EE/CprE/SE 491 WEEKLY REPORT 4

2/20/23 - 2/26/23

Group Number: **16**

Project title: **Feasibility of Solar PV Energy for Puerto Rico**

Client &/Advisor: **Vikram Dalal**

Team Members/Role: **Adam Curtis, Hannah Nelson, Isaac Buettner, Larry Trinh, Manuel Perez-Colon**

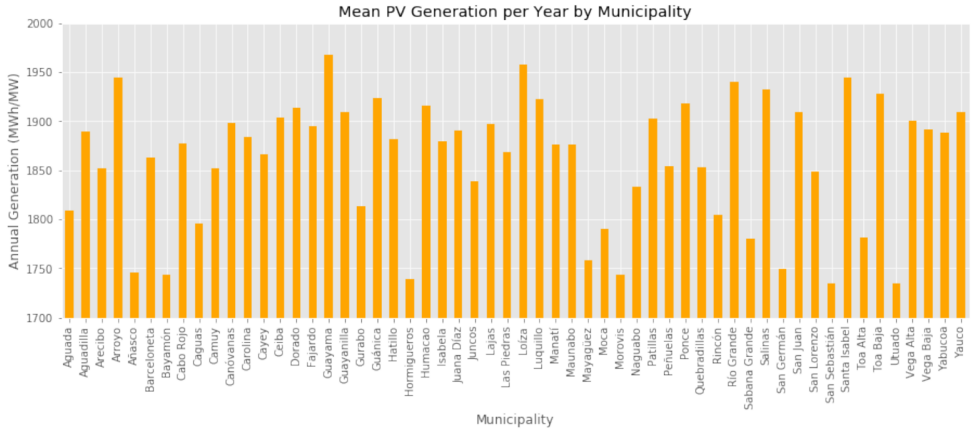
- ***o*** **Weekly Summary**

We had our biweekly meeting with Dalal, where we shared a presentation of what we had all accomplished in the last 2 weeks. Each of us individually presented our work. From there, Dalal asked us some questions and helped us figure out where to go from what we had. This was mainly focused on PV price points across the island and what is feasible for an average resident. We also emphasized finding qualitative data on what current rooftop PV systems provided for the grid.

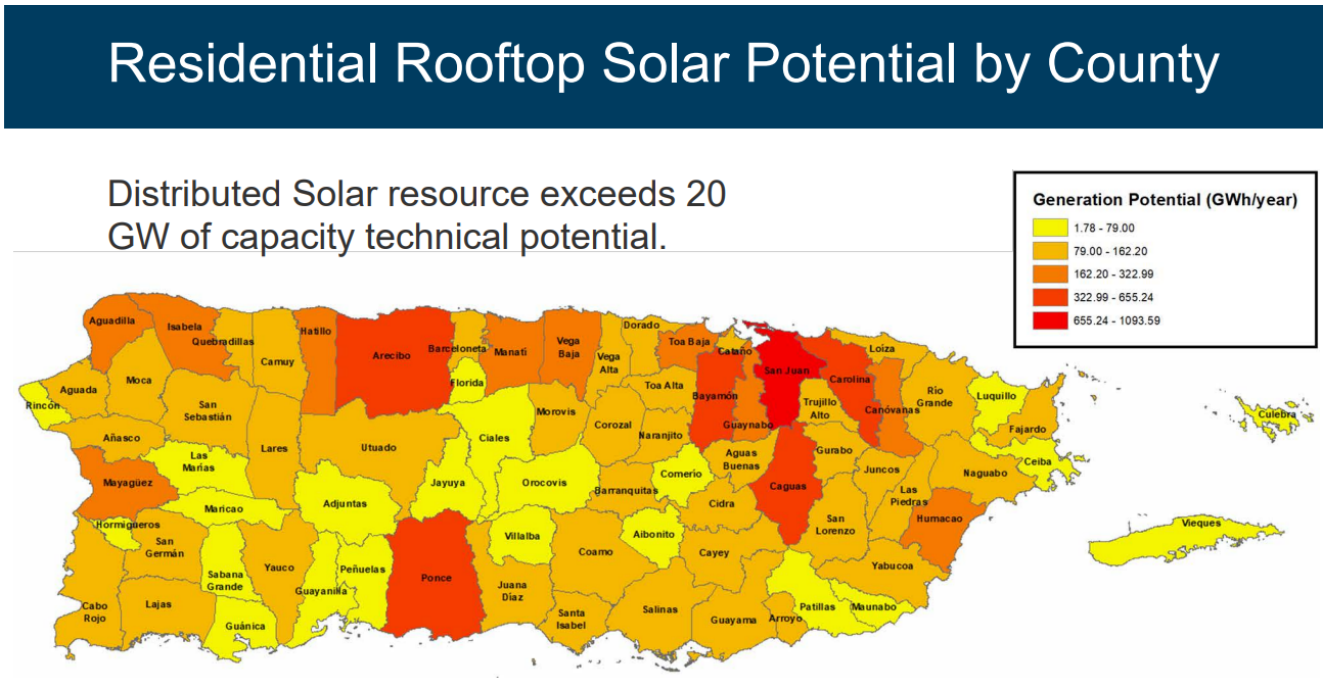
- ***o*** **Past Week's Accomplishments**

Hannah: Educated self on what grid privatization means for the future of renewable energy. Luma Energy still operates and maintains the transmission and distribution systems, whereas Genera PR will operate generation and be in charge of reaching the PR100 goal. In addition, this week, the US approved $1B in funding– the first round will be available this summer. The goal of the first round is to deploy residential PV and battery storage to vulnerable homes and to those will disabilities and/or health concerns. It would be interesting to get a head start on what can be accomplished with that first fund (guessing $500k?). We could calculate how many PV systems that could fund with some battery storage.

Also looked into the NREL Qualitative report. 58/78 municipalities have substantial potential– the lowest of those was a solid 10 MW of solar energy capability. A GHI report (amount of shortwave radiation received from above onto a horizontal surface) and COV report (variability) confirm that SW PR is the best place for large solar farms if needed. Another study shows that wind energy may be the best complement to solar energy at night, so less battery storage is needed. However, these may be more expensive to withstand hurricanes.



Manuel: Did some research on capacity for rooftops PVs largely coming from the "prosumers", meaning residential rooftops. Annual residential solar potential is 24.6 TWh. Also Assess which areas on the island are available for PV development. Similarly compiled the areas of the surrounding bodies of water would be prohibited form being used for Wind power generation.



Adam: Researched the existing power generation systems in Puerto Rico, finding that they are primarily Oil or Diesel powered turbines. Most were built in the 1960s/70s, but I did find one built in 1997 and one in 2007. According to one source, AEEPR , the total installed generation capacity in PR is 5839 MW, with 69% of this coming from fuel (Oil/diesel) turbines[1]. I was also able to find an engineering report prepared for PREPA from a firm called Sargent and Lundy in which they analyzed one specific generation plant called the Cambalanche Power Plant and reported on the condition of the plant, maintenance, capabilities, and provided recommendations as to how the plant can improve its efficiency and provide grid stability. It was determined that the turbine rotors for turbines 2 and 3, the only two still in operation at this plant were aging at the time,

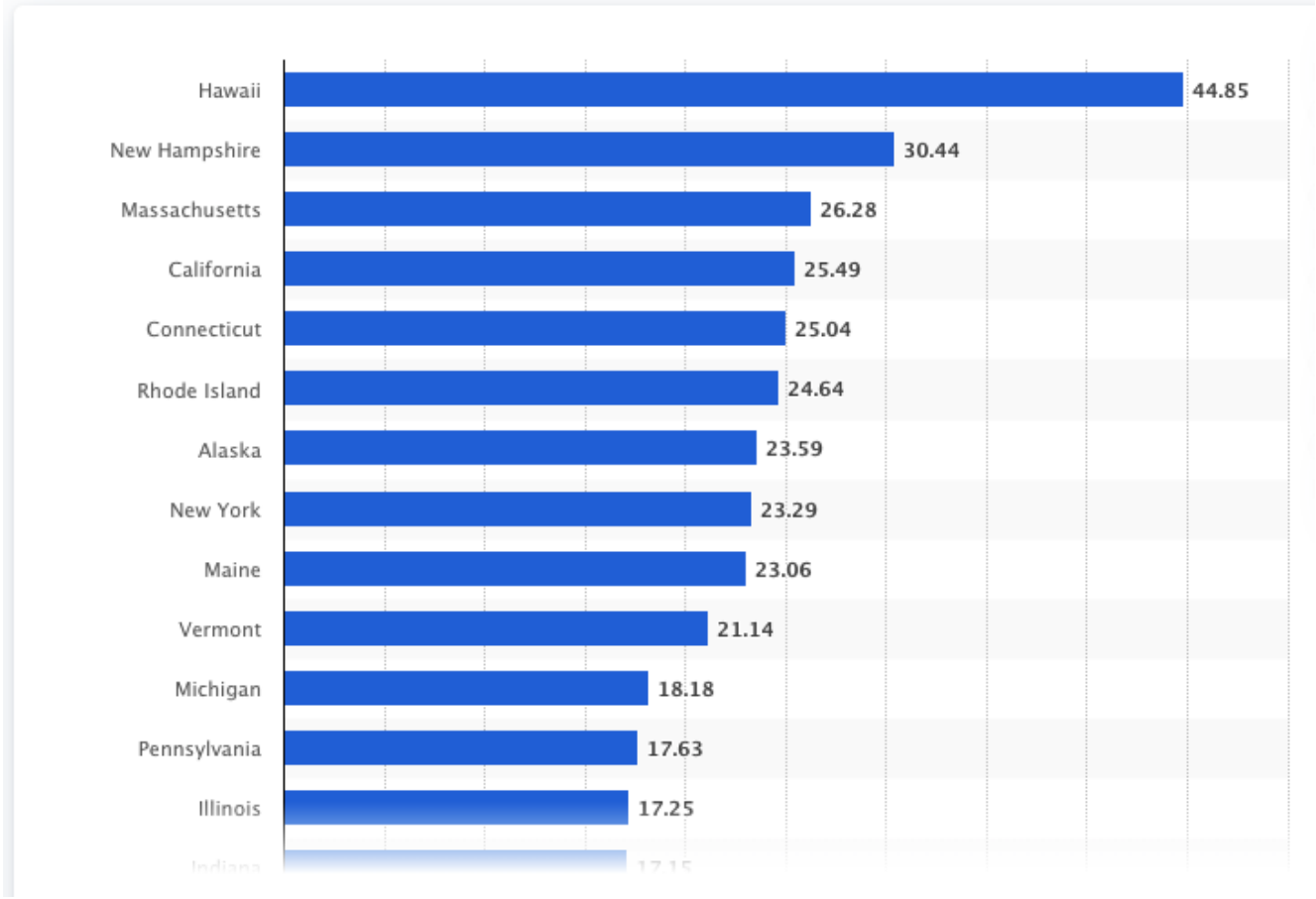
and that it would be extremely expensive to repair or replace them if the need arose. This study was concluded in September of 2021, so it is difficult to say whether PREPA took the recommendations and did anything with them, especially considering the new management the grid is under today [2].

I was also able to find information about the amount of energy generated in Puerto Rico by various sources from the EIA [3]. Unfortunately, the type of renewable generation source was not itemized in this data, but it is clear that the vast majority of generation in Puerto Rico still comes from fossil fuel powered turbines, including as recent as 2020.

PIN	API		2016	2017	2018	2019	2020
		Puerto Rico					
		Generation (billion kWh)	21	17	17	17	17
		Fossil fuels (billion kWh)	21	16	17	17	17
		Renewables (billion kWh)	0.4	0.4	0.2	0.5	0.5
		Hydroelectricity (billion kWh)	(s)	(s)	(s)	(s)	(s)
		Non-hydroelectric renewables (billion kWh)	0.3	0.3	0.2	0.4	0.4
		Capacity (million kW)	6.4	6.4	6	6.3	6.4

[1]https://aeepr.com/en-us/QuienesSomos/Pages/ElectricSystem.aspx#:~:text=This%20system%20comprises%20the%20phases%20of%20power%20generation%2C,Sur%2C%20Complejo%20Aguirre%2C%20San%20Juan%20and%20Palo%20Seco.
[2]https://energia.pr.gov/wp-content/uploads/sites/7/2022/06/SL-015976.CA_Cambalache-IE-Report_Final.pdf
[3]https://www.eia.gov/international/data/world/electricity/more-electricity-data?pd=2&p=0000000000000000000040000000bo&u=0&f=A&v=mapbubble&a=-&i=none&vo=value&t=C&g=none&l=249-020000000000000000080000000000000000200000000020g08&s=315532800000&e=1577836800000&ev=false&

Larry: From the meeting with the advisor on Monday, he required me to do some research on the electricity price in some other high living cost states such as New York, California and Massachusetts. The data below is the price for the residential sector cross the US in September 2022.



Prices

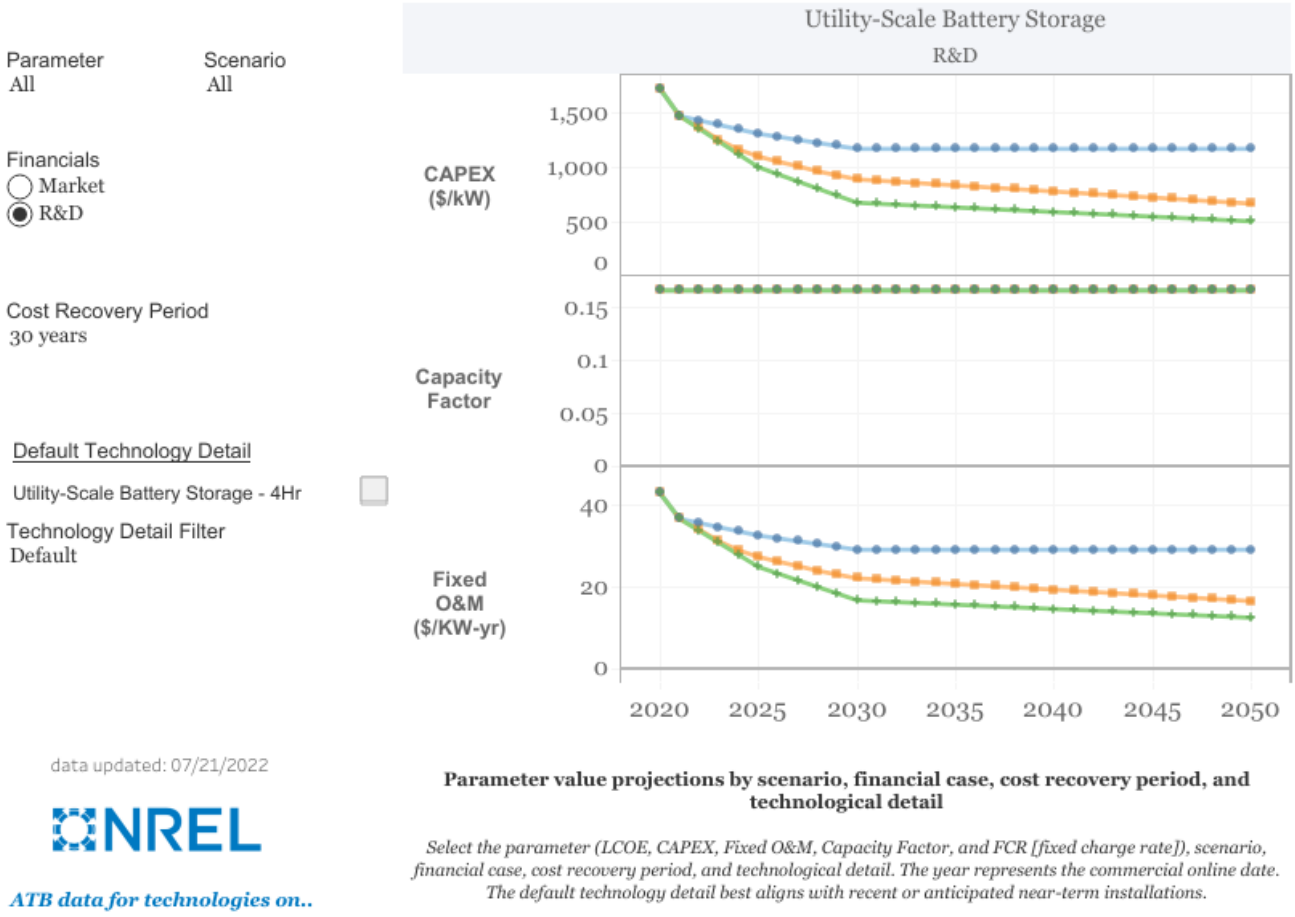
Electricity	Puerto Rico	United States	Period
Residential	26.78 cents/kWh	15.64 cents/kWh	Nov-22
Commercial	30.00 cents/kWh	12.50 cents/kWh	Nov-22
Industrial	27.11 cents/kWh	8.30 cents/kWh	Nov-22

From the comparison, we see that the electricity price of Puerto Rico is higher than most of the states, and it is lower than the electricity price in Hawaii and New Hampshire which are two states that had the highest living cost in 2022.
I was also reading some documentation about solar energy grid planning and operation to understand how the solar energy grid works and what we need to consider when it comes to grid integration.

https://www.statista.com/statistics/630090/states-with-the-average-electricity-price-for-the-residential-sector-in-the-us/
https://www.eia.gov/state/print.php?sid=RQ

https://www.energy.gov/eere/solar/solar-grid-planning-and-operation-basics

Isaac: After last week's meeting, I used this week to focus on what I felt I should have known more on. I primarily focused on costs of energy storage on an energy basis in $/kWh and on a power basis in $/kW. The below figure is from NREL's Annual Technology Baseline or ATB [1]. With data being pulled from sources as recent as 7/21/2022, I felt much more comfortable relying on this data to inform my research. The figure below gives predictions for a 4hr utility-scale Lithium-Ion Battery (LIB), with a focus on Nickel Manganese Cobalt (NMC) and Lithium Iron Phosphat (LIP) batteries in particular. CAPEX stands for capital expenditures and gives a model for how much the initial investment of installing this battery would be. Capacity factor models how often it would be running at full power, which in this data was one-sixth of the time. The fixed O&M costs detail the operating and maintenance costs of each unit by the year, factoring in eventual battery replacement costs.



Parameter value projections by scenario, financial case, cost recovery period, and technological detail

Select the parameter (LCOE, CAPEX, Fixed O&M, Capacity Factor, and FCR [fixed charge rate]), scenario, financial case, cost recovery period, and technological detail. The year represents the commercial online date. The default technology detail best aligns with recent or anticipated near-term installations.

In general, it was reported that in 2021, CAPEX costs for installing a 60MW, 240MWh battery fell 13.14% from $437 to $379 [2]-$369 [1] as detailed in NREL's ATB in the figure below and in articles from PV-Tech

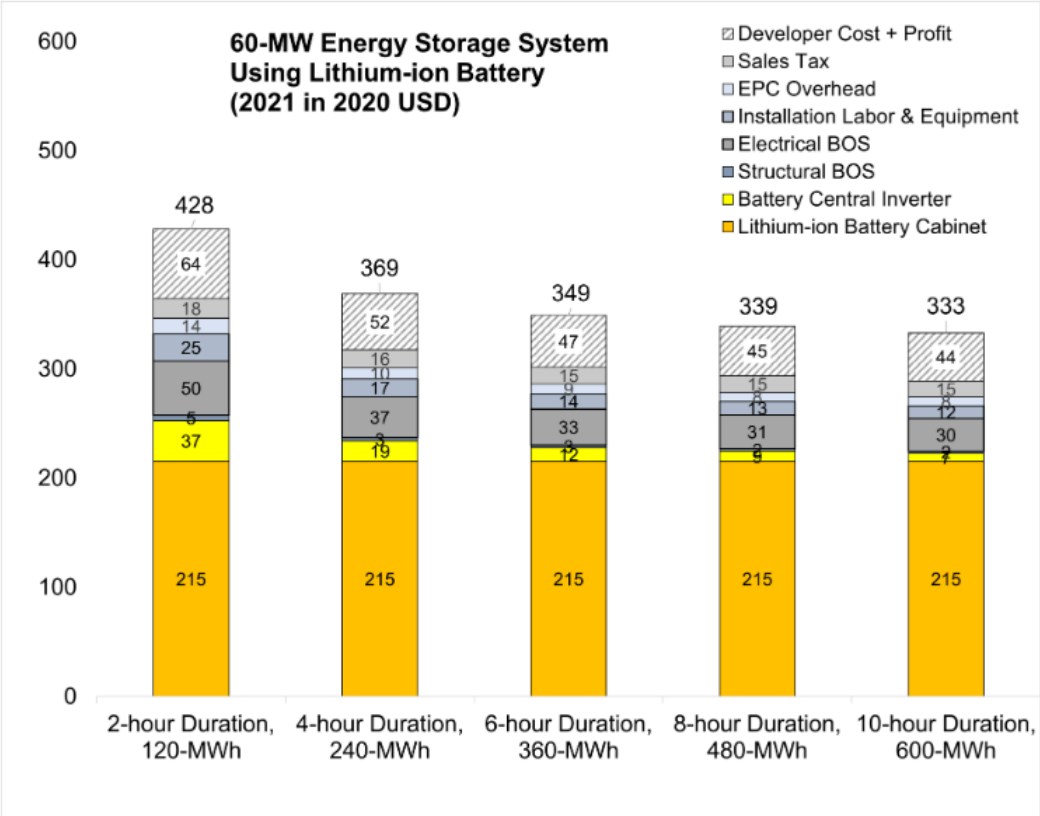


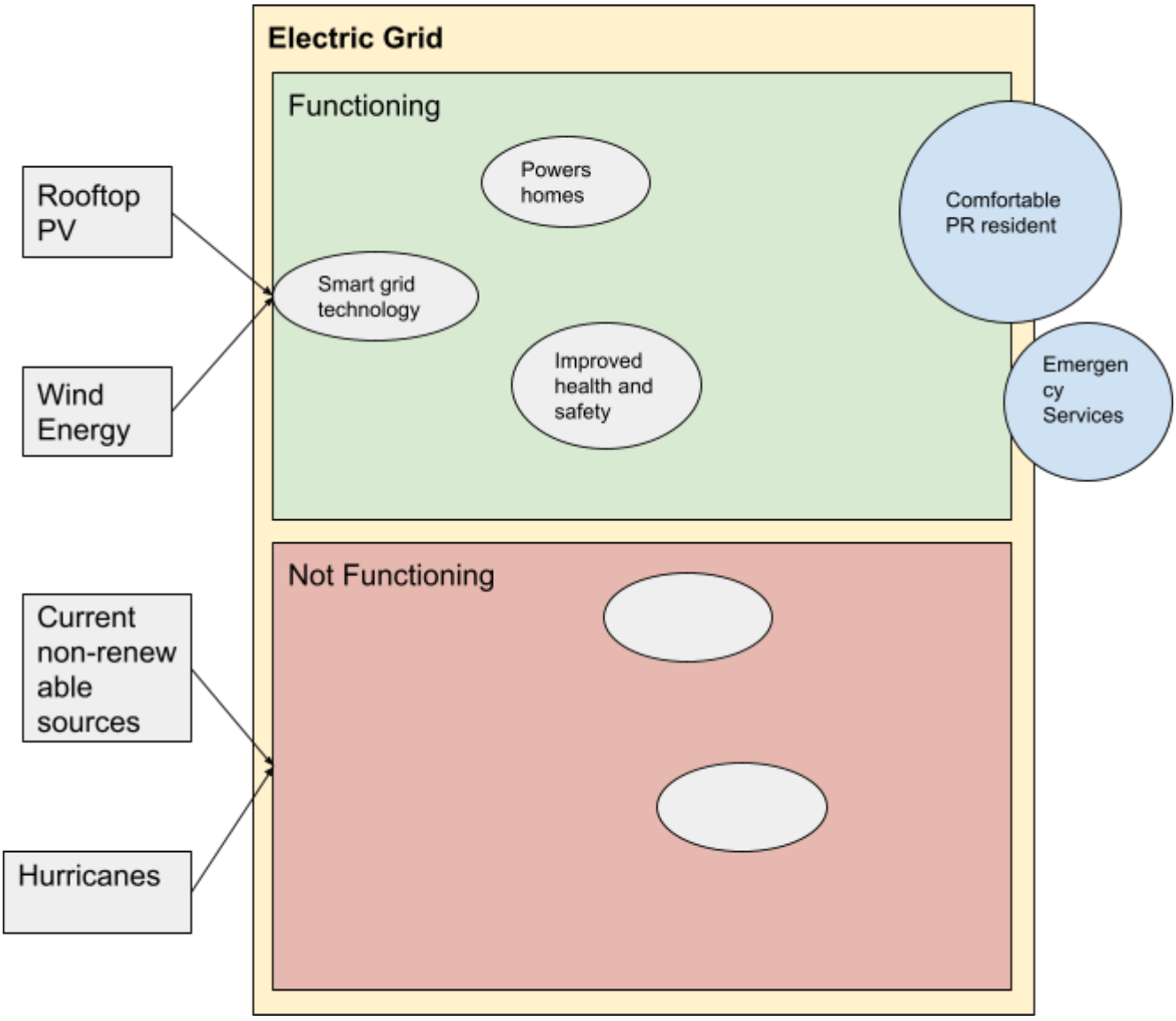
Figure 1. 2021 U.S. utility-scale LIB storage costs for durations of 2–10 hours (60 MW_{DC}) in $/kWh

EPC: engineering, procurement, and construction

[1]https://atb.nrel.gov/electricity/2022/utility-scale_battery_storage

[2]https://www.pv-tech.org/nrel-cost-of-solar-energy-storage-in-us-fell-across-all-segments-from-2020-to-2021/

Use Case Diagram



Individual contributions

NAME	Individual Contributions *(Quick list of contributions. This should be short.)*	Hours this week	HOURS cumulative
Adam Curtis	Research, Professionalism Assignment	5	19
Hannah Nelson	Research, Use-Case, Professionalism Assignment	6	19
Isaac Buettner	Research, Professionalism Assignment	5	15
Larry Trinh	Research, power points	5	17.5
Manuel Perez	Research	3	12

- **Plans for the upcoming week** *(Please describe duties for the upcoming week for each member. What is(are) the task(s)?, Who will contribute to it? Be as concise as possible.)*

Team meeting Monday at 3:15 PM

Hannah - Continue to find qualitative information about the total PR capacity if using rooftop solar. This information is hard to find, but MIT and Princeton did studies I can look into. Also would like to find out what the government has defined a microgrid to be and what regulations for connecting residential PV to transmission lines/how many W can be integrated per system.
Manuel - Pursue finding more precise information, about the viable locations for PV farm installations. Additionally, find cost for offshore Wind Power.
Adam - Find more information itemizing exactly how much power is generated from each source in PR, including wind and solar as well as natural gas. Look deeper into the other power plants besides Cambalanche to find similar information about the condition, age, and reliability of these plants.
Larry - Continue to work on the economy and electricity price. My goal is trying to figure out how much electricity Puerto Rico consumes a year, how much Puerto Rico residents have to pay per KWh. How much electricity the solar energy can supply. I will do some research on that next week. I also have connections with some engineers from my previous company. I will contact them for some more questions. At the same time, I will continue to learn more about solar energy systems and grid integration.
Isaac - Continue to research, look more into cost trends and external impacts (tarriffs, supply chain issues, etc.) Research more to discover how these costs calculated in NREL's ATB which focuses on a general price model for the mainland United States can translate over to other countries or territories, see if there is a trend or conducted data which helps deduce battery pricing in Puerto Rico.