Photovoltaic Feasibility in Puerto Rico

Design Document

SDDEC23-16

Client: Puerto Rico

Advisor: Prof. Vikram Dalal

Isaac Buettner - Research and Tech Analysis

Adam Curtis - Economic Analysis and Research

Hannah Nelson - Client Interaction and Documentation Coordinator

Manuel Perez-Colon - Research and Presentation Organization

Larry Trinh - Economic and Societal Research

sddec23-16@iastate.edu

Team Website

Revised: April 2023/V1

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 Recommended Practice for Utility Interface of Photovoltaic Systems (929-2000)

- Provides guidance on the equipment and function of residential PV systems that are connected in parallel with utility systems. This includes safety, equipment protection, power quality, utility operation, and switches. [1]

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 Puerto Rico's current total energy generation, which currently sits at approximately 16 TWh. [14]
- "Work with" Genera PR to organize updates to the transmission system (lines).
- Reduce the price Puerto Rican people pay for electricity to a level that is fair while still providing profit to the utility company so maintenance can be performed on the new infrastructure.
- Plan must be affordable given the money allocated by the US government for PR100US
    - The US government and other private funds have allocated $3 billion to Puerto Rico to use in the next 10 years to increase its reliance on renewable energy and provide PV systems to low-medium income homes. [13]

  - $1.1 B from federal housing funds for solar and batteries in 30,000 low-medium income homes.
  - $1.3 B to develop microgrids, including one for the hospital.
  - $1 B for an additional 40,000 rooftop PV for impoverished communities.

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.

Table of Contents

Executive Summary	1
Development Standards & Practices Used	1
Summary of Requirements	1
Applicable Courses from Iowa State University Curriculum	2
New Skills/Knowledge Acquired (Not Taught in Courses)	2
Table of Contents	3
Tables	5
Figures	5
1 Team	5
1.1 Team Members	5
1.2 Required Skill Sets for Your Project	5
1.3 Skill Sets covered by the Team	6
1.4 Project Management Style Adopted by the team	6
1.5 Initial Project Management Roles	6
2 Introduction	6
2.1 Problem Statement	6
2.2 Requirements & Constraints	7
2.3 Engineering Standards	7
2.4 Intended Users and Uses	8
3 Project Plan	8
3.1 Project Management/Tracking Procedures	8
3.2 Task Decomposition	9
3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria	9
3.4 Project Timeline/Schedule	9
Table 3.1 Project Schedule	10
3.5 Risks And Risk Management/Mitigation	10
3.6 Personnel Effort Requirements	11
Table 3.2 Personal Effort Requirements	12
3.7 Other Resource Requirements	12
4 Design	12
4.1 Design Context	12
4.1.1 Broader Context	12
Table 4.1 Design Context	13
4.1.2 User Needs	13
4.1.3 Prior Work/Solutions	13
4.2 Design Exploration	14
4.2.1 Design Decisions	14
4.2.2 Ideation	14
4.2.3 Decision-Making and Trade-Off	15
Table 4.2 Viability Assessment	15

4.3 Proposed Design 15
4.3.1 Design Visual and Description 16
Figure 4.3 High Level Project Description 16
4.3.2 Functionality 17
4.3.3 Areas of Concern and Development 17
4.4 Technology Considerations 18
4.5 Design Analysis 18
4.6 Design Plan/Implementation 18
5 Testing 19
5.1 Unit Testing 19
5.2 Interface Testing 19
5.3.1 Integration Testing 19
5.4 System Testing 19
5.5 Regression Testing 19
5.6 Acceptance Testing 20
5.7 Security Testing 20
5.8 Results 20
6 Implementation 20
7 Professionalism 20
7.1.1 Areas of Responsibility 20
Table 7.1 Professional Responsibilities 21
7.2 Project-Specific Professional Responsibility Areas 21
7.3 Most Applicable Professional Responsibility Area 22
8 Closing Material 22
8.1 Discussion 22
8.2 Conclusion 23
8.3 References 23
8.4 Appendices 25
8.4.1 Additional Information 25
8.4.2 Team Contract 25

Tables

Table 3.1 Project Schedule

Table 3.2 Personal Effort Requirements

Table 4.1 Design Context

Table 4.2 Viability Assessment

Table 7.1 Professional Responsibilities

Figures

Figure 4.3 High Level Project Description

Figure 4.4 Basketball Court Roof Estimate

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

After reflection, we have decided we follow the agile management style best. This is because we have (thus far) worked mostly independently, with meetings to come together and decide how to move forward. Our work has been split up by deciding key objectives that need to be done within each week, but we individually work to get those done. As the project progresses, we may find it more useful to adapt the waterfall method, especially when we work on a grid design and simulation. 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 being used 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 for Puerto Rico to use solar energy and battery storage to increase the grid's reliability and lower the electricity price.

2.2 Requirements & Constraints

- Offset Puerto Rico's current total energy consumption, which currently sits at approximately 16 TWh [14]
- "Work with" Genera PR to organize updates to the transmission system (lines)
- Reduce the price Puerto Rican people pay for electricity to a level that is fair while still providing profit to the utility company so maintenance can be performed on the new infrastructure.
- Plan must be affordable given the money allocated by the US government for PR100US
    - The US government and other private funds have allocated $3 billion to Puerto Rico to use in the next 10 years to increase its reliance on renewable energy and provide PV systems to low-medium income homes.
    - $1.1 B from federal housing funds for solar and batteries in 30,000 low-medium income homes
    - $1.3 B to develop microgrids, including one for the hospital
    - $1 B for an additional 40,000 rooftop PV for impoverished communities

2.3 Engineering Standards

IEEE Recommended Practice for Utility Interface of Photovoltaic Systems (929-2000)

- Provides guidance on the equipment and function of residential PV systems that are connected in parallel with utility systems. This includes safety, equipment protection, power quality, utility operation, and switches. [1]

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]

2.4 Intended Users and Uses

Ideally, the average Puerto Rican who uses the existing power grid and has to deal with high prices and unreliability will benefit from the results of our project. They will also care that our solution exists if they feel that they are being let down by the current power grid.

Our solution of photovoltaics and battery storage will be used by the people of Puerto Rico to cut down on their energy costs after a one-time investment, 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 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. The citizens 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 January, we decided we follow the agile management style best. This is because we had (thus far) worked mostly independently, with meetings to come together and decide how to move forward. Our work has been split up by deciding key objectives that need to be done within each week, but we individually work to get those done. As the project progresses, we may find it more useful to adapt the waterfall method, especially if we decide to do a grid design and simulation. 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.

We have adopted a hybrid model at this point (April 2023). 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 may become more agile during the 2nd semester as we try to balance a few 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 the PR 100 goal of 60% renewable reliability by 2040.

Milestone 2: The system has a budget that is within current government funding requirements ($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	Make contact with an NREL researcher for primary source data.	3/27/2023
Task 3	Determine which PV system best suits Puerto Rico (community, farm, rooftop, etc.).	5/1/23
Task 4	Find and apply relevant IEEE standards to our solution	9/18/23

Task 5	Analyze the cost of our solution to ensure economic feasibility.	10/23/2023
Task 6	Develop 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 2: May not be possible to use PSS/E to model the grid. Risk factor: .75.

Risk mitigation: In an ideal situation, using PSS/E would be the most professional way to share our project. However, with only 1 team member with class experience, this just may not be possible. Other ideas include organizing systems by region, an infographic, or another interactive map with quantitative data of our system. We plan to have one or two team members familiarize themselves with the software to improve our ability to model our microgrids.

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

Overall, there are not a lot of risks involved with this project because it is so open-ended and up for us and our advisor to decide and plan as we go. At this point, we are still figuring out what is "too big or broad" to achieve and what is feasible for us as current students.

3.6 Personnel Effort Requirements

*Assuming an average of 6 hours a week/team member and estimated hours each task will take

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	Make contact with an NREL researcher for primary source data. Using email communications.	10
Task 3	Determine which PV system best suits Puerto Rico (community, farm, rooftop, etc.). Research is included in this. Majority of first-semester work.	200
Task 4	Find and apply relevant IEEE standards to our solution Will take less than a week to figure out if spending all hours on this. Will require advising from Dr. Dalal.	20
Task 5	Analyze the cost of our solution to ensure economic feasibility.	120
Task 6	Develop a model/graphic/representation	200

	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.	

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 PSS/E software (can be accessed through a free 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 or directly on their roof; either way 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. Provide jobs to manage the upkeep of grids and training to families who decide to take part.

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 and not be concerned about when the next outage and price hike will occur.

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

- Working off/in parallel to what a past senior design group did. Thus far, we have only referenced their documents to get an idea of the direction we should head in. We may reference their final design to get a scope of what is possible for our end product."
- Solar technology is used widely, so we will use specs 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, basic controls (maybe), 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 do we want electricity to get down to?
- What software should we use to model our final design?
- How can we convince the people of Puerto Rico their investment in our solution will pay off?

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 paired with rooftop systems.

4.2.3 Decision-Making and Trade-Off

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

4.3 Proposed Design

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. At this point, we have a firm grasp of our plan for the second semester. This will be to create a design for community PV systems on top of neighborhood basketball courts and rooftop systems.

4.3.1 Design Visual and Description

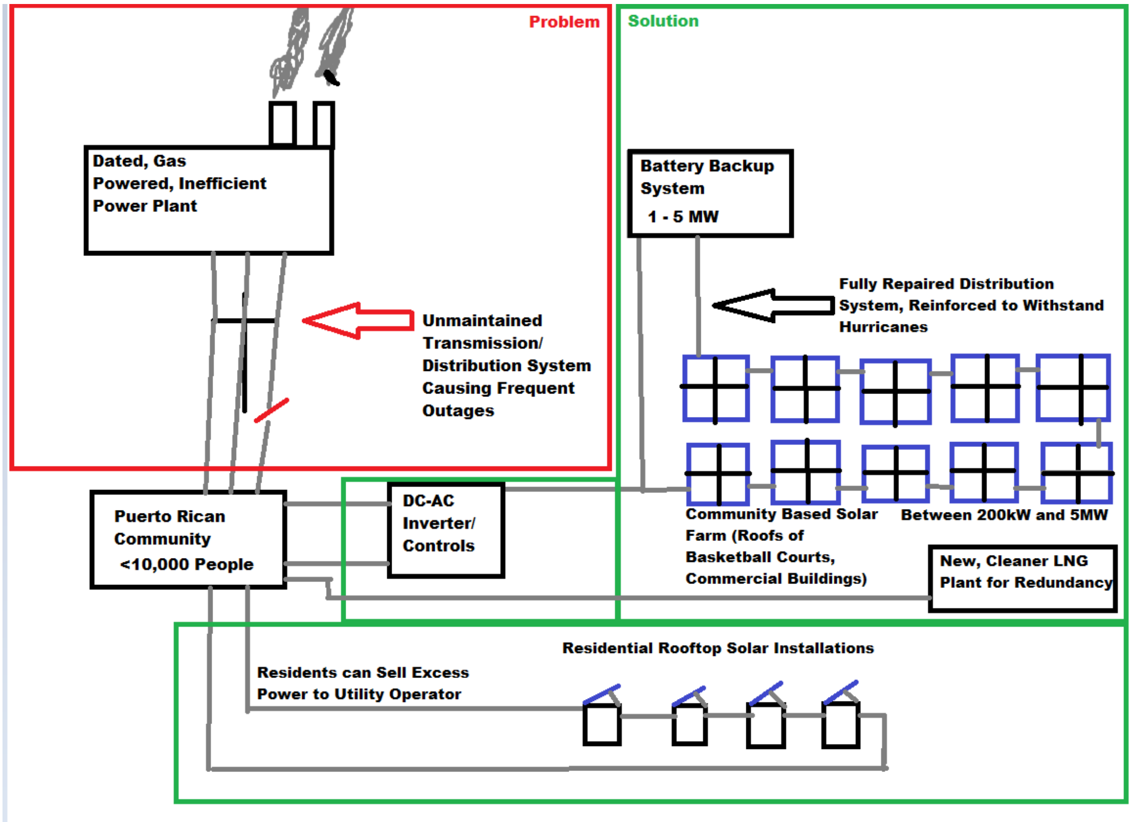

Figure 4.3 High Level Project Description

This diagram shows at a high level what the problem we are trying to solve is, and what solution we are heavily considering to solve said problem. 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 in the past, lead us to our proposed solution of implementing multiple community-based solar farms near population centers in Puerto Rico, as well as planning for a new LNG (Liquid Natural Gas) plant that can supplement the new solar farms in times of need. 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 that must be repaired. This solution is still very generalized in nature, and we plan to add to our plan in greater detail as time goes on and new information is found.

One particular case we plan to implement a design on is 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. 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. 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 in case the main grid is knocked out by storms again and decrease the overall cost of electricity over the next few years.

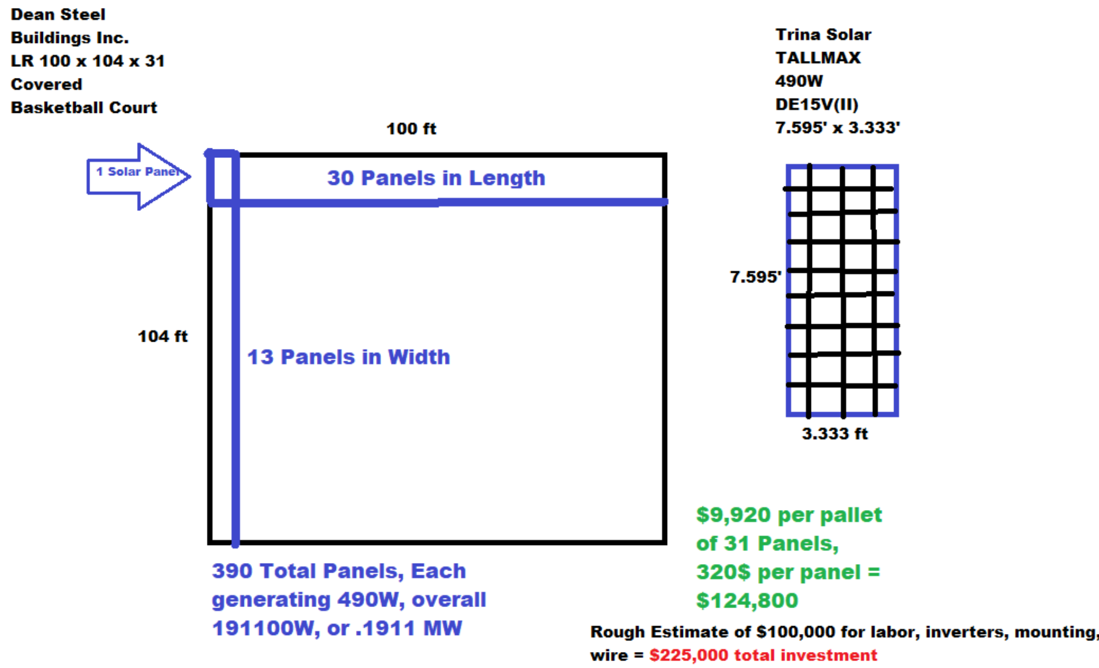

Figure 4.4 Basketball Court Roof Estimate

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.

4.3.2 Functionality

Currently, we do not have a concrete design solution. However, we've been researching possible solutions and different technologies or grid designs we could utilize in our solutions. These include rooftop PVs, large-scale solar farms, community solar farms, microgrids, and inland or offshore wind power generation. These aspects of our solution are in line with our goals of creating a 100% renewable energy grid that is also reliable for the island. Another issue we have recently come to find is PR's dependency on outdated petroleum and diesel generators, we are considering changing these to LNG generators as our backups for our renewable energy production.

4.3.3 Areas of Concern and Development

We do still worry about our solution's resiliency to the strong hurricanes that often impact Puerto Rico's power grid. We also are concerned that if our solution is implemented, the solar farms may not be properly maintained, as the grid operators in Puerto Rico have had a bad track record of making repairs and performing maintenance on the grid.

We are looking to get in touch with a contact at NREL, so we may gain a primary source and a better understanding of the research they have already conducted on Puerto Rico.

We also remain in contact with our advisor, Professor Dalal, who has provided great questions and suggestions on how we might want to solve these complex problems.

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.

We also consider roof design because the type of roof material can affect the cost of future solar installation. In order to implement solar panels, a roof must be able to support the weight of the PV equipment. We need to identify whether the roof installation carries a warranty or if the warranty includes rooftop installation.

PV Equipment and Installation is also one of the technologies considerations. As we design the community PV system and rooftop system, we will have to choose solar panels that are economically viable and efficient enough to produce electricity to justify the cost of installation.

4.5 Design Analysis

At this time, we are doing some research about all possible solutions to compare which one is more efficient and stable for Puerto Rico residents. From what we have done so far in research, 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 rooftop PV systems alone, NREL estimates 4x PR's demand [8]. However, we also plan to use community systems to provide increased reliability.

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 insight and ideas into Puerto Rico's energy crisis.

4.6 Design Plan/Implementation

Once we have finalized the direction of our design – currently heading in the direction of PV on community basketball court coverings and residential rooftops – we will start an analysis of what we hope to and/or can achieve. We need to decide how much of Puerto Rico's electricity demand we would ideally like to meet. From there, we have equations and resources that can help us calculate the area and # of panels this takes. We can further split that up into the # of basketball courts to use and # of houses. The next step of the plan would be to do an economic analysis of the cost of this plan and how much investment would be returned in savings. Since Puerto Ricans already pay so much for electricity, they likely will not want to spend much on their own roof. So, it may take government funding and data that proves how long it will take to pay off. We will also estimate the new LCOE of our PV systems. If time/complexity allows, we could turn our design into a grid model– even on a small scale, it may be possible to show the panels and connection over a basketball court or in a residential sector.

5 Testing

5.1 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, 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 an average rooftop solar installation and different cases of community-based solar farms, for example, above parking lots or on the roof of basketball courts. The reports will also highlight the amount of time it will take for the Puerto Rican people to receive a return on their investment.

5.2 Interface Testing

As of now, we plan to integrate both community and rooftop PV systems. These two systems will have to interact within the grid, and we will need to figure out how to transmit and distribute the clean energy generated from these systems. In terms of tools, we will use software or online calculators to determine the amount of solar and battery storage we need. We will test that against our calculations, including inefficiencies.

5.3.1 Integration Testing

(If we use PSS/E) We will use PSS/E software and IEEE standards to ensure all aspects of our microgrid designs integrate smoothly. For example, we will ensure the Solar panels, transmission lines, and battery backups work together seamlessly.

5.4 System Testing

At the end of our project, we will spend time recalculating our estimates for the cost and payback period for the microgrids and running the simulations under various conditions that could negatively affect our designs. 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 by the Puerto Rican people.

5.5 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.

5.6 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.

5.7 Security Testing

As society becomes more technologically advanced, there is an increasing cybersecurity threat. The grid is becoming increasingly interconnected (IoT). Pre-IoT, compromising the grid required physical access. Now, any IoT device can become an entry point a hacker uses the 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. Hypothetically speaking, if we were to implement this physically, we would want to have a security and penetration testing organization test the smart grid system to ensure there were no obvious access points. In addition, customers will need to be educated on proper maintenance for their rooftop grid and be aware of physical security threats.

5.8 Results

We are not in the project's testing phase at this time, so we do not have any results to share. However, when we do enter the testing phase, the results of our testing will be successful simulations of microgrids showing our designs for rooftop and community grids work as intended and that the costs of those investments are affordable and can be paid off in a reasonable amount of time.

6 Implementation

At this time, implementation is discussed in section 4.6 alongside our *project plan*. This section will be updated in the fall semester.

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 main results of our project come from research and design decisions we have made in the last few weeks. 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.

One of the larger results we have found is that Puerto Rico has the capacity to power 4x its energy demand with PV systems on rooftops [4]. This assures us that there is more than enough potential and gives us a basis for our calculations due to NREL's research about the number of residential roofs there are and their total capacity.

Another important result is that we can use a trendline based on the rooftop PV growth over the last 7 years; it is possible to calculate the # of panels and customers necessary for a set percentage of PR's energy demand.

In addition, our current economic analysis indicates that both residential and community systems have an average investment recuperation of 8-10 years, which is lower than in the continental US.

These results set us up well for next semester to start creating our concrete implementation plan and creating our final deliverable and calculations.

8.2 Conclusion

So far, at the end of the first semester of this senior design project, we have completed extensive research to determine the best methods for implementing solar power in Puerto Rico, and we have decided to take a split approach by designing a rooftop based community solar farm mounted on top of a covered basketball court structure that can be commonly found in Puerto Rico, as well as a model for hospital and commercial building roofs that can be scaled up to the entire island of Puerto Rico over time. Our goals for the second semester are designing detailed models for these grids, including all necessary components and estimates for installation costs that could highlight how investing in these microgrids will benefit Puerto Rican people in the long run in terms of reliability and economic savings.

8.3 References

[1] "929-2000 - IEEE Recommended Practice for Utility Interface of ...," *IEEE Xplore*, 2000. [Online]. Available: https://ieeexplore.ieee.org/document/836389.

[2]"IEEE SA - IEEE 1547-2018," IEEE Standards Association. https://standards.ieee.org/ieee/1547/5915/

[3] "NECA 417 Microgrids," *National Electrical Contractors Association*, Jan-2019. [Online]. Available: https://www.neca-neis.org/docs/default-source/default-document-library/neca-417-microgrids---ansi-recirculation-draft---final-format---20180606.pdf?sfvrsn=0. [Accessed: 23-Apr-2023].

[4] "NFPA 70®: National Electrical Code®," Nfpa.org, 2017. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70

[5] "NFPA 855: Standard for the Installation of Stationary Energy Storage Systems," www.nfpa.org. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855

[6] “Puerto Rico Territory Energy Profile,” *Puerto Rico Profile*. [Online]. Available: https://www.eia.gov/state/print.php?sid=RQ#:~:text=93%2C94-,Renewable%20energy,energy%2C%20hydropower%2C%20and%20biomass.

[7] M. Mooney and K. Waechter, “Puerto Rico Low-to-Moderate Income Rooftop PV and Solar Savings ... - NREL,” 17-Dec-2020. [Online]. Available: https://www.nrel.gov/docs/fy21osti/78756.pdf.

[8] N. Grue, G. Buster, A. Kumler, Y. Xie, M. Sengupta, and M. Baggu, “Quantifying the Solar Energy Resource for Puerto Rico,” National Renewable Energy Laboratory, May-2021. [Online]. Available: https://www.nrel.gov/docs/fy21osti/75524.pdf.

[9] M. Ilic, R. S. Ulerio, E. Corbett, E. Limpaecher, M. Shatz, and E. Austin, “Framework for Evaluating Electric Power Grid Improvements in Puerto Rico,” Lincoln Laboratory, Jul-2019. [Online]. Available: https://www.ll.mit.edu/sites/default/files/publication/doc/2020-07/a-framework-for-evaluating-electric-power-grid-improvements-in-puerto-rico-ilic.pdf.

[10] J. Jun Lee, “Renewing Growth in Puerto Rico: Evaluating the Island's Transition to Distributed Solar Energy,” *Journal of Public and International Affairs*, 20-May-2022. [Online]. Available: https://jpia.princeton.edu/news/renewing-growth-puerto-rico-evaluating-island%E2%80%99s-transition-distributed-solar-energy.

[11] “10-Year Infrastructure Plan,” Puerto Rico Electric Power Authority (PREPA), Mar-2021. [Online]. Available: https://aeepr.com/es-pr/Documents/20201207_PREPA%2010-Year%20Infrastructure%20Plan_vF.pdf.

[12]“Home,” *SunWatts*. [Online]. Available: https://sunwatts.com/200-kw-solar-kits/.

[13] N. Acevedo, “Renewables vs. fuels? Puerto Rico faces a critical time to determine its energy future,” *NBCNews.com*, 03-Feb-2023. [Online]. Available: https://www.nbcnews.com/news/latino/puerto-rico-blackouts-power-grid-ailing-renewable-energy-rcna68754. [Accessed: 23-Apr-2023].

[14]“U.S. Energy Information Administration - EIA - independent statistics and analysis,” *Territory Energy Profile Data*. [Online]. Available: https://www.eia.gov/state/data.php?sid=RQ#Supply. [Accessed: 23-Apr-2023].

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.
****

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______