Photovoltaic Feasibility in Puerto Rico

Design Document

SDDEC23-16

Client: Puerto Rico

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Team Website

Revised: December 2023/V2

Executive Summary

Development Standards & Practices Used

Follow grid standards and best practices when considering what type of solar panel and battery system to use. Must stay consistent with current patterns and practice honesty when estimating prices. Any additional standards deemed pertinent during the second semester of the project will be added. The specific standards most pertinent to the project are listed below.

IEEE 1547: "IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces"

- This standard applies to our project as interconnecting our microgrid designs with the existing grid will be extremely important to execute correctly. [2]

NECA 417-19: Designing, Installing, Operating, & Maintaining Microgrids

- If we choose the route of installing microgrids, we will have to highlight the necessary maintenance and installation procedures to maximize the longevity of the new grids. [3]

NFPA 70 (NEC): National Electrical Code

- This is the standard electrical safety code used in the United States for electrical work, and our plan should fit within its safety guidelines. [4]

NFPA 855: Standard for Installation of Energy Storage Systems

- A large portion of our project will relate to designing battery storage systems for the Photovoltaic systems we install, so we must ensure they are installed and maintained correctly, as laid out in this standard. [5]

Summary of Requirements

- Offset a portion of Puerto Rico's energy generation, which currently sits at approx. 18B kWh [14]
- Lower the levelized cost of electricity (LCOE) to improve affordability for PR residents from 25c/kWh to a price similar to that found in California [18]
- Final plan must be economically feasible given the $1.3B allocated from US Government for improving the grid by the development of microgrids
- Technology must be stable under severe weather events
- Must be easy to maintain and operate

Applicable Courses from Iowa State University Curriculum

- IE 305
- EE 303
- EE 456
- EE 351
- EE 455

- EE 452
- ENGL 309/314

New Skills/Knowledge Acquired (Not Taught in Courses)

One of the key aspects of our project is using economic analysis to determine the best course of action, based upon return of investment, the marginal benefit to utility and consumer, and LCOE. These topics have been briefly discussed in IE 305 and EE 351, but in this project, we have learned how to apply these concepts to real-life scenarios. We have done our own research to find the appropriate specifications needed to calculate results that reflect the current market.

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1 Team

1.1 Team Members

1) Hanah Nelson

2) Manuel Perez-Colon

3) Isaac Buettner

4) Larry Trinh

5) Adam Curtis

1.2 Required Skill Sets for Your Project

Research- We must analyze the initiatives set in place for the future of Puerto Rico's grid and assess the viability of these goals. Acquire knowledge on topics such as PV cost, microgrids, transmission lines, energy storage, and distribution.

Grid Design - using software to model the PR grid and define what a microgrid will look like and how it will connect to transmission systems.

Grid Analysis - how does the current grid or a proposed model stand up to natural disasters or other faults?

Presentation - We must effectively communicate our final project plan to our client Dr Dalal and a panel of professors so they have a clear understanding of what exactly we plan to do to solve the problem. We also must be prepared to answer any questions the client may have for us.

Writing - Combining research from all members together cleanly and effectively to make going through notes, reports, etc., easier and more efficient.

1.3 Skill Sets covered by the Team

Research -Everyone

Grid Design - Hannah, Larry

Grid Analysis - Isaac, Adam, Manuel

Presentation - Manuel

Writing - Isaac, Adam, Hannah

Economic Analysis - Adam, Larry

1.4 Project Management Style Adopted by the team

In the first semester of senior design, we followed the agile management style best. This is because we worked mostly independently, with meetings to come together and decide how to move forward. Our work was split up by deciding key objectives that needed to be done within each week, but we individually worked to get those done. As the project progressed in the second semester, we found it more useful to adapt the waterfall method, especially when we worked on grid design, product specifications, and simulation. This allowed us to be focused on multiple aspects at once. The most challenging part of this is sharing our findings each week and keeping documentation organized.

1.5 Initial Project Management Roles

1. Manuel is responsible for team organization, research, and presentation organizing.
2. Hannah is responsible for client interaction, documentation coordination, and research.
3. Adam is responsible for research, presentation organization, and economic and grid analysis.
4. Larry is responsible for economic and social analysis.
5. Isaac is responsible for technical analysis.

2 Introduction

2.1 Problem Statement

The problem we are attempting to solve is that of the inefficient, outdated, and unreliable fossil fuel-powered grid currently contracted in Puerto Rico. 58% of generation in 2022 came from petroleum, while 28% came from natural gas, 12% from coal, and a measly 2% from renewable resources [6]. Puerto Rico's goal is to be 100% reliant on renewable energy by 2050. Many of the existing fossil fuel-powered generation plants in Puerto Rico are also near the end of their service lives, as they were built in the 1960s and 70s, making them extremely inefficient. These issues, combined with the extreme weather conditions and lack of grid maintenance, create a situation where the price of electricity for Puerto Ricans is relatively high, and they are forced to deal with frequent power outages. We will create a plan that can be applied to many locations in Puerto Rico to use solar energy and battery storage to increase the grid's reliability and lower the price of electricity.

2.2 Requirements & Constraints

- Offset a portion of Puerto Rico's energy generation, which currently sits at approx. 18B kWh [14]
- Lower the levelized cost of electricity (LCOE) to improve affordability for PR residents from 25c/kWh to a price similar to that found in California [18]
- Final plan must be economically feasible given the $1.3B allocated from US Government for improving the grid by the development of microgrids
- Technology must be stable under severe weather events
- Must be easy to maintain and operate

2.3 Engineering Standards

IEEE 1547: "IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces"

- This standard applies to our project as interconnecting our microgrid designs with the existing grid will be extremely important to execute correctly. [2]

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2.4 Intended Users and Uses

We anticipate that the average Puerto Rican using electricity will benefit from our project. Currently, they are forced to pay a high price for an unreliable connection. With our PV system and battery, not only will they benefit during power outages, but they will also see a decrease in the cost of electricity. In addition, there will be a sense of community in the areas that share the system– bringing residents together through the bond of sustainable energy.

Our solution of photovoltaics and battery storage will be used by the people of Puerto Rico to cut down on their energy costs, improve the reliability of power in their homes, and the resiliency of their power grid to the frequent hurricanes that have caused significant damage to the existing grid on the island.

People who have lost power from the main grid due to future severe weather events should still have access to power via a significant battery backup system.

PV systems are better for the environment and sustainable long-term– this will relieve future generations from fossil fuel pollution and other climate change related issues.

Our project can also be utilized to critique the current plans and initiatives carried out by the PREPA and other government agencies. We will be evaluating the proposed solutions and their feasibility. Puerto Ricans can use our criticism of the current system as a way to advocate for change and a different way of progressing in the issue.

3 Project Plan

3.1 Project Management/Tracking Procedures

In the first semester of senior design, we followed the agile management style best. This is because we worked mostly independently, with meetings to come together and decide how to move forward. Our work was split up by deciding key objectives that needed to be done within each week, but we individually worked to get those done. As the project progressed in the second semester, we found it more useful to adapt the waterfall method, especially when we worked on grid design, product specifications, and simulation. This allowed us to be focused on multiple aspects at once. The most challenging part of this is sharing our findings each week and keeping documentation organized.

One of our main project goals is to find the best possible solution for Puerto Rico's power grid, and in the course of our research, some of our ideas will not be viable, so we have to be able to reevaluate our priorities at these times.

With time, we have adopted a hybrid model. This is because our work is broken down into 6 large tasks. Within each task are many subtasks executed in the agile style. Team members work individually or in pairs on certain research topics, but we became more independent during the 2nd semester as we had to balance overlapping tasks such as budget development and grid model.

We can use the Gantt chart we created to track our progress on certain tasks and keep us on schedule for the final presentation. This will be through Excel. In addition, we use Google Drive to organize our research, meeting notes, deliverables, etc. This has proved very helpful in sharing information and reference when needed.

3.2 Task Decomposition

Task 1: Develop key guiding questions and/or areas of research.

Task 2: Make contact with an NREL researcher for primary source data.

Task 3: Determine which PV system best suits Puerto Rico (community, farm, rooftop, etc.).

Task 4: Find and apply relevant IEEE standards to our solution.

Task 5: Analyze the cost of our solution to ensure economic feasibility.

Task 6: Develop a model/graphic/representation of the PV solution for Puerto Rico.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

Milestone 1: The solution has a set power and battery storage capacity that supports a portion of the PR 100 goal of 40% renewable reliability by 2025.

Milestone 2: The system has a budget that is within current government funding requirements ($1.3B).

Milestone 3: A quantifiable model is built that demonstrates how, where, and when PV is used across the island.

3.4 Project Timeline/Schedule

Task Number	Task and Subtasks	Completion Date
Task 1	Develop key guiding questions and/or areas of research	2/13/2023

Task 2	Presentation of three options for solution & further research.	3/27/2023
Task 3	Determine which PV system best suits Puerto Rico (community, farm, rooftop, etc.).	5/1/23
Task 4	Develop rooftop design and plan for what components are needed.	9/18/23
Task 5	Analyze the cost of our solution to ensure economic feasibility.	10/23/2023
Task 6	Create a model/graphic/representation of the PV solution for Puerto Rico.	12/4/23

Table 3.1 Project Schedule

3.5 Risks And Risk Management/Mitigation

Risk 1: Proposed system may not meet 40% of current energy consumption; this is in reference to PR 100's goal of reaching 40% by 2025. Risk factor: .8.

This is an ambitious goal to complete within 2 semesters. As the project becomes more complex and specific, we realize the 40% goal most likely will not be achieved. Instead, we have focused on quantifying the number of community microgrids that can be set up within the budget, and the percent of Puerto Rico's power generation that can then be offset.

Risk 2: May not be possible to use XENDEE to model the microgrid. Risk factor: .5.

In an ideal situation, using XENDEE would be the most professional way to share our project. However, since we will be learning this software from scratch, this just may not be possible to get the exact specifications we need. Other ideas include organizing systems by region, an infographic, or another interactive map with quantitative data of our system.

Risk 3: Due to cost, Puerto Ricans may not want to implement rooftop PV systems. Risk factor: .3.

This risk factor is one of the reasons we decided to take the community solar route. Given such a broad problem statement, deciding which PV solution is the best for Puerto Rico and our scope (residential, community, commercial) is quite the task. From our research, we decided that *community solar* would be the most advantageous and cost effective solution, and doesn't require permission from each homeowner.

Risk 4: Cybersecurity and physical threats to the grid, especially with easily accessible locations. Risk factor: .3.

Pre-IoT, compromising the grid required physical access. Now, any IoT device can become an entry point a hacker uses to pivot into a larger system. To stay up to date with the latest equipment, we will use North American Electric Reliability Corporation (NERC) regulations to ensure that our system is secure. In addition, we will need to be aware of physical threats and if there are any security precautions we should take when developing microgrids.

3.6 Personnel Effort Requirements

*Roughly 550 hours worked throughout both semesters

Task Number	Task and Subtasks	Person-Hours
Task 1	Develop key guiding questions and/or areas of research This does not include the research itself that we do over the course of the semester!	30
Task 2	Presentation of three options for solution & further research.	20
Task 3	Determine which PV system best suits Puerto Rico (community, farm, rooftop, etc.). Research is included in this. Majority of first-semester work.	100

Task 4	Develop rooftop design and plan for what components are needed.	100
Task 5	Analyze the cost of our solution to ensure economic feasibility.	50
Task 6	Create a model/graphic/representation of the PV solution for Puerto Rico. This will include time from start to completion and any backtracking we must do. There will be lots of trial and error, and we anticipate the majority of the second semester will be spent developing this model.	150

Table 3.2 Personal Effort Requirements

3.7 Other Resource Requirements

Identify the other resources aside from financial (such as parts and materials) required to complete the project.

- Access to XENDEE software (can be accessed through a student account)
- NREL representatives or researchers
- Canva for an infographic

4 Design

4.1 Design Context

4.1.1 Broader Context

Area	Description	Examples

Public health, safety, and welfare	Our project has a positive direct impact on the public health, safety, and well-being of Puerto Rican residents. PV systems will be implemented in their communities and will have a positive impact on their health, and physical + mental welfare.	Limited outages during hurricanes, greater emergency responder capacity, reliable power at hospitals, reducing risks (and amount of time) for utility employees to fix power outages, diminishing residents' anxiety over power outages.
Global, cultural, and social	Our solution aligns with the Puerto Rican government's goal of being 100% reliable on renewable energy by 2050. It also aligns with the Puerto Rican people's desire to have a reliable and sustainable grid. This would also give the communities affected by past extreme weather events a sense of security.	The Puerto Rico Energy Resilience Fund is an example of the government also being committed to a cleaner and more resilient future for Puerto Rico's energy infrastructure. Casa Pueblo is another example of the private sector and communities banding together to implement many of the methods we are developing in our projects, such as community grids and rooftop PVs.
Environmental	Overall, there are a lot of environmental advantages because there will be an increase in reliance on renewable energy and a decrease in reliance on fossil fuels.	Significant increase in solar energy usage and decreased oil and coal plants. Sustainable practices of receiving/returning energy from/to the grid, possible minor deforestation if large solar farms are implemented. There is also the ethical issue of where the materials for PV panels come from.
Economic	We seek to decrease the price of electricity through the use of PV, as recent price hikes have made it very unaffordable. We must also take into account the government funding that has been allocated to solar energy and grid restoration.	PV systems (especially those on rooftops) must either be funded by the government or have a significant payoff and advantage for home users. Community solar projects can relieve the price that residents pay with government grants. They also provide jobs to manage the upkeep of grids and training to community members.

Table 4.1 Design Context

4.1.2 User Needs

Puerto Rican residents need reliable and affordable power so they can go about their daily lives, feel assured they will have access to electricity and stable prices.

Emergency Responders need to rescue those in danger and provide care for the injured, but cannot provide quality service if there are multiple barriers resulting from a widespread power outage.

Utility workers *do not* need to be concerned about their safety trying to repair downed power lines and other grid connections because they deserve to have a job where they feel comfortable and can provide for themselves/their families.

Utilities/government agencies need to decrease current electricity prices because PR residents have become overwhelmed by the cost due to unregulated policies and unreliable organizations that have operated generation, transmission, and distribution systems.

4.1.3 Prior Work/Solutions

- Solar technology is used widely, so we will use specifications and economic analysis to find which products we would like to recommend be used on the final design.
- Many studies have been conducted by NREL, Princeton, MIT, etc., and have incredibly advanced technological capabilities that we don't have. These studies discuss findings on solar availability, reliability, rooftop capacity, weather patterns, and grid studies. These are abstract studies and don't connect everything together like we plan to do on a smaller scale. We use these studies and graphics in our research, and we will use them to show evidence of why our plan can be successful. We will cite many of these studies and use them to support our final project.

NREL Rooftop Potential: [7].

Qualitative NREL Data on Puerto Rico: [8.]

MIT's Framework for Evaluating the PR Grid and Potential Ideas: [9].

Princeton's Evaluating the Island's Transition to Distributed Energy [10].

4.1.4 Technical Complexity

1. Parts of the project with multiple components: generation, transmission, distribution modeling, grid interconnections with either rooftop or large-scale PV, with a large economic aspect as well

2. Engineering principles: power flow, transmission and distribution analysis, economic dispatch

3. State-of-the-art requirements: a design for utilizing PV in Puerto Rico that was not developed before

4.2 Design Exploration

4.2.1 Design Decisions

- Are we using rooftop PV, community-based PV, or a solar farm?
- What is our budget, and what price will electricity be (per kWh)?
- What software should we use to model our final design?
- What specific products will we use in our system?
    - PV Cells
    - Inverter
    - Battery
    - Transformer
    - String Controller

4.2.2 Ideation

- Are we using rooftop PV, community-based PV, or a solar farm?

  We chose these options for our primary solution because Puerto Rico has great potential for photovoltaic generation based on data we found from MIT and NREL. There are strong examples for each of these, including large-scale solar farms, Casa Pueblo community, and over 40,000 rooftop systems. We also considered if we would need to pair natural gas with solar to meet PR's energy demand. NREL data informed us that PR has enough capacity to use solely solar. So, we considered multiple combinations of these systems. Our final decision depends on which option is most cost-effective, most reliable, and easiest to maintain for many years; this ended up being community solar.

4.2.3 Decision-Making and Trade-Off

System Design

We are strongly leaning towards community-based solar as our solution moving forward, although rooftop PV is a strong second choice, and large-scale solar farms are still a valid option as well. To help us reach this decision, we researched to highlight the pros and cons of each solution form and broke down these pros and cons into 5 distinct categories. As seen in the matrix below, these categories are cost effectiveness, reliability, lifespan, maintenance, and implementation. Since there are 5 categories, we weighted their importance on a scale from 1-5, with 5 being the most important feature. Then, since we had three options presented as solutions, we ranked each option against each criterion on a scale of 1-3, with 3 being the best performance. After scoring everything and applying weights, and double-checking to make sure everything was scored fairly, we were able to come to the solution presented in the table below, with community-based PV leading with 51/57 points, rooftop PV in second with 43/57 points, and large-scale solar farms coming up last with 37/57 points.

		Options					
		Rooftop PV		**Community-Based PV**		**Solar Farm**	
Criteria	Weight (1-5)	Score (1-3)	Total	Score (1-3)	Total	Score (1-3)	Total
Cost Effectiveness	4	3	12	3	12	2	8
Reliability	5	2	10	3	15	2	10
Lifespan	3	2	6	2	6	3	9
Maintenance	3	1	3	2	6	2	6
Implementation	4	3	12	3	12	1	4

	Total: (0-57)		43		51		37

Table 4.2 Viability Assessment

Solar Panels: We chose the Trina Solar panels for our design as they have been used on similar projects in PR already, the most prominent being on the Puerto Rico Convention Center [15]. They also have a high efficiency of 20.8%.

Inverter: We chose the Solectria XGI 1500 175-480 Inverter primarily because it fit the specifications we were looking for including input and output voltages and current values, as well as being rated for use outdoors. We also received suggestions from a local electrical contractor that recommended this supplier. Paired with this, we chose to use the Solectria XGI 1500 20A String Combiner in order to combine our 12 strings in parallel with each other. The string combiner has 24 strings with 20 A fuses each.

Battery: We chose the EG4 PowerPro WallMount AllWeather battery backup after evaluating a few different suppliers because they are the most cost effective option. The cost is $279.65/kWh, which places it among the best in the market. Made from $LiFePO_4$, these batteries have a long lifespan, are efficient, and have a fast charging/discharging rate.

Transformer: We chose Eaton's Envirotran Solar & Energy Storage 3-Phase Pad-Mounted Inverter due to its specific design for photovoltaics and consideration for the environment. The primary and secondary voltages are fully customizable, which makes it a great choice for our project (480 V and 13.8 kV, 175 kW). Additionally, the dielectric fluid is made from renewable, biodegradable, non-toxic seed oils, which actually extends the life of the transformer and increases efficiency.

4.3 Design

Initial Design (Spring)

So far, we have a lot of research into the geography, economics, and contracts created with Puerto Rico and the AEEPR (Puerto Rico Electric Power Authority). Additional research has gone into looking at current generation capabilities in Puerto Rico, generation limitations, and projections. We have also researched different solar generation setups (i.e. rooftop solar, community solar, solar farm), the pros and cons of each design, energy storage capacity requirements for batteries, solar and battery storage costs, and many other considerations so that we fully understand the requirements that our project needs to meet.

4.3.1 Design Visual and Description

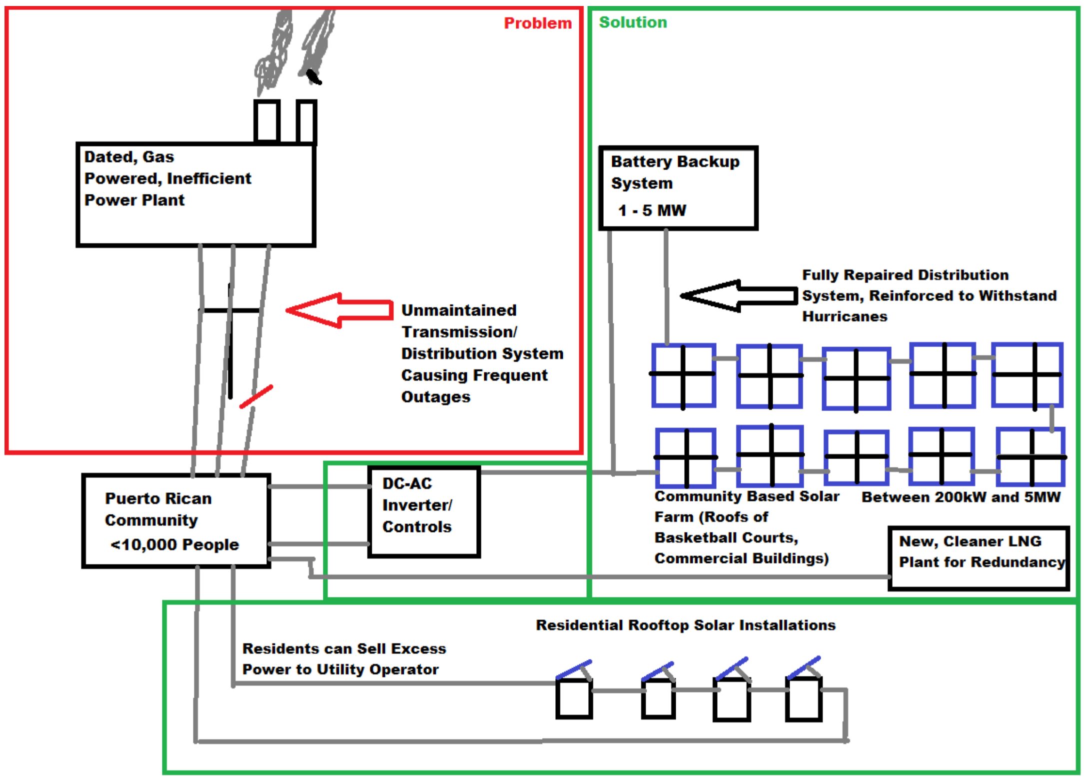

Figure 4.3 High Level Project Description

This diagram shows at a high level what the problem we are trying to solve is, and the three possible solutions. As seen in the diagram, the main problems we are trying to solve are Puerto Rico's dependence on outdated, inefficient gas and diesel-powered generators, many of which are in bad condition due to age and storm damage. The same can be said for the distribution system in Puerto Rico, which has been held together poorly after taking major damage from Hurricanes Irma and Maria, and never permanently repaired [11]. These issues, coupled with the mismanagement of the grid by PREPA, lead us to our proposed solution of implementing multiple community-based solar farms near population centers in Puerto Rico. Additionally, we plan to construct Battery Backup systems near each of these new community-based solar farms that will keep the lights on for the people of Puerto Rico at night and in times when severe storms cause damage to the distribution system.

Our specific project is a PV system on the relatively common basketball courts that appear all over the island of Puerto Rico. The basketball courts are very often covered with a substantial roof supported by steel, and we plan to design a community photovoltaic system with battery backup that can be widely applied to these basketball courts. We believe implementing solar panels on these basketball courts, which are often located near small neighborhoods, could provide much-needed power to the people living there, especially during a severe-weather event where power is down across the island. Seen below is a rough initial estimate of the cost of installing such a system on one of the basketball courts, as well as how much power one of these systems could generate.

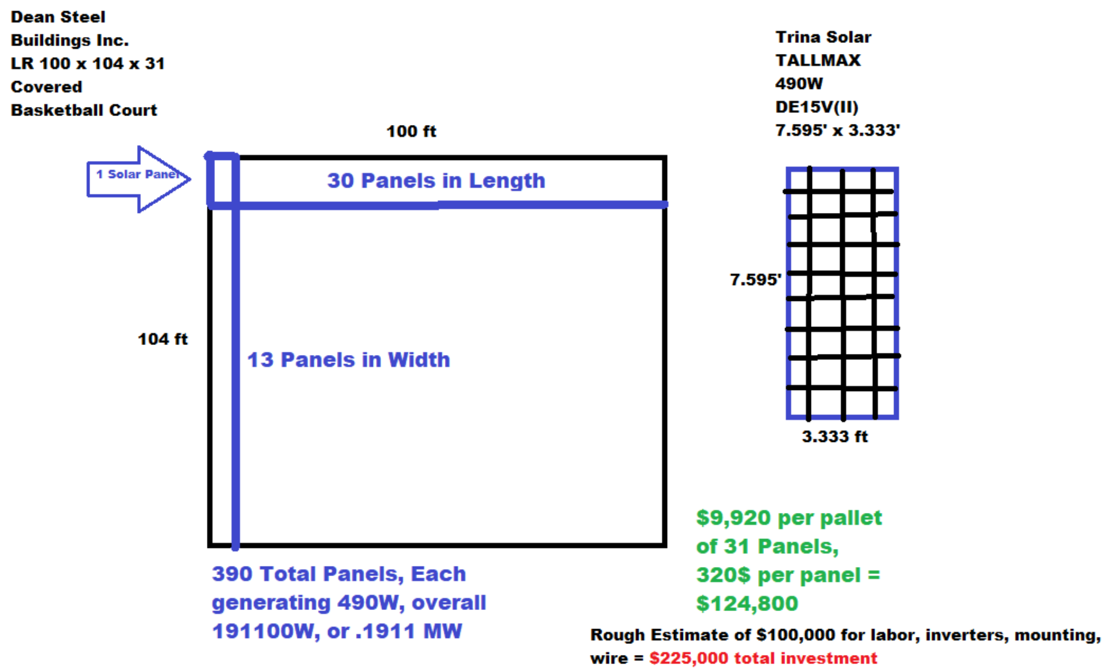

Figure 4.4 Basketball Court Roof Estimate

This initial estimate will generate approximately 200kW, and to show that this is a reasonable estimate, we have found an all in one installation kit for a 200kW solar system that includes all components and labor that costs $250,000 [12], which is within reason of our $225,000 estimate. In the course of the second semester we will refine this estimate so it itemizes all necessary components and estimates time to install, as well as highlighting how many years it will take for this investment to become profitable.

Final Design (Fall)

After proposing our initial plan of a rooftop solar installation for a specific public basketball court location in Puerto Rico during the Spring semester, we had to revisit some of our research and change some of our expectations during the Fall semester. One of our greatest challenges was finding an economically feasible battery backup solution to use with our design, as we wanted to make sure we could provide power 24 hours a day while also being able to significantly decrease the cost of electricity for the people of Puerto Rico.

Another thing that we had to take into greater consideration in the fall semester was the need for significant security measures to protect against both physical and cyber threats to our grid. This issue was brought to our attention during the first semester's final presentation, and so we made sure to research methods to protect our installations with cybersecurity as well as physical security measures to keep people safe and away from the main components of our system, such as the battery backup, inverter, and transformer. More details on our security measures can be found in Section 5: Security.

Additionally, we had to modify the layout of panels on the roof to leave room for maintenance as well as meet NEC standards for voltage of solar installations on rooftops. More detail on these changes can be found in section 5.

One more significant change in our design in the second semester came when we gained access to a software called XENDEE, which has helped us to simulate our design to better understand where it lacks in efficiency as well as show how long until our installation will pay for itself among other things. Early in the Fall semester we found that the battery backup system we had chosen was far too expensive and was significantly hurting the degree to which we could lower the price of electricity for the people of Puerto Rico, so we decided to search for a new solution for the battery backup and we were able to find a less expensive solution that still significantly decreased the cost of electricity. More detail on XENDEE can be found in section 5: Simulation with XENDEE.

4.3.2 Functionality

The panels on the roof of the basketball court generate 158.76 kW of power. That, paired with the 371.8 kWh battery storage, is enough to power around 50 homes in the surrounding neighborhood. The power will be sent through the inverter & charge controller, where the battery charges and discharges based on power available. The inverter will convert power from DC to AC, to be used in the grid, and then sent through a step-up transformer to match the voltage levels of the distribution system. In the event of an outage, we will assume that the small community/neighborhood has the ability to isolate itself from the larger transmission system. Substation breakers can automatically isolate the distribution lines that feed ~50 homes when a fault is detected in the transmission system. This still allows the battery to power homes. In addition, the inverter can isolate itself (called islanding) from the distribution system, when a fault has the potential to damage the infrastructure.

4.3.3 Areas of Concern and Development

There is concern for our solution's resiliency to the strong hurricanes that often impact Puerto Rico's power grid. Especially considering that the panels will be at an elevated height, they may face a greater threat of wind. However, the panels will be mounted to the roof following installation guidelines and codes. The mounting rails we decided to use are rated for up to 160 mph winds, which would be the equivalent of a Category 5 Hurricane[16].

We also are concerned that if our solution is implemented, the system may not be properly maintained, as the utilities in Puerto Rico have had a bad track record of making repairs and performing maintenance on the grid. We will have guidelines for maintenance, but unfortunately, the rest is out of our control.

4.4 Technology Considerations

One of the biggest challenges when designing is trying to figure out the capabilities of battery storage. We are working to calculate what the capacity of our battery backup systems will be in order to store and supply enough energy for Puerto Rico residents. We are also looking at some sources of better batteries in the market to compare the battery capacity and bring the best solutions to the Puerto Rico Residents.

PV Equipment and Installation is also one of the technologies considerations. As we design the community PV system and rooftop system, we had to choose solar panels that are economically viable and efficient enough to produce electricity to justify the cost of installation. This also includes the power infrastructure in our design such as the inverter, transformer, and string combiner.

Lastly, using XENDEE was a learning experience and provided technological challenges. Figuring out how to best model the system was a process of trial and error.

4.5 Design Analysis

We strongly believe that the proposed design from 4.3 will work well because of the following reasons:

First, People in Puerto Rico are stressed under certain environmental conditions such as hurricanes, so it is important to replace the current energy systems with the new, reliable energy systems, and in this case, solar energy.

Second, Puerto Rico has enough infrastructure to set up and generate solar energy by using solely residential rooftop PV systems alone, NREL estimates 4x PR's demand [8]. However, we plan to use community systems to provide increased reliability and avoid having to convince many households to install solar panels on their roofs..

The government's goal is that Puerto Rico will use 100% renewable energy in 2050. With a large budget and well-researched design, we believe our design could provide a good stepping stone towards meeting that goal.

4.6 Design Plan

At the end of the spring semester, we finalized the direction our project would take. We designed a PV system on the roof of a covered basketball court, to be built and copied throughout Puerto Rican towns. Our design powers, and stores power for, 50 surrounding homes of the basketball court. The panels provide 158.76 kW of power, and the battery stores 372 kWh. We have researched, chosen, and integrated power electronics (inverter, transformer, string combiner, charge controller) for our system. Additionally, we have used the software XENDEE to model the 158.76 kW system to see how it imports and exports electricity, how long it will take for the system to pay off, improved levelized cost of electricity (LCOE), cost breakdowns, and internal rate of return (IRR). The technical details are discussed in the following section: Implementation.

5 Implementation

5.1 Technical Design, Layout, Schematic

We have put together a detailed proposal for a solar installation at one specific location in Puerto Rico that we believe can be easily applied to numerous other locations (described later) with very minimal changes. The detailed design and specifications can be found in the following sections.

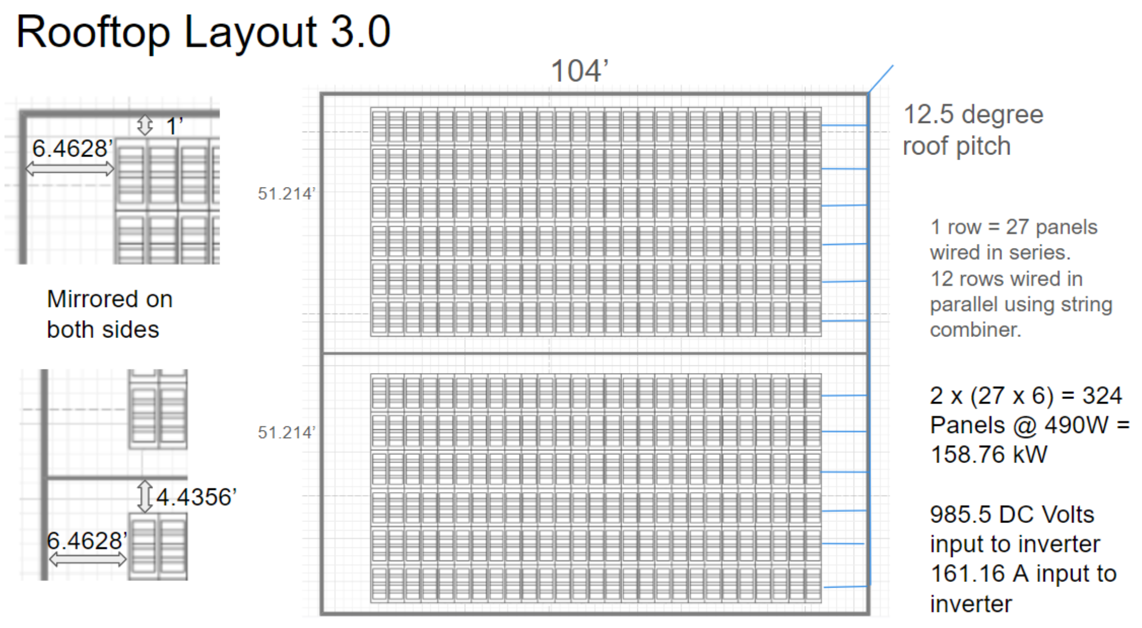

Figure 5.1 Rooftop Layout

Figure 5.1 shows in detail the rooftop layout for one specific location we are proposing to use for our community based PV design. The dimensions of the rooftop of this basketball court are 104' by 100', and the roof has a pitch of 12.5 degrees on each side of the peak. Due to this pitch, we have a total roof area available to use of 10652.512 square feet. Below are the detailed specifications for the spacing of each panel and the space left for maintenance access around the panels.

5.2 Vertical layout:

Dimensions of (1) Trina Solar TALLMAX 490W DE15V(II) Panel: 7.595' x 3.333' ; 6 panels x 7.595'

5 ½" spacing = 5 x .04166666'

1 foot offset from edge = 1'

Total usage = 46.77833'

Room left at peak = 51.21397572 - 46.77833 = 4.4356'

5.3 Horizontal Layout:

27 panels x 3.333' =89.991'

26 ½" spacing = 26 x .04166666' = 1.0833'

Total usage = 89.991 + 1.0833 = 91.0743'

Room remaining = 104' - 91.0743' = 12.92566'

Room on either edge = 12.92566 / 2 = 6.4628' for maintenance access

46.77833' x 91.0743' x 2 = 8520.6 square feet used

8520.6 / 10652.512 = 79.9% of roof space used.

We chose to leave a portion of the roof unused for a couple of reasons. First, because we did not want to exceed the voltage rating for our inverter as well as to stay within the NEC standard for maximum voltage allowed for a PV system on a rooftop,, and second, because we want to minimize the possibility for the high winds of a hurricane to create excessive wind shear below the panels. By leaving room between the peak and the panels we prevent additional wind from getting underneath the panels.

Overall, one of our installations will have 12 rows of 27 panels each, totalling 324 solar panels at 490W each, which will provide a peak output of 158,760kW.

5.4 Rooftop View

Figure 5.2 Rooftop View

5.5 Infrastructure

The drawing below serves as our schematic and detailed system diagram. Starting on the left with the solar panels, we modeled each cell with the equivalent circuit of a light generated current source and diode– keep in mind that there are a total of 324 total panels, but not all of them are shown for simplicity's sake. Each string will connect in parallel to the string combiner which outputs a voltage of 985.5 V and a current of 161.16 A. This then flows into the inverter. The charge controller within the inverter will regulate the current and voltage flowing to the batteries based on their charge levels. The remaining will be routed to a step-up transformer which is 480 V wye-grounded on the primary side and 13.8 kV delta on the secondary side. From there, it is in the distribution lines and fed to homes in the surrounding area.

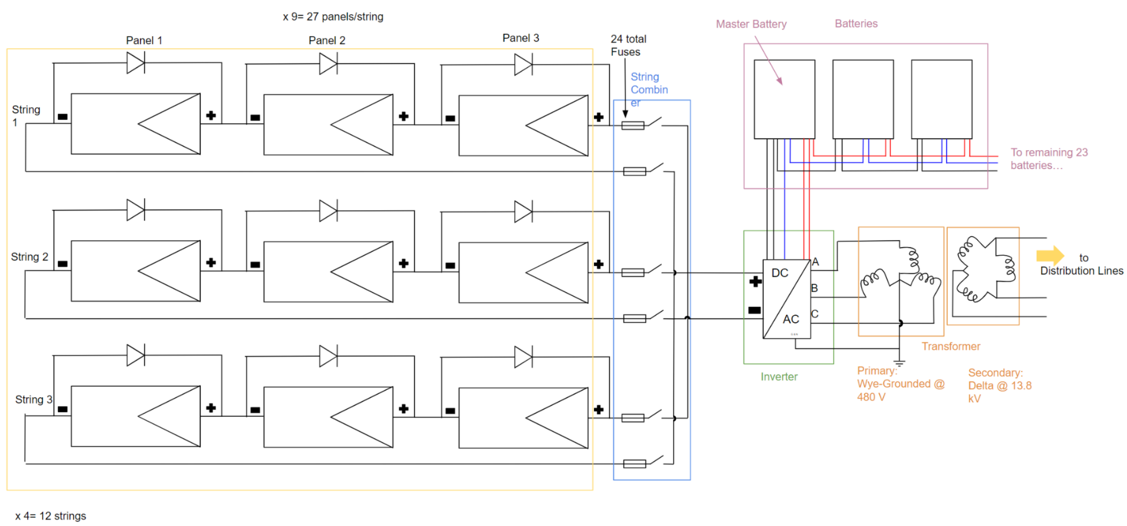

Figure 5.3 Schematic

- Trina Solar TALLMAX 490W DE15V(II) Panels

    - 324 panels = 158.76 kW

    - 20.8% max. efficiency

- Solectria XGI 1500 175-480 Inverter

    - 175 kW power rating

    - Output: 480 VAC, 3-Phase

- Solectria XGI 1500 20A String Combiner

    - 20 A with 24 fuses

- Envirotran 3-Phase Pad Mounted Transformer

    - 480 V Wye-Grounded : 13.8 kV Delta

    - 175 kVA

    - FR3 dielectric fluid: non-toxic, higher performance

- Grid Interconnection

Since our system is under 5 MW, we do not have to submit a system impact study to PREPA, and no insurance is required for a system under 300 kW. All components are rated to comply with IEEE 1547 and UL 1741, which establish requirements for distributed energy resources (DER) and grid interconnections. PREPA mandates any DER must connect to the EPS through a transformer, wye-grounded is required on the inverter side, and delta is required on the EPS side [17]. Both our transformer and inverter have protective capabilities. The inverter is required to “island” with under/over voltage and under/over frequency. The vacuum fault interrupter (VFI) within the transformer will isolate the transformer when a fault is detected inside. The tables below display the inverter’s voltage and frequency limits with their respective trip times.

Voltage Range (± 1%)	Clearing Time (± 0.2 s)	Clearing Time Adjustable Up to and Including (± 0.1 s)
V < 45%	0.16 s	0.16 s
45% <= V < 60%	1.0 s	11 s
60% <= V < 88%	2.0 s	21 s
88% <= V < 110%	No trip	No trip
110% <= V <= 120%	1.0 s	13 s
f > 120%	0.16 s	0.16 s

Table 5.1a Voltage Limits and Trip Times

Frequency Range (± 0.05 Hz)	Clearing Time (± 0.2 s)	Clearing Time Adjustable Up to and Including (± 0.1 s)
F < 57 Hz	0.16 s	10 s
57 Hz <= F < 59.5 Hz	2.0 s	300 s
59.5 Hz <= F < 60.5 Hz	No trip	No trip
60.5 Hz <= F <= 62 Hz	2.0 s	300 s
V > 62 Hz	0.16 s	10 s

Table 5.1b Voltage Limits and Trip Times

5.6 Battery

As mentioned earlier, the batteries we selected for our project are the EG4 14.3 kWh PowerPro batteries. They are rated to withstand the hot temperatures of Puerto Rico and have weather proofing. Our design parallels 26 of them to get a resulting 371.8 kWh of energy storage. This is enough to power about 50 homes for approximately 14 hours, essentially our goal was to get them through the night or through a short power outage. The total cost of these 26 batteries is only $103,

974 or $279.65/kWh, which is truly affordable and advanced compared to other battery storage options. These batteries must be wall-mounted, so we developed a storage solution to protect them from the elements.

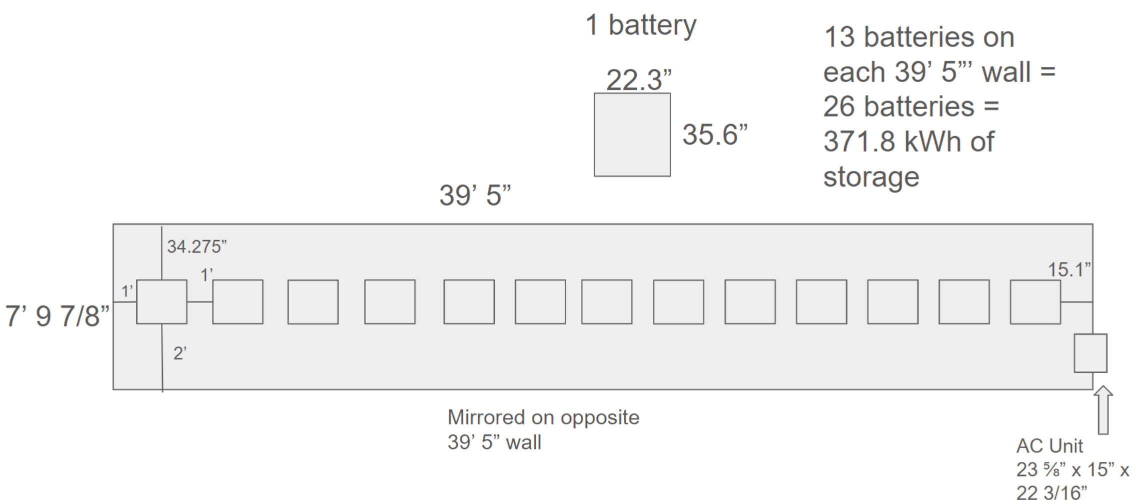

Figure 5.4 Battery Storage Solution

5.7 Simulation with XENDEE

To set XENDEE up properly for our site took a lot of research into both the software and the nature of similar microgrid reference materials. There is a lot to consider even when setting up such a small grid. In terms of financing, we had to research what kind of federal incentives we could tap into, as well as how renewable energy assets depreciate over the project life and what % of these assets can be collected as depreciation tax breaks, and what federal grants were applicable for our project. Even though we established in semester 1 that the United States has allocated over $3 billion in electricity based grants, only $1.3 billion of these dollars could be applied to our project, limiting our scope quite a bit if we wanted to look at the bigger picture. When implementing this in XENDEE, we found a site that matched our specifications exactly for a 104 ft by 100 ft roof. Our next step was to set up an advanced project which could use multiple nodes so that we had access to multi-nodal analysis. This meant we could observe power flow at each node and include more in-depth calculations and model more complicated things like the transformers we needed and different voltages on different stretches of cable as we switched over from the grid which operates at 12.47kV, to the solar panels and batteries, which we have operating at 480V. In terms of how the project would be purchased, we set it up to be purchased as a generation asset for local companies which could provide the energy as a service at a much lower cost than with traditional fossil-fuel plants. Finally we modeled our site under the assumption that the average household has 2.8 people in Puerto Rico. Using NREL’s Puerto Rico - Demand Response Impact and Forecast Tool, or PR-DRIFT, we were able to simulate a business-as-usual (BAU) load forecast for the complete year of 2025 by the hour. Taking the total energy demand and adjusting it down to fit our 50 home model, or 140 people, we were able to properly simulate the forecasted average demand for 2025 and have the software convert it down to the year 2024.

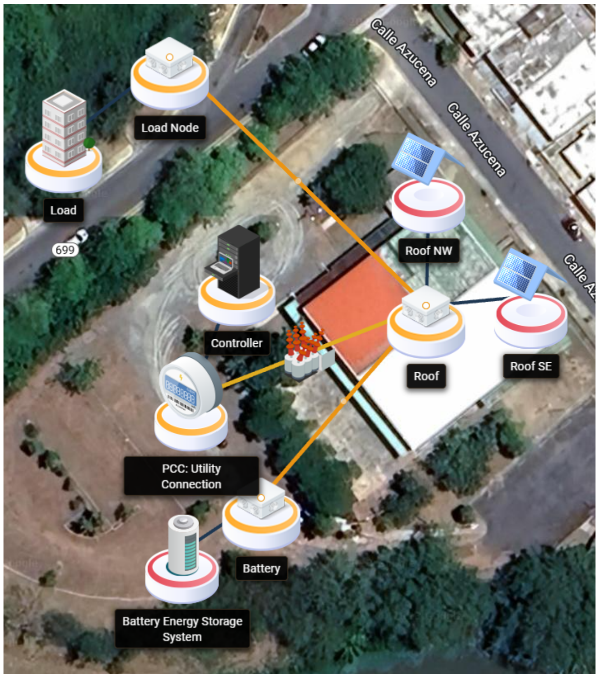

Figure 5.5 XENDEE Aerial Project Layout

Optimization was carried out on the same platform, XENDEE, computed over on their servers and then sent back to you. We carried out multi-nodal analysis for our 50-home module with access to the grid under a net-zero condition. This means our model must import less energy than it exports for a net positive impact in terms of green energy production and consumption. As with any calculations, we do have a precision limit on our results, and for us that was an 8% optimal gap. Additionally, we give our optimization the constraint that it must reduce cost in reference to the current facilities being used to generate electricity, otherwise, economically this project would be a hard sell. When modeling, we do have to turn off federal grants or else it messes up economic calculations such as the internal rate of return (IRR) and net present value (NPV). Unfortunately, XENDEE did have some errors we couldn't resolve, so a bit of the economic calculations were done by excel based off of the basic figures XENDEE provided us with on their cash flow table. More on these results can be found in section 6.9.

5.8 Locations

As a team we outlined what characteristics our prospective location would have to have for us to consider them as sites for our project. The courts would have to have flat roofs, a clear space with no shade, proximity to communities, structural integrity, and accessibility to an already existing part of the grid. With these characteristics in mind we used Google Maps and the Satellite view provided by them to locate and mark our proposed locations, resulting in 168 possible locations for our design[17].

Figure 5.6 Prospective Locations for Projects

5.9 Security

A member of our team met with a cybersecurity professional to determine the cyber risks associated with a microgrid and how to take preventative measures to protect it. We will set up a 5G cellular hotspot at each system's location, connected to a wired ethernet cable at the inverter. Through that *wired* connection, we will use Cisco EasyVPN for connection to the Internet. We will tunnel in through the inverter's web-application to access the inverter data. There is a firewall installed on the inverter firmware, and we will apply the Principle of Least Privilege, meaning that we only allow required traffic inbound AND outbound. All sensors or other wireless systems on the PV panels will be disabled.

This limits outside access to the inverter and grid to the physical connection through an ethernet cable. Additionally, the inverter and 5G hotspot are secured by an 8' tall grounded chain link fence with anti-climb barbed wire, locks, and a camera.

6 Testing

6.1 Unit Testing

Our project will not be a physical product, so testing is difficult. If we build a grid model on a software platform like PSS/E or XENDEE, we will be able to test it with multiple case scenarios on that specific software. In addition, we can use economic analysis to ensure that our plan/design stays within our assigned budget. Specifically, we plan to compile a report outlining the specific costs involved with any investment in the community-based solar farm. This will highlight the improved LCOE and the period of time to recover capital costs.

6.2 Interface Testing

We plan to integrate the community grid to the distribution system. We must determine how our power injection affects the rest of the grid; however, its main purpose is to provide power during an outage. In terms of tools, we will use XENDEE to determine the amount of battery storage needed and the cost of electricity. We will test that against our calculations, including inefficiencies.

6.4 Integration Testing

We will use XENDEE, a microgrid modeling software, ensure system feasibility and that it can be integrated into Puerto Rico's bulk power system. For example, we will ensure the inverter, transformer, and battery are working together to meet the demands of the neighborhood and charging/discharging as necessary.

6.5 System Testing

At the end of our project, we will spend time recalculating our estimates for the cost and payback period for the microgrids. We want to ensure our final design works as intended in the simulation software and that our calculations for the economic aspect of our solution are correct and can feasibly be met.

6.6 Regression Testing

During our simulation of the microgrids and economic analysis for our report, we will have to ensure that any changes we make to either of our primary deliverables for this project result in changes that we expect to see. Our project has very little code involved, so we will not have to be concerned with minor changes in code creating bugs and "breaking" any functionality we already had working.

6.7 Acceptance Testing

It is important that the residents of Puerto Rico want and are willing to participate in the design/program. Specifically, we should do research or propose outreach to understand the general desires of Puerto Rico's population, to ensure the number of PV systems and community systems we are proposing is appropriate for client engagement.

6.8 Security Testing

As society becomes more technologically advanced, there is an increasing cybersecurity threat. The grid is becoming increasingly interconnected to the Internet of Things (IoT). Pre-IoT, compromising the grid required physical access. Now, any IoT device can become an entry point a hacker uses to pivot into a larger system. To stay up to date with the latest equipment, we will use North American Electric Reliability Corporation (NERC) regulations to ensure that our system is secure.

We will test implementation (5G cellular hotpot and inverter software) through Pratum, a Des Moines based cybersecurity consulting firm that offers services throughout the US and US Territories. Specifically, Pratum would conduct a penetration test in a lab environment with a standard configuration. One test for all systems will suffice as every system is identical. The cost of the penetration testing is $5000, divided amongst the number of systems. In addition, we will ask Solectria to verify their web-based monitoring software and ask for a copy of their penetration testing configuration. For our hypothetical scenario, we will assume both pass. However, any areas of concern would be addressed and monitored by Pratum.

Further cybersecurity prevention measures can be found in Section 5: Implementation.

6.9 Results

Running the planned site through XENDEE, we found that our model exceeds the required annual energy consumption of the forecasted 50 homes by quite a bit. The report showed that our model was capable of generating 250,096 kWh of energy annually, allowing for 22.3% of this energy to be sold back to the grid as excess electricity. As mentioned earlier, in section 5.7 we had to turn off federal grants, and import our data from the report into excel to generate more accurate figures, unfortunately. Total upfront costs ended up at $409,935 for our 50-home system. Under actual dollar analysis, we found that we could sell our energy at a rate of $0.1319/kWh for a revenue of $33,000/year per site. This rate of sale was decided so that we could recover a 10% IRR at the end of the project. Under this rate, our project breaks even in year 5, and our payback period would end in year 14. This rate is completely adjustable if a higher return is desired, however it's important that the consumer be kept in mind when setting prices.

Even without federal grants funding this project, we believe it to be highly profitable and a much cleaner and desperately needed alternative form of power generation for Puerto Rico. The only major shortcoming of this grid is that it isn't 100% self-reliant. In terms of utilities most energy at the point of connection to the grid is sent out as exports at 99.2%, however there is still the remaining 0.8% that is purchased from the grid during peak demand in the later parts of the year. Unfortunately, this was unavoidable due to lower peak sunlight hours during the periods of peak demand, as can be observed in the figures below.

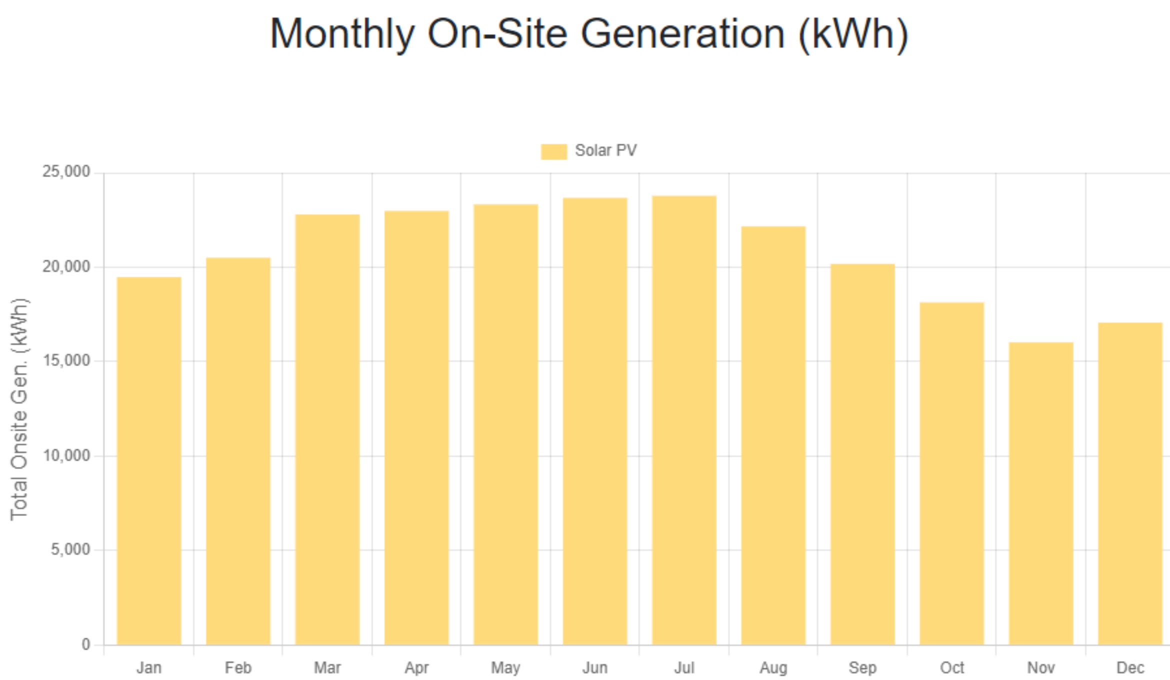

Figure 6.1 Energy Generated on Site per Month.

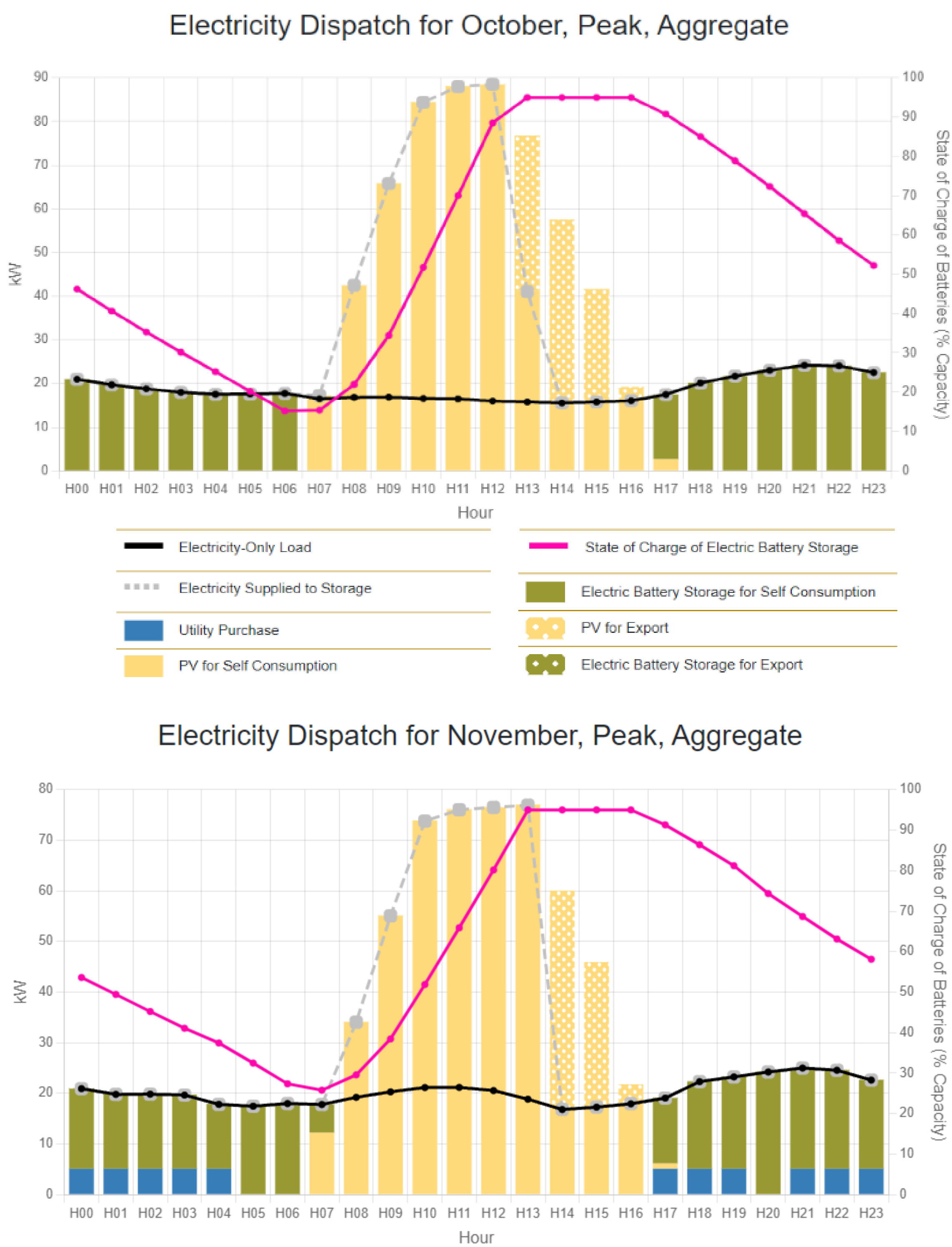

Figure 6.2 Operation under Peak Load October vs. November

7 Professionalism

This discussion is with respect to the paper titled "Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment", International Journal of Engineering Education Vol. 28, No. 2, pp. 416–424, 2012

7.1.1 Areas of Responsibility

Work Competence	Accept criticism, correct others' errors, understand the technology, and seek to improve our competence to better contribute to work and innovation.
Financial Responsibility	Reject bribery and lazily going along with communication, be realistic in expectations and prices.
Communication Honesty	Be honest when making claims and estimates– do not exaggerate abilities or what may be possible.
Health, Safety, & Well-Being	Engineers must accept responsibility for their decisions and how they may affect the public. They have a duty to disclose potentially harmful information to the public.
Property Ownership	Avoid injuring others' property, reputation, employment, and physical health. Take responsibility for actions and receive consequences with grace.
Sustainability	Care for the earth and resources is essential to humanity's existence and future.
Social Responsibility	Treat all people fairly regardless of race, ethnicity, religion, sexual identity, age, gender, etc. Be aware of how technology will impact the public and be seeking to improve the world instead of harming it.

Table 7.1 Professional Responsibilities

7.2 Project-Specific Professional Responsibility Areas

Work Competence: This applies to our project because we wish to provide a high-quality, feasible plan for improving the power grid for the people of Puerto Rico at the end of this project, and to do so, we all must meet deadlines, perform quality research, and compile that research into a feasible plan that could be implemented. Our team is performing at a high level in this area, as we all are keeping track of our sources and compiling our research to get better ideas of how we will eventually put together a plan for Puerto Rico's grid.

Financial Responsibility: This area applies greatly to our project because a large issue with the current grid in Puerto Rico is the high price and low quality of power for the people of Puerto Rico. Our main goal is to create a plan to improve the reliability of the grid and provide it to the people of Puerto Rico at a reasonable price, ideally lower than the current prices they pay. Our team is performing at a high level in this area, as the project's economic feasibility has been one of our main focuses for research since the beginning.

Communication Honesty: Communication honesty is very important to our project, not only because we have to be honest about what research we have done when meeting with our advisor and creating a solution, but also because of the need to eventually convince the people of Puerto

Rico and the government that our proposed solution will work. We also have to make sure our solution is understandable to everyone, meaning we must keep in mind the broad audience of people who may be reading it will not all be electrical engineers. Our team is performing at a high level in this area, as we are always honest with our advisor about our plan and the work we accomplished.

Health, Safety, Wellbeing: This area is applicable to our project primarily because we aim to improve the well being and quality of life of the people of Puerto Rico by improving the reliability and affordability of power in the country. If our project could potentially harm the health and safety of people in Puerto Rico, it is our responsibility to inform them of the risks in our report. We are performing at a medium level in this area right now, as we have not done much as of yet to evaluate any potential risks for harm that could come from our project plan. This is something we will have to look deeper into moving forward.

Property Ownership: One focus of our project is rooftop photovoltaic installations. We must keep property ownership in mind if that is the plan we decide to go with. Some Puerto Rican people may not want solar panels on the roofs of their homes, and if that is the case, we must respect that, as it is their property. We also need to be mindful of giving credit where credit is due in our research and the ideas we come up with, as that is property as well. We are performing at a high level in this area due to our diligence in citing the sources for our research and keeping track of who is doing what task in the project.

Sustainability: Our project is directly related to sustainability. We plan to replace as much power generation via fossil fuels as possible with photovoltaics and other renewable sources of generation, which directly connects to protecting the environment in Puerto Rico. Puerto Rico currently relies heavily on fossil fuels for its electricity generation, and our goal is to greatly decrease the proportion of generation via fossil fuels with our plan. Our team is performing at a high level in this area primarily due to the nature of our project being focused on implementing photovoltaic generation in Puerto Rico, which will greatly improve the sustainability of the power grid in Puerto Rico if implemented correctly.

Social Responsibility: Social responsibility is another important aspect of our project, as our main goal is to improve the quality of life of the people in Puerto Rico in general, regardless of any differences between the users of our solution. We want our project to better people's lives in general, and we will ensure that it does not harm people of any particular group to succeed in this area. We are performing at a high level in this area due to the fact that our goal is to improve the entire power grid of Puerto Rico, which should directly benefit everyone living there, not just one particular group of people.

7.3 Most Applicable Professional Responsibility Area

We chose to focus on communication honesty because it is important to our project, and we demonstrate a high level of proficiency in this. In our official reports, there were a few key aspects to focus on, including communication between our group members, our team and our advisor, our team and our target audience, and the people and government of Puerto Rico. Communication honesty between team members means being honest with each and every individual on the team. If we have problems that will cause delays in the project, we need to communicate them so that each member will be aware so that we know to cover or help each other out when possible. Additionally, we must be honest between our team and our advisor. We must be honest when discussing the project and what we are working on. We also need to be honest in terms of the numbers and data we obtain from our research. Finally, when communicating honestly between our team and our target audience in official reports, we need to be upfront about our biases and how renewables may offer them many advantages but also carry disadvantages. For example, we have discussed how, while renewable energy is most certainly the focus of our project, alternatives such as natural gas power plants come a bit cheaper in the short term and offer around-the-clock reliability, so it is important that we know how to communicate with complete honesty without the promotion of our objective introducing any bias and getting in the way.

8 Closing Material

8.1 Discussion

The results of our project indicate that community solar installations are something the Puerto Rican government may want to look into as an investment for their power grid. Our analysis shows that it is a cost-effective, sustainable, and realistic option. Even without government funding, the system is affordable for a utility or non-profit, and breaks even after just five years! Specifically, the dramatic reduction in LCOE from 25 cents to 13 cents proves that this project is economically feasible [18]. To decrease the cost going forward, battery technology must continue to advance and decrease the price per kWh. That is the biggest way to save on the costs of this project. Maximizing the amount of sunlight that can be absorbed by these panels would also help increase power efficiency, this could potentially be done with rooftop solar tracker systems. Although these are not yet widely available on the market, they most-likely will be in the near future.

Additionally, we have learned abundantly from the research and design decisions we have made in the last year. After extensively pouring over resources from NREL, MIT, DOE, local news outlets, and more, we have educated ourselves on the problem and opportunities to improve PR's grid, and used our unique skill set(s) to design a solution to these issues.

8.2 Conclusion

After this second semester of our project, we feel confident that we have proposed an economically feasible and realistic solution to the problems that the Puerto Rican people are facing in regards to their electrical grid. If widely adopted, our solution of rooftop solar installations on existing infrastructure in Puerto Rican public parks could dramatically decrease the average price of electricity for the Puerto Rican people from 25 cents per kilowatt hour in 2022 for a residential customer to a new price of $0.1319 for a residential customer with access to one of our installations [19]. In addition to the lower price, our systems will provide battery backup power to residents in the immediate vicinity of each of our installations, so even at night or in the event of a power outage, the Puerto Rican people will have ample access to power. Overall, we are proud of our project and believe it to be a success. If our proposed solution was taken up by the Puerto Rican government and many of our proposed PV installations were built, we could have a great positive impact on the reliability and efficiency of Puerto Rico's electrical infrastructure and make a large leap forward towards a fully renewable electrical grid in Puerto Rico.

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8.4 Appendices

8.4.1 Additional Information

		TOTAL			
		Revenue	Sales	Customers	Price
		Thousand Dollars	Megawatthou	Count	Cents/kW
		283,319	1,187,554	1,503,606	23.86
2022	12	351,343	1,316,440	1,503,157	26.69
2022	11	384,680	1,360,142	1,502,969	28.28
2022	10	375,159	1,066,934	1,502,845	35.16
2022	9	413,823	1,433,132	1,501,807	28.88
2022	8	451,655	1,443,965	1,501,210	31.28
2022	7	532,148	1,543,315	1,500,642	34.48
2022	6	434,633	1,523,487	1,501,095	28.53
2022	5	424,674	1,459,614	1,498,006	29.09
2022	4	353,263	1,189,640	1,496,384	29.69
2022	3	367,530	1,219,061	1,494,126	30.15
2022	2	320,654	1,166,134	1,493,550	27.50
2022	1	330,590	1,263,820	1,493,884	26.16

Total MWh for 2022
15,985,684

This is data from EIA on the sales of electricity in Puerto Rico during 2022. This is the data we based our goal of meeting the demand of Puerto Rico on. Refer to the excel sheets located in the "prices" tab on the EIA website [14].

8.4.2 Team Contract

Team Members:
1) Isaac Buttner 2) Adam Curtis
3) Hannah Nelson 4) Manuel Perez-Colon
5) Larry Trinh

Team Procedures
Day, time, and location (face-to-face or virtual) for regular team meetings:
Monday at 3:15, hybrid face-to-face and virtual
Every other week meeting with Professor Dalal

Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
Email, Phone and Discord group chats

Decision-making policy (e.g., consensus, majority vote):
Majority vote

Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
Notes uploaded to Google Docs Meeting Notes Folder

Participation Expectations
Expected individual attendance, punctuality, and participation at all team meetings:
Team members will be present unless extenuating circumstances occur.

Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
Team members will fulfill assignments on time, and will ask for assistance if a deadline cannot be reasonably met.

Expected level of communication with other team members:
Team members will communicate their progress and ideas in a timely manner, and make sure everyone knows what everyone else is working on.

Expected level of commitment to team decisions and tasks:
Team members will complete assigned tasks as expected, and if changes to the scope of a task are made, the team can re-evaluate prior decisions and tasks.

Leadership
Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):

Manuel is responsible for team organization, research and presentation organizer.
Hannah is responsible for client interaction and report coordinator.
Adam is responsible for research and economic analysis.
Isaac is responsible for technical (grid) analyzing/modeling.
Larry is responsible for economic and social research, helping other team members in the design and analysis grid.

Strategies for supporting and guiding the work of all team members:
If team members need additional help, they should feel comfortable reaching out to others. Team members should be willing to help where/when they can and be supportive of needs. Work is guided by weekly meetings and mutual discussion of what needs to be achieved within the next week.

Strategies for recognizing the contributions of all team members:
In each of our PowerPoint that we will present to Dalal, team members can share what they have

done and accomplished the past week.
Ensure our design document clarifies what each team member worked on and contributed.

Collaboration and Inclusion
Hannah - incredibly organized, has good communication skills, and brings ideas together, has practical experience working on a solar farm and using PSS/E
Adam - has hands on experience working in the electrical contracting industry, effective communicator and writer, data analysis
Manuel- fluent in Spanish, originally from Puerto Rico, good communicator and presenter, experience working with substations.
Larry - bachelor's degree in finance, have a background in macroeconomic and microeconomic. Hand on experience working in electronics design industry
Isaac - Good communication and writing skills, good at breaking down larger tasks into manageable chunks. Experience with PSS/E and other modeling softwares.

Strategies for encouraging and supporting contributions and ideas from all team members:
Make sure everyone gets a chance to share their ideas and findings at the meetings every week. Keep in contact during the week and let each other know what we are working on.

Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)
Bring up any issues at our weekly meetings so everyone knows what is going on, and we can all address the issue.

Goal-Setting, Planning, and Execution
Team goals for this semester:
Conduct sufficient research to devise a plan that can be expanded on and implemented in the second semester for expediting the transition to Photovoltaic generation in Puerto Rico.

Strategies for planning and assigning individual and teamwork:
During weekly meetings, curate a list of needs to get done during the week. Divide tasks among team members and plan time as needed. For group work, we will prioritize that during team meetings, and class time for assignments.

Strategies for keeping on task:
Check-ins if we notice something isn't getting done or a deadline is quickly approaching.

Consequences for Not Adhering to Team Contract
How will you handle infractions of any of the obligations of this team contract?
Convene with the group and discuss what needs to be done, if anything.

What will your team do if the infractions continue?
Contact advisor and discuss the best course of action, whether it be removal from the group or some other disciplinary action.
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a) I participated in formulating the standards, roles, and procedures as stated in this contract.
b) I understand that I am obligated to abide by these terms and conditions.
c) I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.

1) Adam Curtis ______________________________________ DATE _____2/19/23_______
2) Manuel Perez-Colon________________________________ DATE _____2/19/23_______
3) Hannah Nelson_____________________________________DATE _____2/19/23_______
4) Isaac Buetter _____________________________________ DATE _____2/19/23_______
5) Larry Trinh____DATE _____ 2/19/23______