duration outage spread over several occurrences throughout a year. In reality, the cost of outages and value of avoided outage costs would vary significantly from year to year. The annual outage costs used in these analyses should be viewed as more of an average value for outage costs avoided throughout the lifetime of the system rather than indicative of expected avoided outage costs occurring in any specific year.

Economic Modeling Inputs and Assumptions

This section details relevant inputs and assumption that were used in modeling the sizing and economics of solar PV and battery storage systems for the four building types in Atlanta, GA; Charleston, SC; Miami, FL; New Orleans, LA; and Wilmington, NC. The section is organized into six categories: **General Economic Assumptions**, **Building Characteristics and Energy Use**, **Energy Resilience**, **Electric Utility Service**, **Solar PV System**, and **Battery Storage System**.

GENERAL ECONOMIC ASSUMPTIONS

Analysis period. The performance and economics of all systems are evaluated over a 25-year period. It is assumed that a solar PV system will have a lifetime of 25 years. Battery systems are assumed to have an initial 15-year operational lifetime, at which point the battery system and associated hardware, such as the inverter, are replaced. Net present value (NPV) is calculated over the entire 25-year period and includes both upfront and system replacement costs.

Discount rate. A discount rate of five percent is used in all NPV calculations.

Federal tax incentives. The analyses assume that all building types can take advantage of the 30 percent federal investment tax credit (ITC) for solar PV. Public schools and fire stations are both owned and operated by government entities, which are not subject to federal taxes. The same would be true for nursing homes and multifamily housing properties that are operated by nonprofit entities, as is common in affordable multifamily housing. The analysis assumes the value of the ITC can be captured through a third-party ownership, leasing, or tax equity partnership arrangement.[5] While these types of financial arrangements may come with additional expenses, such added transactional costs are not considered in this analysis.

The analyses also assume that the ITC can be fully applied to the battery storage portion of a solar+storage system. According to guidance issued by the Internal Revenue Service, battery storage is eligible for the ITC when paired with, and at least 75 percent charged by, onsite solar.[6] The analysis assumes that all solar+storage systems are DC connected, with no ability for the storage system to be charged by the grid. This means that the battery storage system is 100 percent charged by onsite solar and, therefore, eligible to take advantage of the full ITC incentive. It is assumed that the ITC will no longer be available when the battery system is replaced after year 15.

State tax incentives. The State of South Carolina offers a 25 percent commercial tax credit for solar PV systems. The annual value of the tax credit is limited to $3,500 or 50 percent of tax liability, whichever is lower. In cases where the value of the tax credit exceeds $3,500, credits may be carried forward for up to 10 years. For the Charleston analyses, smaller solar systems are assumed to be able to take advantage the full 25 percent tax credit. Larger systems receive the maximum annual tax credit allowed for up to the limit of 10 years. As with the federal ITC, it is assumed all building types can take advantage of the tax credit. Unlike the federal tax credit, the state incentive cannot be applied to the battery storage portion of a system.

Florida, Georgia, Louisiana, and North Carolina do not offer state tax incentives for solar PV or battery storage.

BUILDING CHARACTERISTICS AND ENERGY USAGE

For each city, four building types are evaluated in the modeling analyses: a secondary school, a nursing home, a multifamily housing property, and a fire station. Building sizes, configurations, and energy usage for secondary schools, nursing homes, and multifamily housing are modeled based on the 2012 Commercial Buildings Energy Consumption Survey (CBECS). The CBECS is a national survey of information on the stock of U.S. commercial buildings.[7]

The CBECS datasets include energy-related building characteristics and energy usage data for various commercial building types depending on the primary use case of the facility.[8] Building characteristics vary by location as designated by U.S. census region.

In the analyses:

- Secondary schools are modeled based on the CBECS secondary school building type.
- Nursing homes are assumed to be a mix of residential and inpatient care facilities. The model represents each nursing home as a facility with approximately 67 percent of size and energy use as the CBECS inpatient care facilities building type.
- For multifamily housing properties, only the commercial, common-area portion of the buildings are considered in the analysis. This includes areas such as hallways, offices, and community spaces. The assumption is that the building's loads are individually metered, so that the common areas are collectively metered on a single commercial utility meter and individual tenant units are independently metered, each on a separate residential meter. The analysis focus on common area spaces is done to simplify the modeling as opposed to attempting to incorporate individual tenant housing units, which may have significantly different energy usage profiles and be subject to different utility electric rate tariffs. Multifamily housing common areas are modeled based on the CBECS small office building type.
- Fire station building characteristics and energy usage data are based on a prior analysis that The Greenlink Group prepared for the City of Atlanta.[9] The prior analysis simulated energy usage for a fire station in Atlanta based on the operation of the facility, the building's floor area, and energy consumption modeled from monthly electric bill data obtained from the building owner. The characteristics and energy profile of this Atlanta fire station are assumed to be representative of fire stations in all five cities evaluated, so that all fire stations analyzed share the same building and energy use characteristics.

Energy usage load profiles for the buildings are generated using the U.S. Department of Energy's EnergyPlus™ whole-building energy simulation program.[10] The open-source program is used by engineers, architects, and researchers to model both energy consumption and water usage in buildings. The resulting load profiles include hourly electricity consumption and demand for each building based on climate zone, building size, and primary function. Monthly electricity consumption and monthly peak demand are derived from these load profiles. These annual consumption and peak demand values, along with building floor space (in square-feet) and number of stories, are shown in **Table 3** for each building type and location.

TABLE 3
Building Characteristics and Energy Use

City	Building Type	Floor Space (sq-ft)	Number of Stories	Annual Electricity Consumption (kWh)	Annual Peak Demand (kW)
Atlanta, GA	Secondary school	100,000	2	1,185,000	476
	Nursing home	92,700	2	2,111,000	390
	Multifamily housing	3,500	3	28,000	10
	Fire station	7,600	1	99,000	28
Charleston, SC	Secondary school	210,900	2	3,614,000	1,109
	Nursing home	114,100	3	1,733,000	268
	Multifamily housing	1,200	1	18,000	5
	Fire station	7,600	1	99,000	28
Miami, FL	Secondary school	78,300	2	1,231,000	296
	Nursing home	186,000	3	3,687,000	563
	Multifamily housing	2,500	1	24,000	6
	Fire station	7,600	1	99,000	28
New Orleans, LA	Secondary school	127,200	2	1,762,000	504
	Nursing home	51,000	2	572,000	86
	Multifamily housing	4,500	1	133,000	38
	Fire station	7,600	1	99,000	28
Wilmington, NC	Secondary school	210,900	2	4,120,000	1,353
	Nursing home	58,000	2	1,636,000	250
	Multifamily housing	1,200	3	17,000	5
	Fire station	7,600	1	99,000	28

Building floor space and number of stories is based on data from the Commercial Buildings Energy Consumption Survey. Annual electricity consumption and peak demand are generated from the U.S. Department of Energy's EnergyPlus™ energy simulation program.

ENERGY RESILIENCE

Simply installing a solar+storage system does not ensure that a building improves its energy resilience in the face of severe weather and grid disruptions.[11] In order to deliver reliable backup power during a grid outage, a solar+storage system must be designed and configured to be able to disconnect from the grid and operate independently, a process known as islanding. Depending on the project, this can add significant additional cost to a system design due to additional hardware components, software components, electrical components, and safety and permitting costs. According to the National Renewable Energy Laboratory, the cost of making a system islandable may add an additional 10 to 50 percent to the upfront cost of an installation.[12]

Because of the complexity and uncertainty in evaluating these expenses for any given installation, the analyses do not consider the added cost of making a system islandable when modeling resilient scenarios. While not considered here, these costs are an important factor in any financial decisions regarding a real-world installation designed to provide energy resilience.

Critical loads. Another key factor in any resilient backup power system design is determining which loads are deemed critical. Critical loads are electricity-consuming equipment and devices that must be kept powered during an outage scenario. These can range from computers to lighting to elevators to medical devices, depending on the facility and services provided during an emergency.

For simplicity, critical loads for the four building types evaluated are approximated as a percentage of the full building load during normal operation. The percentages used vary by building type depending on how the facility would be used in an emergency situation.

Critical loads are defined as follows:

- **Secondary school:** 25 percent of normal operational load. This critical load profile is meant to approximate the utilization of a portion of the school, such as a gymnasium, auditorium, or cafeteria, as a temporary emergency shelter during an extended outage.
- **Nursing home:** 20 percent of normal operational load. This critical load profile is meant to approximate the continued operation of critical medical devices, refrigeration of medicines, heating and cooling, and basic services to keep residents comfortable during shorter outages and allow for more time to safely evacuate residents during a prolonged outage.
- **Multifamily housing:** 100 percent of normal operational common area load. Due to complexities in modeling a mix of multi-unit residential loads and commercial loads, only the common area commercial loads are considered in the analysis. The common area loads include hallways, offices, outdoor and emergency lighting, laundry rooms, elevators, and community spaces. Keeping the common areas fully operational would allow critical services such as clean water, heating and cooling, device charging, and communications to remain available to tenants sheltering in place during an emergency.
- **Fire station:** 100 percent of normal operational load. This critical load profile assumes the fire station would need to remain fully powered and completely operational during grid outages in order to continue to provide emergency response and critical life-saving services to surrounding communities.

ELECTRIC UTILITY SERVICE

The electric rate tariffs used in these analyses are based on active electric rate tariffs offered by the utilities serving the majority of customers in each of the five cities.[13] The rate tariff selected for each building type is the rate considered most widely applicable for a commercial customer in the specified utility service territory considering facility type and modeled energy use. **Tables 4–8** detail the cost components for all electric rate tariffs considered in the analysis by location.

TABLE 4

Georgia Power Electric Rate Tariffs for Atlanta Commercial Customers

Building type(s)	Rate tariff	Fixed monthly charge ($)	Energy charge ($/kWh)	Demand charge ($/kW)
Secondary school	School Service (SCH-18)	19.00	0.1183 *(first 3,000 kWh)* 0.1083 *(next 7,000 kWh)* 0.0919 *(next 90,000 kWh)* 0.0679 *(> 100,000 kWh)*	8.60 *(> 30 kW)*
Nursing home **Multifamily housing** **Fire station**	Power and Light Medium (PLM-11)	19.00	0.1126 *(first 3,000 kWh)* 0.1031 *(next 7,000 kWh)* 0.0889 *(next 190,000 kWh)* 0.0690 *(> 200,000 kWh)*	8.24 *(> 30 kW)*

All building types evaluated are subject to tariffs with declining tiered energy charges and moderate demand charges.

TABLE 5

South Carolina Electric & Gas Electric Rate Tariffs for Charleston Commercial Customers

Building type(s)	Rate tariff	Fixed monthly charge ($)	Energy charge ($/kWh)	Demand charge ($/kVW)
Secondary school	School Service (Rate 22)	17.05	0.1164 *(first 50,000 kWh)* 0.1349 *(> 50,000 kWh)*	0.00
Nursing home **Fire station**	Medium General Service (Rate 20)	210.00	0.0556 *(first 75,000 kWh)* 0.0511 *(> 75,000 kWh)*	19.30
Multifamily housing	General Service (Rate 9)	22.75	0.1322 *(first 3,000 kWh)* 0.1407 *(> 3,000 kWh)* 0.1230 *(Winter)*	4.02

All building types evaluated are subject to tariffs with tiered energy charges. Nursing homes and fire stations are subject to a high fixed charge and a fairly high demand charge rate but lower energy charge rates. Multifamily housing and secondary schools are subject to low or no demand charges.

TABLE 6

Florida Power & Light Company Electric Rate Tariffs for Miami Commercial Customers

Building type(s)	Rate tariff	Fixed monthly charge ($)	Energy charge ($/kWh)	Demand charge ($/kW)
Secondary school **Nursing home** **Multifamily housing** **Fire station**	General Service Demand (GSD-1)	25.34	0.0495	10.72

All building types evaluated are subject to a tariff with a low energy charge rate and a moderate demand charge rate.

TABLE 7
Entergy New Orleans Electric Rate Tariffs for New Orleans Commercial Customers

Building type(s)	Rate tariff	Fixed monthly charge ($)	Energy charge ($/kWh)	Demand charge ($/kW)
Secondary school **Nursing home**	Large Electric Service (LE-24)	508.33 *(for first 50 kW)*	0.0508 *(first 5,000 kWh)* 0.0274 *(next 10,000 kWh)* 0.0265 *(next 15,000 kWh)* 0.0262 *(> 30,000 kWh)*	8.58 *(50 - 100 kW)* 8.04 *(100 - 200 kW)* 7.70 *(> 200 kW)*
Multifamily housing **Fire station**	Small Electric Service (SE-24)	12.64 *(for first 3 kW)*	0.0624 *(first 1,000 kWh)* 0.0403 *(next 4,000 kWh)* 0.0367 *(> 5,000 kWh)*	5.17 *(3 - 17 kW)* 6.71 *(> 20 kW)*

All building types evaluated are subject to tariffs with declining tiered energy charges and declining tiered demand charges. Energy charge rates are low for all building types, particularly for electricity consumption beyond the first tier. Secondary schools and nursing homes are subject to a high fixed charge for the first 50 kilowatts of demand or less. The buildings are subject to a minimum $508 monthly charge whether demand in that month is above or below 50 kilowatts. Multifamily housing and fire stations are also subject to a fixed charge for demand, but the rate is significantly lower.

TABLE 8
Duke Energy Progress Electric Rate Tariffs for Wilmington Commercial Customers

Building type(s)	Rate tariff	Fixed monthly charge ($)	Energy charge ($/kWh)	Demand charge ($/kW)
Secondary school	Church and School Service (CSG-50)	28.50	0.1583	7.00
Nursing home **Fire station**	Medium General Service (MGS-50)	28.50	0.0684	6.40
Multifamily housing	Small General Service (SGS-50)	21.00	0.1079	0.00

Secondary schools are subject to a fairly high energy charge rate and moderate demand charge rate. Other building types are subject to lower energy charge rates and moderate or no demand charges.

Electric rate escalation: To incorporate the impact of changing electricity rates over time, the analyses include projected annual escalation rates for the energy and demand portions of utility rate tariffs. These escalation rates are based on the U.S. Energy Information Administration's Annual Energy Outlook 2018 census division specific forecast between 2018 and 2050. Atlanta, Charleston, Miami, and Wilmington are in the South Atlantic region, which is projected to have no escalation in electricity rates after accounting for inflation. New Orleans is located in the West South Central region, which is projected to experience a 0.3 percent compound annual growth rate for electric energy rates.[14]

Net energy metering. All of the utilities considered in the analyses are required to offer full retail rate net energy metering (NEM) except for Georgia Power, which serves Atlanta customers. Retail rate NEM means that any energy that is exported to the grid, not directly consumed or stored onsite, is credited back to the customer at the full retail cost of electricity. There are some restrictions to NEM solar systems, such as a 300-kilowatt system size cap imposed by Entergy New Orleans and limitations on solar generation sizing to no more than typical annual onsite electricity consumption. All solar systems modeled in this analysis comply with existing NEM regulations.

Georgia Power does not offer retail rate net metering. Instead, the utility purchases excess solar generation through its Solar Buy Back program.[15] Commercial solar systems less than 250 kilowatts in size are eligible to sell solar energy to Georgia Power through the utility's renewable energy resources tariff at

TABLE 9
Maximum Solar System Sizing for Each Building Type

City	Building type	Maximum solar system size (kW)
Atlanta, GA	Secondary school	90.9
	Nursing home	84.3
	Multifamily housing	15.3
	Fire station	13.6
Charleston, SC	Secondary school	192.0
	Nursing home	104.0
	Multifamily housing	15.3
	Fire station	13.6
Miami, FL	Secondary school	71.2
	Nursing home	117.0
	Multifamily housing	20.4
	Fire station	13.6
New Orleans, LA	Secondary school	115.7
	Nursing home	30.9
	Multifamily housing	20.5
	Fire station	13.6
Wilmington, NC	Secondary school	192.0
	Nursing home	52.7
	Multifamily housing	15.3
	Fire station	13.6

Modeling assumes that 40 percent of rooftop space is economically available for the installation of solar panels.

Georgia Power's Solar Avoided Cost rate as approved by the Georgia Public Service Commission in Docket No. 16573. At the time of this modeling effort, the Solar Avoided Cost rate for Georgia Power was 3.2 cents per kilowatt-hour.

New Orleans City Council regulations prohibit solar net energy metering within the Central Business District of the city due to safety and reliability assurance concerns. All buildings analyzed in New Orleans are assumed to be located outside of the city's Central Business District, which includes the French Quarter.

SOLAR PV SYSTEM

Solar system sizing. The analyses assume that approximately 40 percent of a building's rooftop space is available for the economically viable installation of solar panels. The remaining 60 percent of roof space is considered unavailable due to a variety of factors including: roof penetrations, such as venting; rooftop equipment, like water tanks and central air conditioning; and building code offset requirements. The analyses assume that 40 percent of rooftop space is the upper boundary for solar PV system sizing. In practice, there are other options for expanding solar system sizing beyond this threshold, such as incorporating solar parking lot canopies, ground-mount solar systems, and elevated rooftop systems, however, these options typically include added upfront costs and are not considered as part of this report series. The solar systems modeled for this report series are assumed to be single-axis roof mount systems.

The maximum solar system sizing for each building type is given in **Table 9**. The differences in system sizing for the same building type in different locations is due to varying building characters as a function of rooftop space, which is determined by total building square-footage as detailed in the *Building Characteristics and Energy Usage* subsection. All solar system sizes presented in this report series are given in DC system sizing.

Solar system cost. Pricing assumptions for the installed cost of a solar PV system are based on data from developers gathered through the Solarize Atlanta campaign, Atlanta's community-based solar bulk purchasing program.[16] This data is categorized into three market segments: small systems, medium systems, and large systems. Cost assumptions for these market segments are detailed in **Table 10**. These installed costs are assumed to be representative of general solar installation cost trends throughout the Southeast.

Solar system performance. Solar system performance is assumed to degrade at an annual rate 0.50 percent over the 25-year expected lifetime of the system.

Solar system incentives. All building types evaluated are assumed to be able to take advantage of federal and, where available, state solar tax incentives. Systems are assumed to participate in solar net energy metering where offered.

Duke Energy Progress, the utility serving Wilmington, is the only utility explored in this report series that offers additional solar incentives. Duke Energy Progress offers a $0.50 per watt solar rebate for commercial customers and a $0.75 per watt incentive for nonprofit customers.[17] The rebate can only be applied the first 100 kilowatts of a solar system, though larger systems can be installed. The program also offers a $0.60 per kilowatt incentive for the first 10 kilowatts of a residential solar installation. The rebate program was fully subscribed for 2018 at the time of this analysis, however, it is assumed that all buildings would be eligible to participate in the program when enrollment opened again in 2019. The Duke Energy Progress solar rebate for nonprofit customers, $0.75 per watt, is applied to solar systems modeled for the school and fire station in Wilmington. The commercial customer rebate, $0.50 per watt, is applied to solar systems modeled for the nursing home and multifamily housing property in Wilmington.

BATTERY STORAGE SYSTEM

Battery storage system sizing, configuration, and performance. Four battery storage system sizing options are considered in the analyses, shown in **Table 11**. These sizing options and their operational characteristics are based on product specifications for commercially available LG Chem battery storage systems.

TABLE 10
Solar PV System Cost Assumptions

Solar system category	System sizing range (kW)	Installed cost ($/W)
Small system	0–10	2.97
Medium system	10–25	2.25
Large system	> 25	1.95

Costs are based on developer data from the Solarize Atlanta campaign.

The analyses assume that all battery storage systems are DC-coupled with onsite solar PV and only charged by solar generation. This configuration allows the battery system to be directly charged by the solar system through a DC charge controller, without efficiency losses due to DC-to-AC and AC-to-DC power conversions. This allows the solar PV and battery storage systems to share a single inverter, reducing overall system costs. DC-coupling also results in a high round trip efficiency for the battery system of 95 percent.

The DC-coupled configuration ensures the batteries are 100 percent charged by onsite solar, allowing the storage system to take full advantage of federal tax incentives for solar. The modeling does not allow for battery systems to be charged by grid electricity at any time.

In modeling each **Resilient Scenario**, the optimal battery system sizing is assumed to be the largest available battery system option with an energy capacity (kilowatt-hour) rating less than the modeled solar system output (kilowatt) rating, unless a larger battery system is required to meet critical load power requirements. For example, a building with a 75-kilowatt solar system would select a 45.7-kilowatt-hour battery system, the Commercial & Industrial—Small system, when modeling the **Resilience Scenario**. This is done for multiple reasons: 1) to ensure a significant duration of backup power, 2) to ensure sufficient solar resources are available to allow for adequate battery system charging, and 3) to minimize overall system cost.

TABLE 11

Battery Storage System Sizing Options and Cost Assumptions

Battery storage system type	Power rating (kW)	Energy capacity (kWh)	Installed cost		Replacement cost	
			($/kWh)	($)	($/kWh)	($)
Small	2.5	9.8	1,060	10,400	568	5,600
Commercial & Industrial—Small	11.8	45.7	1,060	48,400	568	26,000
Commercial & Industrial—Medium	23.7	91.3	1,060	96,800	568	51,900
Commercial & Industrial—Large	35.5	137.0	1,040	142,500	558	76,400

Sizing options are based on commercially available LG Chem product offerings. Costs are based on developer data from the Solarize Atlanta campaign.

Battery storage system cost. Installed costs for battery storage systems are based on data from developers gathered through the Solarize Atlanta campaign, shown in **Table 11**. While battery specifications are based on LG Chem systems, the system prices are not based on any single battery storage product offering or brand. These installed costs are assumed to be representative of general battery storage installation cost trends throughout the Southeast.

Battery systems are assumed to have a 15-year lifetime based on performance specifications and expected operation. After year 15, the battery storage system and related hardware, including the inverter, is replaced.

The cost of battery storage is projected to decline at an annual rate of eight percent, while installed balance of system costs are projects to decline at an annual rate of five percent.[18] Assuming battery storage represents 75 percent of the installed system cost and balance of system costs represent the remaining cost, the annual cost decline is assumed to be seven percent per year. Estimated battery storage replacement costs after year 15 are included in **Table 11**. All NPV calculations for combined solar+storage systems include a 2.5 percent inflation rate to convert nominal dollars to real dollars.

Battery storage system incentives. Because all battery storage systems are modeled to be charged exclusively by onsite solar generation, the battery systems are assumed to be eligible to fully take advantage of the federal ITC for the initial cost of the system. The ITC is not assumed to be available for replacement of the battery system after year 15. No additional battery storage systems incentives exist for the locations evaluated in this report series.

Economic Modeling Results

This section details economic modeling results for the **Economic Scenario** and **Resilient Scenario** for each of the four building types evaluated. The results are organized in two tables for each city, detailing system sizing and costs, maximum hours of backup power, and economic results.

The **first of two tables for each city** details modeled system sizing, cost data, and hours of backup power the system can provide.

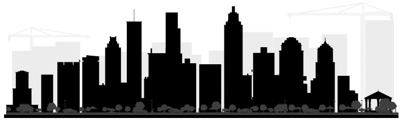
Cost data includes the upfront cost of solar and battery storage components and the NPV system cost. The NPV system cost represents the total cost of the system after accounting for replacement of components and any available incentives. The NPV system cost includes the total installed cost of the solar and battery storage components; battery storage system replacement costs, accounting for declines in system prices and inflation; and all applicable incentives such as the federal ITC.

Backup power results represent the maximum number of hours that a modeled solar+storage system can deliver power to critical loads over a single sustained period of time. Hours of backup power are calculated for maximum system performance both throughout the year and during the September/October peak hurricane season.

It is important to note that backup power values do not represent the total number of hours the system could power critical loads during an extended outage, only the number of hours it could support those loads for a single sustained period of time before the batteries would need to be recharged. For instance, a system that is found to provide a maximum of 12 hours of backup power would be capable of powering critical loads for up to 12 hours when an outage first occurs. When the solar system is again available to power critical loads and recharge the battery storage system, the system would again provide backup power for up to a 12-hour period. This cycle would continue to repeat any days there were sufficient solar resources available to generate electricity. A number of measures could be put into place to extend backup power durations, such as careful management of critical loads. Such measures are beyond the scope of these analyses.

The **second of the two tables for each city** presents economic results—first year savings, NPV, internal rate of return (IRR), and simple payback period. Economic results for the resilient scenarios are presented both with and without savings due to avoided outage costs (AOC), which are difficult to monetize, particularly for public services.

First year savings results are broken down into three categories of savings: electric bill energy savings, electric bill demand savings, and avoided outage costs. Energy savings represent offsetting grid supplied electricity with onsite solar generation, either directly offsetting onsite electricity consumption or through NEM crediting (or solar purchasing in the case of Georgia Power). Demand savings are due to the ability of solar and battery storage to reduce monthly peak demand, which is typically used to calculate the demand charge components of a commercial electric bill. Reducing peak demand results in savings through lower demand-related charges. Avoided outage costs represent avoided losses that would have otherwise been incurred had the system not been able to provide backup power over a defined period (see the section on *Avoided Outage Costs* for a detailed discussion of how these costs are calculated).



ATLANTA, GA

Analysis results for building types in Atlanta, GA are presented in **Table 12** and **Table 13**.

Economic outcomes were found to be stronger for the larger facilities, the school and nursing home, largely due to negative impacts from Georgia Power's low Solar Buy Back rate and the absence of utility demand charges for smaller building types.

The **Economic Scenario** analysis found that solar—without battery storage—would be the most economical option for all four building types in Atlanta, based solely on electric bill savings with no consideration of improved energy resilience. For three of the building types, savings would be maximized by installing the largest solar systems possible for the buildings given constraints on available rooftop space.

A smaller solar system was found to be the optimal solution for the multifamily housing property. The reason for this is that the multifamily housing property does not have enough daytime demand for electricity to use the majority of energy generated from a larger solar system onsite, as do the larger facilities. Even the smaller system still exports 30 percent of its electricity to the grid, making the economics less favorable than for buildings able to directly consume more solar production onsite.

In Atlanta, this has a significant impact on the economics of solar PV, as Georgia Power procures exported solar energy at about one-third of the retail electricity rate paid by the multifamily housing property and other buildings evaluated. Higher levels of solar exports to the grid also negatively impacted economics of solar for the fire station, though to a lesser degree. The multifamily housing property and fire station also face higher installed solar costs per-watt, due to the smaller size of the solar systems relative to the school and nursing home.

When the buildings were analyzed under the **Resilient Scenario**, solar+storage was still found to result in net savings for the secondary school and nursing home, despite the added cost of the battery system. Because the economics of solar PV are not as strong for the multifamily housing property and fire station, and because those buildings do not have high enough electricity demand to incur demand charges—eliminating another value stream for both solar and battery storage—solar+storage was not found to be an economic option for these facilities based on electric bill savings alone.

Factoring in the additional value of avoided outage costs by powering critical loads during grid disruptions significantly improved the lifetime savings for all building types, resulting in positive economics for the solar+storage systems in all cases. In fact, including the savings from avoided outage costs makes the **Resilient Scenario** the most economic option for all building types, with the highest NPV, best IRR, and shortest simple payback period.

Systems modeled for the **Resilient Scenario** can provide backup power to support critical loads for up to 12 hours or more for all building types, except for the nursing home. Due to the energy intensive nature of nursing home operations and constraints on available rooftop space, the solar+storage system modeled for the nursing home is limited to providing a maximum of nine hours of backup power to critical loads at a time, eight hours during hurricane season.

Atlanta ranked as the third best economic opportunity for solar+storage development among the five cities evaluated in this report series.

TABLE 12

Solar PV and Battery Storage System Sizing, Costs, and Maximum Hours of Backup Power for Building Types in Atlanta

Building type	Modeled scenario	Solar (kW)	Battery storage		Installed system cost ($)		Net present value system cost ($)	Backup power (hours)	
			(kW)	(kWh)	Solar	Battery		Annual	Sept/Oct
Secondary school	Economic	90.9	—	—	177,300	—	124,100	—	—
	Resilient	90.9	11.8	45.7	177,300	48,400	189,700	12	11
Nursing home	Economic	84.3	—	—	164,300	—	115,000	—	—
	Resilient	84.3	11.8	45.7	164,300	48,400	179,200	9	8
Multifamily housing	Economic	10.0	—	—	22,500	—	15,800	—	—
	Resilient	15.3	2.5	9.8	34,500	10,400	34,100	14	14
Fire station	Economic	13.6	—	—	30,600	—	21,400	—	—
	Resilient	13.6	2.5	9.8	30,600	10,400	31,400	12	11

Net present value system cost represents the total installed system cost, the cost of replacing battery storage system components, and incorporates incentives available through the federal investment tax credit. Backup power represents the maximum sustained number of hours the system could power critical building loads.

TABLE 13

Solar PV and Battery Storage Economic Modeling Results for Building Types in Atlanta

Building type	Modeled scenario	First year savings ($)				Net present value ($)	Internal rate of return	Simple payback period (yrs)
		Energy	Demand	AOC	Total			
Secondary school	Economic	14,400	3,700	—	18,100	131,800	13.6%	6.8
	Resilient	14,500	4,100	—	18,500	71,900	8.0%	10.2
	Resilient (with AOC)	14,500	4,100	25,600	44,200	300,100	21.1%	4.1
Nursing home	Economic	14,000	900	—	14,800	94,400	11.7%	7.8
	Resilient	14,000	1,700	—	15,700	42,200	6.7%	11.4
	Resilient (with AOC)	14,000	1,700	26,800	42,500	263,600	20.5%	4.2
Multifamily Housing	Economic	1,300	0	—	1,300	2,700	6.2%	12.0
	Resilient	1,900	0	—	1,900	(7,200)	2.3%	17.9
	Resilient (with AOC)	1,900	0	2,600	4,500	4,000	5.7%	11.1
Fire station	Economic	2,100	0	—	2,100	7,600	7.8%	10.4
	Resilient	2,100	0	—	2,100	(1,600)	4.0%	14.9
	Resilient (with AOC)	2,100	0	2,700	4,800	24,000	12.0%	6.6

The economics of the resilient scenarios are considered both with and without savings due to avoided outage costs (AOC). Net present value is calculated over a 25-year period and includes replacement costs for battery storage systems in the resilient scenarios.

CHARLESTON, SC

Analysis results for building types in Charleston, SC are presented in **Table 14** and **Table 15**.

Economic outcomes were found to be positive for all building types across both scenarios, except for the nursing home under the **Resilient Scenario** without accounting for avoided outage costs. These encouraging results are in large part due to the availability of a 25 percent South Carolina state tax credit for commercial solar systems, which creates a strong economic case for solar PV investments. The **Economic Scenario** analysis found that solar PV, without battery storage, would be the most economical option for all four building types in Charleston, based solely on electric bill savings with no consideration of improved energy resilience.

When the buildings were analyzed under the **Resilient Scenario**, solar+storage was still found to result in net savings for the secondary school, multifamily housing property, and fire station, despite the added cost of the battery system. The nursing home and fire station are both subject to a utility rate tariff with significantly lower energy charge rates than those for the school and multifamily housing, less than 6 cents per kilowatt-hour, and significantly higher demand charge rates, more than \$19 per kilowatt—the highest demand charge rate of any of the utility tariffs evaluated in this report series. As a result, the economics of solar are not as strong for the nursing home and fire station than the other building types, as is evidenced by lower IRRs and longer simple payback periods. While higher demand charge rates translate into greater savings through installing battery storage, the savings are not sufficient to offset enough of the cost of the larger battery modeled for the nursing home, which has much higher energy and demand needs to support critical loads than the fire station. Because of this, solar+storage was not found to be a cost-effective option for the nursing home.

Factoring in the additional value of avoided outage costs by powering critical loads during grid disruptions significantly improved the lifetime savings for all building types in Charleston, resulting in positive economics for the solar+storage systems in all cases including the nursing home. Accounting for the savings from avoided outage costs makes the **Resilient Scenario** the most economic option for the nursing home and fire station, with the highest NPV, best IRR, and shortest simple payback period.

Systems modeled for the **Resilient Scenario** can provide backup power to support critical loads for up to 12 hours or more for all building types. The multifamily housing property and secondary school had the best resilience outcomes, with solar+storage systems able to deliver backup power supporting critical loads for up to 15 hours and 13 hours respectively. Charleston ranked second best based on economic opportunities for solar+storage development among the five cities evaluated in this report series.

TABLE 14

Solar PV and Battery Storage System Sizing, Costs, and Maximum Hours of Backup Power for Building Types in Charleston

Building type	Modeled scenario	Solar (kW)	Battery storage		Installed system cost ($)		Net present value system cost ($)	Backup power (hours)	
			(kW)	(kWh)	Solar	Battery		Annual	Sept/Oct
Secondary school	Economic	191.7	—	—	373,800	—	234,700	—	—
	Resilient	191.7	35.5	137.0	373,800	142,500	380,600	13	13
Nursing home	Economic	55.0	—	—	107,200	—	53,258	—	—
	Resilient	103.7	23.7	91.3	202,200	96,800	207,500	12	11
Multifamily housing	Economic	12.0	—	—	27,000	—	12,200	—	—
	Resilient	15.3	2.5	9.8	34,500	10,400	26,000	15	14
Fire station	Economic	10.0	—	—	22,500	—	10,100	—	—
	Resilient	13.6	2.5	9.8	30,600	10,400	24,200	12	11

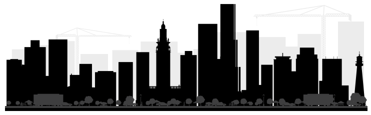
Net present value system cost represents the total installed system cost, the cost of replacing battery storage system components, and incorporates incentives available through the federal investment tax credit and South Carolina state tax credit. Backup power represents the maximum sustained number of hours the system could power critical building loads.

TABLE 15

Solar PV and Battery Storage Economic Modeling Results for Building Types in Charleston

Building type	Modeled scenario	First year savings ($)				Net present value ($)	Internal rate of return	Simple payback period (yrs)
		Energy	Demand	AOC	Total			
Secondary school	Economic	39,000	0	—	39,000	316,200	15.7%	6.0
	Resilient	39,100	0	—	39,100	171,100	8.6%	9.7
	Resilient (with AOC)	39,100	0	18,000	57,100	345,100	12.8%	6.7
Nursing home	Economic	4,300	1,100	—	5,400	22,900	8.5%	9.9
	Resilient	8,000	3,200	—	11,200	(49,800)	2.0%	18.6
	Resilient (with AOC)	8,000	3,200	19,000	30,200	107,800	11.0%	6.9
Multifamily Housing	Economic	2,400	0	—	2,400	21,700	19.0%	5.1
	Resilient	2,900	0	—	2,900	14,800	9.6%	9.0
	Resilient (with AOC)	2,900	0	1,400	4,300	28,600	14.5%	6.0
Fire station	Economic	800	300	—	1,200	6,500	10.3%	8.6
	Resilient	1,100	700	—	1,800	1,600	5.1%	13.3
	Resilient (with AOC)	1,100	700	2,200	4,100	23,100	13.7%	6.0

The economics of the resilient scenarios are considered both with and without savings due to avoided outage costs (AOC). Net present value is calculated over a 25-year period and includes replacement costs for battery storage systems in the resilient scenarios.



MIAMI, FL

Analysis results for building types in Miami, FL are presented in **Table 16** and **Table 17**.

Economic outcomes were mixed the four building types in Miami, with weaker economic benefits than three of the cities evaluated in this report series. The economic case for solar+storage was found to be stronger for the larger facilities, the school and nursing home, due to lower installation costs for larger solar systems and greater opportunities for demand charge savings.

The **Economic Scenario** analysis results varied by building type for Miami facilities. Solar, without battery storage, represented the most economical option for the secondary school and nursing home, based purely on electric bill savings with no consideration of improved energy resilience. Solar was not found to be a cost-effective option for the smaller buildings—the multifamily housing property and the fire station.

The reason solar PV was not found to be positive option for all building types is primarily due to the design of utility electric rate tariffs offered by Florida Power & Light (FPL). The rate tariff applied to all four building types has a very low energy charge rate, less than 5 cents per kilowatt-hour, and a moderate demand charge rate of about $11 per kilowatt. Both of these factors reduce the economic case for solar PV. Solar was found to be marginally cost-effective for the larger building types primarily because of the greater availability of roof space to install larger solar systems with lower installed costs per watt.

The economic picture did not improve under the **Resilient Scenarios**, with battery storage adding additional costs not fully offset by electric bill savings. Solar+storage was not found to be positive economic investment for any of the building types evaluated without accounting for savings from avoided outage costs. This is again a reflection of low bill savings potential due to the design of FPL's commercial electric rate tariff.

Factoring in the additional value of avoided outage costs by powering critical loads during grid disruptions dramatically alters the economics of solar+storage, resulting in positive economics for all building types. Including the savings from avoided outage costs makes the resilient scenario the most economic option for all four buildings types, with the highest NPV, best IRR, and shortest simple payback period.

For the school and nursing home, accounting for avoided outage costs results in short simple payback periods of less than three years. These impressive results are largely a reflection of extended outages experienced by FPL customers in 2017, primarily due to Hurricane Irma. Avoided outage costs for commercial customers in FPL's service territory were calculated to be significantly higher than other regions analyzed in the Southeast because of these recent prolonged electric service disruptions.

Systems modeled for the **Resilient Scenario** can provide backup power to support critical loads for up to 11 hours or more for all building types, except for the nursing home. Due to the energy intensive nature of nursing home operations and constraints on available rooftop space, the nursing home's solar+storage system is limited to providing a maximum of 7 hours of backup power to critical loads at a time, 6 hours during hurricane season.

Miami ranked fourth among the five cities evaluated based on the economic opportunity for solar+storage development.

TABLE 16

Solar PV and Battery Storage System Sizing, Costs, and Maximum Hours of Backup Power for Building Types in Miami

Building type	Modeled scenario	Solar (kW)	Battery storage		Installed system cost ($)		Net present value system cost ($)	Backup power (hours)	
			(kW)	(kWh)	Solar	Battery		Annual	Sept/Oct
Secondary school	Economic	40.0	—	—	78,000	—	54,600	—	—
	Resilient	71.2	11.8	45.7	138,795	48,400	143,697	14	10
Nursing home	Economic	25.0	—	—	48,800	—	34,100	—	—
	Resilient	112.7	23.7	91.3	219,800	96,800	246,900	7	6
Multifamily housing	Economic	—	—	—	—	—	—	—	—
	Resilient	10.0	2.5	9.8	22,500	10,400	25,700	15	14
Fire station	Economic	—	—	—	—	—	—	—	—
	Resilient	13.6	2.5	9.8	30,600	10,400	31,400	11	11

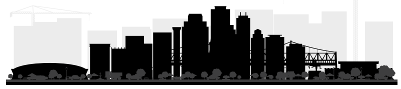
Net present value system cost represents the total installed system cost, the cost of replacing battery storage system components, and incorporates incentives available through the federal investment tax credit. Backup power represents the maximum sustained number of hours the system could power critical building loads.

TABLE 17

Solar PV and Battery Storage Economic Modeling Results for Building Types in Miami

Building type	Modeled scenario	First year savings ($)				Net present value ($)	Internal rate of return	Simple payback period (yrs)
		Energy	Demand	AOC	Total			
Secondary school	Economic	3,200	1,200	—	4,500	8,800	6.1%	12.2
	Resilient	5,800	2,100	—	7,900	(32,500)	2.1%	18.2
	Resilient (with AOC)	5,800	2,100	46,000	53,900	410,800	33.2%	2.7
Nursing home	Economic	2,000	500	—	2,500	1,400	4.9%	13.6
	Resilient	9,200	2,800	—	11,900	(78,600)	1.0%	20.7
	Resilient (with AOC)	9,200	2,800	77,700	89,700	670,800	32.0%	2.8
Multifamily Housing	Economic	—	—	—	—	—	—	—
	Resilient	800	200	-	1,000	(12,200)	(1.0%)	26.9
	Resilient (with AOC)	800	200	2,400	3,400	11,100	9.0%	7.6
Fire station	Economic	—	—	—	—	—	—	—
	Resilient	1,100	300	—	1,400	(11,300)	0.5%	22.1
	Resilient (with AOC)	1,100	300	4,900	6,300	35,500	16.0%	5.0

The economics of the resilient scenarios are considered both with and without savings due to avoided outage costs (AOC). Net present value is calculated over a 25-year period and includes replacement costs for battery storage systems in the resilient scenarios.



NEW ORLEANS, LA

Analysis results for building types in New Orleans, LA are presented in **Table 18** and **Table 19**.

Without accounting for avoided outage costs, economic outcomes were found to be poor for the four building types evaluated in New Orleans. These outcomes are primarily due to the design of electric rate tariffs offered by Entergy New Orleans.

Solar was not found to be an economical investment for any of the building types evaluated under the **Economic Scenario**. Because solar was found to have a negative NPV in all cases, the most cost-effective solution for the buildings evaluated would be the business-as-usual case of not installing a solar PV system of any size.

The secondary school and nursing home are subject to Entergy's Large Electric Service tariff, which has an energy charge rate of 5 cents per kilowatt-hour for the first 5,000 kilowatt-hours of energy consumption in each billing period. The energy charge rate then drops to less than 3 cents per kilowatt-hour for remaining consumption. This very low second-tier energy charge rate makes it difficult for solar to compete with the price of grid electricity. The Large Electric Service tariff also includes a fixed demand charge of $508.33 for the first 50 kilowatts of energy demand. Because Entergy has structured the charge as a fixed fee, large electric service customers are charged $508.33 each billing period regardless of whether their demand is below 50 kilowatts for that period. This again undercuts the bill savings solar and battery storage can achieve. For example, if installed solar PV and battery storage were to reduce peak demand during a billing period from 50 kilowatts to 30 kilowatts, no demand saving would be realized under this rate tariff structure.

The multifamily housing facility and the fire station are subject to Entergy's Small Electric Service tariff, which has an energy charge rate of 6 cents per kilowatt-hour for the first 1,000 kilowatt-hours of energy consumption in each billing period. The energy charge rate then drops to about 4 cents per kilowatt-hour for remaining consumption. While these rates are higher than for Large Electric Service customers, solar is still not economic for these smaller facilities. Part of the reason for this is that the smaller facilities only have enough roof space available to install a smaller solar system, which costs more to install on a per watt basis. The small electric service tariff also includes a fixed demand charge but, at $12.64 for the first 5 kilowatts of demand, its impact is minimal.

The economic picture does not improve under the **Resilient Scenarios**, with battery storage adding additional costs not fully offset by electric bill savings. Solar+storage was not found to be positive economic investment for any of the building types evaluated without accounting for savings from avoided outage costs. This is again a reflection of low bill savings potential due to the design of Entergy's commercial electric rate tariffs.

Similar to the Miami analyses, factoring in the additional value of avoided outage costs by powering critical loads during grid disruptions significantly alters the economic opportunity for solar+storage. The value of avoided outage costs was found to be much higher than the potential for electric bill savings for all building types evaluated. Factoring these savings into the analysis results in positive economics for the four building types, though the economics of solar+storage is only moderately favorable for each building type, except for the fire station. The fire station was found to have the strongest economic case for solar+storage, with a less than seven-year simple payback period when accounting for avoided outage costs.

All systems modeled for the **Resilient Scenario** can provide backup power to support critical loads for up to 12 hours or more. The New Orleans nursing home is the only case evaluated in the report series where a larger battery system was modeled to ensure critical loads could be adequately powered during grid disruptions. The secondary school had the best resilience outcome, with a solar+storage system able to deliver backup power supporting critical loads for up to 14 hours throughout the year and up to 13 hours during hurricane season.

New Orleans ranked last among the five cities evaluated based on the economic opportunity for solar+storage development.

TABLE 18

Solar PV and Battery Storage System Sizing, Costs, and Maximum Hours of Backup Power for Building Types in New Orleans

Building type	**Modeled scenario**	**Solar (kW)**	**Battery storage**		**Installed system cost** ($)		**Net present value system cost ($)**	**Backup power** (hours)	
			(kW)	**(kWh)**	**Solar**	**Battery**		**Annual**	**Sept/Oct**
Secondary school	Economic	—	—	—	—	—	—	—	—
	Resilient	115.7	23.7	91.3	225,500	48,400	250,852	14	13
Nursing home	Economic	—	—	—	—	—	—	—	—
	Resilient	30.9	11.8	45.7	60,300	96,800	88,700	12	12
Multifamily housing	Economic	—	—	—	—	—	—	—	—
	Resilient	20.4	2.5	9.8	46,000	10,400	42,200	12	11
Fire station	Economic	—	—	—	—	—	—	—	—
	Resilient	13.6	2.5	9.8	30,600	10,400	31,366	12	12

Net present value system cost represents the total installed system cost, the cost of replacing battery storage system components, and incorporates incentives available through the federal investment tax credit. Backup power represents the maximum sustained number of hours the system could power critical building loads.

TABLE 19

Solar PV and Battery Storage Economic Modeling Results for Building Types in New Orleans

Building type	Modeled scenario	First year savings ($)				Net present value ($)	Internal rate of return	Simple payback period (yrs)
		Energy	Demand	AOC	Total			
Secondary school	Economic	—	—	—	—	—	—	—
	Resilient	4,900	2,800	—	7,800	(143,600)	(2.5%)	33.0
	Resilient (with AOC)	4,900	2,800	23,200	31,000	6,900	4.8%	10.8
Nursing home	Economic	—	—	—	—	—	—	—
	Resilient	1,300	400	—	1,600	(65,500)	(5.6%)	53.9
	Resilient (with AOC)	1,300	400	28,600	30,200	800	4.5%	10.4
Multifamily Housing	Economic	—	—	—	—	—	—	—
	Resilient	1,200	400	—	1,600	(19,600)	(0.9%)	26.4
	Resilient (with AOC)	1,200	400	2,400	4,000	3,600	5.4%	10.5
Fire station	Economic	—	—	—	—	—	—	—
	Resilient	800	200	—	1,000	(16,900)	(2.0%)	30.6
	Resilient (with AOC)	800	200	2,000	3,000	17,200	10.3%	6.9

The economics of the resilient scenarios are considered both with and without savings due to avoided outage costs (AOC). Net present value is calculated over a 25-year period and includes replacement costs for battery storage systems in the resilient scenarios.

WILMINGTON, NC

Analysis results for building types in Wilmington, NC are presented in **Table 20** and **Table 21**.

Economic outcomes were found to be positive for all four building types across both scenarios, except for the fire station under the **Resilient Scenario** without accounting for avoided outage costs. These encouraging results are due in large part to the solar rebate program offered by Duke Energy Progress—the only utility evaluated with a solar incentive program. The **Economic Scenario** analysis found that solar PV, without battery storage, would be the most economical option for all four building types in Wilmington, based solely on electric bill savings with no consideration of improved energy resilience.

When the buildings were analyzed under the **Resilient Scenario**, solar+storage was still found to result in net savings for the secondary school, nursing home, and multifamily housing property, despite the added cost of the battery system. The nursing home and fire station are both subject to the Duke Energy Progress Medium General Service rate tariff, which, at less than 7 cents per kilowatt-hour, has much lower energy charge rates than the school or multifamily housing facility. As a result, the nursing home and fire station have less opportunity for solar electric bill savings, with lower IRRs and longer simple payback periods than the school and multifamily housing.

The nursing home is a larger facility with more available roof space than the fire station, and it can install a larger solar PV system at a lower cost based on dollars per watt, resulting in better overall economics for the nursing home.

The economic case for solar+storage is only marginally better for the multifamily housing property. The multifamily housing property, on Duke Energy's Small General Service tariff, pays a much higher energy charge rate of about 11 cents per kilowatt-hour, but the tariff does not have a demand charge, which eliminates the potential for battery storage to deliver additional electric bill savings.

Factoring in the additional value of avoided outage costs by powering critical loads during grid disruptions significantly improves the lifetime savings for all four building types, resulting in positive economics for the solar+storage systems in all cases, including the fire station. Accounting for the savings from avoided outage costs makes the **Resilient Scenario** the most economic option for the fire station, with an IRR of more than 35 percent and a simple payback period of less than three years.

Systems modeled for the resilient scenario can provide backup power to support critical loads for up to 12 hours or more for all building types, except for the nursing home. Like in other locations, the energy intensive nature of nursing home operations and constraints on available rooftop space limit the duration of backup power the solar+storage system can deliver to support critical loads. The nursing home's solar+storage system is limited to providing a maximum of 6 hours of backup power to critical loads at a time, 4 hours during hurricane season.

Wilmington ranked the best based on its economic opportunities for solar+storage development among the five cities evaluated in this report series.

TABLE 20

Solar PV and Battery Storage System Sizing, Costs, and Maximum Hours of Backup Power for Building Types in Wilmington

Building type	Modeled scenario	Solar (kW)	Battery storage		Installed system cost ($)		Net present value system cost ($)	Backup power (hours)	
			(kW)	(kWh)	Solar	Battery		Annual	Sept/Oct
Secondary school	Economic	192.0	—	—	374,400	—	209,600	—	—
	Resilient	192.0	35.5	137.0	374,400	142,500	349,100	12	12
Nursing home	Economic	52.0	—	—	101,400	—	52,800	—	—
	Resilient	52.0	11.8	45.7	101,400	48,400	110,241	6	4
Multifamily housing	Economic	12.0	—	—	27,000	—	14,700	—	—
	Resilient	15.3	2.5	9.8	34,400	10,400	28,800	16	16
Fire station	Economic	13.6	—	—	30,600	—	14,300	—	—
	Resilient	13.6	2.5	9.8	30,600	10,400	24,200	12	11

Net present value system cost represents the total installed system cost, the cost of replacing battery storage system components, and incorporates incentives available through the federal investment tax credit and the solar rebate offered by Duke Energy Progress. Backup power represents the maximum sustained number of hours the system could power critical building loads.

TABLE 21

Solar PV and Battery Storage Economic Modeling Results for Building Types in Wilmington

Building type	Modeled scenario	First year savings ($)				Net present value ($)	Internal rate of return	Simple payback period (yrs)
		Energy	Demand	AOC	Total			
Secondary school	Economic	44,500	3,500	—	48,000	472,400	22.3%	4.4
	Resilient	44,400	5,400	—	49,800	361,900	13.3%	7.0
	Resilient (with AOC)	44,400	5,400	5,100	54,900	411,000	14.6%	6.4
Nursing home	Economic	5,200	200	—	5,400	23,100	8.5%	9.8
	Resilient	5,200	800	—	6,000	200	4.6%	18.5
	Resilient (with AOC)	5,200	800	5,400	11,400	78,200	8.7%	9.7
Multifamily Housing	Economic	1,700	0	—	1,700	9,900	10.5%	8.4
	Resilient	2,100	0	—	2,100	1,000	4.9%	13.6
	Resilient (with AOC)	2,100	0	2,200	4,300	32,100	11.8%	6.8
Fire station	Economic	1,400	100	—	1,400	6,000	8.4%	9.9
	Resilient	1,400	200	—	1,500	(2,400)	3.5%	15.7
	Resilient (with AOC)	1,400	200	8,100	9,600	75,300	35.4%	2.5

The economics of the resilient scenarios are considered both with and without savings due to avoided outage costs (AOC). Net present value is calculated over a 25-year period and includes replacement costs for battery storage systems in the resilient scenarios.

Endnotes

1 Net present value (NPV) is defined as the difference between the present value of economic benefits and the present value of expenses over the life of the system. Future benefits and expenses are discounted over time. A positive NPV indicates that it would be economically beneficial to install the system, whereas a negative NPV would indicate that the system would not result in net savings over time. See the Economic Analysis Assumptions section for more information about the inputs used in calculating NPVs for this analysis.

2 Demand charges, which are usually applied only to commercial utility customers, are typically billed based on the highest rate of electricity consumption a customer experiences during a billing period, measured in kilowatts. This highest level of demand is known as peak demand. For more information about demand charges and how energy storage can lower peak demand, see "An Introduction to Demand Charges," Clean Energy Group, August 2017, *https://www.cleanegroup.org/wp-content/uploads/Demand-Charge-Fact-Sheet.pdf*.

3 Lawrence Berkeley National Laboratory and Nexant, Inc, "The Inter-ruption Cost Estimate (ICE) Calculator," Transmission Permitting and Technical Assistance Division of the U.S. Department of Energy's Office of Electricity (OE) Delivery and Energy Reliability, Contract No.: DE-AC02-05CH11231, Accessed February 20, 2019, *https://icecalculator.com/home*.

4 For context, the national average duration for outages in 2015 was just under four hours, with a frequency of 1.4 outages per year. Only Duke Energy Progress performed better than this national average, highlighting a potentially greater need for resilience in the Southeast. See Eto, Joseph H., "Reliability Metrics and Reliability Value-Based Planning," Lawrence Berkeley National Laboratory, October 2, 2017, *https://emp.lbl.gov/sites/default/files/6._170928_necpuc_training_reliability_metrics_and_rvbp.pdf*.

5 For more information about solar and battery storage third-party ownership financing structures, see Milford, Lewis and Robert Sanders, "Owning the Benefits of Solar+Storage: New Ownership and Investment Models for Affordable Housing and Community Facilities," Clean Energy Group, February 5, 2018, *https://www.cleanegroup.org/ceg-resources/resource/owning-the-benefits-of-solar-storage*.

6 Elgqvist, Emma, Kate Anderson, and Edward Settle, "Federal Tax Incentives for Energy Storage Systems," National Renewable Energy Laboratory, January 2018, *https://www.nrel.gov/docs/fy18osti/70384.pdf*.

7 U.S. Energy Information Administration, "Commercial Buildings Energy Consumption Survey (CBECS)," October 31, 2018, *https://www.eia.gov/consumption/commercial*.

8 See U.S. Energy Information Administration, "Commercial Buildings Energy Consumption Survey (CBECS): Building Type Definitions," Accessed February 20, 2019, *https://www.eia.gov/consumption/commercial/building-type-definitions.php* for descriptions of each building type.

9 The Greenlink Group has previously performed more than a dozen analyses on the economics of solar, battery storage, and the combination of the two in the Southeast.

10 National Renewable Energy Laboratory (NREL), "EnergyPlus," U.S. Department of Energy's (DOE) Building Technologies Office (BTO), version 9.0.1, October 10, 2018, Accessed February 20, 2019, *https://energyplus.net*.

11 Some solar inverter manufacturers offer a secure power supply option that allows a standard electric outlet to remain energized during a grid outage. This option is not considered to be a feasible backup power solution for the building types evaluated.

12 McLaren, Joyce and Seth Mullendore, "Valuing the Resilience Provided by Solar and Battery Energy Storage Systems," National Renewable Energy Laboratory (NREL), January 31, 2018, *https://www.cleanegroup.org/ceg-resources/resource/valuing-resilience-solar-battery-energy-storage*.

13 The details and availability specific electric rate tariffs are subject to change as utilities alter offerings and propose adjustments to current offerings. The rate tariff details presented here represent those used in the economic analysis and reflect rates details that were current and available to customers as of Fall 2018.

14 All future electricity rates are measured in real 2017 dollars in order to account for price fluctuations due to inflation.

15 Georgia Power, "Solar Buy Back," Accessed February 20, 2019, *https://www.georgiapower.com/company/energy-industry/energy-sources/solar-energy/solar/solar-buy-back.html*.

16 Solar CrowdSource, "Solarize Atlanta," Accessed February 20, 2019, *https://www.solarcrowdsource.com/campaign/atlanta-ga*.

17 Duke Energy, "Renewable Energy: North Carolina Rebates," Accessed February 20, 2019, *https://www.duke-energy.com/home/products/renewable-energy/nc-solar-rebates*.

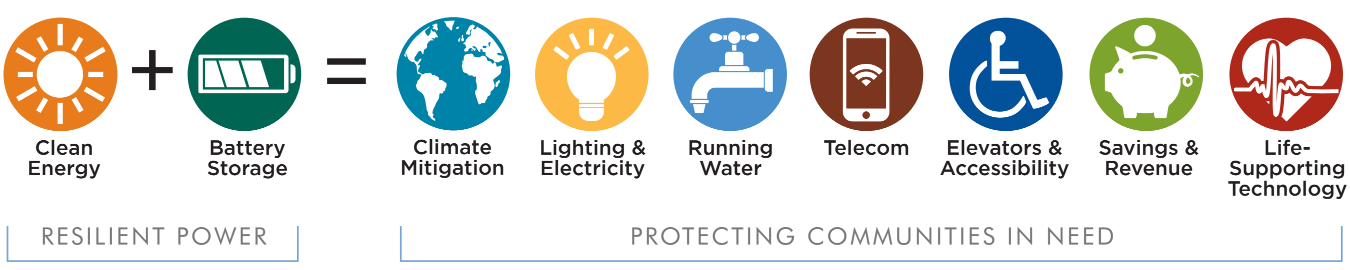
18 Wood McKenzie, "U.S. Front-of-the-Meter Energy Storage System Prices 2018–2022," May 9, 2018, *https://www.woodmac.com/our-expertise/focus Power--Renewables/U.S.-Front-of-the-Meter-Energy-Storage-System-Prices-2018-2022*.

RESILIENT SOUTHEAST

Technical Appendix

RESILIENT POWER

A project of Clean Energy Group



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April 2019