PUERTO RICO DISTRIBUTED ENERGY RESOURCE INTEGRATION STUDY

Load, Energy Efficiency, and System Cost

FEBRUARY 2021

ENERGY FUTURES GROUP

Puerto Rico Distributed Energy Resource Integration Study – Load, Energy Efficiency, and System Cost

Achieving a Renewable, Reliable, and Resilient Distributed Grid

Contact Information

Anna Sommer
Principal
Energy Futures Group
315-386-3834
asommer@energyfuturesgroup.com

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Disclaimer

This model has been independently developed by CAMBIO, PR Inc in collaboration with IEEFA and consultants and in no way represents any proposal, projection or representation of the Puerto Rico Electric Power Authority.

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1. Executive Summary

In October 2018, Queremos Sol – a multisector group advocating for self-sufficient and sustainable energy - released a report entitled, "Queremos Sol: Sostenible, Local, Limpio."[1] In the report, Queremos Sol set an ambitious goal to achieve a Renewable Portfolio Standard (RPS) of 50% by 2035 and 100% by 2050, and an Energy Efficiency and Conservation Policy Objective of 25% by 2035. In addition, it advocated for a clear public policy for the following:

- Efficiency, conservation, and demand management.
- Renewable distributed generation based on rooftop solar and storage
- Accelerated elimination of fossil fuels.

At the request of CAMBIO and the Institute for Energy Economics and Financial Analysis (IEEFA), Energy Futures Group ("EFG") collaborated with consulting firms Telos Energy ("Telos") and EE Plus to conduct an analysis of the feasibility, operability, and cost of achieving two energy goals related to the Queremos Sol proposal. Specifically, this collaborative effort sought to examine the operational and cost impacts of achieving a 25%, 50%, and 75% RPS target with two, primary tools:[2]

- Ensuring 50%, 75%, and 100% of homes in Puerto Rico are "resilient" to hurricanes. Resiliency was defined as each home having, on average, 2.7 kW of solar and 12.6 kWh of battery backup; and
- Achieving a 25% reduction in island-wide energy consumption by 2035.

These scenarios provide a pathway to meet and exceed the Queremos Sol 2035 RPS objectives and put the system on a trajectory to achieve 100% clean energy by 2050. The study participants also constructed, for comparison purposes, a Base Case of the system as it exists today.

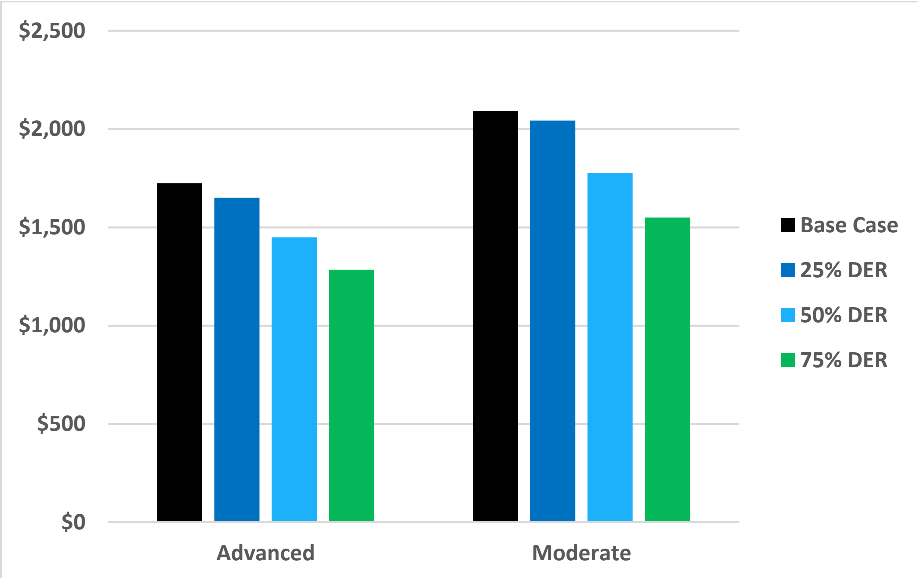
The analysis of the DER and energy efficiency goals involved a coordinated, detailed, and unique combination of modeling simulations looking at the dispatch of Puerto Rico's fleet of generators under these differing scenarios and the operation of the distribution and transmission lines under that dispatch. EFG's role was to develop the load and energy efficiency assumptions and then bring together data from all the simulations into a total system cost. (Collectively, we call these analyses the "CAMBIO Study".) The dispatch and power flow modeling is detailed in Telos Energy's report, while EE Plus's report discusses the distribution system simulations.

[1] Queremos Sol, https://www.queremossolpr.com/

[2] Distributed solar with battery storage and energy efficiency were the primary distributed energy resources (DER) deployed in the study scenarios.

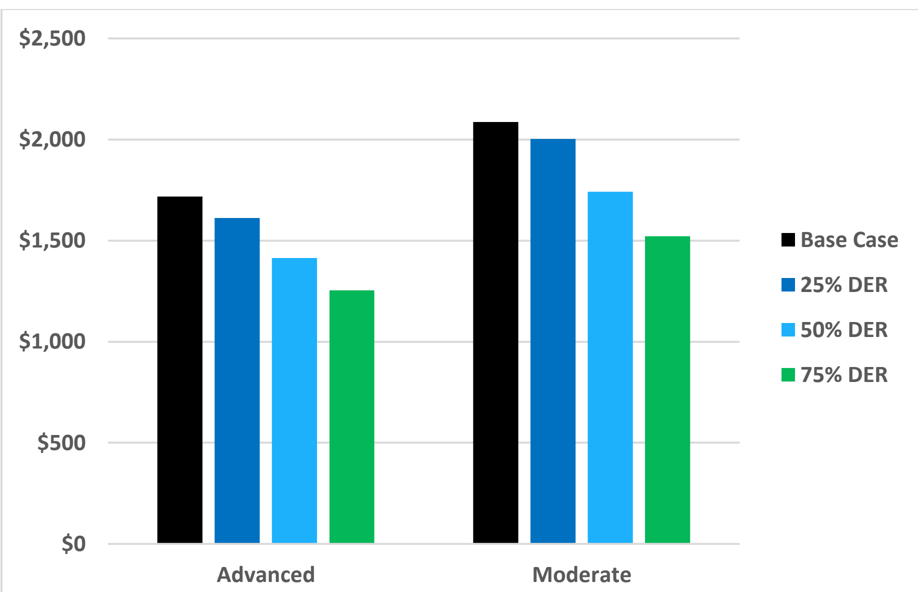
Under a discount rate similar to PREPA's cost to raise debt before it filed for bankruptcy, all DER scenarios are cheaper than a business-as-usual case (Base Case) as shown in Figure 1.

Figure 1: Total Operating & Carrying Costs at 6.5% (Millions of 2020$)



If we assume that these scenarios should be judged using a discount rate that is more indicative of an individual ratepayer's personal financing rate for a rooftop solar and battery storage system, then all DER scenarios become even lower cost relative to the Base Case (Figure 2).

Figure 2. Total Operating and Carrying Costs at 3.99% (Millions of 2020$)



It is important to note that the Base Case assumes Puerto Rico's electric grid continues largely as it stood in 2020. There are no additional distributed renewables or natural gas nor any maintenance upgrades of the existing fleet. Because the DER scenarios, with increasing penetration, decreasingly rely upon PREPA's current thermal fleet there is a reliability benefit (in addition to a resiliency benefit) to the DER scenarios that is not quantified or monetized. We largely do not capture that concern in this study because we have no meaningful method to assess this value despite its very real nature. However, the DER scenarios indubitably provide more reliability because they would allow between 500,000 and 1 million households the ability to meet their critical loads even after a critical event such as a hurricane.

2. Putting the CAMBIO Study in Context

The Puerto Rico Electric Power Authority ("PREPA") is responsible for electricity generation, power distribution, and power transmission in Puerto Rico. The design of Puerto Rico's electrical grid, as is typical of most systems, has been a centralized approach that includes large fossil fuel power plants that rely on long transmission lines to bring power from the generators located in the southern portion of the island to the load centers located in northern Puerto Rico. Relying on large-scale generators to supply power to residents makes Puerto Rico's grid vulnerable to wide scale power outages from natural disaster and other events. Exacerbating the vulnerability of the electrical grid in Puerto Rico is PREPA's history of mismanagement and lack of investment in necessary infrastructure.

The destruction wrought by Hurricanes Irma and Maria brought attention to the important role that a decentralized electrical grid could play in providing resiliency in the face of natural disasters. Following hurricanes Irma and then Maria in 2017, 25% of the transmission towers and 40% of the 334 substations were damaged, which left millions of Puerto Ricans without power for a significant period of time.[3] While most of PREPA's generation assets were not damaged from the hurricanes, several earthquakes in 2020 caused severe damage to the Costa Sur units. Costa Sur is one of the largest power plants on the island and supplies about 25% of the electric power in Puerto Rico.[4] In order to mitigate the loss of Costa Sur, the Federal Emergency Management Agency ("FEMA") provided funds to cover costs for 28 peaking generator units to operate until the Costa Sur units could come back online.[5] The combination of the transmission and distribution damage from the hurricanes and the damage to Costa Sur caused by the earthquakes, put in stark terms the dangers of relying on a primarily centralized electric grid in Puerto Rico. These experiences show the importance of the need for Puerto Rico's electric grid to focus on decentralized generation for resiliency and sustainability. The broadening use of distributed solar PV and energy storage, in addition to implementing energy efficiency and demand management to help lower customer use of electricity, would all

[3] O'Neill-Carrillo, E., & Irizarry-Rivera, A. (2019). How to Harden Puerto Rico's grid against hurricanes. *IEEE Spectrum*, *56*(11), 42-48.

[4] https://www.fema.gov/press-release/20201013/fema-obligates-over-238-million-prepa-earthquake-damage

[5] Ibid.

contribute to a more resilient grid. The use of local and renewable generation will also provide the benefit of fostering the socio-economic development of communities.[6]

After the hurricanes, multiple organizations internal and external to Puerto Rico focused on how to rebuild the island's grid. The National Science Foundation funded several sessions to discuss stakeholder visions on how to rebuild Puerto Rico's electric system. Those stakeholder groups included professionals from the energy committee from the Puerto Rico Chamber of Commerce, local trade organization of PV installers and contractors, members of communities across the island, and employees from an out-of-state utility that helped with restoration. During these activities, several focus groups discussed what went wrong with the electric system once the hurricane hit and recommendations to avoid those problems in the future. One of the focus groups included members of professional and trade organizations who noted that rooftop PV systems did not see much damage. Given the strength of winds during the hurricanes, this was clear evidence that when rooftop PV systems are correctly installed, they are able to withstand hurricane-force winds.[7] Not only can solar PV systems help foster resiliency for residents and communities during natural disasters, but solar PV systems have become economically feasible in Puerto Rico.[8,9] The average price of electricity in Puerto Rico has ranged between 20 and 27 U.S. cents per kWh, and this is anticipated to rise above 30 U.S. cents per kWh if a rate increase is factored in for servicing PREPA's debt obligation.[10] In comparison, our study estimates that the cost of a PV system in Puerto Rico in 2021 is about 9.8 cents per kWh. Solar PV is also a very viable resource, since approximately 70% of the population resides in a location with an excellent solar resource.[11] The combination of economic feasibility and resiliency make rooftop solar PV systems a viable option for utilizing local generation.

One of the main criticisms against widespread adoption of rooftop solar PV systems is the variation in generation that occurs with renewable resources. Several studies have looked at a combination of microgrid systems integrating solar PV, energy storage, and demand

[6] O'Neill-Carrillo, E., & Irizarry-Rivera, A. (2019). How to Harden Puerto Rico's grid against hurricanes. *IEEE Spectrum*, *56*(11), 42-48.

[7] Oneill, E., McCalley, J., Kimber, A., & Haug, R. (2019, January). Stakeholder perspectives on increasing electric power infrastructure integrity. In *ASEE annual conference & exposition*.

[8] O'Neill-Carrillo, E., Jordan, I., Irizarry-Rivera, A., & Cintron, R. (2018). The long road to community microgrids: adapting to the necessary changes for renewable energy implementation. *IEEE Electrification Magazine*, *6*(4), 6-17.

[9] O'Neill-Carrillo, E., Mercado, E., Luhring, O., Jordán, I., & Irizarry-Rivera, A. Community Energy Projects in the Caribbean.

[10] O'Neill-Carrillo, E., & Irizarry-Rivera, A. (2019). How to Harden Puerto Rico's grid against hurricanes. *IEEE Spectrum*, *56*(11), 42-48.

[11] O'Neill-Carrillo, E., Jordan, I., Irizarry-Rivera, A., & Cintron, R. (2018). The long road to community microgrids: adapting to the necessary changes for renewable energy implementation. *IEEE Electrification Magazine*, *6*(4), 6-17.

management to serve households in communities within Puerto Rico.[12,13] In order to address the concerns related to cloudy days or large-scale system outages, energy storage will need to be co-located with the rooftop PV so that households can still serve their critical loads during those periods of time.

With broader adoption of rooftop solar PV across Puerto Rico, microgrids become more feasible as well. Microgrids consist of local distributed energy resources and loads, and they can operate in two different modes: grid-connected and isolated from the grid. When a microgrid is in grid-connected mode, it can import or export power to the main electricity grid. When a microgrid is in isolated mode, it relies on the local generation resources to supply power to the customers connected to it. Microgrids offer more resiliency than the centralized power system structure in the face of natural disasters.[14] In the event of a natural disaster, such as Hurricane Maria, microgrids can help critical facilities remain operational and they can also help provide power for rural communities who are not easily restored following power outages.

Utilizing local resources can also provide resiliency, in addition to economic, social, and environmental benefits to Puerto Rico. There is a large potential role for communities to play in establishing and managing their grids. There is the potential to build on Puerto Rican experience managing community-based projects primarily through community-operated water aqueducts in over 200 rural communities that own the water resource and manage the distribution system.[15]

The CAMBIO study looks fifteen years down the road to a time when Puerto Rico has retired the dirtiest of its fossil-fuel power plants, has made a coordinated and extensive effort to ensure resilient and efficient production and consumption of electricity, and has upgraded its distribution system to best practice standards. The primary purpose of this study was to assess the feasibility and cost of achieving the 2035 resiliency goals previously discussed. Both this and Telos' report also discuss a sensitivity looking at a 2024 stepping stone that will enable Puerto Rico to achieve a 75% resilient homes goal.

[12] O'Neill-Carrillo, E., Jordan, I., Irizarry-Rivera, A., & Cintron, R. (2018). The long road to community microgrids: adapting to the necessary changes for renewable energy implementation. *IEEE Electrification Magazine*, *6*(4), 6-17.
[13] Jordán, I. L., O'Neill-Carrillo, E., & López, N. (2016, October). Towards a zero net energy community microgrid. In *2016 IEEE Conference on Technologies for Sustainability (SusTech)* (pp. 63-67). IEEE.
[14] Carrión, G. A., Cintrón, R. A., Rodríguez, M. A., Sanabria, W. E., Reyes, R., & O'Neill-Carrillo, E. (2018, November). Community microgrids to increase local resiliency. In *2018 IEEE International Symposium on Technology and Society (ISTAS)* (pp. 1-7). IEEE.
[15] O'Neill-Carrillo, E., Mercado, E., Luhring, O., Jordán, I., & Irizarry-Rivera, A. Community Energy Projects in the Caribbean.

3. Load and Energy Efficiency

Perhaps the single most important input into a study such as this is the load forecast or a projection of how much energy consumers will demand. Total load is a function of the number of customers in each class (residential, commercial, industrial, etc.), the types of electrical end-uses (refrigerators, air conditioning units, etc.), and the impacts of any programs intended to influence electrical consumption, e.g. energy efficiency programs. In Puerto Rico, there exists data on consumption by customer class, but very little data on typical end-uses. And with no meaningful history of energy efficiency ("EE") in Puerto Rico, it is a real challenge to develop reliable projections of energy efficiency savings or of the impact of natural uptake of efficient technologies on Puerto Rico's overall system load.

Prior load forecasts produced for PREPA's Integrated Resource Plan ("IRP") filings are publicly available. However, those forecasts include no adjustment for "naturally occurring"[16] energy efficiency which, in our opinion, makes them unreliable.

In its most recent IRP filing, PREPA included detailed information for a hypothetical set of energy efficiency programs. Unfortunately, the combination of flawed effective useful life assumptions[17] and limited measure types also makes those figures less than reliable.

Because a prediction of load is so key to planning exercises like this one and because the island now has robust energy efficiency goals established by the Puerto Rico Energy Bureau, a different approach to forecasting load and EE was needed. EFG performed a high-level analysis of the aggregate effect of the following factors in reducing electric energy use on the Island between 2020 and 2035:

- "Naturally-occurring" energy efficiency that reduces electricity use due to:
  - Technology innovations and market pressures that increase baseline equipment efficiencies;
  - Increasing federal appliance and equipment efficiency standards;
- Energy efficiency programs implemented by PREPA or others to provide informational and financial support to customers in making energy efficiency improvements for their homes and businesses;
- Large-scale replacement of residential electric water heating with solar water heating.

Because of the dearth of information on the end-use characteristics of the Island's electric loads, it was necessary for EFG to make several significant assumptions in order to carry out the

[16] Naturally occurring energy efficiency is energy savings that occur under normal market forces without intervention. A major driver of naturally occurring energy efficiency is increasing appliance standards. These standards cause the minimum efficiency of electrical consuming technologies available in the market to increase over time and drive an increase in the average efficiency of the stock of those appliances. That, in turn, causes electricity consumption to go down.

[17] Meaning that PREPA assumed that energy efficiency measures such as LED lightbulbs had lifetimes well in excess of the assumptions typically made for energy efficiency measures.

analysis. First, Puerto Rico lacks reliable appliance saturation data that would characterize existing consumption by end-use type,[18] so we looked to another source, specifically the Energy Information Administration's projection of nationwide average end-use efficiency to determine the consumption of existing end-use technologies. Using information from the Electric Power Research Institute and from a study led by Dr. Irizarry,[19] we developed an estimate of the combined impact of the EIA's projected end-use efficiency and the consumption by those end-uses in Puerto Rico. EFG believes the results are illustrative of a path that leads to Queremos Sol's 25% cumulative energy consumption reduction goal but cautions that a next critical step to defining the path will be further research and data gathering.

These are the steps we took to develop forecasted 2035 load:

Step 1: 2020 Sector Loads

> EFG used the average of the PREPA historical sector loads for 2016, 2018, and 2019 from PREPA's most recent IRP as the basis for establishing annual consumption by customer class in 2020. We did not use 2017 data for the obvious reason that system-wide outages after Hurricane Maria rendered those data unrepresentative of expected usage under typical conditions. We could not fully remove the impact of the hurricane related outages since hundreds of thousands of people remained without power well into 2018. But we also felt it could be important to capture how load may have changed because of the hurricane even after service was returned, so we tried to strike a balance by taking the average of 2016, 2018, and 2019. For each sector, the three-year average sector load was divided by the reported number of accounts to determine the expected load for an average account/customer within the sector.

Step 2: Naturally Occurring Energy Efficiency

> In Step 2, EFG estimated the potential "naturally occurring" energy efficiency, i.e. the reductions that will occur in the expected energy requirements of typical sector loads over time due to technology improvements and advances in codes and standards. To do this, EFG first had to disaggregate the average sector loads by end use, as different levels of naturally occurring efficiency are expected for different types of loads.
>
> For example, the average 2020 residential energy load that was determined in Step 1 above is 4,650 kWh per year. This is the total, on average, of the electric use of all of the

[18] A residential appliance saturation study ("RASS") should be undertaken to more definitively understand the electric consumption characteristics of Puerto Rico's homes. A similar energy use baseline study should also be undertaken to understand the load characteristics of the Island's business customers. The data supplied by these studies will be useful to refine energy efficiency program concepts and applications in order to implement a broad and meaningful set of energy efficiency programs that will achieve the desired savings.

[19] Irizarry-Rivera, Agustín, et al. "A case study of residential electric service resiliency through renewable energy following hurricane Maria," Mediterranean Conference Power Generation, Transmission, Distribution, Energy Conversion (MEDPower), Dubrovnik, Croatia, Nov 12-15, 2018.

different electrical equipment in a home including lighting, refrigeration, cooling, and so on. The amount of electricity used by different end uses varies by region due to differences in climate, economic conditions, and other factors, and as was mentioned above there are virtually no data on electric use by end use specific to Puerto Rico. Therefore, EFG estimated end use electricity by category for the residential and commercial sectors.

EFG used end use load shapes that are available from the Electric Power Research Institute ("EPRI") for Florida as a starting point, and then adjusted the estimated use by end use category based on input from Dr. Irizarry. Specifically, compared to the EPRI Florida data, as a percentage of total residential loads, cooling and water heating electric use were increased significantly for Puerto Rico, refrigeration was increased slightly, and clothes dryer, dishwasher, lighting, and home electronics use were all decreased significantly.

EFG then applied estimates of naturally occurring energy efficiency through 2035 to each of the disaggregated adjusted end use loads, using the change in projected end use energy by category from the Energy Information Administration's 2020 Annual Energy Outlook 2020.

Step 3: Energy Efficiency Programs

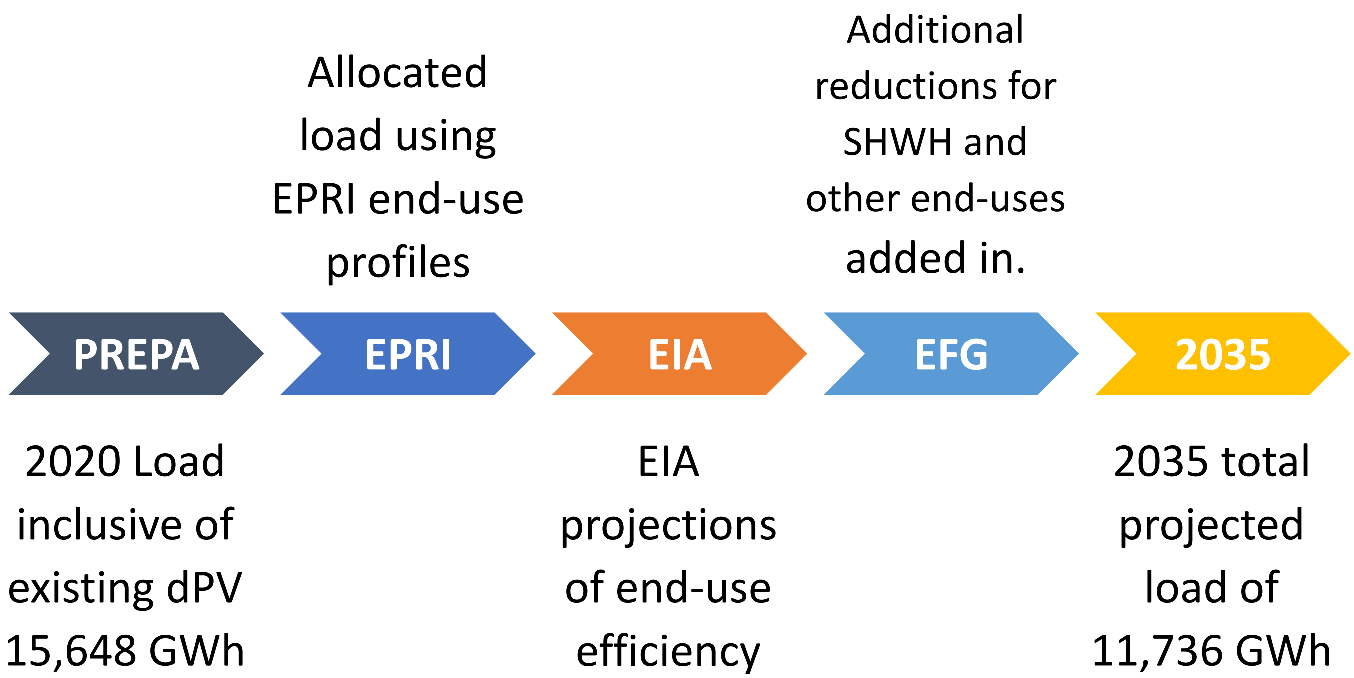
On top of naturally occurring energy efficiency EFG assumed savings in certain end uses based on implementation of energy efficiency programs. In the residential sector EFG estimated that the loads for cooling, lighting, and home electronics could all be reduced through efficiency programs more than would be possible simply through naturally occurring energy efficiency. Similarly, in the commercial sector EFG assumed additional program savings for cooling, lighting controls, refrigeration, office equipment and computing, as well as miscellaneous commercial loads. The adjustments were made on the basis of expert judgment – EFG staff have critically evaluated and helped developed hundreds of energy efficiency programs.

Step 4: Solar Water Heating

Given that residential water heating is estimated to consume as much as 30% of 2020 household electric use and given the abundance of solar resources in Puerto Rico, EFG included in its load forecast the assumption that aggressive programs to encourage solar hot water heating ("SHWH") could achieve a total conversion of 70% of residential electric hot water heating to solar by 2035.

These steps are illustrated in Figure 3. Our 2020 estimated starting point load was 15,648 GWh of sales. This was the figure from which the energy efficiency and solar hot water heating adjustments that would occur through 2035 were subtracted.

Figure 3. Flow Chart of EFG's Process to Develop a 2035 Load Projection



Applying the steps listed above to account for feasible energy efficiency and hot water heating conversions results in projected 2035 sales of 11,736 GWh – a total reduction of 25 percent. This is the level of energy that must be supplied through all modeled scenarios and sensitivities with one exception. The Accelerated Retirement sensitivity discussed in Telos Energy's report and later in this document was based on projected 2024 load. We used the same approach described previously to develop our 2024 load assumption though we conservatively assumed that solar hot water heating conversions would have no significant impact on load by 2024. This gave us an 11 percent reduction in energy consumption for total sales of 13,392 GWh.

4. New Resource Pricing

A significant task within EFG's scope of work in this study was to develop cost estimates for the distributed energy resources (DERs) in each scenario. Three primary cost assumptions needed to be developed: residential PV, commercial PV, and residential scale batteries. The explosion of interest and adoption of these technologies throughout the U.S. has generated more and better quality data characterizing their costs than has been the case in years prior. However, Puerto Rico has some important differences from other parts of the U.S. including different tax rates, a different supply chain, and different labor costs. We, therefore, sought to gather information specific to Puerto Rico as much as possible, though there is little publicly available in the way of PV and battery prices.

4.1. Residential and Commercial Solar (PV)

In consideration of the many factors that make pricing DERs in Puerto Rico a unique exercise, we relied on residential PV prices provided to us by CAMBIO. These data are for estimates to construct multiple residential rooftop installations. Just as in other jurisdictions, we expect that prices will decline over time. So going forward from 2020 we applied National Renewable Energy Lab's (NREL) Alternative Technology Baseline[20] (ATB) cost curve to the starting point data provided to us by CAMBIO. This yields two trajectories of declining costs. Using the nomenclature adopted by NREL, the first is a Moderate case, i.e., a business as usual case. And the second is the Advanced Case which assumes greater R&D and innovation in solar technology.[21] All estimates include the cost of the PV panels themselves, as well as Balance of System (BoS) and financing costs.

The key assumptions used to determine both total capital expenditure (CAPEX) and the economic carrying charge ("ECC", a mortgage payment equivalent view of cost) were:

1. 2020 Residential Solar Price - \$1.86 per W_{DC}; this includes all costs needed to permit and construct the solar panels.[22]
2. Inflation Rate
    - This value was set at 2.5% consistent with NREL's ATB inflation assumption.
3. Discount Rate[23] (WACC)
    - The WACC was set to 6.5% as a proxy for PREPA's cost to raise debt.[24]
    - A second sensitivity was conducted assuming a 3.99% discount rate. This discount rate is an estimate of the financing rate an individual would face to finance a rooftop solar and battery storage system if that system were also accompanied by a guarantee or some form of buy-down (either by the Puerto Rican or federal government).

[20] https://www.nrel.gov/news/program/2020/2020-annual-technology-baseline-electricity-data-now-available.html

[21] More information about NREL's development of both cases is available here: https://atb.nrel.gov/electricity/2020/index.php?t=sr

[22] Estimate based on direct quote for a 2020 Puerto Rico community roof-top solar installation.

[23] A discount rate is necessary to account for the "time value" of money, i.e, the manner in which people differently value money in their possession now versus the future. There are different ways to set discount rates. A common way is to assume a proxy for the utility's cost to raise capital, we also use a proxy for an individual's cost to borrow money.

[24] This figure presumes that PREPA can emerge from bankruptcy and raise capital. Prior to its bankruptcy filing, PREPA issued bonds for long-term debt in the 5 – 7 percent range, so we chose a value that was conservatively high compared to the interest rates faced by other public power utilities.

Because we lacked any real-world data for commercial PV installations, we relied upon the ATB to characterize those costs entirely. The key assumptions used to determine both total capital expenditure (CAPEX) and the economic carrying charge were:

1. 2020 Commercial Solar Price - \$1.642 per W_{DC} in the Advanced case and \$1.664 per W_{DC} in the Moderate case; this includes all costs needed to permit and construct the facility but no financing costs.
2. Inflation Rate
   - This value was set at 2.5% consistent with NREL's ATB inflation assumption.
3. Discount Rate (WACC)
   - The WACC was set to 6.5% as a proxy for PREPA's cost to raise debt.
   - A second sensitivity was conducted assuming a 3.99% discount rate. This discount rate is an estimate of the financing rate an individual would face to finance a rooftop solar and battery storage system if that system were also accompanied by a guarantee or some form of buy-down (either by the Puerto Rican or federal government).

A primary goal of the study was to first meet the RPS objectives through distributed, rooftop solar, and secondarily through solar distributed across commercial and industrial customers, solar carports, and repurposed landfills. Because the ATB cost estimates for commercial PV installations are lower than the cost estimates for residential PV installations, the weighted cost of installation assumed varies across the scenarios. As the renewable energy target increases, the ratio of commercial to residential PV installations also increases. As a result, the final cost estimates represent an installed-capacity-weighted-average as shown in Table 1.

Table 1: Installed PV Price Estimates (2020 $/kW DC)[25]

	Unit	25% DER	50% DER	75% DER
Total PV Capacity	MW AC	1,493	3,237	4,982
Res PV Capacity %	Weight %	90%	63%	54%
C&I PV Capacity %	Weight %	10%	37%	46%
PV Cost (ATB Moderate)	$/kW DC	$1,857	$1,849	$1,846
PV Cost (ATB Advanced)	$/kW DC	$1,855	$1,840	$1,836

These cost estimates are adjusted annually using the ATB cost assumptions through 2035. Though total system costs are reported in the Executive Summary and in Section 5 for a single year, we did not assume that the solar and battery installations would be built overnight. Instead, in order to capture the reality of how Puerto Rico would achieve the level of DERs in each scenario, the project team developed an installation trajectory by year through 2035. Those trajectories are given in Table 2.

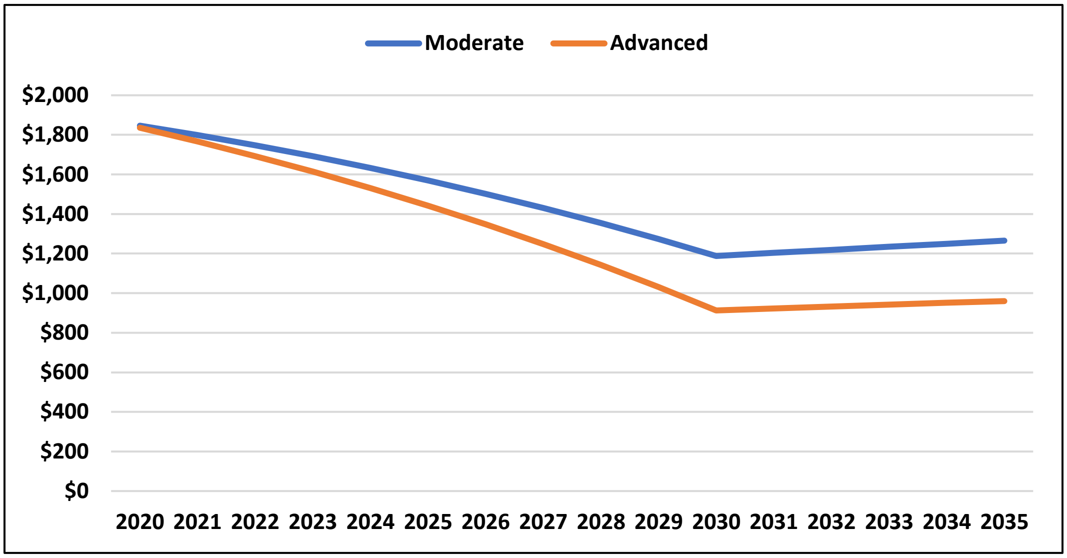
Table 2. Trajectory of Cumulative Solar Installations by Scenario (MW_{AC})

Fiscal Year	Base Case	25% DER	50% DER	75% DER
2020	172	172	172	172
2021	172	337	337	337
2022	172	502	502	502
2023	172	667	667	667
2024	172	833	833	833
2025	172	998	998	998
2026	172	1,163	1,163	1,163
2027	172	1,328	1,328	1,328
2028	172	1,493	1,493	1,493
2029	172	1,493	1,784	2,075
2030	172	1,493	2,074	2,656
2031	172	1,493	2,365	3,238
2032	172	1,493	2,656	3,819
2033	172	1,493	2,946	4,401
2034	172	1,493	3,237	4,982

The combined impact of that trajectory for the 75% DER scenario and the per unit cost predictions from the NREL ATB are given in Figure 4.

[25] Please note that the prices in this table do not include the impact of the ITC.

Figure 4: PV Weighted Price Cases, 75% DER (Nominal $/kW DC)



Please note that the weighted prices for the 25% and 50% DER cases are not shown but are slightly higher because they both include a higher percentage of residential installations, which are more expensive than commercial installations due to economies of scale.

To arrive at capital costs per year, these prices were multiplied by the installed capacity of solar PV per year as shown in Table 2.

4.2. Battery Energy Storage System (BESS)

The ATB's battery system costs are only offered at the utility-scale, so we turned to a popular website selling batteries for residential scale applications in Puerto Rico – the altE Store – to price the batteries that are installed with residential solar. These prices are specific to residential customers in Puerto Rico and adjustments were made so that the battery specifications were consistent with the manner in which they were modeled. As did Telos, we assumed an inverter efficiency of 96% applied to these systems.

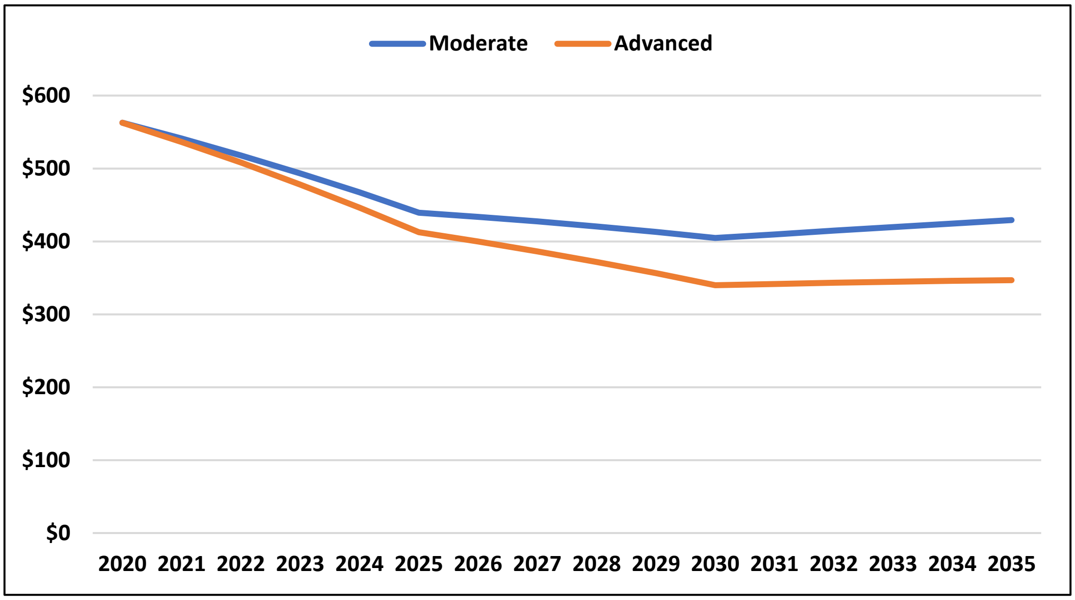
While a number of different battery chemistries are available for residential applications, lithium ion batteries are the most cost-competitive per cycle (a full charge and discharge) and were, therefore, the basis for our battery pricing assumptions.

Our 2020 starting point assumption, given this, was $563 per kWh.[26] To arrive at the battery-only capital costs per year, these prices were multiplied by the installed capacity of batteries in each year. We applied the ATB's Moderate and Advanced cost curves to our starting point

[26] Battery prices quoted in "per kWh" are not levelized over the total number of kWh discharged from the battery during its lifetime, but rather are the cost of the battery divided by the useable kWh provided by the battery in a single discharge.

assumption since residential batteries are also experiencing significant cost improvements and are expected to do so going forward (Figure 5).

Figure 5: Battery-Only Price Cases (Nominal $/kWh AC)



4.3. Transmission System

The power flow studies conducted by Telos identified reliability risk when periods of very high inverter-based generation are reached. Among the possible mitigations for this are the addition of synchronous condensers (SC).[27] If the technology progresses quickly enough, so-called "grid forming" inverters may also be able to mitigate the identified problems, so we did not include a cost of synchronous condensers. No other transmission related upgrades were identified in the Telos study.

4.4. Distribution System

The distribution system modeling performed by EE+ identified the mitigations in all scenarios that would be necessary to ensure stable and reliable operation. The mitigations shown in Table 3 are necessary in the Base Case and all DER scenarios.

[27] Synchronous condensers are essentially half a thermal power plant, they are a generator whose shaft is unconnected to anything and spins freely. Their function is to help provide essential grid services that mitigate reliability problems.

Table 3. Distribution Systems Mitigations Needed in Base Scenario

Region	Total Line Miles	Line Miles Reconductored	Line Miles Rebuilt	% Mitigation	Transformer Upgrades
Arecibo	4,790	13.7	315.9	6.9	0
Bayamon	2,442	81.7	106.6	7.7	0
Caguas	6,761	136.9	317.3	6.7	0
Carolina	3,310	100.7	140.8	7.3	0
Mayaguez	5,482	37.7	303.9	6.2	0
Ponce ES	2,828	12.1	127.7	4.9	0
Ponce OE	2,526	21.4	125.5	5.8	0
San Juan	2,908	29.1	95.2	4.3	0
Vieques	166	0.8	10.4	6.7	0
Culebra	68	1	2.4	5	0

Table 4 shows the additional mitigations that would be needed in order to accommodate the buildout of the 75% DER scenario.[28]

Table 4. Distribution Systems Mitigations Needed in 75% DER Scenario

Region	Total Line Miles	Line Miles Reconductored	Line Miles Rebuilt	% Mitigation	Transformer Upgrades
Arecibo	4,790	19	381.8	8.4	15
Bayamon	2,442	114.4	131	10.1	22
Caguas	6,761	191.6	384	8.5	30
Carolina	3,310	141	172.3	9.5	15
Mayaguez	5,482	52.7	365.7	7.7	18
Ponce ES	2,828	16.9	160	6.3	11
Ponce OE	2,526	26.8	177.3	8.1	10
San Juan	2,908	35	133.4	5.8	28
Vieques	166	1	14.5	9.3	0
Culebra	68	1.2	3.6	7.1	0

These mitigations are further described in the EE+ report.

To price out the cost of these mitigations we used data given to us by EE+ based on their experience upgrading distribution systems throughout North America. The distribution system presents a particular point of vulnerability for Puerto Rico, as it does for all electrical systems, so we added in a 20% hardening cost to address at least a portion of the hurricane risk to the system. The per unit upgrade costs are given in Table 5.

[28] Only one scenario was summarized in this report for brevity. The needed mitigations in each scenario are given in the EE+ report in the tables in Section V.

Table 5. Per Unit Distribution Mitigation Costs

Mitigation	Cost
Reconductoring	$94,556 per mile
Rebuilding	$157,594 per mile
Transformer Upgrade	$49,200 per MVA

These upgrade costs were then multiplied by the volume of mitigations needed in each scenario as described in the EE+ report.

4.5. Existing Thermal Generation

Three sources were used to estimate the cost of operating and maintaining (O&M) the existing fleet of thermal generation.

1. Telos study report [29]
   - Table 9 summarizes the fuel, variable O&M and startup costs in each of scenario; Base Case, 25% DER, 50% DER, and 75% DER.

2. PREPA IRP
   - The fixed O&M costs in $/kW-year were multiplied by the installed capacity, net of retirements, in the CAMBIO Study to estimate fixed O&M in each scenario.

3. Energy Information Administration (EIA)[30]
   - EIA commissioned a cost study in 2019 that characterized the cost of capitalized maintenance for different generating technologies by size and age. The cost estimates in $/kW-year were multiplied by the installed capacity, net of retirements, in each scenario to estimate capitalized maintenance.

Table 6 gives representative Fixed O&M (FOM) and capitalized maintenance (CAPEX) values assumed in this study.

[29] Puerto Rico DER Integration Study, Telos 2020, Table 9, page 26
[30] Generating Unit Annual Capital and Life Extension Costs Analysis, Sargent & Lundy, December 2019

Table 6: Thermal FOM and CAPEX Representative Values (2020$/kw-yr)

Case	FOM	CAPEX
Coal	$38.37	$22.55
Combined Cycle Gas	$25.99	$20.31
Oil/Gas Steam	$29.99	$9.69

To adjust fuel prices for the Advanced case we assumed a 40% decrease in prices from the Moderate case. Those results are shown in Section 5.6.

4.6. Carbon

The externality value of carbon dioxide emissions were priced using the Social Cost of Carbon ("SCC") from the EPA's Intergovernmental Working Group's (IWG) Central Estimate[31] at a 3% discount rate. The SCC is an externality value, meaning that it is an attempt to monetize the climate impact of greenhouse gases that are not regulated (internalized). Externality values like the SCC allow economic analyses like this one to explicitly account for the damage caused by greenhouse gases.

Table 7: Price of Carbon Emissions

Year of Emission	2020 $/Ton
2020	$69
2025	$76
2030	$81
2035	$87

The 2035 SCC cost was multiplied by the carbon emissions estimates from Telos' production cost modeling[32] to arrive at the cost of carbon emissions in 2035.

5. Scenario Cost Results

The results of the cost analysis for each major cost category appears in the following sections. First, we show the three primary system costs, solar PV, BESS and the distribution system upgrades using a levelization approach called a "economic carrying charge" (ECC). ECCs spread the total cost of a capital investment evenly across the lifetime of that investment and can be thought of as a mortgage payment. In order to create this levelized payment one must assume a discount rate. We use the two discount rates, 6.5% and 3.99%, described in Section 4.1, above.

[31] https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html
[32] Telos report, Table 8

5.1. Solar (PV)

The costs of solar PV appears in the following table. Because we assumed a lifetime for solar panels greater than 15 years the panels do not have to be replaced during the study period and so the results shown in Table 8 are the sum the “mortgage payment" associated with the installed solar. The term for this in the energy industry is “economic carrying charge” (ECC). Renewable costs are often recovered from customers as a levelized payment, so this is a reasonable approximation of the cost in rates in 2035. These costs are different than the total investment in PV assumed in this study which are given in Section 7.

Table 8: PV Cost Results (Millions of 2020$)

Price Case	Metric	Unit	25% DER	50% DER	75% DER
Moderate	ECC @ 6.5%	2020 $/Year	$145	$248	$354
	ECC @ 3.99%	2020 $/Year	$122	$224	$329
Advanced	ECC @ 6.5%	2020 $/Year	$134	$213	$295
	ECC @ 3.99%	2020 $/Year	$112	$190	$272

5.2. BESS

Like solar, these ECC values are the sum of the levelized costs of batteries installed through the period from 2021 to 2035. Because the batteries have a 14-year life, no replacement cost was assumed. These values do not represent the total investment need to realize any of the DER scenarios.

Table 9: BESS Cost Results (Millions of 2020$)

Price Case	Metric	Unit	25% DER	50% DER	75% DER
Moderate	ECC @ 6.5%	2020 $/Year	$145	$248	$354
	ECC @ 3.99%	2020 $/Year	$186	$262	$336
Advanced	ECC @ 6.5%	2020 $/Year	$182	$238	$292
	ECC @ 3.99%	2020 $/Year	$174	$237	$299

5.3. Distribution System

To calculate the ECC equivalent of the distribution system costs, we took the sum of the total costs of all mitigations and levelized that sum using the 6.5% and then 3.99% discount rates. Table **10** shows the cost per category of mitigations needed to enable the DER build out. Because the Base Case mitigations are additive to the DER scenarios, the DER scenario costs include the Base Case mitigations.

Table 10. Distribution Mitigation Costs by Scenario and Mitigation (2020$)

Scenario	Transformer Upgrade Cost	Reconductor Cost	Rebuild Cost	Total Cost
Base	$0	$41,141,424	$243,592,659	$284,734,084

25% DER	$0	$77,545,581	$455,887,200	$533,432,781
50% DER	$2,410,800	$76,269,071	$516,119,531	$594,799,403
75% DER	$7,330,800	$97,837,352	$546,739,997	$651,908,149

The cost includes a 20% adder for hardening based on a report by the World Bank[33] that estimates the hardening costs for a variety of power related infrastructure.

5.4. Thermal Operating Costs

The cost to operate the existing thermal generation fleet inclusive of fuel, variable O&M, fixed O&M, startup costs, and capitalized maintenance are shown in Table 11. The "Moderate" price case equates to the base case prices as modeled by Telos and the "Advanced" price case equates to a lower fuel price scenario, where fuel prices decrease by about 40%. The Advance case estimate was based on observed, historical volatility in oil and gas commodity prices. No volatility in coal pricing was assumed due to lack of data specific to Puerto Rico.

Table 11: Thermal Costs in 2035 (Millions of 2020$)

Price Case	Unit	Base Case	25% DER	50% DER	75% DER
Moderate	Millions of 2020 $	$1,341	$1,188	$883	$603
Advanced	Millions of 2020 $	$973	$819	$614	$431

All costs except the capitalized maintenance were derived from data from PREPA, primarily in its 2019 IRP and supporting workpapers. In order to account for at least an estimate of the cost of major maintenance associated with the thermal units we used a 2019 report prepared by Sargent & Lundy on behalf of the Energy Information Administration ("EIA").[34] Normally this type of maintenance would be capitalized, i.e. booked to rate base with a rate of return assigned to it. Conservatively, we assumed it was simply expensed to ratepayers.

Table **12** provides a breakdown of thermal costs by type and by scenario under Moderate case assumptions.

Table 12: Thermal Generation Costs at Mod. Prices (Millions of 2020$/yr)

Case	Base	25% DER	50% DER	75% DER
Fuel Costs	$1,003	$926	$677	$432
Fixed O&M + Cap. Maint.	$255	$198	$151	$130
Variable O&M	$59	$32	$21	$13
Startup Costs	$24	$31	$34	$28

[33] Miyamoto International. "Increasing Infrastructure Resilience Background Report." February 2019. Available at: http://documents1.worldbank.org/curated/en/474111560527161937/pdf/Final-Report.pdf
[34] U.S. Energy Information Administration. "Generating Unit Annual Capital and Life Extension Costs." December 2019. Available at: https://www.eia.gov/analysis/studies/powerplants/generationcost/pdf/full_report.pdf

Total Costs	**$1,341**	**$1,188**	**$883**	**$603**

It is worth noting that virtually the entirety of the fuel costs in each scenario are exports of Puerto Rican dollars to off-island entities. This has been and remains a material point of price risk for Puerto Rico and for the stability of PREPA's rates.

5.5. Carbon Costs

As with the thermal operating costs in the previous section, the cost of carbon emissions is expressed in 2020 dollars. Carbon dioxide emissions are priced at the Social Cost of Carbon mid-point trajectory as determined by the Environmental Protection Agency's Intergovernmental Working Group.

Table 13: CO_2 Emissions Cost (Millions of 2020 $/yr)

Metric	Unit	Base Case	25% DER	50% DER	75% DER
Emissions Cost	2020 $/Year	$729	$476	$339	$215

5.6. Total Costs

The total cost to operate the system under each scenario is the sum of annual operating and carrying (levelized) costs for all five cost categories: PV, BESS, distribution system, thermal operating costs and carbon costs. The sum of these costs appears in the following two tables using each of the two discount rates used throughout this report.

Table 14: Total Cost Results at 6.5% Discount Rate (Millions of 2020 $/yr)

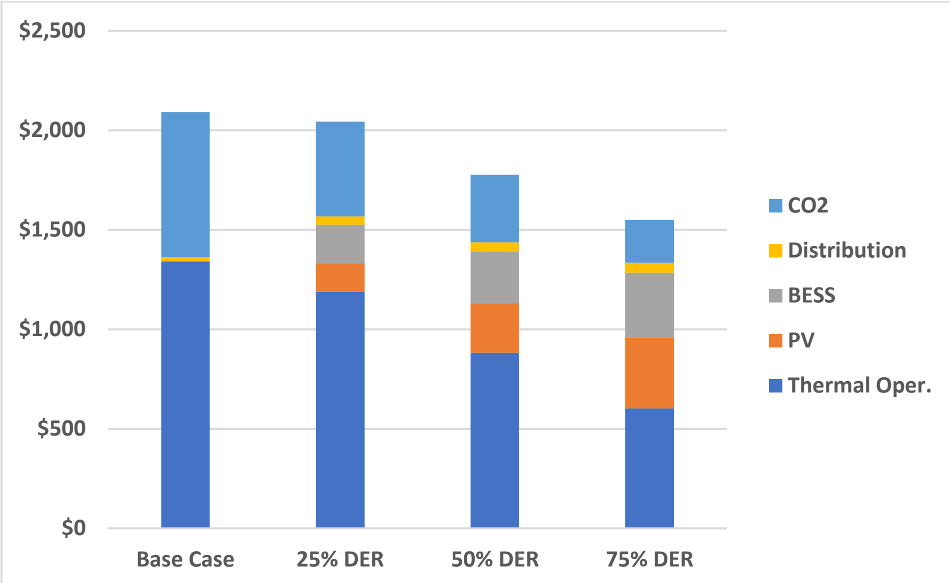
Metric	Unit	Base Case	25% DER	50% DER	75% DER
Moderate	$/Year	$2,091	$2,043	$1,776	$1,549
Advanced	$/Year	$1,724	$1,651	$1,448	$1,284

Table 15: Total Cost Results at 3.99% Discount Rate (Millions of 2020 $/yr)

Metric	Unit	Base Case	25% DER	50% DER	75% DER
Moderate	$/Year	$2,086	$2,002	$1,742	$1,521
Advanced	$/Year	$1,718	$1,612	$1,414	$1,255

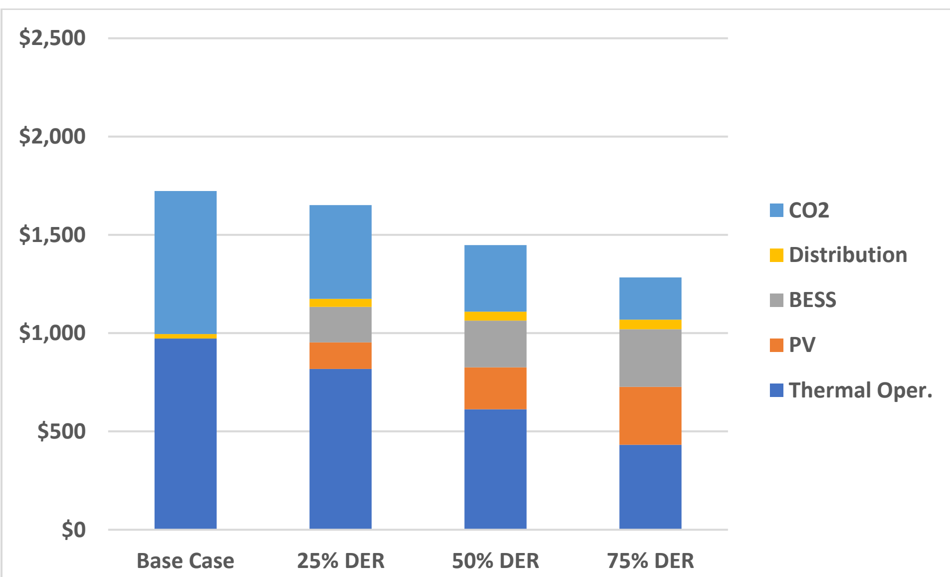
The following figure combines all of the annual costs into a single chart by cost category under Moderate pricing assumptions. Total system costs in the Base case and 25% DER scenario are very similar. Costs are much lower in the 50% and 75% DER scenarios because of the increasing utilization of lower cost solar in the commercial and industrial sectors, because of larger displacement of oil-fired generation (the highest cost fuel), and because of the decreasing magnitude of carbon dioxide externalities relative to the other scenarios.

Figure 6: Total Operating & Carrying Costs with Moderate Prices at 6.5% (Millions of 2020$)



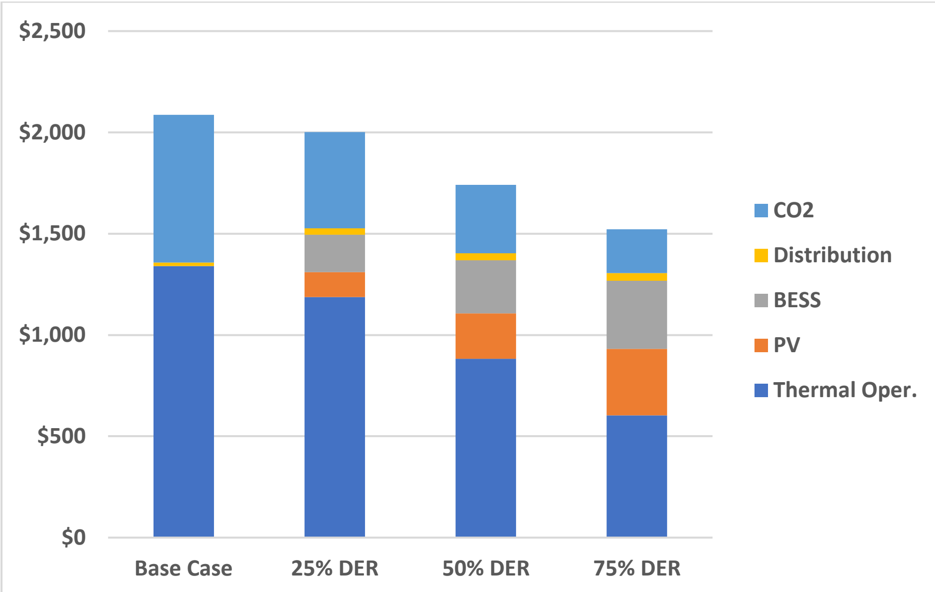
The relative cost dynamic of the scenarios is little changed under Advanced case pricing. PV and BESS capital costs decline, but so do fuel costs and because those predominate in the Base Case its overall cost is greatly reduced as well.

Figure 7. Total Operating & Carrying Costs with Advanced Prices at 6.5% (Millions of 2020$)



These results look similar under the alternative discount rate assumption of 3.99% as shown in Figure 8. The 75% DER Scenario is very clearly preferable over the Base Case. And the same is true for the 25% and 50% DER Scenarios.

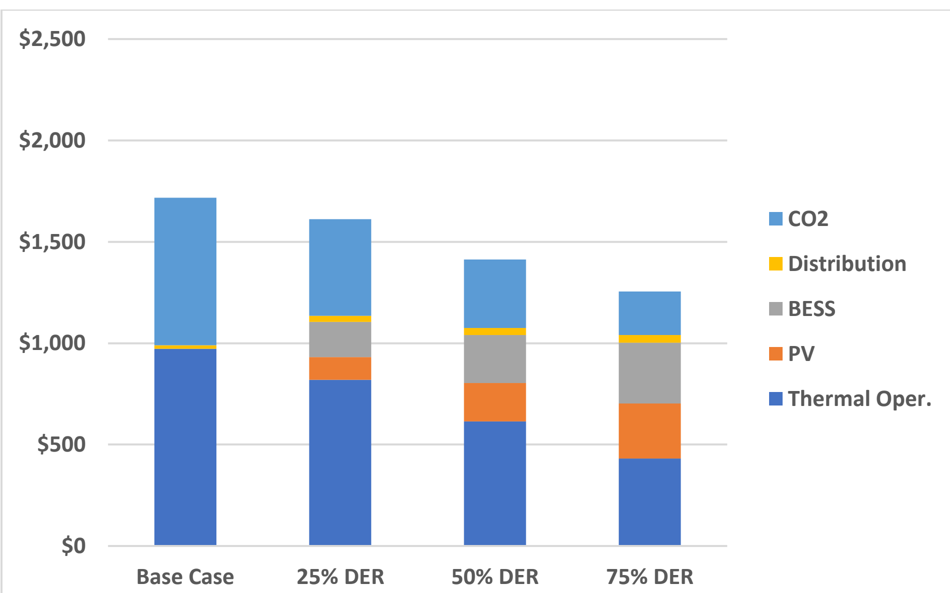
Figure 8. Total Operating and Carrying Costs with Moderate Prices at 3.99% (Millions of 2020$)



This result is simply the product of a changed assumption about the time value of money from 6.5% to 3.99%.

Similarly, under Advanced pricing assumptions, the DER Scenarios look much more preferable relative to the Base Case.

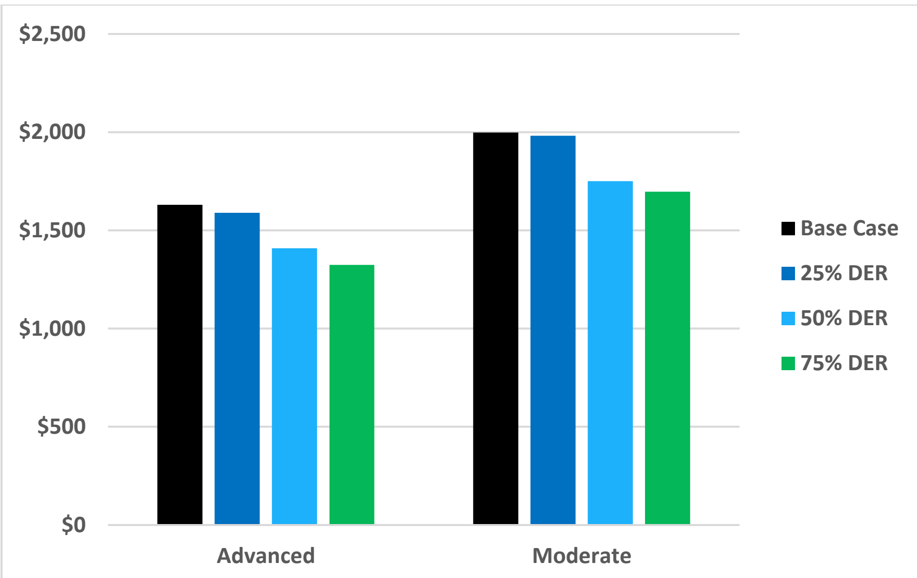
Figure 9. Total Operating and Carrying Costs with Advance Prices at 3.99% (Millions of 2020$)



6. Sensitivity Results

Telos also ran two sensitivities examining the impacts of imposing a minimum inertia constraint and synchronous ratio to ensure system reliability under current operational conditions. These constraints served to keep additional thermal generation online (though it did not change retirements). The net effect is to increase system cost, particularly in the 75% DER scenario which, but for the inertia constraint, would have had significantly more hours of 100% inverter-based generation.

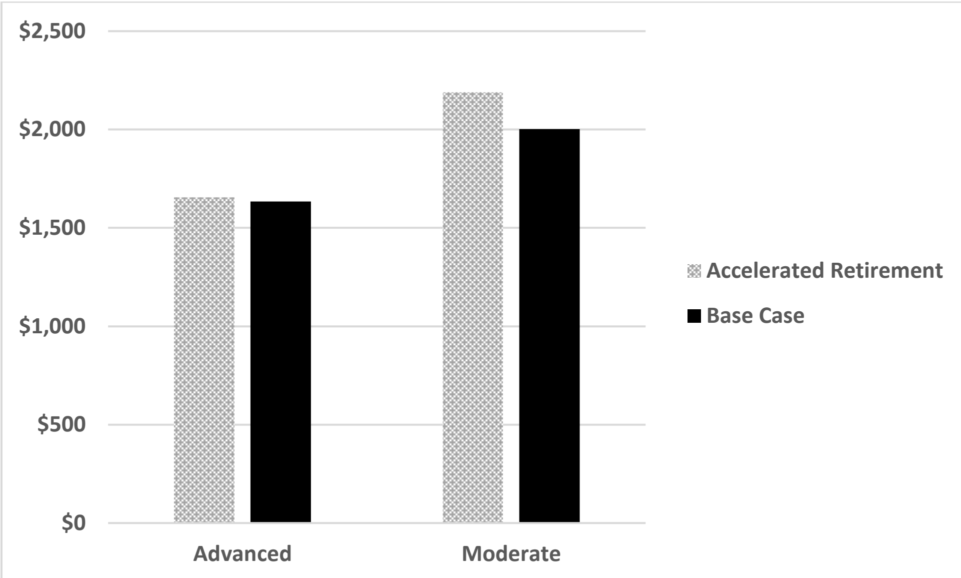
Figure 10. Total Operating & Carrying Costs Under Grid Stability Sensitivity (Millions 2020$)



This sensitivity eliminates a significant portion of the benefit of the 75% DER scenario, i.e, reduced oil spending. The higher DER scenarios still contain the same level of PV and BESS investment, but require more fuel in order to satisfy the minimum inertia and synchronous ratio constraints. Even so, the 75% DER scenario was still significantly cheaper than the Base Case.

We also looked at a second sensitivity exploring early retirement of AES (Figure 11). This sensitivity examined PREPA's grid in 2024 assuming that the AES units had been retired. Under Moderate case assumptions early retirement is slightly more expensive than the Base Case which includes the AES units. This result is largely expected because the Base Case makes no assumptions about additional costs to mitigate coal ash disposal and other environmental burdens imposed by the AES units (beyond pricing its carbon dioxide related externalities). Under Advanced Case assumptions, retirement is even in cost with a cleaner portfolios of resources.

Figure 11. Total Operating & Carrying Costs Under AES Accelerated Retirement Sensitivity (Millions 2020$)



7. Comparison to 2019 PREPA IRP

At the time that we began this analysis the outcome of PREPA's 2019 IRP was uncertain. The case was awaiting an order from the Puerto Rico Energy Bureau and there was, therefore, no clarity on whether the Bureau would adopt PREPA's preferred plan in that IRP – the so-called Energy System Modernization ("ESM") plan or rule on a different plan altogether. Rather than compare the DER scenarios to a plan that may be out of date by the time the analysis was completed, we chose to compare the DER scenarios to the system as it existed at the start of 2020.

While our results may not be fully comparable to PREPA's 2019 IRP because of differing assumptions about load and the fact that we are simulating only 2035 rather than the full IRP planning period of 2019 - 2038, there is still a useful comparison that can be made – between the total generation and transmission investment under the ESM plan versus the DER scenarios.

That investment is summarized in Figure 12, below.

Figure 12. Total Capital Investment, 2020 – 2035

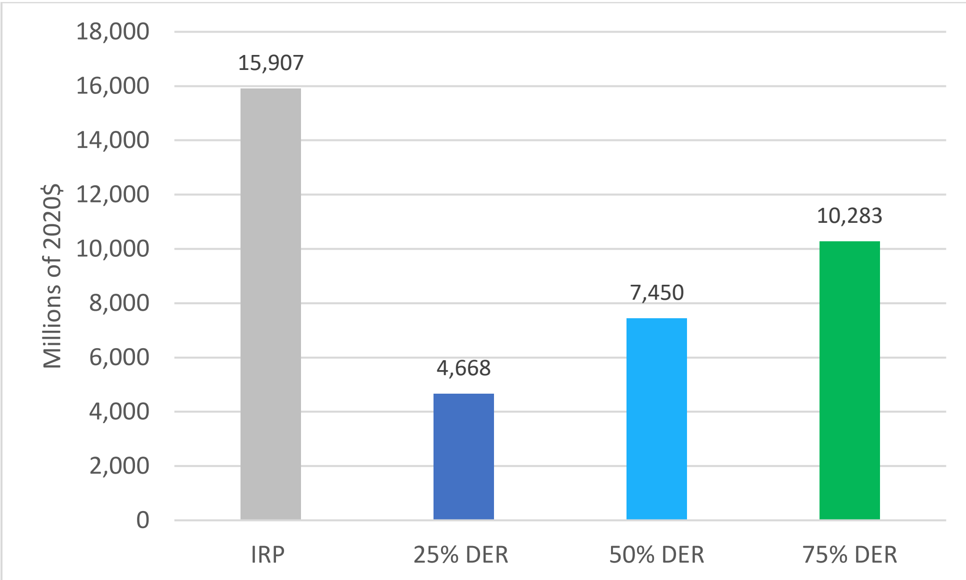
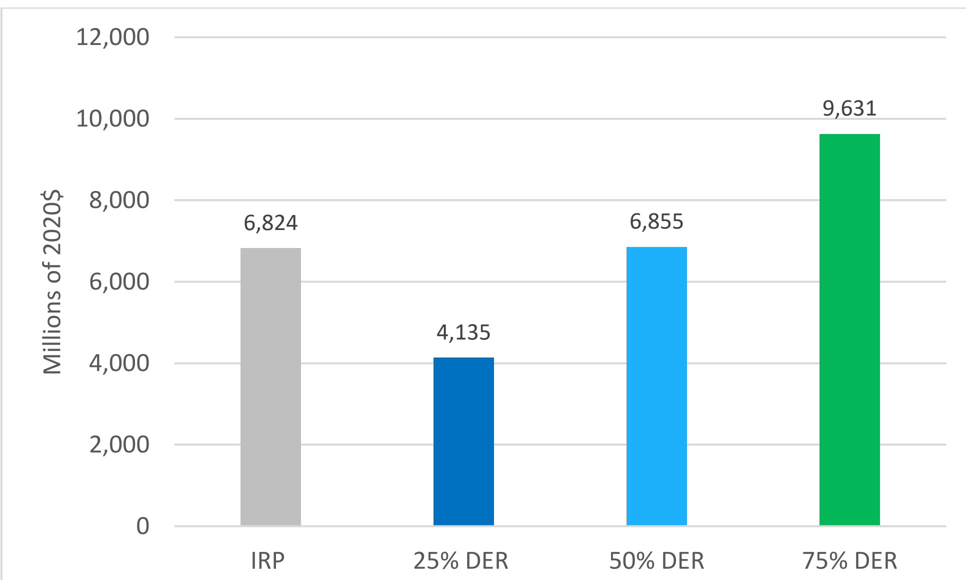


Figure 13 and Figure *14* show the capital investment given in Figure 12 broken down between generation and transmission and distribution expenditures.

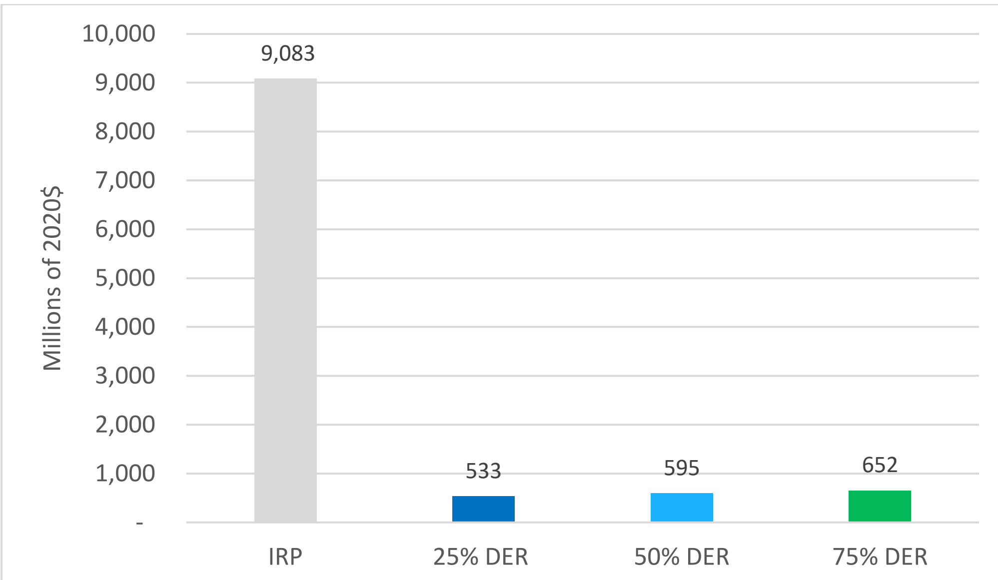
Figure 13. Total Generation Investment, 2020 – 2035



IRP total generation investment does not include the 848 MW of distributed solar by 2035 that was included in the ESM. It is solely the product of utility scale solar, battery storage, and gas assets that were proposed as part of the ESM. For that reason alone, the $6.824 billion of generation investment in the IRP is understated in comparison to the DER scenarios. Either way it makes sense that the DER scenarios would have more generation investment because they are predominantly served by fuel-less power plants and therefore more cost goes into capital than into fuel and operating expenses.

The opposite is the case when comparing total transmission and distribution investment in the IRP to the identified investment in the DER scenarios (Figure 14). Total transmission and distribution investment dwarfs that identified in EE+'s modeling. There are several reasons for this.

Figure 14. Total Transmission and Distribution Investment

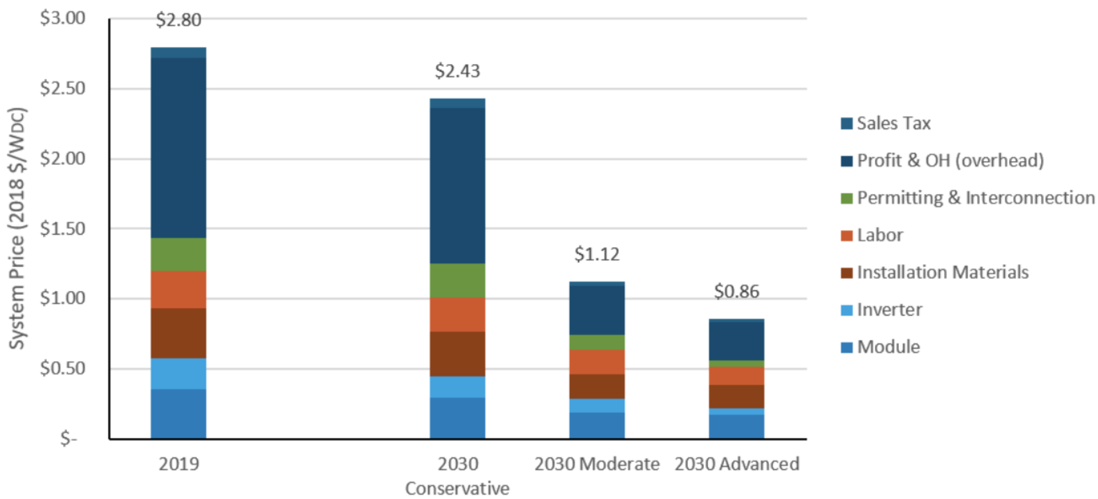


First, the minigrid/microgrid component of the ESM was very costly – at least $5 billion was devoted to that purpose alone. Second, at least $3 billion of the proposed IRP T&D investment was to address hardening and aging in existing infrastructure. Our study can provide no insight into those expenditures because, as described in their report, EE+ had to extrapolate the seven representative circuits provided by PREPA across the entire island. Therefore, EE+ lacked the data to assess the existing condition of distribution system assets. We cannot conclude, therefore that all or a portion of the $3+ billion in aging and hardening expenditures would be needed (or not) in any future scenario. Even if $3 billion in aging and hardening expenditures needed to be added to all scenarios we evaluated, distribution system costs would still be over $5 billion lower than those proposed as part of the ESM. We believe this raises substantial questions about the merits of PREPA's minigrid/microgrid concept as the least cost way to deliver resiliency to Puerto Rico's grid.

8. Opportunities to Lower Total System Costs

Achieving the 75% DER scenario in particular will take concerted and robust policy and regulatory steps. The manner in which the PV and BESS are deployed can also influence the ability to achieve this goal and total system cost. Targeted deployment that installs rooftop systems by neighborhood, for example, could likely reduce cost. A similar approach was used in the Netherland's Energiesprong housing retrofit program. Within four years of starting the program per unit cost had been reduced by 60%.[35] We do not know what magnitude of cost reductions is likely to be achievable for a similar program focused on the buildout of rooftop solar, but we believe is very reasonable to think cost reductions would be had.

Figure 15. Breakdown of Residential Solar Cost Components[36]



The 2020 ATB included NREL's projection of residential solar prices by cost component. Figure 15 clearly shows that there are significant "soft costs" embedded in current solar prices and to the extent that policy tools can be used to remove profit and overhead for example, near-term costs could come down even further.

Finally, there is a significant opportunity for Puerto Rico to offset the cost of deploying the solar and battery storage buildouts in this study by leveraging federal funding. A Community Development Block Grant – Disaster Recovery (CDBG-DR) grant of over $1.5 billion has been allocated to Puerto Rico. At least a portion of those funds are to be directed to the Community Energy and Water Resilience Installations Program which will provide single family homeowners, business and/or public facilities energy and water efficiency improvements to promote resilience with the installation of PV systems with battery back-up for critical loads and water storage system. Additionally, FEMA has allocated over $10 billion for the rebuilding and upgrading of Puerto Rico's electrical system. Those funds are essentially unconstrained and can and should be used to invest in generation that will improve system reliability and resiliency rather than further cementing Puerto Rico's centralized generation model.

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[35] https://sbcanada.org/wp-content/uploads/2017/09/Energiesprong-Summary-Report.pdf

[36] Taken from NREL 2020 ATB: https://atb.nrel.gov/electricity/2020/index.php?t=sr

9. Conclusions

The project team members on this study engaged in a detailed and complex set of analyses to simulate Puerto Rico's electric grid under high DER penetration. After many months of effort we conclude that a system predominately served by distributed solar is feasible, achievable, and very likely to reduce overall system costs. Among our primary findings are the following:

1. All the DER scenarios were either comparable to or much less costly than a business-as-usual case.
2. More DER also enables Puerto Rico to realize more of the benefits of reduced fuel consumption because greater quantities of oil generation are offset.
3. Under a business-as-usual scenario (Base Case), Puerto Rico would expend $1 billion a year to primarily foreign entities on fuel alone. With load served by 75% DERs those expenditures are more than halved.
4. It is important that Puerto Rico chart a path (and soon) to realizing the benefits of energy efficiency as a way to provide further rate stability and electric bill reductions to all Puerto Ricans.
5. Technologies under development such as smart inverters will be key to unlocking the full economic benefits of the high DER scenarios analyzed here.
6. This study made no attempt to monetize the considerable value of increased reliability or the ability of millions of Puerto Ricans to self-supply at least their critical loads in the event of another hurricane.