The Evolving Solar Energy Innovation Ecosystem in Puerto Rico

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A report from the project, "*Developing socially and economically generative, resilient PV-energy systems for low- and moderate-income communities: Applications for Puerto Rico.*"

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This project is a joint effort of Arizona State University's Center for Energy and Society; the University of Puerto Rico-Mayaguez's Center for Hemispheric Cooperation in Research and Education in Engineering and Applied Science, Sustainable Energy Center, and National Institute for Energy and Island Sustainability; and the National Renewable Energy Laboratory.

The project seeks to understand the place of energy in low-income communities in Puerto Rico, the opportunities for solar energy to provide solutions to the energy challenges facing these communities, and the capacity of the solar energy innovation ecosystem in Puerto Rico to deliver relevant solar solutions for these communities. We define the solar energy innovation ecosystem as the diverse actors and stakeholders whose collective networks and actions—and the flows among them of ideas, knowledge, data, influence, money, and equipment, as well as the rules that govern those flows—are essential to the success of renewable energy markets and projects.

This report presents results from the first year of the project's research, which has concentrated on several key goals: (1) characterizing the trajectory of solar energy development in Puerto Rico in the three years since Hurricane María; (2) mapping and characterizing the current solar energy innovation ecosystem in Puerto Rico, including the technical potential for solar energy in Puerto Rico, and the business and policy landscape shaping solar developments; and (3) beginning to characterize the broad landscape of community energy initiatives underway in Puerto Rico. To pursue these goals, we engaged in a systematic review of solar energy developments in Puerto Rico and conducted interviews with over 100 members of the solar energy innovation, including policy, business, finance, research, and civil society leaders, as well as solar users. Solar technical potential data for Puerto Rico was developed by the National Renewable Energy Laboratory (NREL) and is publicly available at: https://data.nrel.gov/submissions/144. The documentation for the NREL dataset is included as Appendix A.

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I. Executive Summary and Key Findings

Low-income communities around the world face significant energy challenges. They often pay significantly higher proportions of their incomes on energy than wealthier communities. They suffer from inadequate and efficient energy infrastructures that lower their access to critical energy services, raising energy costs and increasing vulnerability to climate and other risks. In turn, these diverse forms of energy insecurity worsen economic, food, water, health, and other forms of insecurity. The upshot of these dynamic feedbacks—which increasingly are referred to, collectively, as the energy-poverty nexus—is to perpetuate and even exacerbate poverty.

In Puerto, in the years since Hurricane Maria, the disastrous effects of the energy-poverty nexus have been on full display. In response, many groups and organizations, inside and outside of Puerto Rico, have begun to ask whether solar energy might contribute not only to making Puerto Rico's energy grid more sustainable and resilient but also to addressing the intersecting challenges of energy, economic, and human insecurity that confront the commonwealth's low-income communities. This report begins to lay the groundwork for systematically answering that question by reviewing the trajectory and current status of solar energy in Puerto Rico in the wake of Hurricane Maria. In particular, the report explores the place of solar energy in the imagination of Puerto Ricans, developments in solar energy markets and policy, and the technical potential for distributed rooftop solar energy among low-income communities in Puerto Rico.

Key findings from the report include:

- In the wake of Hurricane María and the resulting long-duration energy outages suffered by many communities, *there is now a very high level of interest in solar energy* among policymakers, businesses, and communities across Puerto Rico. To put it succinctly, solar energy has captured the imagination of the people of Puerto Rico. Evidence for this can be found in (a) the prevalence of growing solar energy markets and businesses providing commercial and residential installations, (b) new policies that establish renewable portfolio standards of 100% by 2050, and (c) a growing number of community initiatives organized to bring solar energy to local inhabitants, among other indicators.
- The societal enthusiasm for solar energy in Puerto Rico is driven by two primary considerations. *The most widely cited reason for adopting solar energy is, across incomes and stakeholder types, to create a more resilient and secure future energy supply that can supplement grid-based electricity during and after future disasters*. There is widespread sentiment that the Puerto Rico electricity grid is extremely vulnerable to environmental disruption and technological failures. This leads to a particular emphasis on systems capable of functioning as backup power supplies during grid outages and, therefore, to supplementing solar with batteries. It has also contributed to a cyclical pattern in markets, in which interests in solar energy spikes during electricity outages, when hurricanes are present, or during other disasters, e.g., the recent series of earthquakes in southern Puerto Rico. Many respondents to our interviews have also expressed the idea that Puerto Rico should rely on its locally available solar resources to replace carbon-based energy imports in the future.
- *Despite the high social enthusiasm for solar energy in Puerto Rico, the pace of solar installations in Puerto Rico has not kept pace.* Solar markets and policy are active in Puerto Rico, but they are not translating into rapid adoption of solar energy. While data on solar installations is sparse for Puerto Rico, indications are that rooftop installations in 2018 averaged about 1000 per month but dropped off after that. Most solar businesses reported up and down markets over the past 24 months, and sales have not dramatically increased

from pre-hurricane levels, which had seen about 12,000 total rooftop installations in the decade leading up to 2017. Data on solar panel imports do not indicate growth but rather continued low levels of adoption. Solar energy remains expensive for many households, especially given the low average household income (relative to the US as a whole), high unemployment due to the economic impacts of the hurricane and structural austerity programs imposed on Puerto Rico by the Congressional fiscal oversight board (PROMESA) in an attempt to address unsustainable debt levels, and the overall costs of household recovery from hurricane damage. Federal assistance funds have been slow to arrive, restricting opportunities for investing in more resilient energy systems. In addition, rules governing federal disaster assistance have prevented them from being used to upgrade or transform Puerto Rico's electricity system, and they have, instead, largely been used to build back the previous system.[2] Policy uncertainty in the energy sector has also contributed to lower willingness to invest in solar energy systems. Initiatives to privatize Puerto Rico's electricity utility (PREPA), to retrofit and replace oil-fired power plants with natural gas power plants, and to raise electricity bills and tax distributed solar generation are all creating confusion for potential solar customers. Most solar businesses therefore reported sales of solar systems primarily to higher income households and to successful commercial businesses looking to create more stable energy supplies for their operations.

- *The social sensitivity of Puerto Rican households to disruptions in energy supply remains very high*. A number of solar businesses have told us that power outages or events that have the potential to create power outages (e.g., near misses by hurricanes) generate upticks in business. The recent earthquakes have also created a strong resurgence of solar energy as a topic of conversation among residents of Puerto Rico, further emphasizing the significance of energy resilience as a driver of public interest in solar energy. We continue to encounter new communities expressing an interest in pursuing community-oriented solar solutions in a rooftop level.
- *Distributed rooftop solar energy offers an enormous technical potential to provide for the electricity needs of Puerto Rican communities, including low-income communities*. Data analyzed by the National Renewable Energy Laboratory shows that distributed rooftop solar energy has the potential to more than meet the needs of low-income communities in Puerto Rico. Rooftop solar on all Puerto Rico residential buildings has the potential to provide up to 24.5 TWh of electricity generation, while buildings occupied by low- and moderate-income households have the potential to provide 9.8 GW of electricity and 11.9 TWh of annual electricity generation. This compares to annual residential electricity consumption of approximately 6 TWh for all Puerto Rican households. In each of Puerto Rico's 78 municipalities, the total technical potential for rooftop solar energy generation on low-income residential buildings exceeds the electricity consumption of low-income households by at least a factor of two and, in the vast majority, by a factor of three. A parallel analysis indicates that 50% of Puerto Rican households would have 50% or more of their electricity needs met by a 2 kW solar system, a fact which could have made a big difference to the last 200,000 households reconnected to the grid after Hurricane María, who suffered over 150 days without power and were responsible for 1/3 of the total customer hours lost during the blackout. By contrast, utility-scale solar facilities took almost 15 months to return to pre-2017 levels of total generation.

[2] Stafford Act, as Amended, and Related Authorities., Public Law 93-288, Title 42 United States Code (2019).

- *The design of Puerto Rico's solar energy future matters.* Solar energy is a key tool for Puerto Rico's energy future, but the question is, "Which solar?" Solar panels are a highly flexible technology that can be integrated into social, economic, and ecological landscapes in lots of different ways. Design options include scale (utility, community, rooftop), ownership (household, community, investor), relationship to the grid (off-grid, micro-grid, solar+battery, grid-tied), and more. Equally important are choices about the social purposes to which to put solar: to increase the resilience of households to electricity outages, to accelerate the transition to carbon-neutrality, to reduce the costs of energy, to replace energy imports with locally generated energy, to create more self-reliant communities, to alleviate poverty, etc. While we do not carry out a systematic assessment of these options in this report, our findings suggest that rooftop and distributed solar energy solutions have the potential to play a significant role in Puerto Rico's energy future by providing extensive power, meeting household energy needs, improving resilience, reducing energy costs, and creating value for low-income individuals, households, and communities.

II. Background to the Report

In late September 2017, Puerto Rico was devastated by Hurricanes Irma and María, leading to one of the largest and most destructive electricity outages in the history of the United States.[3] Customer hours of lost electricity service (CHOLES) totaled 2.9 billion. Nearly the entire population of Puerto Rico, over 3 million people, was without power for a month or more, and significant portions of the archipelago remained without power for as long as 11 months. The official duration of the outage was marked at 329 days, although some houses which were badly damaged by the hurricane still do not have power.[4] One remarkable fact was that roughly one-third of the total CHOLES stemmed from the final 200,000 customers who were reconnected, many of whom lived in some of the lowest income and most isolated communities.[5] The outage contributed to extensive economic damage, illness, and thousands of deaths throughout Puerto Rico.[6]

Within weeks of María's landfall on September 20th, 2017, the idea emerged and began to spread widely through social media and news accounts of the disaster that perhaps solar energy could contribute meaningfully to helping solve the immediate energy crisis while also contributing more long-term to a sustainable and resilient energy future for Puerto Rico. A high-profile Twitter exchange between Puerto Rico's governor and Elon Musk on Oct. 5th garnered widespread attention to the potential of solar energy to contribute to the disaster response and stimulated a bevy of

[3] An exhaustive account of the devastation caused by Hurricane María can be found in Ariel Lugo, *Socio-Ecological-Technological Effects of Hurricane María on Puerto Rico*. Dordrecht: Springer. 2018.
[4] Robles, F. (2018). "Puerto Rico Spent 11 Months Turning the Power Back On. They Finally Got to Her." *The New York Times*. Aug. 14, 2018. https://www.nytimes.com/2018/08/14/us/puerto-rico-electricity-power.html
[5] Castro-Sitiriche, Marcel, Yonatan Cintrón-Sotomayor, and Jonathan Gómez-Torres. "The longest power blackout in history and energy poverty." *Proc. 8th Int. Conf. Appropriate Technol.*. 2018. http://www.appropriatetech.net/media/attachments/2019/06/20/8th-icat---policy-standards-ethics.pdf#page=36
[6] Several studies have estimated deaths and damages from Puerto Rico. A few include: *Ascertainment of the Estimated Excess Mortality from Hurricane María in Puerto Rico*, Milliken Institute School of Public Health, George Washington University, 2018. N. Kishore et al., "Mortality in Puerto Rico after Hurricane Maria," *New England Journal of Medicine* 379:162-170, 2018. S. Hsiang and T. Houser, "The Mind-bending and Heart-breaking Economics of Hurricane Maria," Sept. 29, 2017, http://www.impactlab.org/news-insights/the-mind-bending-and-heart-breaking-economics-of-hurricane-maria/. Smith-Nonini, Sandy. "The Debt/Energy Nexus behind Puerto Rico's Long Blackout: From Fossil Colonialism to New Energy Poverty." *Latin American Perspectives* 47.3 (2020): 64-86.

national media coverage. In response, numerous groups inside and outside of Puerto Rico began to mobilize distributed solar energy projects that could provide immediate energy relief, including campaigns to distribute solar lanterns,[7] a few hundred philanthropic projects to provide solar power for critical infrastructure buildings, such as hospitals, police and fire stations, and health clinics,[8] and local efforts to design and build community solar power resources for remote communities who suffered from the longest outages.[9] In addition, groups like the Rocky Mountain Institute began organizing dialogues around the idea that solar energy could provide the foundation for a 100% renewable energy future for Puerto Rico.[10]

These events fed into a robust, long-term dialogue about the future of sustainable energy already underway in Puerto Rico. Beginning in the early 2000s, Puerto Rico began developing policies to encourage renewable energy development. In 2007, legislation was passed allowing solar energy owners to receive compensation for renewable energy supplied to the grid, building on earlier policies, established in 2004, to grant tax credits to renewable energy projects. In 2008, a multi-sector roundtable on renewable energy was established by the Tropical Institute for Energy, Environment, and Society.[11] The roundtable brought together governmental, industrial, unions, academic and community organizations toward the goal of designing "*an electricity system that is a sustainable and innovative social and material system that anticipates and assimilates market changes and consumption patterns and uses local and renewable energy resources*."[12]

One upshot of these efforts was the funding of a study by the Puerto Rico Energy Affairs Administration to explore the potential technological basis of sustainable electricity generation. The study, *Achievable Renewable Energy Targets for Puerto Rico's Renewable Energy Portfolio Standard*, was conducted by researchers at the University of Puerto Rico and documented the extensive local energy resources available in Puerto Rico to power a renewable energy future, including solar, wind, biomass, and ocean energy, as well as energy efficiency and conversation.[13] The study illustrated, notably, that solar energy was a significant potential source of renewable electricity and that rooftop solar energy, in particular, had the potential to supply a large fraction of Puerto Rico's electricity needs. Over the next several years, from 2011-17, 150 MW of utility-scale solar projects were constructed. At the same time, a modest residential rooftop markets emerged, growing more rapidly after 2015. While not large in volume, these projects demonstrated that solar energy could thrive in the right policy environment.

Building on the roundtable's work, the National Institute for Energy and Island Sustainability (INESI) convened multi-year dialogues among energy decision-makers, researchers, activists,

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[7] See, e.g., "Gómez-Colón '21 featured at World Economic Forum," https://www.andover.edu/news/2020/gomez-colon-21.
[8] A map of philanthropic projects is collected here: https://www.puertoricosolarmap.org.
[9] For illustrations of local solar relief and resilience project, see, e.g., https://casapueblo.org/index.php/casa-pueblo-collaborates-with-googles-project-sunroof/ and https://epics.ieee.org/solar-power-aid-puerto-rico/.
[10] Rocky Mountain Institute, "The Role of Renewable and Distributed Energy in a Resilient and Cost-Effective Energy Future for Puerto Rico," December 2017. https://rmi.org/wp-content/uploads/2017/12/Insight_Brief_Puerto_Rico_Resilient_CostEffective_Energy.pdf
[11] O'Neill-Carrillo, E., et al. "The role of engineers as policy entrepreneurs toward energy transformations." *Proceedings of the ASEE 123rd Annual Conference*. 2016.
[12] Mesa de Dialogo del Sistema Electrico de Puerto Rico. (2009). *Plan Estratégico para Promover la Sostenibilidad del Sistema Eléctrico de Puerto Rico.* Tropical Institute of Energy, Environment and Society.
[13] Irizarry Rivera, A., Colucci Rios, J., & O'Neill Carrillo, E. (2009). *Achievable Renewable Energy Targets for Puerto Rico's Renewable Energy Portfolio Standard.* Puerto Rico Energy Affairs Administration.

and community leaders about a Puerto Rico energy transition. This forum helped establish an interdisciplinary network of experts and community leaders across Puerto Rico to contribute to sustainable energy development.[14] Among its goals, the network established greater visibility and designed alternative solutions for energy challenges facing remote and low-income communities with inequitable access to energy services. Members of the network played important roles in the response to Hurricane María, identifying and analyzing the long-term, underlying causes of Puerto Rico's energy crisis, drawing public and media attention to the need for a sustainable and resilient energy future, strengthening relations between federal, state, and municipal governments, and working with mountain and coastal communities to identify and design solar solutions to the immediate and long-term challenges these communities face in the wake of María.[15]

The long history of energy transition advocacy in Puerto Rico—combined with the events that followed Hurricane María—fired the popular imagination for solar energy. Significant numbers of people now see solar energy as the solution to Puerto Rico's diverse energy challenges, including persistent grid instability, recurring natural disasters, high electricity costs, and significant energy poverty, all of which persist even in the wake of the official restoration of the electricity grid. In early 2019, the legislature and governor passed a bill setting a 100% renewable energy target for Puerto Rico by 2050. There are good reasons to believe that deployment of solar energy would potentially bring significant benefits to Puerto Rico. For example, Puerto Rico spends $3 billion per year to import and burn carbon-based fuels for electricity, transportation, and industry. Even a modest reinvestment of those funds into locally owned, locally generated energy could bring significant economic benefits.

Yet, despite its visibility and potential value, solar energy continues to struggle to find its footing in Puerto Rico. Near-term energy policy remains in flux, with strong advocates for many different energy sources and futures, including the privatization of electricity systems and services, fuel switching from oil and coal to natural gas, reforms to create smaller, more resilient micro-grids across the island, and the growth of renewables. Government institutions, including PREPA, hold significant debt and have not been able to deploy significant new financial resources to tackle the energy system's challenges, although the Puerto Rico government has moved forward on some aspects of both privatization and fuel switching. Solar markets for individual businesses and homes are growing, albeit slowly, in fits and starts. Many low-income communities have launched initiatives around the use of solar energy to enhance their long-term resilience, but these initiatives have been almost entirely bottom-up in organization, lacked coordination across communities, and struggled to mobilize significant financial resources behind their plans.

III. Summary of the Project's Objectives and Plans

Against this backdrop, this report describes initial research results from a study of solar energy innovation in Puerto Rico. The three-year study aims to identify and evaluate the potential of solar energy solutions to reduce energy poverty in low-income communities in Puerto Rico. The project

[14] Vega, A. (2016). *INESI crea el primer catálogo de recursos | Ciencia Puerto Rico*. https://www.cienciapr.org/es/external-news/inesi-crea-el-primer-catalogo-de-recursos. Instituto Nacional de Energia y Sostenibilidad Isleña. (2016). *Catálogo de Recursos: En Energía y Sostenibilidad de la Universidad de Puerto Rico.* Universidad de Puerto Rico. The resources in INESI platform have been identified as a lead in interdisciplinarity expertise that could provide a foundation to the Puerto Rico energy transition, see, e.g., United States Department of Energy. (2018). *Energy Resilience Solutions for the Puerto Rico Grid.*

[15] Instituto Nacional de Energia y Sostenibilidad Isleña. (2018). *Annual Report 2017- 2018*. University of Puerto Rico.

is jointly being carried out by Arizona State University, the University of Puerto Rico-Mayaguez, and the National Renewable Energy Laboratory.

The overarching objective of the study *is to evaluate the ability of solar energy to untangle the energy-poverty nexus.* We use the language of energy-poverty nexus to refer to recent theoretical advances that have shown that traditional concepts of energy poverty, which focus on either the cost of energy (affordability) or the unavailability of energy (access) to energy users, fall short of describing the complexity of the self-reinforcing, dynamically interacting feedback loops that occur in contemporary societies between energy insecurities and poverty.[16] (Francois and Poganietz 2018; Biswas 2020). For low-income communities, in general, and especially for communities living in extreme poverty, these feedback loops make it more difficult to either escape poverty or to resolve energy insecurities. In other words, the organization of energy systems helps to perpetuate poverty and vice versa. Many factors contribute to the energy-poverty nexus, including: (a) high energy burdens, including high electricity prices; (b) lack of access to financial resources among low-income households for investing in energy innovation or infrastructure upgrades that could lower long-term energy costs; (c) trade-offs between energy and other critical household needs, such as food; and (d) health difficulties that arise due to the inability to pay energy bills or the impacts of energy insecurities on critical aspects of wellbeing. These are compounded by energy governance and decision-making processes that, in Puerto Rico and between Puerto Rico and federal decision-making in Washington, DC, are relatively inaccessible to individuals and low-income communities, with relatively weak external oversight and regulation of the energy sector.

As an illustration of the challenges posed by the energy-poverty nexus in Puerto Rico, low-income households and communities in Puerto Rico face exceptionally high energy burdens, especially in comparison to the rest of the US. Energy burden is defined as the fraction of income that a household pays, monthly, for one or more sources of energy. For example, for the lowest income households (<30% area median income, AMI), energy burdens average 33% across Puerto Rico, only accounting for electricity and household natural gas use (see Figure 1).[17] As incomes go up, those burdens decline, as electricity costs at the household level don't change very much across LMI households by income ($944 for <30% AMI to $1139 for 60-80% AMI). For all LMI households (<80% AMI), energy burdens average 12%, which is high by national standards (on average, LMI households in the US experience energy burdens average 7.2%, while non-LMI households experience energy burdens of only 2.3%).[18]

The key question explored by this study is whether solar energy contributes to reversing the energy-poverty nexus and addressing the high energy burden in low-income communities by creating significant social and economic value for individual or groups of users and positive feedback loops at the community level that are socially and economically generative.[19] We refer to this as the ability of energy systems to deliver social value. We take a user-centric approach to analysis

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[16] D. E. Francois and W.-R. Poganietz, "Context energy scenarios for the energy-poverty nexus: looking beyond the number of people with access to modern energies." ESS International Conference 'Energy Scenarios - Construction, Assessment, and Impact' (2018), Karlsruhe, Germany, September 24–25, 2018. Biswas, Saurabh. *Creating Social Value of Energy at the Grassroots: Investigating the Energy-Poverty Nexus and Co-Producing Solutions for Energy Thriving*. PhD Diss. Arizona State University, 2020.

[17] Data from the DOE Low-Income Energy Affordability Data (LEAD) Tool: https://www.energy.gov/eere/slsc/maps/lead-tool.

[18] A. Drehbol and L. Ross, *Lifting the High Energy Burden in America's Largest Cities* (ACEEE, 2016).

[19] Miller, Clark A., et al. "Poverty eradication through energy innovation: A multi-layer design framework for social value creation." *ASU-AE4H Joint Working Paper* (2018). Miller, Clark A., et al. "The social value of mid-scale energy in Africa: Redefining value and redesigning energy to reduce poverty." *Energy Research & Social Science* 5 (2015): 67-69.

that focuses on the ability of users to derive social value from their use of energy and the (social, financial, and technical) organization of energy systems. This approach shares a great deal of

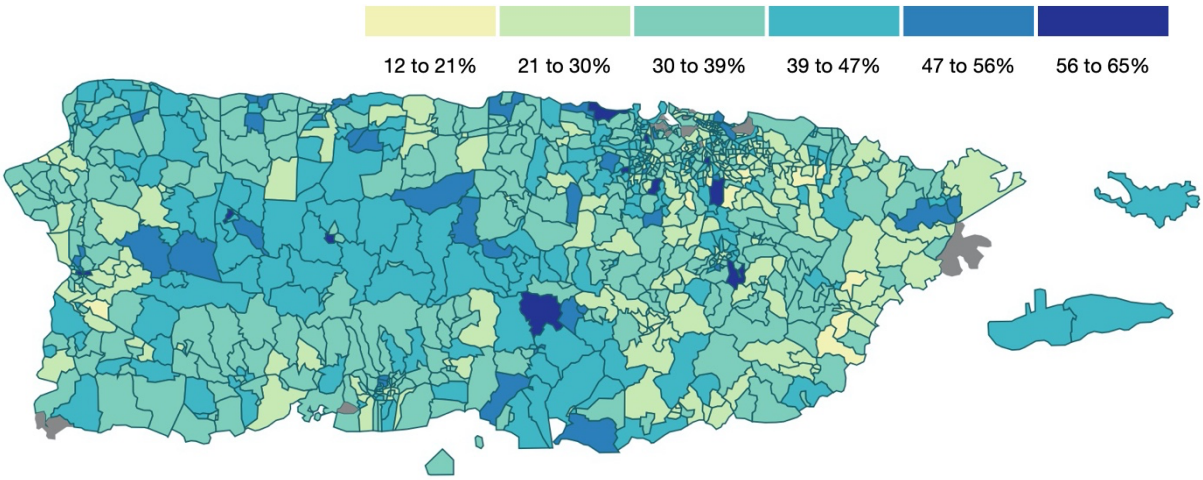


Figure 1. Energy burden (costs of electricity and household natural gas use) among lowest income households (<30% of Area Median Income) in Puerto Rico, by Census tract. Data from the DOE Low-Income Energy Affordability Data Tool: https://www.energy.gov/eere/slsc/maps/lead-tool.

similarities with a social practices approach to energy analysis,[20] expanded to focus on the net value proposition of energy for individuals and communities.

There are several reasons why solar energy solutions might bring benefits to low-income communities. First, solar energy is increasingly inexpensive, at least on a per kilowatt-hour basis, with costs that are now competitive under many conditions with other fuels and other technologies for making electricity. Second, solar technologies are more flexible than other kinds of technologies in terms of being able to be integrated into novel arrangements, both physically (e.g., they can be deployed in smaller, rooftop or ground-mount systems, rather than just in large power plants) and financially (e.g., ownership options are available that are more distributed than conventional public or private power models, including household, collective, and community-based ownership possibilities). Third, solar energy has the potential to be able to be generated locally, from locally available resources, rather than depending on the import of fuels from other parts of the world. Fourth, as batteries and electric vehicles come into more widespread use, solar systems have the potential to be designed to satisfy and benefit from a wider array of energy uses (e.g., improved and low-carbon mobility services) and thus have more impact on household or small business budgets than electricity alone.

If solar energy is able to generate significant benefits for low-income communities, that would provide a major opportunity for the solar industry both to expand its markets into new parts of the United States and the world and to address concerns about social justice that have been continuously raised about solar energy solutions. These concerns have included both the high up-front investments required to install solar energy (which often are not affordable to low-income households and businesses) and also the potential impact of wealthy households and businesses defecting from the grid and driving prices for grid electricity higher. In terms of scale, the potential

[20] Shove, Elizabeth, and Gordon Walker. "What is energy for? Social practice and energy demand." *Theory, Culture & Society* 31.5 (2014): 41-58.

market for solar in low-income communities includes several hundred GW of solar energy potential and billions of dollars of industry revenues.[21]

To understand the potential for solar energy to address the energy-poverty nexus and deliver meaningful value to low-income communities involves a number of key elements. These include: (1) understanding the dynamics and causes of the energy-poverty nexus; (2) mapping the potential opportunities for solar systems to disrupt, untangle, or reverse the energy-poverty nexus and, where possible, instead create social and economic value for individuals, households, businesses, and communities; (3) analyzing possible designs of solar systems—in terms of not only technical parameters but also financial, ownership, and governance arrangements—to evaluate how well different designs are able to take advantage of opportunities to end the energy-poverty nexus and create value for energy users; and (4) understanding the capabilities and limitations of existing solar energy innovation ecosystems to deliver the kind of solar solutions that would benefit low-income communities.

Phase one of the study focuses on two key challenges: first, understanding the dynamics of the solar energy innovation ecosystem in Puerto Rico and, especially, how low-income communities fit into that ecosystem; and, second, mapping the technical potential for solar energy to meet the energy needs of low-income communities in Puerto Rico. This report presents a few high-level results from the mapping of the technical potential, which was conducted by the National Renewable Energy Laboratory. The study methods and resulting data from the NREL study are publicly available at the NREL Solar-for-All website (https://maps.nrel.gov/solar-for-all/). This report therefore primarily focuses on the first part of the study, presenting a few final results from the NREL work where it illuminates problems discussed here.

To conduct the analysis of the solar energy innovation ecosystem, as we describe more fully below, we have conducted over 102 interviews over the past year to explore how solar energy innovation has evolved in Puerto Rico since Hurricane María, how solar markets, businesses, and policies have developed, and how low-income communities have sought to take advantage of solar energy to serve their goals and objectives. The results of this effort are described in more detail below. Initial results from the NREL data and analysis are also presented in this report.

The future phase two of the project will involve detailed data collection and analysis regarding the energy-poverty nexus in case studies with several partner communities in Puerto Rico and construction of models for evaluating potential solar solutions for community needs. Phase three of the study, which will follow in 2021-2022, will involve collaborative inquiry with the project's partner communities to identify, explore, simulate, and evaluate possible solar solutions for community solar development to meet community needs, enhance community resilience, and create generative community outcomes—and to explore potential pathways via which the solar energy innovation ecosystem in Puerto Rico might deliver those solutions to low-income communities.

IV. Research Methods

To carry out this study, we conducted 102 interviews with participants and stakeholders in the Puerto Rico solar energy innovation ecosystem between June 2019 and February 2020. We interviewed individuals associated with all seven groups of actors identified in Figure 6, including

[21] Sigrin, Benjamin O., and Meghan E. Mooney. *Rooftop solar technical potential for low-to-moderate income households in the United States*. No. NREL/TP-6A20-70901. National Renewable Energy Lab (NREL), Golden, CO (United States), 2018.

energy businesses (16), suppliers (2), policymakers (13), financers (2), influencers (23), researchers (18), and users (24). An initial list of potential subjects was generated from newspaper coverage of solar energy in Puerto Rico, which we then added to using snowball methods, asking each interviewee to suggest additional names. We selected individuals within each group of actors to represent a diversity of different modes of participation and perspectives on solar energy innovation (e.g., in the energy business group, we interviewed equipment suppliers, equipment retailers, installers, and others). Our interview protocols for each group were organized around a general framework of questions designed to elicit information about the organization and dynamics of the solar energy innovation ecosystem in Puerto Rico, adapted to the specific roles and responsibilities of each group within the ecosystem. We also incorporated questions to begin to allow us to explore how well the ecosystem is able to serve low-income communities.

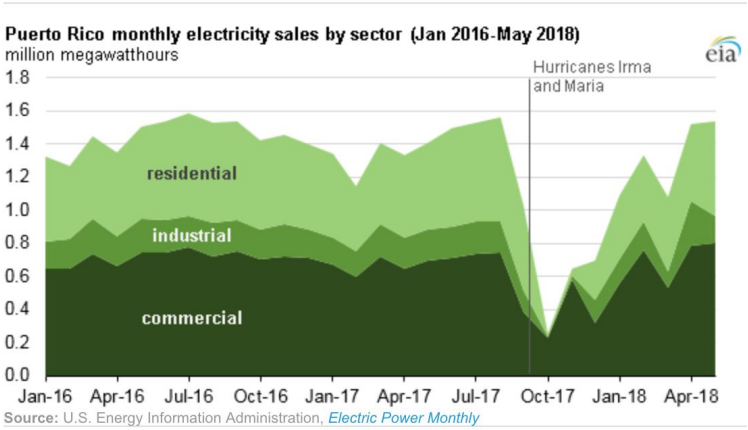
We used an open-ended, semi-structured format for the interviews in order to allow participants to provide us with narrative answers that captured both detailed information about ecosystem organization and dynamics and also contextual factors shaping their own individual experiences within it. We were not looking for correct or incorrect answers. Participants had the choice to answer questions in the way that they found most appropriate given their own experiences and perspectives, and the team adapted to their responses in order to continue to guide the conversation in ways that addressed the larger questions of the survey. In this way, we aimed to secure the trust of key informants and to capture their knowledge and expertise in their own lives, businesses, and social worlds, as well as to capture their ideas and insights regarding how to advance solar energy and how solar energy can create value for low-income energy users and communities. This approach allowed us to have the flexibility and be able to capture the topics when they fluidly arose during the conversation and helped us explore how key relationships varied across study sites, discover new topics relevant to our research, and generate authentic relations with participants in the study.[22]

For policy and influencer actors, our questions explored the current state of solar energy policy in Puerto Rico and the solar energy future. The instrument used four main areas: (1) *State of solar development*: What is the current state of solar energy in Puerto Rico, and what are the trends that are affecting solar energy development going forward? These questions focused on events after 2017, how those differed from pre-Maria settings, and the actions taken by the organization related to solar energy. (2) *Policy and regulation*: What are the policies in place that promote solar development in the island? What policies are under construction? What policies would help strengthen solar energy development for Puerto Rico? (3) *The future of solar energy*: What is your vision for the future of solar energy? How do you see solar energy as integrated into the transition of Puerto Rico's energy system post-María? (4) *The social value of energy*: How can access to solar energy be expanded for low-income individuals, households, or communities? How can it create social value for these groups? For researchers, we used a similar set of questions, adding one about what kind of solar research they do?

For actors in business and finance, our questions explored the current state of solar energy markets in Puerto Rico and the solar energy future: (1) *Business description*: What kind of business is theirs? What type of equipment that they sell? Who are their customers? Does their business serve low-income communities? If yes, how? How do people typically pay for their systems? (2) *The state of solar markets*: How is the solar business in their area? What is the size of the solar

[22] Shensul, S. L., Schensul, J. J., & LeCompte, M. D. (1999). *Essential Etnography Methods: Observations, interviews and questionaries*. Werner, O., & Schoepfle, G. M. (1987). Systematic fieldwork: Ethnographic analysis and data management (Vol.2). Newbury Park, CA: Sage. Introduced the concept of consultants as a cultural experts instead of key informants.

market? (3) *The future of solar markets*: From their experience, how do they expect the future of solar markets to evolve? (4) *Social value of energy*: What are the benefits for customers if they want to use solar as an energy source?



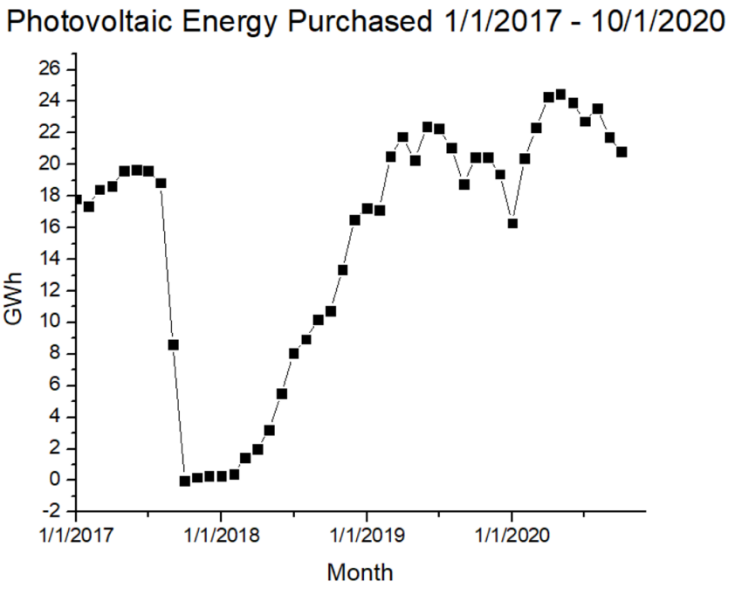


Figure 1a. Electricity sales in Puerto Rico, 2016-2018. https://www.greentechmedia.com/articles/read/puerto-ricos-electricity-sales-have-rebounded-almost

Figure 1b. Solar energy sales to PREPA, 2017-2020. https://indicadores.pr/fa_IR/dataset/generacion-consumo-costo-ingresos-y-clientes-del-sistema-electrico-de-puerto-rico

For communities and energy users, our questions explored the form and extent of solar energy engagement in their communities and their views of the future of solar energy: (1) *Description of their project*: Why did the community or individual decide to engage with solar? What kind and size of project do they have? How is the project administered? (2) *The social value of solar in the community*: What benefits come from having solar in the community? (3) *The future of solar for their communities*: How do they envision their project in the future?

V. The Trajectory of Solar Energy in Puerto Rico

Solar Before María: As described earlier, in Section II, Puerto Rico has had an active dialogue about solar energy as part of a sustainable energy future since the 2000s. That dialogue helped create the social and policy foundations for a modest but active solar industry prior to 2017, including both a number of utility-scale solar projects and a growing number of rooftop solar energy installations. According to EIA data, in July 2019, Puerto Rico had 16 solar generating stations larger than 1 MW, with 8 operating, 7 not operating but expected to return to service, and 1 not expected to return to service (Medtronic's solar facility was one of the few solar projects destroyed in the hurricane). All 16 had been built and placed in service between 2011, after new solar legislation was passed, and 2017, with a total capacity of 147.7 MW (38.2 MW operational in July 2019, 105.5 MW expected to return to service, and 4.0 MW destroyed).[23] These power plants include several operating under power purchase agreements from PREPA, Puerto Rico's electric utility, and several more operating "behind the meter" at large industrial and public water infra-

[23] https://www.eia.gov/electricity/data/eia860M/

structure facilities. Puerto Rico also had a slowly growing residential rooftop solar market, including an expanding leasing market for rooftop solar systems, that had grown to approximately 10,000 rooftop solar installations through 2017.[24] In total, pre-Maria, Puerto Rico had roughly 200 MW of utility-scale and distributed solar, with peak electricity generation on the entire grid of approximately 2.6 GW.

Post-María Developments: Hurricane María arrived in Puerto Rico on September 20, 2017. The immediate damage from Hurricane María's high winds to the electricity infrastructure was extensive, downing transmission and distribution infrastructure across the US territory as the hurricane swept across the full length of Puerto Rico from southeast to northwest (see Figure 1a). Within days it was clear that Puerto Rico's electricity grid would be out of action in many places for a long time. Much of the archipelago remained without power for at least four months, and some places didn't recover power for eleven months. By standard measures of the number of lost customer hours of service, Hurricane María measures as the largest and longest electricity outage in US history.[25] Figure 1b also shows the impact of Hurricane María on solar energy generation in Puerto Rico, which dropped precipitously and did not fully recover for fifteen months.

In most places, destruction of the scale wrought by Hurricane María would be followed almost exclusively by stories of rebuilding and reconstruction of what was lost. Puerto Rico's story of electricity reconstruction has been different, however. Even before reconstruction began to ramp up significantly, an alternative narrative emerged and rapidly captured the public imagination, offering up Puerto Rico as a place for new thinking about the future of energy. Could Puerto Rico be a place where renewable energy could create a more resilient, sustainable future in the face of the growing risks of climate change and extreme weather facing the Caribbean and other island and coastal communities?

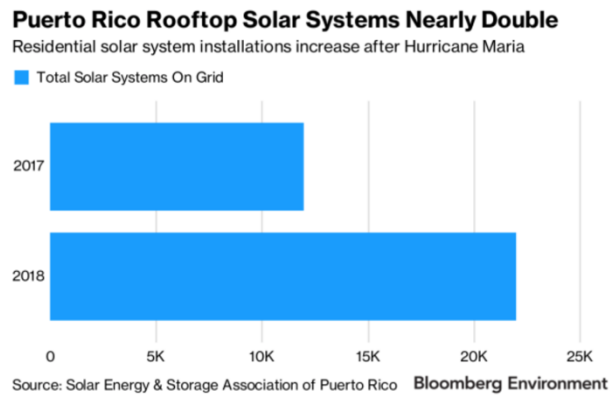


Figure 2. Increase in rooftop solar installations in Puerto Rico after Hurricane María. *https://news.bloombergenvironment.com/environment-and-energy/rooftop-solar-nearly-doubles-in-puerto-rico-one-year-after-maria*

On October 4th, 2017, just two weeks after María's landfall, Brian Kahn, a reporter for the online environmental magazine *Earther*, posted a story from San Juan under the ambitious title, "Puerto Rico has a once in a lifetime opportunity to rethink how it gets its electricity." His account began with "a rare bright spot on Puerto Rico," the story of Alina Saenz, a San Juan resident whose house was still lit at night on an island where everyone else's was dark: "A tidy row of solar panels on her roof and a battery storage system ensures that as long as there's sun, Saenz will have electricity that most of her neighbors are without. 'We only depend on the sun to shine, which happens on this island almost every day,' Saenz wrote to

[24] One company, Sunnova, was the major supplier of Puerto Rico rooftop systems pre-María (some estimates suggest 90% of Puerto Rico's systems were from Sunnova through 2017). Beginning the summer of 2017, Sunnova experienced an ongoing public controversy and lawsuits over its systems, which were grid tied with no batteries and therefore did not function during Puerto Rico's relatively frequent grid outages or after the hurricane struck. In early 2019, the Puerto Rico Energy Bureau released a report criticizing the company's disclosure practices and requiring changes to those practices.
[25] Op cit. note 5.

Earther in an email. '[Other] people have struggled trying to find diesel or gasoline, a frustrating task during this catastrophe.'" Kahn went on to interview diverse experts who suggested that solar energy might indeed provide a viable alternative to the island's historically fossil-fuel-based systems for producing electricity (Kahn 2017).

Kahn was not the only one whose reporting began to build a narrative of Puerto Rico's energy future oriented around solar energy. The same day as Kahn's story appeared, Ashleigh Popera reported in *Architect* magazine that technology companies Sunrun, Sunnova, and Tesla were already sending solar energy systems, batteries, and microgrids. Her story was tipped off by an announcement from Sunnova, on Oct. 2nd, that they were working with the Governor's office and the Trump Administration to bring additional equipment to Puerto Rico to provide emergency power (Popera 2017). On Oct. 3rd, Reuters also reported on a flower farm in central Puerto Rico that was back up and running in less than 24 hours thanks to its solar and battery systems (Bronstein and Stargardter 2017).

But it was Kahn's story that exploded into tweets heard around the world. At 6:37 am on Oct. 5th, Scott Stapf (@stapf) posted the story to his Twitter feed with the tag line: "Could @elonmusk go in and rebuild #PuertoRico's electricity system with independent solar and battery systems?" Musk replied 20 minutes later: "The Tesla team has done this for many smaller islands around the world, but there is no scalability limit, so it can be done for Puerto Rico too. Such a decision would be in the hands of the PR govt, PUC, any commercial stakeholders and, most importantly, the people of PR." Later that day, the Governor of Puerto Rico, Ricardo Rossello, responded directly to Musk: "@elonMusk Let's talk. Do you want to show the world the power and scalability of your #TeslaTechnologies? PR could be that flagship project."

Exhibit 3-1. Zone Level Distributed Generation in Service

Region	Distribution DG *MW*	Transmission DG *MW*	Total DG *MW*
ARECIBO	11.91	4	15.83
BAYAMON	23.24	7	30.56
CAGUAS	22.16	9	30.74
CAROLINA	12.27	4	16.09
MAYAGUEZ	20.15	2	21.90
PONCE ES	7.51	4	11.38
PONCE OE	12.71	4	16.71
S.JUAN	20.05	9	29.54
Total	**130.00**	**42.75**	**172.75**

Source: PREPA, Siemens

Figure 3. Geographic current distribution of rooftop generation in Puerto Rico. *http://energia.pr.gov/wp-content/uploads/2019/02/PREPA-Ex.-1.04-IRP-2019-Appendix-4-Demand-Side-Resources.pdf*

Subsequently, the story snowballed. The past two years have seen an enormous number of stories across every major national news outlet in the United States about the potential of solar energy to alter the future of Puerto Rico. The Rocky Mountain Institute, one of the world's most respected think tanks focused on the future of renewable energy, quickly ramped up a major effort in collaboration with industry stakeholders in Puerto Rico and across the Caribbean to explore strategies for using solar and wind energy to restore electricity more quickly and sustainably. That effort resulted in a report in December 2017 arguing for: "A coordinated effort by the Puerto Rico government, regulatory commission, and utility to catalogue, prioritize, and competitively procure potential renewable and distributed energy projects," that could enhance the reliability, resilience, sustainability, and cost-effectiveness of Puerto Rico's electricity future. A little over a year later, in March 2019, Puerto Rico's legislature passed innovative legislation calling for one of the nation's most aggressive renewable energy targets: 100% of Puerto Rico's electricity to be provided by renewable energy by 2050. Soon thereafter, a coalition of energy advocacy groups in Puerto Rico released a plan to achieve 100% renewable energy known as Queremos Sol.

The rise of a new solar rhetoric that puts solar energy at the center of Puerto Rico's energy future has been matched by the development of new a solar imaginary in Puerto Rico, itself. Almost everyone that we have spoken to has emphasized that solar energy is the long-term future of Puerto Rico, and a wide array of actors are increasingly active in the solar energy innovation ecosystem, including businesses, non-governmental organizations, researchers, and policy advocates at a local level. As we describe below, there is a still small and targeted solar rooftop market across the island, including both commercial and residential installations. The market almost doubled the number of solar rooftop installations in the 12 months following Hurricane María (see Figure 2) to about 24,000 systems, yet, as we detail below, the market has been on-and-off through 2019 and early 2020. According to the draft PREPA Integrated Resource Plan, released in early 2019, this rooftop generation is largely distributed across the island's northern tier of regions and amounts to roughly 130 MW of generation (see Figure 3).

There is also a growing passion among low-income communities and among advocates for them for how solar energy might be used to help relieve extraordinarily high energy costs that face Puerto Rico's poorest families and, especially, to enhance energy resilience to future hurricanes or other disasters (e.g., the recent earthquakes that have devastated southwest Puerto Rico). All over the island, philanthropic dollars are steadily putting solar energy to work, primarily to provide emergency power for critical infrastructure services in low-income communities. It is an essential need. Yet, philanthropic projects represent only a modest number of new solar systems (see Figure 4). The Clinton Foundation estimates a total of 402 projects have been announced (albeit fewer than 250 completed) as of March 2020, for a total of 13 MW. By comparison, if the 10,000 additional solar rooftop installations in 2018 reported by Bloomberg (see Figure 2) averaged a conservative 3 kW, they would have added 30 MW of distributed solar generation in 2018 alone, which roughly matches estimates of annual distributed generation growth by PREPA in its draft 2019 IRP filing. Last but not least, to our knowledge, no new utility-scale solar projects have been developed since 2017 in Puerto Rico.

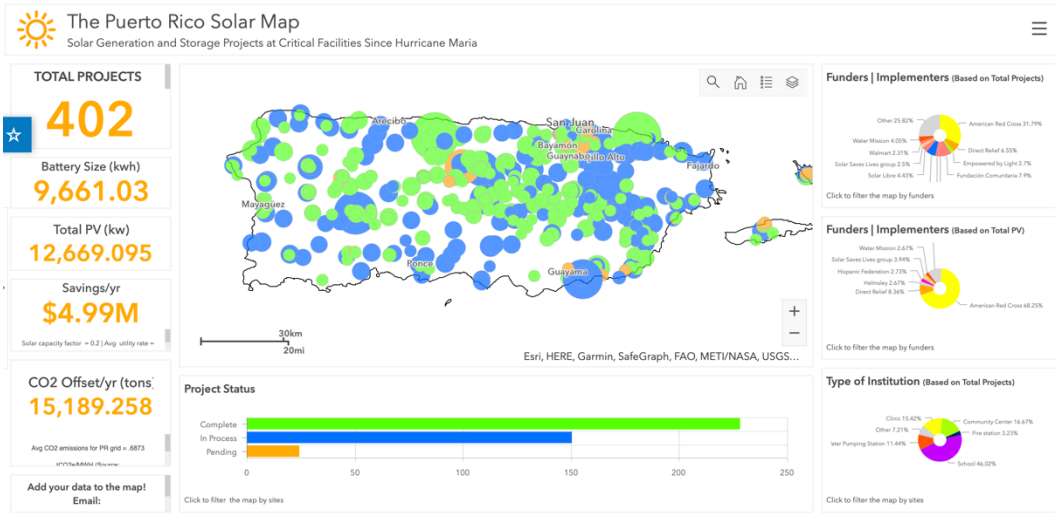


Figure 4. Philanthropic solar energy projects in Puerto Rico. Each circle represents an individual project, with the circle size proportional to project size. http://www.puertoricosolarmap.org. Data downloaded March 2020.

Overall solar developments in Puerto Rico are reflected in persistent but modest imports of solar panels into Puerto Rico. There are no domestic manufacturers of panels, and all imports travel

through the San Juan District/Port. Since 2015, monthly import data indicate periodic pulses of panel imports, driven by utility-scale projects, combined with very low but steady background import rates for rooftop markets (see Figure 5). Import data reflect the end of utility-scale solar plant construction in mid-2017. The only exception is the reconstruction of the second Fonroche Humacao 20 MW plant during mid-2018. After nearly completing construction in mid-2017, the second Fonroche Humacao plant was destroyed by María, even as its neighbor, the first Fonroche Humacao plant (also 20 MW, built in 2015) was largely untouched. Continued low-level imports reflect the small rooftop market.

Throughout the past two years, the story of solar energy in Puerto Rico has also been caught up in the larger story of Puerto Rico: the size and restructuring of the territory's debt, which includes the extensive debt of PREPA, the public utility; the challenges of public administration in the territory, including PREPA's difficulties in contracting grid reconstruction services in late 2017 that delayed widespread rebuilding for months; reports authored by numerous entities in the electricity sector, including a group of electric utilities in New York, Siemens, AES, and the US Department of Energy, all of whom have weighed in with varying visions of the future of the Puerto Rican electricity grid; the policy determination by the Commonwealth government to privatize significant portions of PREPA and the initial efforts to implement that process; a second policy determination to pursue a medium-term shift in the fuels used for electricity generation away from oil and coal toward imported natural gas and the construction of an LNG terminal to import it; decisions in Washington, DC, to delay deployment of reconstruction funds from the US government to Puerto Rico for almost two years; and finally a political scandal in the Governor's office that led to the resignation of former Governor Rosselló. These events are not the focus of our report, but they are an important background that has contributed to the struggles of the solar energy innovation ecosystem to find its footing over the past two years in a place where there is widespread agreement that it is the technology of choice for the long-term future.

Future Projections: The future of solar energy in Puerto Rico is uncertain. Few projections exist, at least that have been made public, regarding new utility-scale or distributed solar generation. As of its June 2019 draft, PREPA's proposed IRP scenario 4 is viewed by the IRP analysts as the

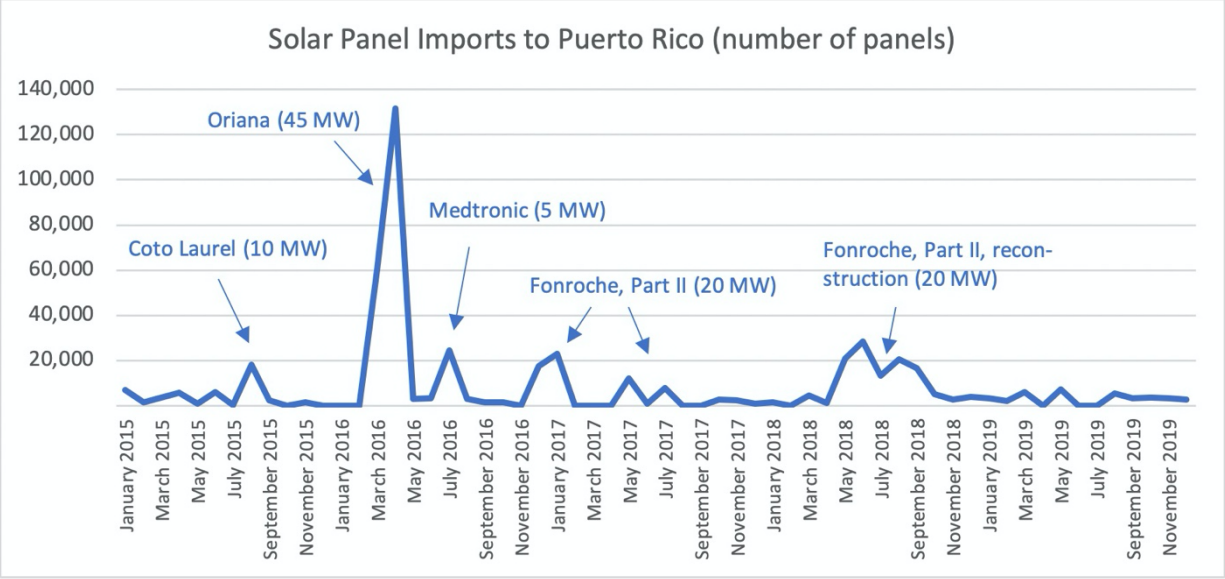


Figure 5. Solar panel imports into Puerto Rico. Data source: USA Trade Online, US Census Bureau. Power plant labels are best estimates based on power plant construction dates, size, and, where available, known panel type or size. Construction dates estimated from news reporting and satellite imagery.

least cost, most resilient strategy. This scenario, which includes significant new investments in natural gas infrastructure,[26] anticipates 1.4 GW of utility-scale solar energy additions in 2020-22, with another 1 GW by 2028.[27] The ability of Puerto Rico to meet these timelines remains uncertain, however. At the same time, the scenario anticipates 1 GW of new distributed solar generation between 2018 and 2038 (or approximately 50 MW per year, starting with 30 MW per year in 2019, growing to 60 MW per year by 2038), based on projections of the levelized cost of residential solar energy that decline by a factor of two during this time period.[28] This would amount to roughly 333W per person, or perhaps 1.5 kW per household, on average. Given the proposed new tax on solar energy generation, however, contained within the PREPA debt restructuring agreement, on the one hande, as well as continued price declines in the solar industry and the possibility of future federal disaster assistance for rooftop solar installations, on the other hand, this estimate should be considered highly uncertain and could easily be higher or lower.

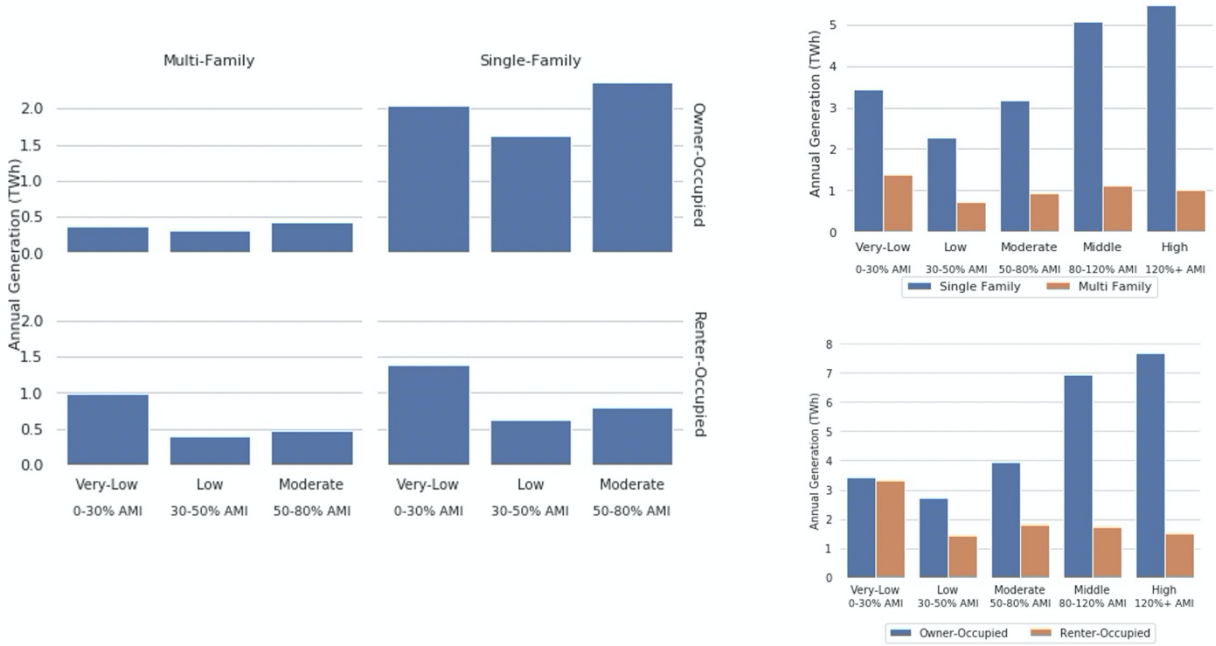


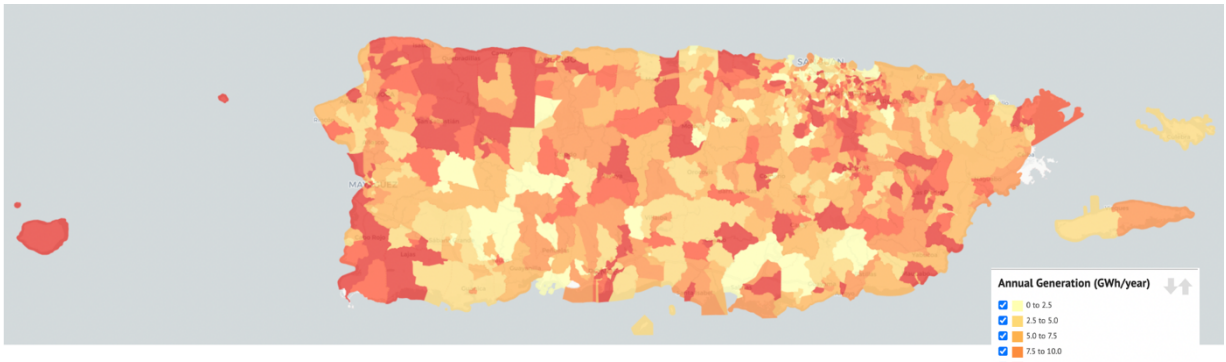
Figure 6. Estimates of annual generation potential of rooftop solar energy by building ownership (owner-occupied vs. renter-occupied) and resident income. Figure by NREL.

A recent analysis by the National Renewable Energy Laboratory as part of this project (see Appendix A for links to the NREL datasets) suggests that Puerto Rico could easily meet the PREPA IRP scenarios—and more—using rooftop solar energy. Using 3 cm LIDAR data that has recently become available, NREL computed the rooftop space available on Puerto Rico's residential buildings for solar energy deployment, based on calculations of flat rooftop areas with appropriate angles of incidence and shading. They find that all residential buildings (~1 million) in Puerto Rico

[26] Marcel Castro-Sitiriche, "Anotaciones relacionadas a la ponencia en las vistas públicas del Plan Integrado de Recursos de la Autoridad de Energía Eléctrica," Mayagüez, Puerto Rico, 22 de febrero de 2020, http://bit.ly/anotacionesAEEirp2020.

[27] See Part 8, section 8.2, exhibit 8-13, of https://aeepr.com/es-pr/QuienesSomos/Ley57/Plan%20Integrado%20de%20Recursos/IRP2019%20-%20Ex%201.00%20-%20Main%20Report%20%20REV2%2006072019.pdf.

[28] See Appendix 4, section 3, exhibit 3-10 of https://aeepr.com/es-pr/QuienesSomos/Ley57/Plan%20Integrado%20de%20Recursos/IRP2019%20-%20Ex%201.04%20-%20%20Appendix%204%20-%20Demand%20Side%20Resources.pdf.



Census tract LMI technical potential (GWh)

Figure 7a. Total rooftop solar technical potential on LMI households by census tract.

Figure 7b. Ratio of technical potential for solar energy generation on low-income buildings to aggregate low-income electricity consumption in each municipality. Figures courtesy of NREL.

are capable of generating 20.35 GW DC of solar energy potential and 24.5 TWh of total annual electricity generation.[29] Proportioning this total for those buildings inhabited by low-income households (<80% of Area Median Income), they find that low-income residential buildings (~510,000) could provide 9.84 GW and 11.87 TWh of electricity generation. For comparison, PREPA's IRP indicates that current residential electricity consumption for all households in Puerto Rico is approximately 6 TWh.[30] Figure 6 shows how this potential is distributed as a function of building ownership and resident income. Geographic analysis is presented in Figure 7a, which presents the total rooftop technical potential for low-income households for each census tract in Puerto Rico, and 7b, which illustrates that for all 78 of Puerto Rico's municipalities, the aggregate technical potential for rooftop solar energy for low-income residential buildings is more than double the electricity consumption for the households living in those buildings, and for the vast majority of municipalities, the ratio is more than triple consumption.

The potential for rooftop solar energy to meet household electricity demand, especially for low-income communities in remote areas, can also illuminate the potential benefits of providing households with minimum-sized solar rooftop systems (e.g., a 2 kW PV system). A recent analysis of

[29] While meeting this potential would require a major programmatic effort, recent experiences suggest that significant rooftop solar deployment on this scale can be accomplished very quickly. In Vietnam, for example, 9 GW of rooftop solar energy was added in 2020. Gunther, E. "Vietnam rooftop solar records major boom as more than 9GW installed in 2020," *PV Tech*, Jan. 6, 2021, https://www.pv-tech.org/vietnam-rooftop-solar-records-major-boom-as-more-than-9gw-installed-in-2020/. Downloaded Mar. 2, 2021.

[30] Op cit. note 27, exhibit 3-1.

the electricity demand of Puerto Rico households estimated the minimum size of PV system necessary to meet their needs.[31]

The results are based on Census Data[32] and energy consumption data from work by Héctor Cordero-Guzmán based on Census ACS 2017 monthly cost of electricity[33] and show (Figure 8):

- 51,000 families (3.3%) reported low levels of annual energy consumption that could be supplied by a 1 kW PV system.
- An additional 83,000 families (5.3%) have an energy consumption that needs an estimated 1.0-1.5 kW PV system.
- Together, these 134,000 families (8.6%) have annual energy consumption for which a 2 kW PV system would be too large. These families would generate an estimated daily excess of solar energy of 2.8 kWh (83k families), 4.4 kWh (43k families), and 6.4 kWh (8k families), for a daily total of 473 MWh unused energy and an annual total of 173 GWh. This excess energy could either supply energy demand growth for these families or, if supplied to the grid, provide a small income stream for these households.
- 251,000 families (16.1%) have annual electricity consumption that could be supplied by a 1.7-2.1 kW PV system.
- 385,000 families need a PV system that is 2.1 kW or smaller.
- 414,000 families need a PV system that ranges from 2.1 kW and 4.0 kW.
- A total of 799,000 (51%) families need a PV system that is 4.0 kW or smaller.
- 665,000 (42%) families could use a 2.0 kW PV system and cover from 50% to 100% of their annual energy needs while another 134,000 (8.6%) families could use a 1.0 kW PV system to cover from 77% to 100% of their annual energy needs.

Information regarding how many households could cover their energy needs with a solar system of a given size helps put into context proposals to deploy large numbers of small solar rooftop systems to support the 200,000 Puerto Rico households that spent more than 5 months without electricity after Hurricane María.[34] While such proposals would undoubtedly entail logistical challenges (although the US solar energy industry designs and installs many times this number of systems annually),[35] remote communities suffered very real logistical, economic, health, and other hardships during their survival without grid power for more than 150 days. Figure 9 shows the geographical location of the last 28,000 households re-connected to the grid, clearly indicating that remote communities in the central mountain areas face the greatest vulnerability to long term

[31] Marcel Castro-Sitiriche, "Bottom-up Grid for a Resilient Puerto Rico", Panel on Alternative Energy: Disasters as Windows of Opportunity for Alternative Energy Pathways, Resilience through Innovations in Sustainable Energy Conference 2019, November 19, 2019.
[32] Ibid.
[33] Hector R. Cordero-Guzman, "The Socio-Economic Impacts of the Puerto Rico Electric Power Authority (PREPA) Restructuring Support Agreement (RSA) on the Population of Puerto Rico," September 2019, https://ieefa.org/wp-content/uploads/2019/12/PREPA-RSA-Cordero-Guzman-UTIER-REPORT-9-10-19-FIN-ENGLISH.pdf.
[34] Marcel Castro-Sitiriche, "Household Emergency Preparedness: Decentralized Community Power for Puerto Rico," Power Policy Brief No. 1, Native Power Research Group, University of Puerto Rico Mayagüez, April, 2019. https://app.box.com/v/CHoLES
[35] See, e.g., the comments of Sergio Marxuach in https://theintercept.com/2020/02/09/puerto-rico-energy-electricity-solar-natural-gas/.

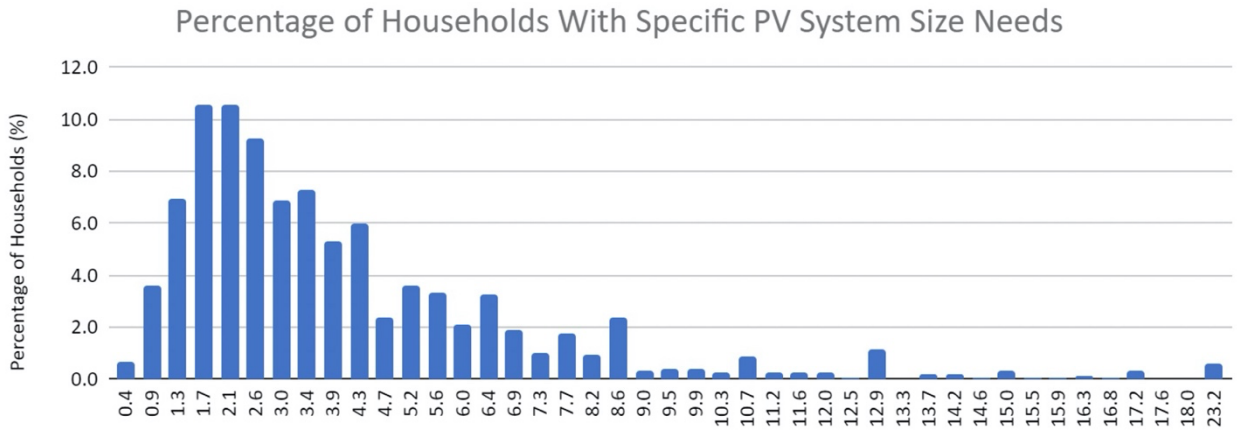


Figure 8. Estimate percentage of residential customers that need a specific solar PV system size

power outages.[36] The grid restoration efforts for households in these communities was very slow, with an average of 588 households reconnected per day in May, 258 for June, 67 for July and 17 during the first two weeks of August. It is unclear, given past and current experience, that large-

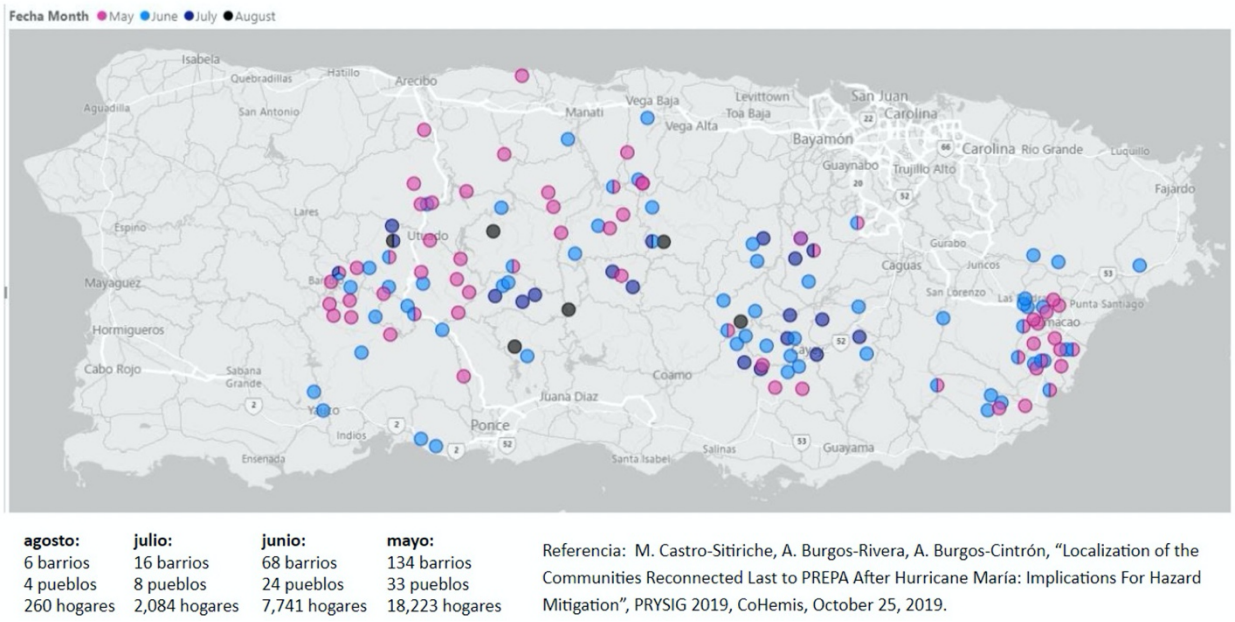


Figure 9. Location of the communities where the last 28,000 households were connected back to the grid after Hurricane María during the months of May, June, July and August of 2018.

scale, grid-based solar systems will provide the secure access to electricity that remote communities in Puerto Rico need to ensure resilience in the face of current grid instabilities and future potential disasters, due to the ongoing difficulties of maintaining and repairing the electricity distribution network serving those communities, given the current budgetary, political, and geophysical uncertainties and risks. Small rooftop systems provide alternative possible solutions to the conundrum of ensuring low-income households have access to electricity during future outages.

[36] M. Castro-Sitiriche, A. Burgos-Rivera, A. Burgos-Cintrón, "Localization of the Communities Re-connected Last to PREPA After Hurricane María: Implications For Hazard Mitigation," PRYSIG 2019, CoHemis, October 25, 2019.

The main takeaways from this analysis are that approximately half of the Puerto Rican households have energy needs that could be significantly covered (at least 50%) with PV Solar systems that are rated at 2 kW DC or smaller and that sufficient rooftop technical potential exists on low-income residential buildings to meet this need. Even though a deeper analysis using income data is not completed, ongoing work indicates that lower income households report less energy consumption, as expected. Many Puerto Rican households will face significant difficulties purchasing such systems, however, and thus innovative financial mechanisms will be crucial to enable low and middle income families to acquire small solar PV rooftop systems.

VI. The Solar Energy Innovation Ecosystem in Puerto Rico

In the rest of this report, we survey the solar energy innovation ecosystem in Puerto Rico responsible for distributed, rooftop solar energy development and installation. We borrow the concept of innovation ecosystem from the Waterloo Institute for Sustainable Energy Innovation Lab in 2017,[37] which convened an interdisciplinary mix of researchers and stakeholders to identify and assess barriers to renewable energy adoption in low-income communities around the globe. They produced a conceptual map of the stakeholders whose collective work—and flows of ideas, knowledge, data, influence, money, and equipment, as well as the rules that govern those flows—are essential to the success of renewable energy markets and projects (see Figure 10).

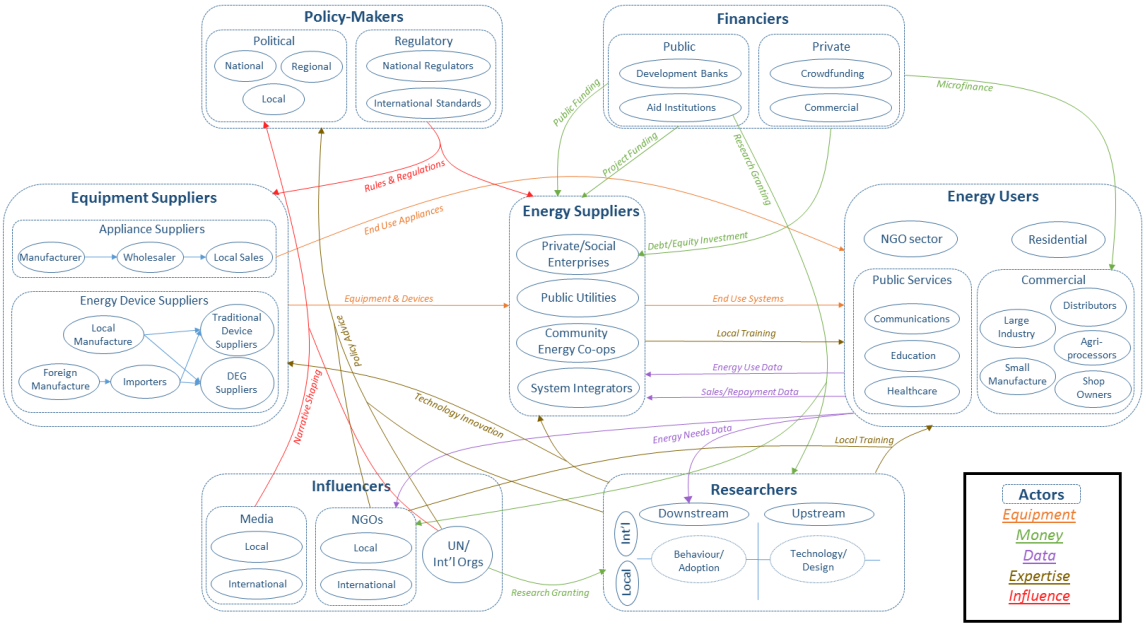


Figure 10. A generic model of a solar energy innovation ecosystem. From: *Miller et al. 2018.*

In Puerto Rico, all of these actors are present and interact in various ways:

- **Solar energy suppliers**: The principal supplier of energy is PREPA, which owns most of its own generation facilities but also purchases power from a small number of independent power producers who operate gas and oil plants. As described above, this includes 15 utility-scale solar power plants, owned by independent groups, that operate on the island,

[37] https://ae4h.org/projects/innovation_lab_current/innovation_lab_2017

for approximately 150 MW total generation and 20GWh of annual sales to PREPA. Through its purchasing decisions, PREPA plays a major role in controlling the pace of large-scale solar development. In addition, there is approximately 172 MW of distributed solar generation, split between rooftop and commercial-scale operations, which are primarily owned by households or commercial building owners. A very small number of community solar projects also exist. Since 2017, no new large-scale solar facilities have been built, while distributed solar generation has grown relatively quickly. After 2017, philanthropic donations of solar systems grew significantly, especially for critical infrastructure, reaching 13 MW.

- **Solar equipment suppliers and installers**: All solar panels and inverters are imported from off-island from a range of European, US, and Chinese suppliers. Major electrical equipment suppliers, such as Roger Electric and Warren ECM, play a key role in selling and installing solar systems, and there are also a variety of solar installation companies that range from large installers, like Maximo, Sunrun, and Melpro Group, to smaller companies, like Borintek, in Jayuya. These companies are largely located in San Juan, the northwest, and the west, but all work across Puerto Rico, and they subcontract smaller companies to do installations. Many electricians also install solar systems in their areas of work, which are purchased directly from equipment suppliers, and the number of small businesses starting up to supply emerging solar markets is growing. Do-it-yourself and informal installations of solar and batteries are growing, as are the number of companies selling batteries.
- **Solar energy users**: Puerto Rico electricity rates are high by US standards, and Puerto Rico's electricity system is also relatively unreliable by US standards, both of which encourage the purchase of distributed solar and battery systems. The high up-front capital cost of solar and/or batteries precludes many people from participating, however, and distributed solar installations have primarily occurred among wealthier residents and businesses. Many low-income individuals and communities across the island are exploring options for solar, but it remains very expensive and limited in size and scope. There is a lot of interest in cheaper options.
- **Solar financiers**: Some financing options exist for solar systems in Puerto Rico. Companies like Maximo and Sunrun offer financing for rooftop systems, but this is relatively expensive. This financing is provided primarily by US mainland banks. Local Puerto Rico cooperative banks have done little to create local financing options, although a few programs were offered in the immediate aftermath of Hurricane María, and some groups are working to try to create new opportunities. There is some possibility that financing may become available in the near future for some low-income households and other entities via the US federal government, through community block grant funding. A preliminary plan was released by the Puerto Rico housing authority, Vivienda, for public review in late 2020. A major limitation in Puerto Rico is that current US federal law, which incentivizes solar energy purchases through an income tax credit, does not help in Puerto Rico, where most people do not pay federal income taxes.
- **Solar influencers**: Puerto Rico has an active NGO community focused on both environmental protection and poverty. This community strongly supports solar energy, although the community of NGOs is divided into at least three different groups with very different priorities. Some NGOs, including The Rocky Mountain Institute, which has a strong presence on the island, the Hispanic Federation, and Fundación Borincana, are focused on the development of a strong solar industry in Puerto Rico and the transition to renewable energy, including the development of markets and policies that support solar energy busi-

nesses. A second group of NGOs, exemplified by Queremos Sol, an alliance of solar activist organizations, is focused on strengthening distributed solar energy as an option for Puerto Ricans to satisfy their own energy needs. Finally, a third group of NGOs is active in working with low-income communities to develop solar energy projects, including Casa Pueblo, AMANESER 2025, Fundación Communitaria, and many others.

- **Solar researchers**: Many researchers across Puerto Rico are active in environmental and energy research, networked by the National Institute for Energy and Island Sustainability (INESI). Of particular importance is the Electrical Engineering Department at the University of Puerto Rico-Mayaguez, which has historically played a significant role in power systems research, research on the renewable energy potential of Puerto Rico, and research on solar energy and microgrids, including in collaboration with a number of low-income communities. In the immediate aftermath of Hurricane María, many US mainland universities also sent solar energy students and researchers to Puerto Rico, many of which continue to work in collaboration with communities on solar and related projects.
- **Solar policy**: Solar policy is largely set by a trio of key policy institutions: the Puerto Rico legislature, which establishes energy law; the Puerto Rico Energy Bureau, which is the electricity regulator; and PREPA. The Puerto Rico courts also adjudicate energy law disputes. See details below regarding key developments in Puerto Rico solar energy policy.

In the rest of this section, we decribe in more detail the Puerto Rico solar energy innovation ecosystem. In subsection A, below, we describe the results of our interviews with participants in this ecosystem involved in solar energy markets, including the equipment and energy suppliers and financiers. In subsection B, we describe the results of our interviews with participants who influence solar energy markets in Puerto Rico through policy, advocacy, and research. Finally, in subsection C, we discuss the place of low-income communities within this ecosystem.

A. Solar Businesses and Markets in Puerto Rico

This section describes, characterizes, and illustrates the dynamics of solar energy markets in Puerto Rico. Through semi-structured interviews conducted with diverse business stakeholders across Puerto Rico's solar energy markets, we gathered stories and information to create an understanding that reflects how diverse elements of the business ecosystem are interrelated and also how they function across different contexts. These elements include: the geography of solar energy businesses and installations; available financing options; primary challenges in growing solar markets; opportunities for future growth; and stories of market change.

Our inquiry guided us through an evolution of Puerto Rico's solar energy markets that was frequently characterized by our informants as "before and after Hurricane María." As described above, before María, total household rooftop installations amounted to about 10,000 systems. In the immediate aftermath of the hurricane, all of the businesses interviewed experienced a very rapid rise in sales that doubled or tripled their experience prior to María. Data suggest another 10,000+ systems were installed in 2018 alone. As one informant noted: "After the 2017 hurricane, the market rose 300 percent. We could not sell more because you could not find more materials." Even with this rapid growth, however, only a small fraction of homes in Puerto Rico that could potentially do so have been able to add solar. As the same informant observed to us: "In Puerto Rico there are more than 750,000 homes that are well suited for solar systems, only 14,000 are installed through net metering, 5000 more additional with small systems."

The rapid acceleration of solar adoption was accompanied by a significant shift in narrative and valuation in Puerto Rico markets. Before 2017, the focus of solar adoption was on reducing energy bills. During this period, the solar energy market in Puerto Rico grew slowly. Many of the solar energy businesses that we interviewed were established well before Hurricane María. A solar business established in the market in 2009 informed us that, at that time: "There were very few people selling or adopting solar … A lot of people didn't know how solar works, and it was very challenging to sell." The implementation of Act 114 (2007) (see below) allowed the interconnection of solar to the electricity grid for customers who installed solar electric equipment or any other source of renewable energy capable of producing electric energy; granted credits in electricity bills for the electricity generated by this equipment; and compensated for the unused excess energy generated. In the experience of our interviewees, this combination allowed electricity customers to reduce their energy bills and expenses by combining upgrades of household appliances to increase energy efficiency with the adoption of solar and net metering. According to one informant, using this approach, an individual could reduce her or his energy bill to four dollars monthly. During this time, typical systems installed were 2-10kW in size.

The rationale for adopting solar energy changed significantly after Hurricane María, however, and as a result, the kinds of systems sold changed, too. Instead of focusing on reducing their energy bills, solar customers post-2017 focus instead on resilience and value the ability to keep power flowing in the case of (relatively frequent) grid outages in Puerto Rico. One of the trends that best illustrates this before-after characterization is the incorporation of battery storage capacity as part of installed solar photovoltaic systems after the hurricane. Before María, installed rooftop solar systems were almost entirely grid-tied and did not include batteries. After María, systems with batteries became the overwhelming choice of customers. Our interviewees broadly agreed with the observation of one informant: "Before the hurricane, approximately 95 percent of the systems were with no batteries. It was very rare to see a solar system with batteries, because it almost doubles the price of the system." As another informant noted, however: "Everything changed after the hurricane. Now it is different. Now nobody wants a solar system without batteries. Everyone wants batteries. From the hurricane up to date, we have only installed two systems without batteries and a lot of systems with batteries."

Another aspect of this before-after trend has been the emergence of the idea of an "emergency photovoltaic system." These very small systems of PV plus batteries, minimized in size to reduce the costs, reflect a much higher valuation of and expressed user needs for energy security, resilience, physical and mental health, and justice to the most vulnerable sectors of the population. As observed by one installer, whose business mostly covers the southwest region of the main island: "There is a lot of necessity. In the case of solar systems, people have seen this necessity, due to any bad weather or the current economic issue we are living today, where the cost of electricity have risen, so the people look for options." He and many others talked about the emergent idea of the "emergency solar energy system with storage" that came to be the most common system customers wanted. The "emergency solar energy system with storage" is understood by customers and businesses to be a small system (1-2 kW, max) with enough capacity to run a refrigerator, a few lights, and usually a fan that are at least essential for survival and can be considered to be critical needs. As one informant noted, in response to the question "What are customers looking for when they visit your business?": "Usually, customers are looking for a solution that they can use in case of an emergency, like a hurricane or any other disaster like that, so we have small systems that are more affordable and just for very critical loads."

Part of the reason that small emergency systems are now popular is the financial challenge that confronts many Puerto Ricans who'd like to go solar. Our interviewees all agreed that this was one of the main challenges for the solar industry in Puerto Rico: "People may like or may want a

solar system, but if they don't have a steady work, they could not secure financing, so they could not invest in solar." Especially in low-income communities, households purchase systems by financing through banks. As the president of a solar business explained, at the end of the day, financing stops projects: "The limit is if the person has a good credit score or cash, and the people that keep suffering are the ones with low economic level. … We have some financing options in Puerto Rico, but they are limited. [Our local financing options] are not very good compared to those in the United States [the mainland]. But we have some financing that [customers] use, or they have the capital to pay for it or at least half maybe."

Some businesses noted, for example, that they had not seen a cash sale for the last 8 months. They explained that the available financing is a 5-year loan via US institutions, a 10- or 12-year loan with local cooperatives and other banks, or a 25-year loan with Sunnova. As one informant noted: "If [the customer agrees to] a 25-year financing contract, it is because they are sure that they are staying on the island…It is regrettable that in this island the financing institutions from outside Puerto Rico offer more attractive finance options. Seventy percent of my sales are through Sunnova because the [minimum] financing score is 650 [which is lower than local Puerto Rico banks and cooperatives offer]. This is money that could be staying in the local economy, but it goes straight to the US." Many of our informants expressed concern that the economic crisis and the lack jobs in Puerto Rico are preventing solar markets from growing more rapidly. They noted, for example, that each time the government announces that people are going to lose their jobs or that recovery funds are not going to come, sales of solar systems drop. Hidden along these lines is the growing concern across Puerto Rico that many people leaving the island are in the workforce and of a working age, while the ones staying are an aging population. As a result, the number of people able to secure financing for solar may be falling over time.

Another challenge for solar energy markets stems from Puerto Rico's housing infrastructure. According to our informants, many houses have old zinc roofs with poor wood support. In the last census estimate, 44.9% of Puerto Rico's population lives under the poverty line. This contributes to poor housing maintenance. Most of the installers we interviewed mentioned that in many cases additional investment is required to strengthen the roof in these houses, further increasing the cost of rooftop solar projects.

Finally, our interviewees highlighted that some of the challenges of growing solar markets in Puerto Rico are on the business and policy side. Some of the challenges identified included a shortage of trained solar installers and clear rules about who is allowed to install systems, the need to reduce the costs of permitting and engineering studies to lower overall system cost, and the need to identify and grow opportunities for leveraging climate mitigation benefits to help fund solar projects.

Despite these and other challenges that we are analyzing with the data from the interviews, our interviewees also identified many benefits to the adoption of solar energy in Puerto Rico. Among the benefits that our informants identified for the archipelago are greater control over electricity expenditures, increases in food security, increases in overall energy resilience, especially with batteries, and opportunities for boosting other sectors such as food production in the island and other agricultural activities. Additional benefits associated with solar energy included the opportunity to develop a solar industry in Puerto Rico and to create new jobs opportunities and collaboration partnerships along with the University of Puerto Rico students. One specifically mentioned wanting to create pathways for young engineering graduates to have professional futures in Puerto Rico. And, of course, many mentioned the importance of reducing climate change and air, water, and soil pollution from the burning of carbon-based fuels.

The following are examples extracted from the interviews that highlight some of the benefits that solar energy can provide for the archipelago and especially for the people. One informant noted: "You have control over your monthly bill, so now you have control on how much you are going to spend on electricity, and before solar you don't have control, only on your consumption. But you cannot control how much you are going to spend on the electric bill, you just wait for that." Another informant noted: "You have control with your food, that it doesn't get lost because you don't have a functioning fridge. You have control with your lights. You can continue living in your place during any emergency. In every year, we are at the mercy of hurricanes. We expect hurricane every year, but we don't get hurricanes every year, but you don't know when you are going to need some batteries in your house."

Interviewees also identified opportunities for solar to aid small businesses. One business told us a story, for example, of how they are working collaboratively with farmers on the island: "We work with a lot with farmers because we offer them a convenient package. For example, a typical farmer, what we do is to offer them three basic services: we offer to do the design of the system, we offer to [file the paperwork for them] to an appropriate agency (it can be rural development or the department of agriculture), so we develop the proposal to get the money and to help them find the money. And obviously the installation and the design of the system. … We worked, for example, with a dairy farm in the Morovis area where we were able to get for the guy 70% of the cost so he put only 25% and when we did the return of investment estimate it was about 4 years that he would have received his investment back and that is excellent."

One last interesting observation from our interviews about the survival of solar systems during Hurricane María. We found general agreement among solar businesses that rooftop solar systems largely survived the hurricane unscathed. For example, one business informant observed: "Very few systems [were damaged]. I would say less than 5 percent of systems that we installed [were impacted], and that was mostly because of projectiles damaging some modules. So, none of the systems was fully damaged, but we had couple of solar panels [broken], and we just replaced them, and they are fully back [functioning]." Another solar energy business observed that fewer than 10% of the rooftop photovoltaic systems they had installed were damaged during the hurricane. The majority of those damaged were located in the region where María made landfall: "Many of the systems that were lost during the storm hadn't finished being installed yet. We have 1800 systems installed, and only around 130 were damaged. The fully installed systems in Humacao, they all were lost." Another solar energy business shared: "We are happy to tell that after María we didn't lose a single panel, including two systems that we had in Culebra Island, and that island received basically the full force of the two hurricanes Irma and María. By that time, we had two systems there, and two months after the hurricane we received a call from one customer, and I thought that it was to tell us that the panels were already in Saint Thomas Island, but the call was to thank us because they were there and had electricity. It is an interesting construction they have there, it is an eco-house, so they collect the rain water with the roof, and they have a well in the middle of the house. Actually, the walls of the living room are the water reservoir, and they had the PV system so they were living the good life there in Culebra after the hurricane, and that was good news for us because it proves that our design was at least a good one." These observations are consistent with an informal visual survey that we undertook of utility-scale solar fields in Puerto Rico during Hurricane María using Google Earth imagery. That survey suggested most fields sustained only minor damage to the panels, although two were destroyed entirely.

B. Solar Policy and Advocacy in Puerto Rico

The recent development of solar energy markets in Puerto Rico has occurred within the context of an evolving electricity sector and policy landscape. Electricity in Puerto Rico is provided predominantly by the Puerto Rico Electric Power Utility (PREPA). PREPA is a public utility and government agency that produces 80% of the generation, transmits, distributes and sells energy, with the mission to provide efficient, safe, economical, and reliable energy to their consumers (AEE, 2019; EIA, 2019). Until 2014, PREPA was governed by the decisions of its leadership, who were appointed by the Governor, and those of the Puerto Rico legislature. Act No. 57-2014, created the "Oficina Independiente de Protección al Consumidor" (OIPC) and established the Puerto Rico Energy Commission (PREC) as an independent regulatory commission. Subsequently, PREC was renamed the PR Energy Bureau (PREB) and its regulatory powers were altered.

PREPA faces a number of ongoing challenges. PREPA has been operating in bankruptcy since 2017, with approximately $8 billion in total debt and, at various times, a shortfall in payments for electricity, which are already among the most expensive in the United States, at over 20 cents/kWh, versus the costs of running the system. PREPA's infrastructure was also already in poor shape and in need of significant upgrades before María, and, even as it restored power, the post-hurricane reconstruction effort in 2017-18 did little to change the need for major investments in new electricity infrastructure to ensure reliable and efficient operation and to enhance resilience to future disasters.

Several discussions are underway to attempt to chart a future for PREPA and for electricity in Puerto Rico that provide a context for the development of solar energy.

- One discussion focuses on a proposed deal with financial institutions that hold PREPA's debt to restructure it at a lower level in exchange for new electricity surcharges for Puerto Rican electricity customers to pay off the remaining debt. To date, the proposed agreement between PREPA and the Financial Oversight and Management Board has not been approved by either Puerto Rico officials or the court overseeing bankruptcy.
- Another discussion is the effort, begun by the government via Act 120 (2018), to privatize portions of PREPA's infrastructure, including, initially, some of its generating assets, to pay off debt, and to put PREPA on stronger financial footing. This effort is being overseen by the Puerto Rico Public-Private Partnerships Authority. The first step in the privatization process was a controversial 15-year contract to manage grid operations granted to LUMA.
- A third discussion is focused on the development of an Integrated Resource Plan, developed in conjunction with Siemens, that would lay the groundwork for developing an upgraded, more resilient electricity system going forward. PREPA submitted a draft IRP in February 2019 and an updated revision in June 2019. The PREB approved the IRP in August 2020 but rejected PREPA's intended switch to natural gas and instead directed PREPA to invest heavily in new solar energy generation.

All of these discussions are intertwined, remain in flux, are politically contested, and have created an environment of high uncertainty regarding the future vision for electricity in Puerto Rico. In this context, it is not surprising that solar energy policy also remains in flux, with developments both significantly advancing and threatening to curtail solar energy innovation and markets.

Policy for solar energy in general and for rooftop solar energy more specifically has developed in Puerto Rico over the past three decades. The overall timeline of those developments since the

early 1990s is presented in Figure 11 (located at the end of the report). Of these policies, the most important for rooftop solar energy and community solar initiatives have been:

- Act 325 (2004) established tax exemptions for the purchase of solar and renewable energy equipment.
- Act 114 (2007) established a net metering (or "net measurement") policy for Puerto Rico that allowed solar owners to sell electricity to PREPA.
- Act 133 (2016) established a policy to diversify Puerto Rico's electricity system via renewable energy, including defining community solar and allowing for the possibility of developing community solar energy efforts.
- Act 17 (2019) required that Puerto Rico achieve a 40% renewable energy portfolio standard by 2025 and a 100% target for 2050. It also directs the PREC to develop frameworks for enabling the integration of microgrids, community solar projects, electricity cooperatives, and other distributed renewable energy strategies into the electricity system.
- Act 60 (2019) reiterated that all subsidies and benefits for solar energy remain in place (Act 60 doesn't appear in Figure 11, as it was passed after the timeline was created).

While the earlier legislative policies left solar decision-making to PREPA, more recent policies, including Act 133 (2016) and Act 17 (2019), have instead put the PREC in charge of developing plans for integrating renewable energy into the electricity system. PREC has been moving forward with this agenda and has increasingly become an important focus of attention for solar policy in Puerto Rico. In May 2018, for example, they issued preliminary rules for microgrids to be developed and integrated into the overall grid architecture.

For households considering rooftop solar energy in Puerto Rico, current policies and rules allow them to take advantage of net metering credits to their bill. As noted above, net metering was established in Puerto Rico with Law 114 of 2007. Systems must be installed by certified electrical professionals according to rules in Regulation 8915 and the relevant documentation provided to PREPA. Limits are provided on the maximum size of systems interconnected to the grid. Credits accumulate on the owner's account to offset electricity consumed and, if in excess at the end of the year, customers are paid $0.10/kWh (a fraction of this payment is reserved by PREPA to help cover the costs of electricity for schools). In 2010, Puerto Rico also established a 30% tax credit, up to $1500, toward the purchase of solar energy systems, but this credit is no longer active. Because most Puerto Rico households do not pay US federal income tax, they are also not eligible for the 30% US federal tax credit.

At the same time, while distributed solar energy retains a reasonably strong place in Puerto Rico's policy landscape, uncertainties remain regarding where the future will go. Rooftop and community solar energy policies have therefore continued to develop, and, as discussed above, in the most recent draft of the PREPA IRP from June 2019, PREPA anticipates a significant amount of distributed solar generation to continue to develop over the next 20 years, up to 1.2 GW, which would represent 10% of total supply in 2038. Current issues under discussion among policymakers could also have a significant impact on rooftop solar development. For example, a tax on solar energy is currently being discussed as part of the bond deal that would require people who self-generate electricity at home using solar panels to pay a tax on that energy to help pay off PREPA's debt. If implemented, such a tax would make solar energy much less affordable for households. Another discussion involves how to spend (long delayed) federal reconstruction money to support community resilience. One proposal actively under discussion would use some of the community block

grants to allow low-income households to purchase emergency solar systems. If approved, this could dramatically increase the number of such systems in Puerto Rico.

C. Community Innovation in Solar Energy in Puerto Rico

The ultimate goal of this project is to identify strategies for using solar energy to benefit low-income communities and reverse the energy-poverty nexus. As part of the first-year research effort, therefore, we began to explore how low-income communities across the archipelago fit into the solar energy innovation ecosystem in Puerto Rico. The short answer encompasses two parts. On the one hand, low-income communities in Puerto Rico have really struggled to find ways to make solar markets and policy work for them, as they have elsewhere in the country and around the globe. On the other hand, low-income communities in Puerto Rico have been very active, post-María, in pursuing community-based efforts to advance solar energy access for community members. As we will illustrate in more detail below, one of the interesting features of these efforts is just how independent and distinct these movements have been.

Historically, rooftop solar energy systems were an expensive technology that principally benefited wealthy households (Miller et al. 2015). In recent years, of course, solar prices have dropped precipitously. Still, however, the high up-front investment needed to invest in solar systems, the high credit requirements for loans, the reduced levels of homeownership in low-income communities, and other barriers have made it difficult for low-income communities to take advantage of solar energy. In a few states, solar policies have explicitly sought to counter these barriers with programs designed especially for low-income communities, such as California's Single-Family Affordable Solar Homes and Multi-Family Affordable Solar Housing programs and Colorado's program for solar gardens and other low-income solar projects.[38] Puerto Rico does not have such a policy, however, and these programs have not yet demonstrated strong track records of success in growing solar deployments that benefit low-income households and communities.

In principle, low-income communities in Puerto Rico have the opportunity to participate in many of the policies that support solar energy development in Puerto Rico, including incentive programs (Act 83, 2010), net metering (Act 114, 2007), tax exemptions (Act 325, 2004), and community solar projects, microgrids, electricity cooperatives, and other possibilities (Act 133, 2016). In practice, low-income communities have struggled to meet the requirements set by these policies to secure benefits. Low-income communities in Puerto Rico often struggle not only with low income levels but also with high levels of unemployment, high proportions of older populations living on fixed incomes, poor housing infrastructure, outmigration, and other social and economic challenges that make access to solar energy problematic. Together, these combinations of policy standards and diverse facets of poverty have contributed to limiting access by these communities to the financial resources for solar projects. More recently, the rise of possible taxes on distributed solar generation in order to help secure the financial resources to repay PREPA's debt has raised considerable concerns among low-income communities, as well, as an additional barrier that would raise the cost of solar projects supporting low-income communities.

Low-income communities have also struggled to get their voices heard in the policy process and in solar markets. Currently, communities are not well represented in the governmental apparatus. If a community from rural Puerto Rico wants to participate in a public hearing, for example, it can take them more than a week to organize and reach the metropolitan area to participate. That is one of the reasons that groups like Casa Pueblo, Earth Justice, El Puente, Emerge Puerto Rico,

[38] https://www.lowincomesolar.org

Environmental Defend Fund, Rocky Mountain Institute, Hispanic Federation, Fundación Comunitaria, CAMBIO, and Queremos Sol have sought to encourage policy change toward renewable energy including the low-income communities. Queremos Sol, for instance, is an initiative that proposes self-sufficiency and sustainability for Puerto Rico based on the use of solar energy. The initiative advocates for local ownership, economic progress, and inclusive structures and processes. The proposal aims to create policy change in the energy sector through an energy vision adopted by a previous initiative, the Puerto Rico Energy Dialogue Roundtable, in support of communities that are prosperous, just, democratic, sustainable, and happy.[39] The proposal calls for clear public policy, ending measures that penalize communities, investing in development of smart grid technologies, allocating funding to and legal support for local ownership, providing mechanisms to facilitate access to solar energy for low-income communities and include solar systems in mortgages, training personnel to interconnect solar systems with the grid, and developing a regenerative economy through endogenous energy production (Queremos Sol, 2019).

Despite these difficulties, low-income communities across the island have been increasingly active in pursuing solar energy as a solution to their energy security and energy resilience needs. Communities in Puerto Rico are committed to and excited about solar energy, especially among those communities that were last to reconnect to the grid after the destruction wrought by Hurricanes Irma and María. Many of these communities spent eleven months without power and anticipate similar outages (and similar delays in reconnection compared to other parts of the archipelago) in future disasters. Given the absence of coordinated Puerto Rico-wide policies and initiatives, however, communities have largely been forced to identify their own resources, advisors, and strategies in these efforts. Especially immediately after the hurricane, some solar businesses and local financial institutions stepped in with specific programs targeted at low-income communities that matched special loan programs with low-cost emergency solar systems. These programs were only partially successful, and it has been hard to maintain interest in them among businesses and financial institutions—and to some degree also among communities as the power has come back on.

What has emerged, therefore, among those low-income communities who are engaging with solar, is a wide variety of different types of solar projects, with different levels of coordination, different types of governance, and different types of solar solutions. These projects include solar energy cooperatives, solar energy initiatives with local business and philanthropic groups, solar energy community corporations, exchange programs with local communities' organizations, self-installation programs, and many more. These projects are happening all over the island, with a concentration in the communities in the mountainous regions at the center of the main island. As we use the term here, a community could be a small neighborhood, a street, a church, a downtown area, a local resource management organization, or others, and can have many forms of organizations while engaging with solar energy. Here we offer a few examples of some of the community-based projects, to illustrate some of the diversity that we have observed:

Utuado: COSSAO is a community-based project located in Utuado. The organization of the project focuses on the intersection of energy and community services. Initially, in the absence of health services during the hurricane aftermath, a local clinic was established in the community employing local resources. In collaboration with a local solar energy business, as well as philanthropic sponsors, the electricity needed to run the clinic's operations is powered by a rooftop solar energy system with battery storage. The project has subsequently grown to include a school and

[39] Mesa de Dialogo del Sistema Electrico de Puerto Rico. (2009). *Plan Estratégico para Promover la Sostenibilidad del Sistema Electrico de Puerto Rico.*

a radio station, both powered by solar energy, to provide multiple community services to this remote community. The project is now considering ways that it might organize solar systems throughout nearby low-income neighborhoods as back-up systems and energy bill reducing opportunities.

Veguita Zama: Located in Jayuya, the community of Veguita Zamas has developed a grassroots organization to advance solar energy for sustainability and resilience. They collaborate with an organization called AMANESER 2025 to equip the community with the organizational resources and material resources to improve their resiliency. Their bottom up initiative has allowed them to install small emergency solar systems with batteries in approximately 15% of the households in their community. To support their efforts, they received a modest seed grant that allowed them to purchase the first few systems. As those households paid them back for these systems, they have been able to cycle in additional systems and households. To save money, a handful of community members have learned to do the installations for the initiative.

Corcovada: The Corcovada community is located in Aguada. The community has been well organized for more than 50 years around water issues, with a self-managed community aqueduct that provides water for households and businesses. Currently, the aqueduct uses a photovoltaic array in combination with batteries to power the water pump and operate their community water system. Savings from powering the community water system operations with solar are being reinvested in other facilities in the community like a gym focused on cardiovascular equipment and a community center that can be rented out for events. They are now considering different strategies that might enable them to move towards their vision of powering each house in their community with solar energy systems.

Toro Negro: The Toro Negro Community is located in Ciales Puerto. The initiative is a community solar project that constitutes the first cooperative microgrid in Puerto Rico. The project has been developed in collaboration with the Fundación Communitaria (FCPR), which helps fund community projects, and SOMOS solar, a nonprofit organization in Puerto Rico. With their support, the local community was able to build a microgrid composed of 28 households. In the aftermath of Hurricane María, the Toro Negro community experienced a power outage of about 8 months; to alleviate those problems, FCPR and SOMOS solar donated solar energy technology for the community microgrid. However, the community's goals were deeper than having access to energy, they also wanted to be able to reduce their dependence on PREPA and the larger Puerto Rico grid and take control of the microgrid and the revenues it generates.[40] The Toro Negro community is in charge of maintenance and operations for the microgrid, and FCPR is providing the legal and technological advice to make this community solar project possible.[41]

Adjuntas: In Downtown Adjuntas, Casa Pueblo and the local business community are generating a "Red Comunitaria de Generación, Almacenaje y Distribución de Energía Solar" (a community network for the generation, storage, and distribution of energy) that will provide energy security to the town of Adjuntas. The project was made possible by contributions from the Hannold foundation and Rivan company that provided 600 solar panels and batteries for the project. The goal of the project is to use a cooperative model to allow businesses in Adjuntas to reduce their energy

[40] Nieves, Ramon L. "The Community Effort to Bounce Back from Puerto Rico's Eight-Month Blackout." *The Hill*, 30 Sept. 2018, https://thehill.com/opinion/energy-environment/409135-the-community-effort-to-bounce-back-from-puerto-ricos-eight-month.
[41] Primera Hora. "Familias En Ciales Toman La Energía En Sus Manos." *Primera Hora*, 20 June 2018, https://www.primerahora.com/noticias/puerto-rico/notas/familias-en-ciales-toman-la-energia-en-sus-manos/.

consumption and their fixed costs. The initial phase of this project will target 15 businesses in downtown Adjuntas to transition to solar energy. The model then envisions that the businesses will leverage the energy savings from the solar energy systems to create a fund to support installation of future solar systems for low-income households that live in Adjuntas near Downtown.[42]

Conclusions

Puerto Rico has faced a stark energy environment, post-Maria. The destruction of Puerto Rico's electricity grid, reconstruction that focused on building back the pre-existing system, and the relatively conservative approach to energy system decision-making and planning from the government and PREPA have led to modest opportunities and a challenging environment for new solar energy development in the short term. Major barriers to the future of solar energy persist, including, e.g., high uncertainty about energy policy surrounding the future of PREPA, the electricity grid, and existing electrical generators; high levels of unemployment, a weak economy, and high levels of public sector debt; relatively low incomes across the Puerto Rican population; demographics increasingly concentrated among the elderly as younger Puerto Ricans continue to migrate to the rest of the US for jobs; and financial barriers that limit opportunities for investing in solar energy.

By contrast, reflecting a potentially more robust face of energy democracy in Puerto Rico, solar energy has become more visible, more popular, and more central to the public imagination of longer-term energy futures, both at the household and community level and, more broadly, for the archipelago as a whole, especially as captured by new legislation calling for 100% renewable energy by 2050. Solar energy is now viewed as a key contributor to improved resilience, lower energy costs, and improved environmental and health outcomes.

The solar energy innovation ecosystem in Puerto Rico has responded positively to the difficulties posed by the hurricane season of 2017, the reconstruction of Puerto Rico's electricity grid, and the recent earthquakes in the south for Puerto Rico's electricity grids. The ecosystem has grown and, especially, provided diversified offerings to respond to newly identified and expressed concerns about energy resilience and security. This includes new solar policies, including legislation requiring 100% carbon neutrality and intermediate renewable portfolio standards, as well as new and expanded solar markets and products, e.g., small emergency solar systems with batteries.

Even in the face of the challenges described above, solar is projected to do reasonably well going forward in Puerto Rico, at least as reflected in the draft PREPA integrated resource planning preferred scenario aiming to meet the 60% RPS set by the legislature by 2040, with roughly 3.0 GW of new solar generation, including 1.2 GW of customer-owned solar generation and 1.6 GW of battery electric storage, compared to new capacity additions of 2.0 GW of new natural gas.[43] Not surprisingly, many solar advocates would like to see solar go faster and fewer new investments in natural gas infrastructure.

[42] Almodovar, José. "Adjuntas Será El Primer Pueblo Solar De Puerto Rico." *La Perla Del Sur*, 24 Apr. 2019, https://www.periodicolaperla.com/adjuntas-sera-el-primer-pueblo-solar-de-puerto-rico/.

[43] See exhibits 8-12 and 8-13 in https://aeepr.com/es-pr/QuienesSomos/Ley57/Plan%20Integrado%20de%20Recursos/IRP2019%20-%20Ex%201.00%20-%20Main%20Report%20%20REV2%2006072019.pdf

Within the current policy and market frameworks, however, that comprise the Puerto Rico solar energy innovation ecosystem, it is unlikely that low-income communities will be significant beneficiaries of solar energy development. Too many barriers are stacked against them. They may make continued slow progress, but it will take new approaches either to markets or policy or both to transform solar energy into a significant tool for advancing low-income community well-being and resilience and reducing poverty.

New efforts to support distributed solar energy solutions would have strong benefits. In the wake of Hurricane María and the resulting long-duration energy outages suffered by many communities, *there is now a very high level of interest in solar energy* among policymakers, businesses, and communities across Puerto Rico. To put it succinctly, solar energy has captured the imagination of the people of Puerto Rico. Evidence for this can be found in (a) the prevalence of growing solar energy markets and businesses providing commercial and residential installations, (b) new policies that establish renewable portfolio standards of 100% by 2050, and (c) a growing number of community initiatives organized to bring solar energy to local inhabitants, among other indicators.

The societal enthusiasm for solar energy in Puerto Rico is driven by two primary considerations. *The most widely cited reason for adopting solar energy is, across incomes and stakeholder types, to create a more resilient and secure future energy supply that can supplement grid-based electricity during and after future disasters*. There is widespread sentiment that the Puerto Rico electricity grid is extremely vulnerable to environmental disruption and technological failures. This leads to a particular emphasis on systems capable of functioning as backup power supplies during grid outages and, therefore, to supplementing solar with batteries. It has also contributed to a cyclical pattern in markets, in which interests in solar energy spikes during electricity outages, when hurricanes are present, or during other disasters, e.g., the recent series of earthquakes in southern Puerto Rico. Many respondents to our interviews have also expressed the idea that Puerto Rico should rely on its locally available solar resources to replace carbon-based energy imports in the future.

Despite the high social enthusiasm for solar energy in Puerto Rico, the pace of solar installations in Puerto Rico has not kept pace. Solar markets and policy are active in Puerto Rico, but they are not translating into rapid adoption of solar energy. While data on solar installations is sparse for Puerto Rico, indications are that rooftop installations in 2018 averaged about 1000 per month but dropped off after that. Most solar businesses reported up and down markets over the past 24 months, and sales have not dramatically increased from pre-hurricane levels, which had seen about 12,000 total rooftop installations in the decade leading up to 2017. Data on solar panel imports do not indicate growth but rather continued low levels of adoption. Solar energy remains expensive for many households, especially given the low average household income (relative to the US as a whole), high unemployment due to the economic impacts of the hurricane and structural austerity programs imposed on Puerto Rico by the Congressional fiscal oversight board (PROMESA) in an attempt to address unsustainable debt levels, and the overall costs of household recovery from hurricane damage. Federal assistance funds have been slow to arrive, restricting opportunities for investing in more resilient energy systems. In addition, rules governing federal disaster assistance have prevented them from being used to upgrade or transform Puerto Rico's electricity system, and they have, instead, largely been used to build back the previous system.[44] Policy uncertainty in the energy sector has also contributed to lower willingness to invest in solar energy systems. Initiatives to privatize Puerto Rico's electricity utility (PREPA), to retrofit

[44] Stafford Act, as Amended, and Related Authorities., Public Law 93-288, Title 42 United States Code (2019).

and replace oil-fired power plants with natural gas power plants, and to raise electricity bills and tax distributed solar generation are all creating confusion for potential solar customers. Most solar businesses therefore reported sales of solar systems primarily to higher income households and to successful commercial businesses looking to create more stable energy supplies for their operations.

The social sensitivity of Puerto Rican households to disruptions in energy supply remains very high. A number of solar businesses have told us that power outages or events that have the potential to create power outages (e.g., near misses by hurricanes) generate upticks in business. The recent earthquakes have also created a strong resurgence of solar energy as a topic of conversation among residents of Puerto Rico, further emphasizing the significance of energy resilience as a driver of public interest in solar energy. We continue to encounter new communities expressing an interest in pursuing community-oriented solar solutions in a rooftop level.

Distributed rooftop solar energy offers an enormous technical potential to provide for the electricity needs of Puerto Rican communities, including low-income communities. Data analyzed by the National Renewable Energy Laboratory shows that distributed rooftop solar energy has the potential to more than meet the needs of low-income communities in Puerto Rico. Rooftop solar on all Puerto Rico residential buildings has the potential to provide up to 24.5 TWh of electricity generation, while buildings occupied by low- and moderate-income households have the potential to provide 9.8 GW of electricity and 11.9 TWh of annual electricity generation. This compares to annual residential electricity consumption of approximately 6 TWh for all Puerto Rican households. In each of Puerto Rico's 78 municipalities, the total technical potential for rooftop solar energy generation on low-income residential buildings exceeds the electricity consumption of low-income households by at least a factor of two and, in the vast majority, by a factor of three. A parallel analysis indicates that 50% of Puerto Rican households would have 50% or more of their electricity needs met by a 2 kW solar system, a fact which could have made a big difference to the last 200,000 households reconnected to the grid after Hurricane María, who suffered over 150 days without power and were responsible for 1/3 of the total customer hours lost during the blackout. By contrast, utility-scale solar facilities took almost 15 months to return to pre-2017 levels of total generation.

The design of Puerto Rico's solar energy future matters. Solar energy is a key tool for Puerto Rico's energy future, but the question is, "Which solar?" Solar panels are a highly flexible technology that can be integrated into social, economic, and ecological landscapes in lots of different ways. Design options include scale (utility, community, rooftop), ownership (household, community, investor), relationship to the grid (off-grid, micro-grid, solar+battery, grid-tied), and more. Equally important are choices about the social purposes to which to put solar: to increase the resilience of households to electricity outages, to accelerate the transition to carbon-neutrality, to reduce the costs of energy, to replace energy imports with locally generated energy, to create more self-reliant communities, to alleviate poverty, etc. While we do not carry out a systematic assessment of these options in this report, our findings suggest that rooftop and distributed solar energy solutions have the potential to play a significant role in Puerto Rico's energy future by providing extensive power, meeting household energy needs, improving resilience, reducing energy costs, and creating value for low-income individuals, households, and communities.

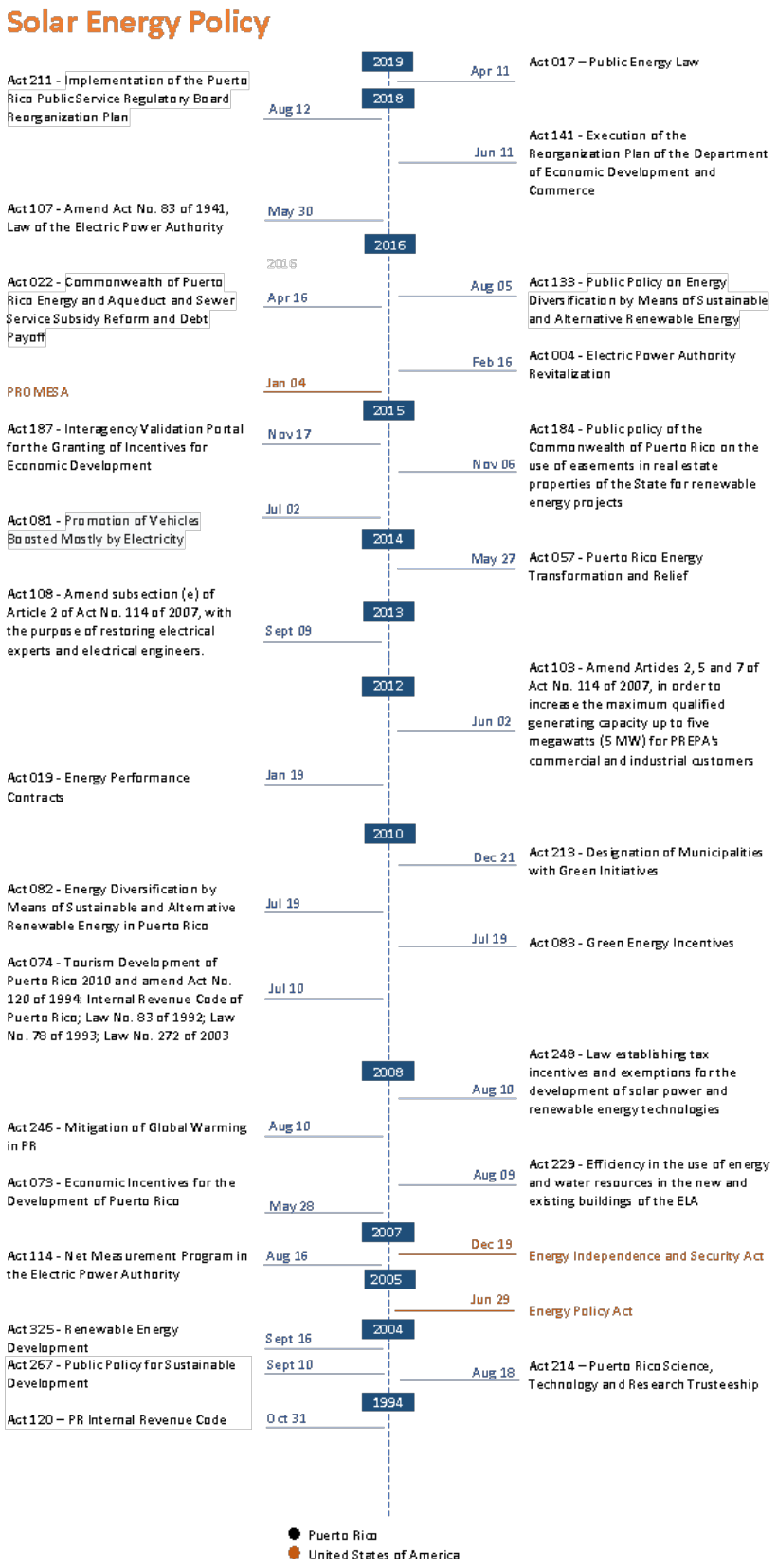


Figure 11. A timeline of energy policy in Puerto Rico through early 2019

Appendix A.

Puerto Rico LMI PV Rooftop Technical Potential and Solar Savings Potential Dataset[45]

Data Documentation

AUGUST 2020

Data Overview

The Puerto Rico Low and Moderate Income (LMI) Photovoltaic (PV) Rooftop Technical Potential and Solar Savings Potential Dataset is a tract-level data set that provides estimates of LMI rooftop solar technical potential at the tract level and LMI solar savings potential at the County level. This dataset was produced by the National Renewable Energy Laboratory, in collaboration with Arizona State University and the University of Puerto Rico Mayaguez, as part of a larger U.S. Department of Energy's Solar Energy Technologies Office funded project to enhance the social value of energy for low-income communities in Puerto Rico. The core datasets consist of two wide format comma-separated values (csv)* files ("pr_lmi_pvr_potential.csv" and "pr_lmi_solar_savings.csv") that can be tagged to tract or county geometry files using the GEOID. This dataset is intended to give researchers, planners, advocates, and policy-makers access to credible data to analyze low-income solar opportunities in Puerto Rico.

Acronyms

ACS	American Community Survey
ASU	Arizona State University
AMI	Area Median Income
DOE	U.S. Department of Energy
EIA	Energy Information Administration
HUD	U.S. Department of Housing and Urban Development
FMR	Fair market rent
kWh	kilowatt-hour
kW	kilowatt
LiDAR	Light Detection and Ranging
LEAD	Low-Income Energy Affordability tool
LMI	Low and Moderate-Income
MWh	megawatt-hour
MW	megawatt
PREPA	Puerto Rico Electric Power Authority
USGS 3DEP	United States Geological Survey 3D Elevation Program
NASA G-LiHT	National Aeronautics and Space Administration Goddard's LiDAR, Hyperspectral and Thermal Imager
PR	Puerto Rico
PV	Photovoltaic
SAM	System Advisory Model
NREL	National Renewable Energy Laboratory

[45] Data at the tract level for Puerto Rico LMI rooftop technical potential and at the municipality level for residential consumption and offsettable consumption can be downloaded from: https://data.nrel.gov/submissions/144. The raw GIS data of roof planes for all buildings in Puerto Rico is available through the DOE Open Energy Data Initiative and hosted on Amazon Web Services: https://data.openei.org/submissions/2862.

Data Table Structure

The Puerto Rico LMI PV Rooftop Technical Potential and Solar Savings Potential Dataset is comprised of two different LMI datasets: i) the **PR LMI PV Rooftop Technical Potential Dataset** provided at the Census Tract level, and ii) the **PR LMI Solar Savings Potential Dataset** available at the County level. Both datasets are broken out by Area Median Income (AMI), tenure, and building type and they are both delivered in a wide-table format with each row representing a single tract or county. Table 1 provides a general overview of both datasets.

Table 1: Datasets included as part of the Puerto Rico Solar For All dataset

Column	Source	Field Types
PR LMI PV Rooftop Technical Potential	Developed by NREL; derived from high resolution 2015-2017 LiDAR data from NASA G-LiHT and USGS 3DEP, building footprints from HOTOSM, demographic variables from the American Community Survey (2011-2015), solar resource from the National Solar Radiation Database (NSRDB; 2017), and system generation estimates from the System Advisory Model (SAM).	(1) Number of households (2) Number of solar-suitable buildings (3) Number of developable roof planes (4) Total area of developable planes (m^2) (4) Total solar capacity (MW), and (6) Total annual solar generation (MWh) -- for each AMI income group (0-30% AMI, 30-50% AMI, 50-80% AMI, 80-120% AMI, >120% AMI), building type (multi-family or single-family), and tenure (renter or owner)
PR LMI Solar Savings Potential	Developed by NREL; derived from the PR LMI PV Rooftop Technical Potential dataset, PREPA 2018 residential energy consumption and billing, and the LEAD estimates of electricity expenditures by tenure and building type.	(1) Number of clients (2) PV rooftop annual generation potential (MWh) (3) Total electric consumption (MWh) (4) Average cost of electricity ($/kWh) (5) Total annual electric bill ($/year) (6) Total bill savings potential ($/year) (7) Percent electric consumption offsetable by rooftop PV generation -- for each AMI income group (0-30% AMI, 30-50% AMI, 50-80% AMI, 80-120% AMI, >120% AMI), building type (multi-family or single-family), and tenure (renter or owner)

An important note on uncertainty

These data are estimates derived from statistical modeling and data munging of datasets sourced from varied geographic units and with varied levels of uncertainty. Care should be taken when interpreting these results particularly for policy-planning or regulatory considerations, particularly tract-level estimates. For a detailed discussion on uncertainty in the data, refer to Sigrin and Mooney (2018).[46]

i. LMI Rooftop PV Technical Potential

The Puerto Rico LMI PV Rooftop Technical Potential dataset provides estimates of technical potential for Puerto Rico's LMI communities at the Census Tract level, broken out by AMI income

[46] Sigrin, Benjamin O., and Meghan E. Mooney. *Rooftop solar technical potential for low-to-moderate income households in the United States*. No. NREL/TP-6A20-70901. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2018.

bin, building type, and tenure. These data are derived from rooftop suitability modeling using 2015-2017 high-resolution LiDAR data from NASA G-LiHT and USGS 3DEP. Demographic data was pulled from the 2011-2015 American Community Survey (ACS) 5-Year Estimates and overlaid with LiDAR data to estimate technical potential per U.S. Census tract by income, building type, and tenure. Fields available include estimates of number of households, number of suitable buildings, number of developable planes, area of developable planes (m^2), total capacity potential (MW), and total annual generation potential (MWh) for each of the 20 demographic combinations of AMI income group (0-30% AMI, 30-50% AMI, 50-80% AMI, 80-120% AMI, >120% AMI), housing type (multi-family or single-family), and tenure (renter or owner). The result is an array of 120 fields related to LMI solar potential for each Census Tract.

ii. LMI Solar Savings Potential

The Puerto Rico LMI PV Rooftop Solar Savings Potential dataset provides estimates of rooftop solar bill savings potential for Puerto Rico's LMI communities at the County level, broken out by AMI income bin, building type, and tenure. These data were calculated from the overlay of PREPA-provided 2018 residential bill and consumption data at the County level and the Puerto Rico LMI Rooftop PV Technical Potential dataset. Fields available include total number of clients, rooftop PV annual generation potential (MWh), total electric consumption (MWh), average cost of electricity ($/kWh), total annual electric bill ($/year), total bill savings potential ($/year) capped at the total bill, and the percent electric consumption offsetable by rooftop PV generation, for each of the 20 demographic combinations of AMI income group (0-30% AMI, 30-50% AMI, 50-80% AMI, 80-120% AMI, >120% AMI), housing type (multi-family or single-family), and tenure (renter or owner). The result is an array of 140 fields related to LMI solar potential for each Census Tract.

Data Dictionary

Table 2: PR LMI PV Rooftop Technical Potential ("pr_lmi_pvr_potential.csv") Data Dictionary

Column	Description
geoid	GEOID
very_low_mf_own_hh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Household Count
very_low_mf_rent_hh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Household Count
very_low_sf_own_hh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Household Count
very_low_sf_rent_hh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Household Count
low_mf_own_hh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Household Count
low_mf_rent_hh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Household Count
low_sf_own_hh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Household Count
low_sf_rent_hh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Household Count
mod_mf_own_hh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Household Count
mod_mf_rent_hh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Household Count
mod_sf_own_hh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Household Count
mod_sf_rent_hh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Household Count
mid_mf_own_hh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Household Count
mid_mf_rent_hh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Household Count
mid_sf_own_hh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Household Count
mid_sf_rent_hh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Household Count

high_mf_own_hh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Household Count
high_mf_rent_hh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Household Count
high_sf_own_hh	High Income (>120% AMI), Single-Family, Owner-Occupied - Household Count
high_sf_rent_hh	High Income (>120% AMI), Single-Family, Owner-Occupied - Household Count
very_low_mf_own_bldg_cnt	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
very_low_mf_rent_bldg_cnt	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
very_low_sf_own_bldg_cnt	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Suitable Building Count
very_low_sf_rent_bldg_cnt	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Suitable Building Count
low_mf_own_bldg_cnt	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
low_mf_rent_bldg_cnt	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
low_sf_own_bldg_cnt	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Suitable Building Count
low_sf_rent_bldg_cnt	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Suitable Building Count
mod_mf_own_bldg_cnt	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
mod_mf_rent_bldg_cnt	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
mod_sf_own_bldg_cnt	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Suitable Building Count
mod_sf_rent_bldg_cnt	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Suitable Building Count
mid_mf_own_bldg_cnt	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
mid_mf_rent_bldg_cnt	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
mid_sf_own_bldg_cnt	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Suitable Building Count
mid_sf_rent_bldg_cnt	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Suitable Building Count
high_mf_own_bldg_cnt	High Income (>120% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
high_mf_rent_bldg_cnt	High Income (>120% AMI), Multi-Family, Owner-Occupied - Suitable Building Count
high_sf_own_bldg_cnt	High Income (>120% AMI), Single-Family, Owner-Occupied - Suitable Building Count
high_sf_rent_bldg_cnt	High Income (>120% AMI), Single-Family, Owner-Occupied - Suitable Building Count
very_low_mf_own_devp_cnt	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
very_low_mf_rent_devp_cnt	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
very_low_sf_own_devp_cnt	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Developable Plane Count
very_low_sf_rent_devp_cnt	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Developable Plane Count
low_mf_own_devp_cnt	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
low_mf_rent_devp_cnt	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
low_sf_own_devp_cnt	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Developable Plane Count
low_sf_rent_devp_cnt	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Developable Plane Count
mod_mf_own_devp_cnt	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
mod_mf_rent_devp_cnt	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
mod_sf_own_devp_cnt	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Developable Plane Count
mod_sf_rent_devp_cnt	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Developable Plane Count
mid_mf_own_devp_cnt	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
mid_mf_rent_devp_cnt	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
mid_sf_own_devp_cnt	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Developable Plane Count

mid_sf_rent_devp_cnt	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Developable Plane Count
high_mf_own_devp_cnt	High Income (>120% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
high_mf_rent_devp_cnt	High Income (>120% AMI), Multi-Family, Owner-Occupied - Developable Plane Count
high_sf_own_devp_cnt	High Income (>120% AMI), Single-Family, Owner-Occupied - Developable Plane Count
high_sf_rent_devp_cnt	High Income (>120% AMI), Single-Family, Owner-Occupied - Developable Plane Count
very_low_mf_own_devp_m2	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
very_low_mf_rent_devp_m2	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
very_low_sf_own_devp_m2	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
very_low_sf_rent_devp_m2	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
low_mf_own_devp_m2	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
low_mf_rent_devp_m2	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
low_sf_own_devp_m2	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
low_sf_rent_devp_m2	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
mod_mf_own_devp_m2	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
mod_mf_rent_devp_m2	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
mod_sf_own_devp_m2	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
mod_sf_rent_devp_m2	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
mid_mf_own_devp_m2	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
mid_mf_rent_devp_m2	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
mid_sf_own_devp_m2	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
mid_sf_rent_devp_m2	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
high_mf_own_devp_m2	High Income (>120% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
high_mf_rent_devp_m2	High Income (>120% AMI), Multi-Family, Owner-Occupied - Developable Surface Area (sq.m)
high_sf_own_devp_m2	High Income (>120% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
high_sf_rent_devp_m2	High Income (>120% AMI), Single-Family, Owner-Occupied - Developable Surface Area (sq.m)
very_low_mf_own_mw	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
very_low_mf_rent_mw	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
very_low_sf_own_mw	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
very_low_sf_rent_mw	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
low_mf_own_mw	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
low_mf_rent_mw	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
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low_sf_rent_mw	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
mod_mf_own_mw	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
mod_mf_rent_mw	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
mod_sf_own_mw	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
mod_sf_rent_mw	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
mid_mf_own_mw	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)

mid_mf_rent_mw	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
mid_sf_own_mw	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
mid_sf_rent_mw	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
high_mf_own_mw	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
high_mf_rent_mw	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Capacity (MW)
high_sf_own_mw	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
high_sf_rent_mw	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Capacity (MW)
very_low_mf_own_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
very_low_mf_rent_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
very_low_sf_own_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
very_low_sf_rent_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
low_mf_own_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
low_mf_rent_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
low_sf_own_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
low_sf_rent_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mod_mf_own_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mod_mf_rent_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mod_sf_own_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mod_sf_rent_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mid_mf_own_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mid_mf_rent_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mid_sf_own_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
mid_sf_rent_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
high_mf_own_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
high_mf_rent_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
high_sf_own_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)
high_sf_rent_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Annual Generation Potential (MWh)

Table 3: PR LMI Solar Savings Potential ("pr_lmi_solar_savings.csv") Data Dictionary

Column Name	Description
cnty_geoid	County GEOID
cnty_name	County Name
very_low_mf_own_clients	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_mf_rent_clients	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_sf_own_clients	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_sf_rent_clients	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
low_mf_own_clients	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients

low_mf_rent_clients	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_sf_own_clients	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
low_sf_rent_clients	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_mf_own_clients	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_mf_rent_clients	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_sf_own_clients	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_sf_rent_clients	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_mf_own_clients	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_mf_rent_clients	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_sf_own_clients	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_sf_rent_clients	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_mf_own_clients	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_mf_rent_clients	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_sf_own_clients	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_sf_rent_clients	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_mf_own_pvr_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_mf_rent_pvr_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_sf_own_pvr_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_sf_rent_pvr_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
low_mf_own_pvr_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_mf_rent_pvr_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_sf_own_pvr_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
low_sf_rent_pvr_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_mf_own_pvr_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_mf_rent_pvr_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_sf_own_pvr_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_sf_rent_pvr_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_mf_own_pvr_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_mf_rent_pvr_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_sf_own_pvr_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_sf_rent_pvr_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_mf_own_pvr_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_mf_rent_pvr_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_sf_own_pvr_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_sf_rent_pvr_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_mf_own_elec_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_mf_rent_elec_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_sf_own_elec_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_sf_rent_elec_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients

low_mf_own_elec_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_mf_rent_elec_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_sf_own_elec_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
low_sf_rent_elec_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_mf_own_elec_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_mf_rent_elec_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_sf_own_elec_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_sf_rent_elec_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_mf_own_elec_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_mf_rent_elec_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_sf_own_elec_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_sf_rent_elec_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_mf_own_elec_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_mf_rent_elec_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_sf_own_elec_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_sf_rent_elec_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_mf_own_dlrs_per_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_mf_rent_dlrs_per_mwh	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Number of Clients
very_low_sf_own_dlrs_per_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_sf_rent_dlrs_per_mwh	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Number of Clients
low_mf_own_dlrs_per_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_mf_rent_dlrs_per_mwh	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Number of Clients
low_sf_own_dlrs_per_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
low_sf_rent_dlrs_per_mwh	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_mf_own_dlrs_per_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_mf_rent_dlrs_per_mwh	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Number of Clients
mod_sf_own_dlrs_per_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mod_sf_rent_dlrs_per_mwh	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_mf_own_dlrs_per_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_mf_rent_dlrs_per_mwh	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Number of Clients
mid_sf_own_dlrs_per_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
mid_sf_rent_dlrs_per_mwh	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_mf_own_dlrs_per_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_mf_rent_dlrs_per_mwh	High Income (>120% AMI), Multi-Family, Owner-Occupied - Number of Clients
high_sf_own_dlrs_per_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
high_sf_rent_dlrs_per_mwh	High Income (>120% AMI), Single-Family, Owner-Occupied - Number of Clients
very_low_mf_own_elec_bill_dlrs	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
very_low_mf_rent_elec_bill_dlrs	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
very_low_sf_own_elec_bill_dlrs	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)

very_low_sf_rent_elec_bill_dlrs	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
low_mf_own_elec_bill_dlrs	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - $/year)
low_mf_rent_elec_bill_dlrs	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Electric Bill ($/year)
low_sf_own_elec_bill_dlrs	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
low_sf_rent_elec_bill_dlrs	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mod_mf_own_elec_bill_dlrs	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mod_mf_rent_elec_bill_dlrs	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mod_sf_own_elec_bill_dlrs	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mod_sf_rent_elec_bill_dlrs	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mid_mf_own_elec_bill_dlrs	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mid_mf_rent_elec_bill_dlrs	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mid_sf_own_elec_bill_dlrs	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
mid_sf_rent_elec_bill_dlrs	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
high_mf_own_elec_bill_dlrs	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
high_mf_rent_elec_bill_dlrs	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
high_sf_own_elec_bill_dlrs	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
high_sf_rent_elec_bill_dlrs	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Annual Electric Bill ($/year)
very_low_mf_own_billsave_dlrs	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
very_low_mf_rent_billsave_dlrs	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
very_low_sf_own_billsave_dlrs	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
very_low_sf_rent_billsave_dlrs	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
low_mf_own_billsave_dlrs	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
low_mf_rent_billsave_dlrs	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
low_sf_own_billsave_dlrs	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
low_sf_rent_billsave_dlrs	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mod_mf_own_billsave_dlrs	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mod_mf_rent_billsave_dlrs	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mod_sf_own_billsave_dlrs	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mod_sf_rent_billsave_dlrs	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mid_mf_own_billsave_dlrs	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mid_mf_rent_billsave_dlrs	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mid_sf_own_billsave_dlrs	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
mid_sf_rent_billsave_dlrs	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
high_mf_own_billsave_dlrs	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
high_mf_rent_billsave_dlrs	High Income (>120% AMI), Multi-Family, Owner-Occupied - Total Bill Savings Potential ($/year)

high_sf_own_billsave_dlrs	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
high_sf_rent_billsave_dlrs	High Income (>120% AMI), Single-Family, Owner-Occupied - Total Bill Savings Potential ($/year)
very_low_mf_own_pct_kwh_offset	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
very_low_mf_rent_pct_kwh_offset	Very Low Income (0-30% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
very_low_sf_own_pct_kwh_offset	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
very_low_sf_rent_pct_kwh_offset	Very Low Income (0-30% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
low_mf_own_pct_kwh_offset	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
low_mf_rent_pct_kwh_offset	Low Income (30-50% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
low_sf_own_pct_kwh_offset	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
low_sf_rent_pct_kwh_offset	Low Income (30-50% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mod_mf_own_pct_kwh_offset	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mod_mf_rent_pct_kwh_offset	Moderate Income (50-80% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mod_sf_own_pct_kwh_offset	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mod_sf_rent_pct_kwh_offset	Moderate Income (50-80% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mid_mf_own_pct_kwh_offset	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mid_mf_rent_pct_kwh_offset	Middle Income (80-120% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mid_sf_own_pct_kwh_offset	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
mid_sf_rent_pct_kwh_offset	Middle Income (80-120% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
high_mf_own_pct_kwh_offset	High Income (>120% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
high_mf_rent_pct_kwh_offset	High Income (>120% AMI), Multi-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
high_sf_own_pct_kwh_offset	High Income (>120% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation
high_sf_rent_pct_kwh_offset	High Income (>120% AMI), Single-Family, Owner-Occupied - Percent Electric Consumption Offsetable by Rooftop PV Generation

Methods and Assumptions

LMI Rooftop PV Technical Potential

The PR LMI PV Rooftop Technical Potential Dataset was derived from rooftop suitability modeling using high resolution LiDAR data overlaid with demographic variables to classify potential by income group, building type, and tenure. This analysis is a Puerto Rico extension of the work described in Sigrin and Mooney (2018) and with updated assumptions on PV Rooftop suitability and performance. Documented in this section are the methods for i) the rooftop suitability modeling, and ii) the LMI demographic estimation of potential.

i. Rooftop Suitability Modeling Methods

The rooftop suitability modeling uses NREL's PV Rooftop Suitability Model v2.0, which uses LiDAR data[47] and geospatial computation to estimate the suitability of a roof plane based on its

[47] The PR work uses LiDAR data from NASA G-LiHT (3 cm resolution collected in spring 2017; limited spatial coverage of PR) and USGS 3DEP (0.03-m resolution collected in 2015; near-complete spatial coverage of PR).

orientation (azimuth and tilt), shading, and size. For details on the PV Rooftop Suitability Model v1.0, see Gagnon et al. (2016). As noted, the assumptions used in the PR technical potential analysis relies on updated assumptions on what makes a plane suitable for PV. As a result, the PR technical potential estimates are not directly comparable to the 2018 SEEDSII REPLICA data layers for the 50-states. Differences in assumptions include new panel power densities (182 W/m^2), inclusion of north facing planes, relaxation of minimum size requirements to be >= 1.62 m^2 (i.e., the size of single 60-cell 250 watt solar panel), and adjustments to how shading is calculated for each developable surface. Table 4 details the specific assumptions used to determine a plane's suitability. Once suitable planes have been generated, we run the NREL System Advisory Model (SAM) to calculate the performance of PV at each plane. Table 5 details the assumptions applied for PV performance simulations that were fed into SAM and ran for each developable plane.

Table 4: Assumptions for Suitability

Requirement	***Description***
Shading	Measured shading for four seasons and required an average of 80% unshaded surface
Azimuth	All possible azimuths
Tilt	Average surface tilt <= 60 degrees
Minimum Area	>= 1.62 m^2 (area required for a single 60-cell solar panel)

Table 5: Assumptions for PV Performance Simulations

PV System Characteristics	***Value for Flat Roofs***	***Value for Tilted Roofs***
Tilt	15 degrees	Tilt of plane
Ratio of module area to suitable roof area	0.70	0.98
Azimuth	180 degrees (south facing)	Midpoint of azimuth class
Module Power Density	182 W/m^2	
Total system losses	Varies (SAM defaults + individual surface % shading)	
Inverter efficiency	96%	
DC-to-AC ratio	1.2	

ii. LMI Demographic Estimation of Technical Potential

From the LiDAR PV rooftop data set described above, we extend the data set to estimate tract-level solar technical potential by building income, tenure, and building size. This consists of two broad steps: (1) Intersecting individual building technical potential estimates with demographic factors from the Census Bureau 2011–2015 American Community Survey; (2) Aggregating the building-level estimates to the tract, county, and state level and conducting Monte Carlo runs to determine the median estimate. This work relies on demographic data from the ACS's 2011–2015 5-year estimates; see Table 6 for a detailed account on tables used in this analysis. The ACS publishes these data as smaller crosstabs, with much of the detail available only at the larger (i.e., county) geographic levels. To account for this, we use random weighted sampling and proportional allocation methods to disaggregate demographic data into a tract-level cross-tabulation of household counts by AMI income group, per building type and tenure. Using this demographic crosstab, we rely on a series of methods tailored toward translating the counts of households per building type (e.g., single-family detached, 2–4 units, 5+ units) into estimates of building counts

by building size class (i.e., small as 5,000 ft^2 or less, medium as 5,000-25,000 ft^2, large as 25,000 ft^2 or more) and use this information to bootstrap residential buildings. The final tract-level estimates are determined based on the median of a 100-sample Monte Carlo simulation. The methods used for the PR LMI estimation are based on the methodology used in the U.S. national analysis. For a detailed discussion of the LMI estimation from LiDAR data, see Sigrin and Mooney (2018).

Table 6: 2015 Five-Year American Community Survey Published Tables Used

Table	Source Code
Household Income in the Past 12 Months (in 2015 Inflation-Adjusted Dollars)	B19001
Tenure by Household Income in the Past 12 Months (in 2015 Inflation-Adjusted Dollars)	B25118
Tenure by Units in Structure	B25032
Tenure by Household Size by Units in Structure	B25124

ii.i Definition of LMI

This work uses the AMI definition to define LMI households. The AMI definition uses the Department of Housing and Urban Development's (HUD) AMI income limits[48] which is based on local geography and the relative cost of living in a particular location. HUD's AMI income limits are used to determine the eligibility of applicants for federal assistance programs. They are based off the median income for Fair Market Rent (FMR) areas (i.e., metropolitan areas, parts of some metropolitan areas, and non-metropolitan counties) and are adjusted based on the family size[49]. Using these AMI income thresholds, we categorize households into the following low- to moderate-income groups, as defined by the Community Development Block Grant (CBDG)[50], based on household income and the number of people in the household:

- Very Low Income: 0% to 30% of AMI
- Low Income: 30% to 50% of AMI
- Moderate Income: 50% to 80% of AMI
- Middle Income: 80% to 120% of AMI
- High Income: >120% of AMI

iii. LMI Solar Savings Potential

The LMI Solar Savings Potential analysis builds off of the technical potential work by comparing the total generation potential to electric consumption and billing data to estimate how much rooftop solar could help the Puerto Rican LMI communities save on electric bills. Municipality level residential electric consumption and total bill accountings were provided by PREPA for the 2018 calendar year. Using the PREPA data and LEAD energy expenditure by income, tenure, and building type, we estimated the total consumption and annual bill at the County level and compared these estimates with our rooftop generation potentials.

[48] https://www.huduser.gov/portal/datasets/il.html#2018

[49] The HUD baseline numbers for each income limit are based off the 4-person family size. For households with larger or smaller sizes, percentage adjustments are made to the income break limits based off the number of people in the household. Source: https://www.huduser.gov/portal/datasets/il/il16/IncomeLimitsBriefingMaterial-FY16.pdf

[50] The CBGD income class delineation was chosen here because it includes a class for moderate income, whereas the standard Section-8 definition does not.