APPLYING THE ENERGY JUSTICE FRAMEWORK TO RESILIENCY STUDIES IN POWER SYSTEMS

by

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ABSTRACT

EMILY ABBATE. Applying the Energy Justice Framework to Resiliency Studies in Power Systems. (Under the direction of DR. BADRUL CHOWDHURY)

In the power system design process, engineers account for three topics outside of the technical feasibility. Those principles are economic feasibility, environmental impacts, and safety. This thesis argues that socioeconomic factors should also be included in this design process. Without properly accounting for social equity from the initial design of the power system, the resulting system has inequities. This thesis applies a three-tenet approach towards determining social inequities present and finding solutions to correct the inequity. This framework was applied to a resiliency study of a coastal city in North Carolina that is susceptible to Hurricanes and other extreme weather events.

In this first tenet, *distributional justice*, a data-driven approach was undertaken to prove more socially vulnerable communities had longer power outages during extreme weather events. In the second tenet, *recognition justice*, a community member was interviewed to gain insight and context on how different communities within the area are treated and what social barriers these communities face. By combining the information gleaned in the first two tenets, the third tenet, called *procedural justice*, presented solutions to improve the disparity shown in earlier data analysis. The solutions presented were undergrounding portions of the electric system, constructing a microgrid in a more socially vulnerable neighborhood, and establishing a community engagement program between the local utility and the community.

DEDICATION

I dedicate this thesis to all the powerful women that inspired my education into engineering. To my mom, who taught me femineity is knowing how to change a tire. To Edith Clarke, for paving the way for all future female electrical engineers. And finally, to Karen Mullins, who saw my potential in high school calculus class and encouraged me to peruse an education in engineering.

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Second, I would like to thank my thesis advisor, Dr. Badrul Chowdhury. Through his guidance, I was able to create a thesis that is both nuanced and powerful in the message it delivers. I would also like to thank Dr. Robert Cox and Dr. Valentina Cecchi for their continued support and guidance as well.

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And finally, thank you to the community member I interviewed. Your interview was an enlightening experience that helped me develop this work further in a way that would truly help a disadvantaged community in a southeastern coastal city of North Carolina.

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LIST OF ABBREVIATIONS

AC Alternating Current

AMI Advance Metering Infrastructure

ASAI Average Service Availability Index

BESS Battery Energy Storage System

BLVD Boulevard

BPS Bulk Power System

BRIC Building Resilient Infrastructure and Communities

CDC Center for Disease Control

CPCN Certificate of Public Convenience and Necessity

CPUC California Public Utilities Commission

DA Distributed Automation

DC Direct Current

DOT Department of Transportation

EaaS Energy-as-a-Service

EITF Energy Innovation Task Force

EO Executive Order

FEMA Federal Emergency Management Agency

HILF High Impact Low Frequency

HMGP Hazard Mitigation Grant Program

ICC Illinois Commerce Commission

IIT Illinois Institute of Technology

KVA kilo-volt-amps

KW kilowatt

MaaS Microgrid-as-a-Service

MED Major Event Day

MW megawatt

MWh megawatt-hour

NCUC North Carolina Utilities Commission

NWA Non-Wire Alternative

PG&E Pacific Gas and Electric Company

PPA Power Purchase Agreement

PSPS Public Safety Power Shutoff

PUC Public Utility Commission

PV Photovoltaic

SAIDI System Average Interruption Duration Index

SCADA Supervisory Control and Data Acquisition

SGIP Self-Generation Incentive Program

SVI Social Vulnerability Index

T&D Transmission and Distribution

UFE Unaccounted For Energy

UPRM University of Puerto Rico- Mayagüez

CHAPTER 1: INTRODUCTION

This chapter will provide a high-level review of the content and structure of this thesis. Additionally, this chapter will provide a discussion on the motivations in developing this thesis.

1.1 Motivation

Engineers are taught early on in our education that we exist to invent products and processes that will improve the livelihood of others. Simply put, we exist to help others. Additionally, the code of ethics for engineers states that an engineer is responsible to “hold paramount the safety, health, and welfare of the public” [1]. However, as an engineer delves deeper into their respective studies, we are taught the design process includes three major factors. First, is the design technically feasible? Second, is the design economically feasible? And finally, will the product be safe for customer use? Upon first glance, one can see that public welfare is not placed into consideration at all. The societal impact of the design is not always studied even though these designs often result in monumental sociological consequences.

As with any design factor or constraint, if the engineer does not place a value on a specific factor in the design process, then the final product will not exhibit that factor. For example, if a bridge is designed without adequate safety factors, the resultant bridge is likely to cause potential safety concerns. A failure to value safety in the design process results in a product that is not safe. Likewise, if socioeconomic factors are not evaluated during the design process of the electric grid, then the resulting grid will contain social inequities. A failure to value social equity and inclusion into the design process results in a system that is not socially equitable or inclusive. This is not an intentional choice engineers make; it is a natural consequence of the design process.

This thesis was designed to argue that social factors including equity and inclusion must be incorporated into the design process. As engineers design new technologies and configurations of the power system, social equity and inclusion must be placed in the process to correct past injustices and prevent future injustices. This thesis will discuss the current social inequities present in the power system and provide solutions. For every engineer reading this paper, read with an open mind and remember we exist to improve the public welfare of everyone in society, not just the rich and powerful.

1.2 Topical Overview of Thesis

This thesis is divided into five additional chapters. Chapter 2 will provide background information on the energy justice framework, the concept of resiliency, and microgrids. Chapter 3 will provide data analysis proving a physical disparity between communities with differing levels of social vulnerability. In this section, a data driven approach was taken comparing the average power outage duration in given feeders against a measure of social vulnerability, known as SVI. It was concluded through this analysis that more socially vulnerable communities experienced longer power outages on average when compared to the rest of the system. Chapter 4 will provide a discussion on the historical roots and prevailing exclusion of socially vulnerable communities in the selected area of study. In this chapter, a community member was interviewed to gain insight and context. Chapter 5 will provide solutions to correct the disparities discovered in Chapter 3. In this chapter the following solutions were presented: undergrounding portions of the system, constructing a microgrid, and implementing a community engagement program. Finally, Chapter 6 will discuss future work to be completed and conclude all findings. The southeastern coastal region of North Carolina was specified as the area of study due to its history of social inequities and major hurricanes.

CHAPTER 2: LITERATURE REVIEW

As is customary with any formal research paper, a comprehensive literature review must be conducted. For this investigation, the topics of energy justice, resiliency, and microgrids were researched. The findings from that research are discussed in this chapter.

2.1 Energy Justice

Energy justice is a social science theory that states “all individuals in society should have access to energy that is affordable, safe, and sustainable” while also having the ability to participate in the decision-making process for future energy investments [2]. This concept is relatively novel to the scientific community. Energy justice first appeared in a research paper in 2010 [3]. By 2013, the concept became clearly defined, and a framework for application of the theory was also developed. In 2014, additional governing principles were added into the framework [3]. The concept of energy justice has developed out of the earlier environmental justice and climate justice movements. The environmental justice movement, which began in the 1970s, focused on adverse health effects underprivileged communities faced due to infrastructure developments. The climate justice movement, beginning in the 1990s, focused on climate change mitigation plans. While the energy justice movement borrows principles from both the environmental justice and climate justice movements, energy justice focuses on the social inequities within the energy industry specifically [4]. Figure 2.1 provides a synopsis of each movement along with a timeline explaining the emergence of each concept.

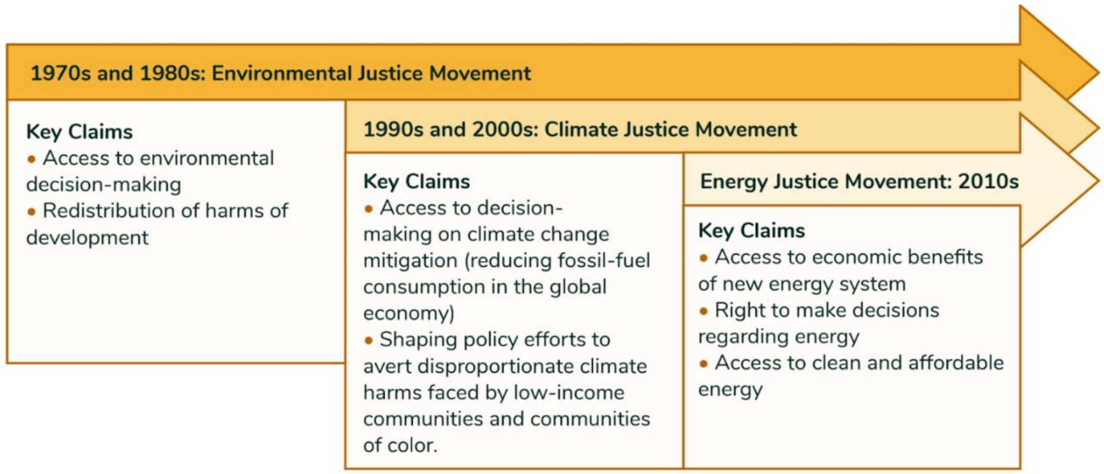

Figure 2.1: Timeline Comparing Environmental, Climate and Energy Justice Movements [4]

The framework for energy justice is divided into four tenets: distributional justice, recognition justice, procedural justice, and restorative justice. Distributional justice refers to the physical inequitable distribution of benefits of the energy system. This tenet can refer to physical locations of infrastructure, access to energy services, along with many other dimensions. Recognition justice states that all individuals must have equal political rights, be free from physical threats, and be fairly represented in the energy system. To apply recognition justice, scholars analyze historical and prevailing interactions with underprivileged communities to find instances of cultural or political domination [5, 6]. Applying this tenet provides context for why a certain distributional injustice may exist and provides guidance for how injustices can be corrected. Procedural justice advocates for an energy system in which individuals are engaged in a non-discriminatory way. This tenet is achieved through institutional representation, disclosure of information, and local mobilization through knowledge [5]. Finally, restorative justice refers to actions that can be taken to correct any injustices noted in the other three tenets [6]. The goal of applying restorative justice is to correct the wrongs of previous injustices to create an energy system that aligns with the energy justice concept. In layman's terms, the four tenets of energy justice can be summarized as 'what is the inequity', 'who is affected', 'what needs to be fixed', and 'how can it be fixed'. The governing principles of energy justice are availability, affordability, due process, transparency, accountability, sustainability, inter and intra-generational equity, and responsibility [3]. Figure 2.2 provides a visualization of the four tenets and guiding principles of energy justice.

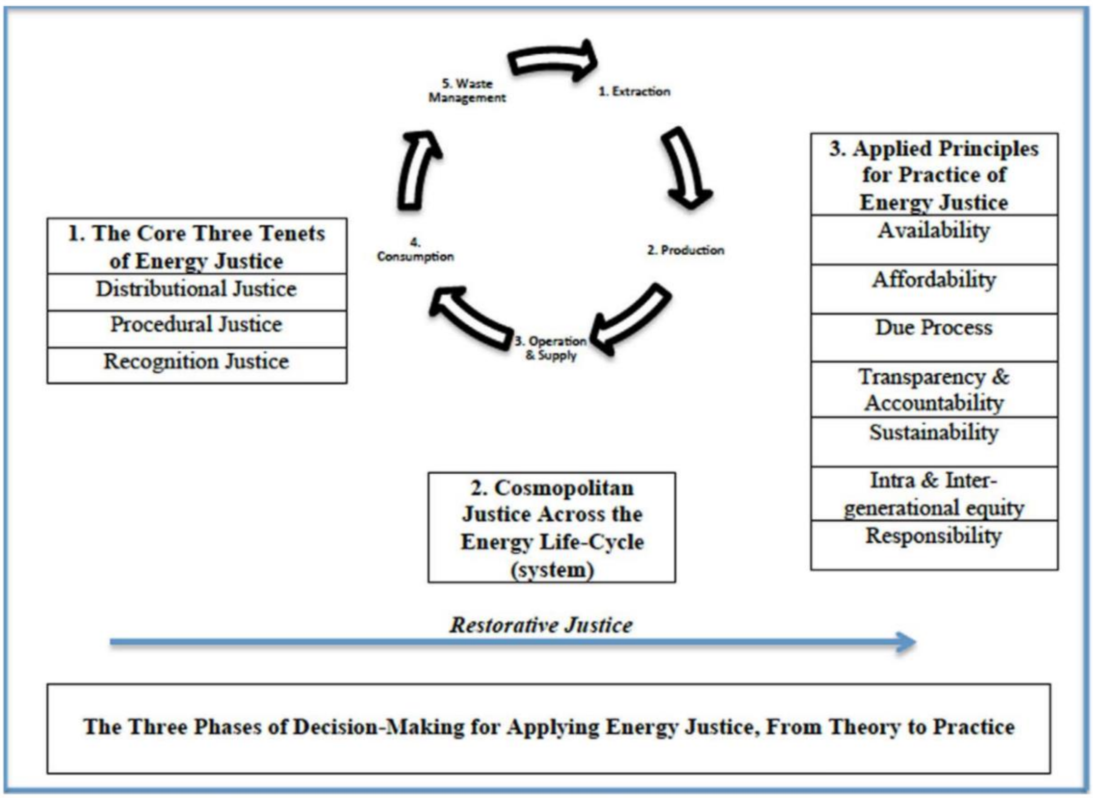

Figure 2.2: Visualization of Energy Justice Principle [3]

A natural question that might precede this discussion is "why is energy justice important?". At first glance, one can see that the consequences of climate change will disproportionally affect disadvantaged and marginalized communities. The energy system currently struggles with two conflicting problems simultaneously. First, there is a presence of too much energy in society in the forms of pollution, waste, and overconsumption. However, at the same time, there is not enough energy in certain aspects of society that are shown through energy poverty, under-consumption, and lack of access to modern energy services. While all of these disparities and social inequities are true, energy planners continue to base investments decisions solely on technical and economic considerations [7].

With this current system, hazards of the industry are unevenly imposed on marginalized communities [8, 9]. For example, 70% of the United States' contaminated waste sites are located near low-income housing. Among these waste sites, coal ash deposit sites specifically are known to contain mercury, lead, and arsenic. All of these contaminants are known carcinogens. The EPA estimates that 1.5 million people of color live in area where exposure to coal ash is likely [10]. Marginalized communities also struggle to gain access to the benefits of modern energy technology, and the decision-making process for further industry investment excludes those communities [8]. An example of this phenomenon can be seen by examining the Keystone pipeline controversy. In this example, the TransCanada Keystone XL pipeline was designed to run through native land belonging to more than 38 tribes. The tribes were not consulted about the project until the construction process began and, when asked for comment, Lou Thompson of TransCanada said, "There is no legal obligation to work with tribes [11]." From examining the two examples discussed above, one can clearly see that there is a moral implication to decisions made by the energy industry. Therefore, the energy industry should utilize the energy justice framework as a decision-making tool when designing new investment opportunities [8]. By utilizing this framework, future injustices can be prevented, and past injustices can be corrected.

2.2 Resiliency Studies

Electricity service providers are required to maintain a power system that is safe, affordable, and reliable. Reliability of a power system can be calculated using metrics defined in IEEE standard 1366. This standard is specifically used to analyze the reliability of the distribution system. One of the most common metrics is referred to as System Average Interruption Duration Index (SAIDI) and calculated using the following formula.

$$SAIDI = \frac{\sum Customer\ Minutes\ of\ Interruption}{Total\ Number\ of\ Customers\ Served}$$

SAIDI values are typically calculated on a daily basis and are reported to the Public Utility Commission (PUC). The PUC reviews a utility's SAIDI metrics to ensure the system's reliability is performing at a certain level. If SAIDI numbers are higher than expected, the utility must make additional infrastructure investments to improve the reliability metrics.

For reporting purposes, SAIDI values occurring on days of unusually high impact of power outages are excluded. These reporting days are designated as major event days (MEDs). To designate a reporting day as a MED, first daily SAIDI values for five consecutive years are calculated. Then, the natural logarithm is applied to the SAIDI values. Finally, the SAIDI values are applied to the following equation to calculate a threshold value (referred to as TMED).

$$T_{MED} = e^{(\alpha + 2.5\beta)}$$

$$\alpha = avg(\ln(SAIDI\ for\ each\ day))$$

$$\beta = std\ deviation\ (\ln(SAIDI\ for\ each\ day))$$

For any reporting day with a SAIDI value above the threshold, the day is denoted as a MED and is not included in reporting metrics. This process is referred to as the Beta method [12].

While these methods provide an accurate snapshot of clear sky operations within the power system, the Beta method excludes information about how the power system responds to extreme weather scenarios. Additionally, the frequency and severity of power outages caused by extreme events has significantly increased in the last decade [13]. Figure 2.3 demonstrates the number of system disturbances caused by extreme weather from 1992-2009. An exponential relationship can be noted suggesting that extreme weather events have increased in severity and frequency over time.

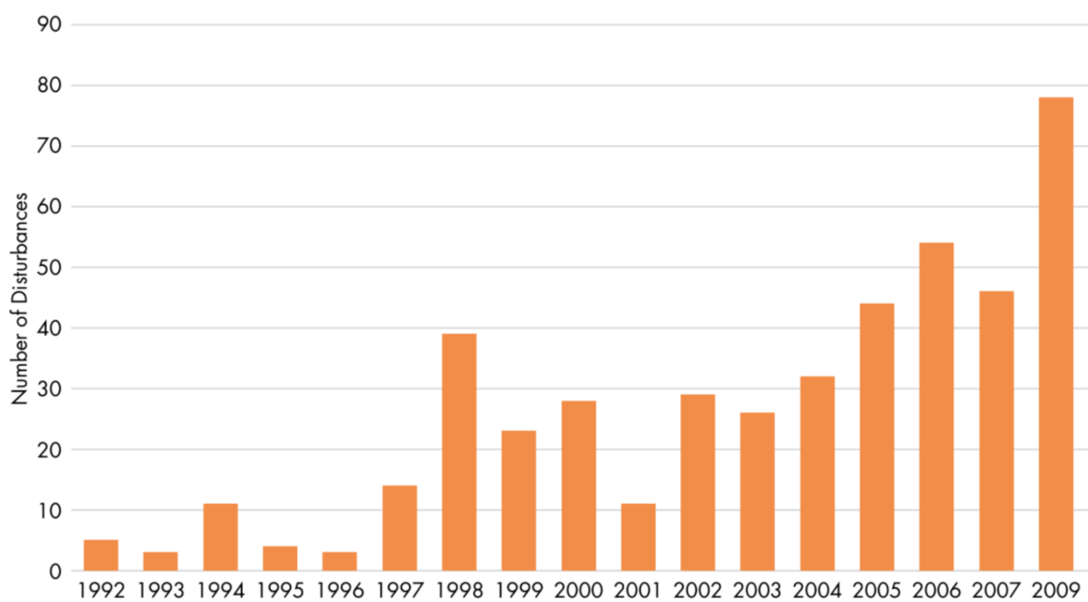

Figure 2.3: Number of System Disturbances Caused by Extreme Weather Events [14]

Extreme weather events, often referred to as high impact low frequency (HILF) events, differ from typical operational challenges within the power system [14]. HILF events can cause the entire power system to collapse. These kinds of events can also result in complex restoration efforts [13].

Additionally, extreme weather events currently are considered the highest cause of electric power outages in the United States [l, n]. Between 2003 and 2012, 679 system wide outages were attributed to extreme weather events. A graphic depicting the recent rise in weather related power outages versus non-weather related events in shown in Figure 2.4 [16].

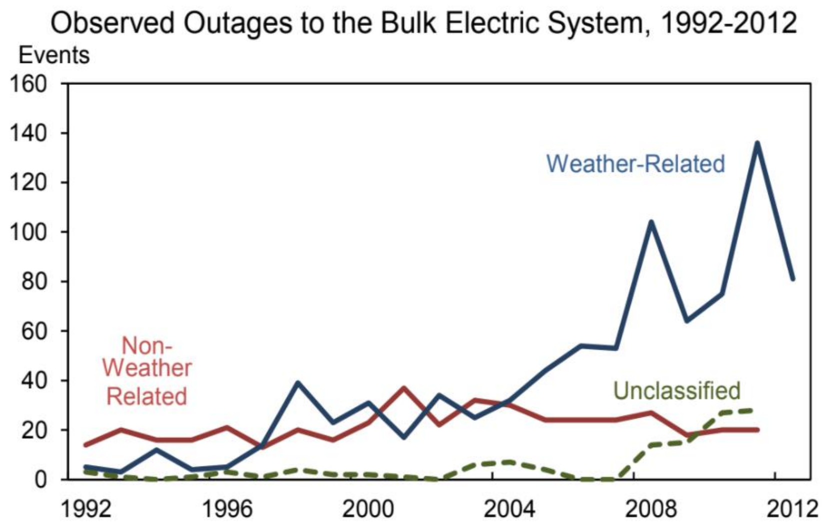

Figure 2.4: Observed Outages Weather-Related vs. Non-Weather Related [16]

It is important to note that Figures 2.3 and 2.4 depict power outages within the Bulk Power System (BPS) or better known as the transmission system. For resiliency studies and IEEE standard 1366, the distribution system is solely analyzed. While extreme weather events affect the BPS in an impactful way, the outages experienced on the distribution system are even more extreme in terms of customers affected, outage duration, and physical damage to the system.

Due to the factors mentioned above, a new concept has been introduced to power systems research called resiliency. Resiliency is defined as the ability of a system to recover quickly from disruption [13]. There are four principles of resiliency: (i) robustness, (ii) resourcefulness, (iii) rapid recovery, and (iv) adaptability. Robustness refers to the ability to continue operating despite non-ideal conditions. Resourcefulness refers to the ability to effectively manage a crisis-like scenario. Rapid recovery refers to the ability of the system to return to normal operating conditions. Finally, adaptability refers to the ability to learn from past mistakes to improve operations in future crisis situations [17]. Resiliency differs from reliability because resiliency focuses on how the power system reacts to MEDs. (MEDs events, HILF events and extreme weather events are all synonymous terms.) The relationship between reliability and resiliency is similar to squares and rectangles. A resilient system must be a reliable one, but a reliable system is not necessarily a resilient one [13].

Similar to the energy justice principle, there is a framework for resiliency studies. This framework suggests that there are four stages for every extreme weather event: prevention, degradation, restoration, and adaptive. The prevention stage occurs prior to an extreme weather event. The degradation stage describes the transition the system takes from normal operating conditions to a fully damaged state. During the restoration stage, the system transitions from the fully damaged state back to normal operating conditions. In the adaptive stage, the power system returns to normal operating conditions. During this stage, power system operators and utility providers should investigate which methods can be adjusted to improve the system response for the next extreme weather event. The time series representation of these stages is commonly referred to as a resilience triangle.

Figure 2.5 illustrates the resilience triangle with labeled stages [13].

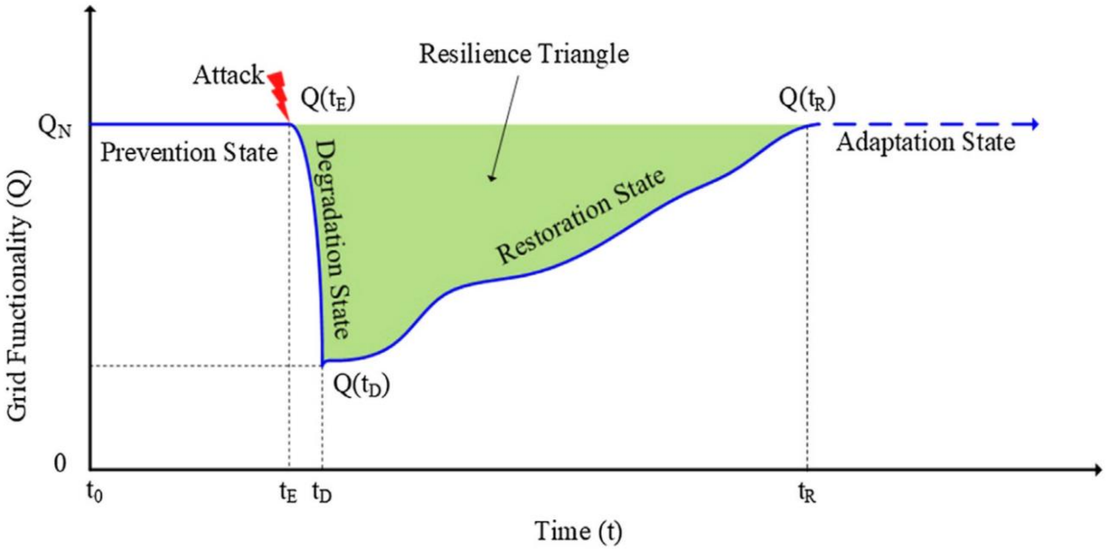

Figure 2.5: Illustration of Resilience Triangle [13]

In certain scenarios, the power system will remain in a damaged condition for an extended period of time. In these situations, a fifth stage is added into the resiliency framework denoted as degraded state. With the addition of a fifth stage, the resilience triangle becomes a resilience trapezoid. Figure 2.6 illustrates the resilience trapezoid with labeled stages [13].

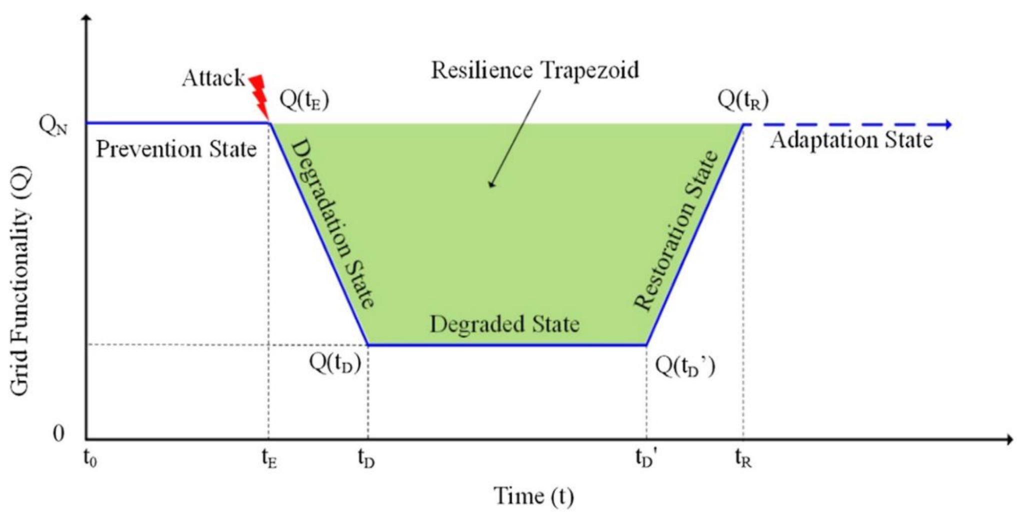

Figure 2.6: Illustration of Resilience Trapezoid [13]

There are various methods that can be employed during the adaptive stage to improve the power system's resilience. These solutions fall into two categories: system hardening and improving the restoration process [18, 19]. System hardening refers to physically changing existing infrastructure to prevent damage. Table 2.1 illustrates various system hardening activities that can be employed to improve system resiliency [18].

Table 2.1: Power System Hardening Activities [18]

Hardening	Activities
Flood Protection	Elevating Substations/control rooms/pump stations Relocating/constructing new lines and facilities
Wind Protection	Upgrading damaged poles and structures Strengthening poles with guy wires Burying power lines underground
Modernization	Deploying sensors and control technology Installing asset databases/tools

Currently, restoration practices lack situational awareness. Essentially, a majority of the restoration process is still dependent on complaint calls from customers to identify points of failure. Distributed automation (DA) and advanced metering infrastructure (AMI) are two potential grid investments that could improve the situational awareness regarding major power outages. Additionally, current restoration practices result in communities coping with a lack of power for days, sometimes even weeks. This phenomenon is referred to as degraded customer survivability. The implementation of a microgrid, in select areas, can help improve customer survivability [15]. This solution will be explained in further detail in section 2.3.

To improve resiliency of a given power system, a combination of all of these mitigation strategies and infrastructure investments is needed. Resiliency improvements are not a one size fits all solution [20]. Multiple factors, including type of weather events or vegetation, will affect what combination of corrective actions will be used to improve resiliency of the system.

2.2.1 Connecting Resiliency and Energy Justice

Improving power system resiliency is important because the modern world is dependent on electricity [20]. Power outages result in schools and businesses closing. They prevent the distribution of emergency services, and affect the individual lives of people within the community [16]. However, a discrepancy in recovery patterns between different communities with varying social vulnerabilities has been noted in previous studies [21]. A recent study performed by a research team, associated with Texas Southern University, observed this pattern during Winter Storm Uri in Texas. The research team discovered that socially vulnerable communities had longer duration outages during the storm, and the communities that did experience outage were more socially vulnerable than surrounding communities that were not affected by the storm [22]. This study and the study presented in this thesis highlight the importance of integrating socio-economic considerations into resiliency studies. According to the team at Texas Southern University, “A failure to integrate equity into resilience considerations results in unequal recovery and disproportionate impacts on vulnerable populations [22].” Other researchers have argued that resiliency is only useful if system improvements help disadvantaged communities [21].

2.3 Microgrids as a Resiliency Solution

The traditional power system has a centralized structure. In this structure, the power system is divided into four separate tiers: generation, transmission, distribution, and end users. A large power plant generates power in a remote location. The transmission system transports said power towards communities, and the distribution system distributes the power across communities. In this system, power flows in one direction and has limited flexibility [23]. Figure 2.7 provides a visual representation of these tiers in the power system.

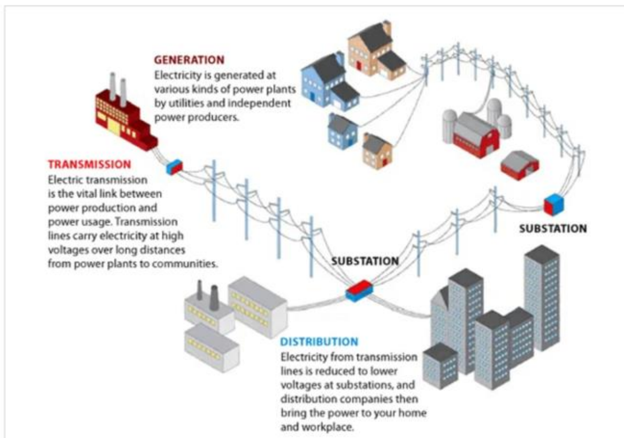

Figure 2.7: Visual Representation of Centralized Power System [23]

This current structure comes with technical challenges. Mainly, the unidirectional power flow contributes to losing about 8% of generated power due to the use of the transmission network. The centralized power system is a hierarchical tiered system with generation facilities at the top. With this current structure, any anomaly in the distribution system can result in widespread blackouts. With 90% of power outages occurring within the distribution system, there is enough motivation to adjust this structure [24].

Instead of continuing to use a centralized structure, the power system is moving towards a decentralized or distributed structure. In a decentralized structure, power is able to flow in both directions and smaller generating facilities are connected to the distribution network directly [25]. At the center of this new structure is the microgrid. A microgrid is defined as the placement of distributed generation units within the distribution network [26]. A microgrid is also defined as a medium to low voltage distribution feeder that includes distributed load, generation, and storage capabilities [18].

A microgrid can operate in two modes: grid-connected and islanded. In grid connected mode, the microgrid is connected to the larger power system providing additional power and ancillary services. In islanded mode, the microgrid is able to separate from the larger power system and operate independently. In this mode, a microgrid is able to supply power to certain areas while the rest of the system is experiencing a blackout [25, 27]. A microgrid can use a variety of sources to generate power. These resources include solar (photovoltaic), wind, and diesel. However, the most popular configuration of modern microgrids is to use a combination of photovoltaic (PV) generation and battery energy storage [25]. Figure 2.8 illustrates the structure of a microgrid.

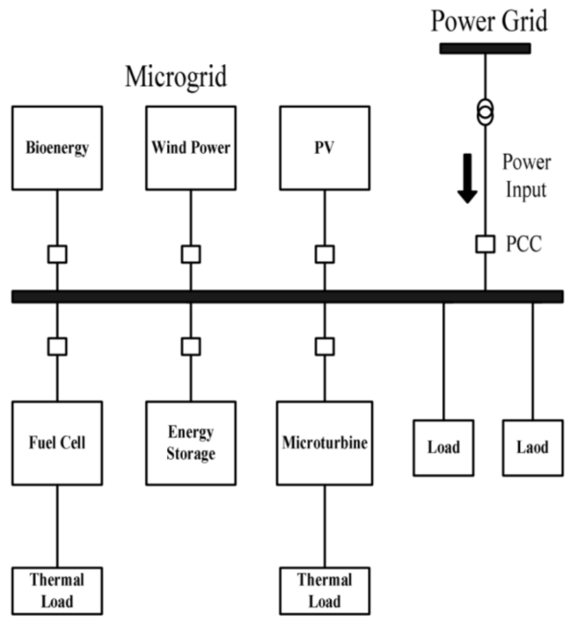

Figure 2.8: Typical Structure of a Microgrid [25]

Microgrid technology is considered a resiliency improvement method because of its ability to operate in islanded mode. Essentially, this functionality provides localized power to an affected area [15]. In islanded mode, a microgrid is able to restore power to critical infrastructure, i.e., hospitals, and residential homes with little to no disruption to the loads [16, 18]. This ability reduces the overall number of people losing power during a major weather event and provides survivability for those affected. An example of a microgrid performing this function can be seen by examining the Sendai Microgrid in Japan. In 2011, a large earthquake occurred, and the Tohoku Power Company struggled to restore power for three days. However, for two and a half days the Sendai Microgrid was able to supply power so individual customers did not experience a power outage even though the larger power system was down [15]. The microgrid's ability to operate in an islanded mode assists in the restoration process by minimizing the number of customers experiencing an outage thereby increasing the customer's survivability.

From this discussion, the benefits of a microgrid from a resiliency perspective are easily seen. From an energy justice perspective, the introduction of microgrid technology provides an opportunity for utility owners. The application of microgrids symbolizes a transition the power industry is undergoing from a centralized system to a decentralized system. In this new format, the power system must be designed with individual communities in mind and requires community engagement to create a system that will benefit the community. Many researchers argue that the best microgrid projects are ones in which the community was able to participate in an open process [28]. Therefore, microgrids present a solution on two fronts. The technology is an excellent solution to improve resiliency of the power system while also presenting an opportunity to enact procedural justice.

In the next chapter, the first tenet of the energy justice framework will be applied to the area of study.

CHAPTER 3: DISTRIBUTIONAL JUSTICE- DATA ANALYSIS PROVING DISPARITY

This chapter is an application of the first tenet of the energy justice framework. Distributional justice examines physical inequities present within the power system. For this application, the physical inequity investigated was outage duration and dispatch times during extreme weather events. A data-driven approach was applied to this investigation to prove physical inequities.

3.1 Data Sources

For this investigation, multiple data sources were utilized. Historical power outage data was provided by the local utility. This data is a record of all sustained power outages, lasting longer than fives minutes, over the course of the past decade, from 2010 to 2019. This data set contains a plethora of information for each outage instance including locational information, notes from crews, customer information, outage duration, and device information. For the purposes of this analysis, a focus was placed on the following fields within the data set:

(i) outage begin time, outage end time,

(ii) outage duration (in minutes),

(iii) circuit number, device county,

(iv) crew dispatch time, and

(v) clearing device type.

Along with the historical outage data set, power system models were provided by the local utility. These models were in .sxst file format and used the power system modeling software CYMEDIST. This modeling software contains information on the physical elements with the distribution network including device locations, conductor types, topology of the network, and customer information. These models also have the ability to have geographic maps overlaid onto the network schematic. Figure 3.1 showcases an example distribution feeder as shown in CYMEDIST. The local utility provided this information for a number of feeders within the area of study.

Figure 3.1: Picture of a Distribution Network in CYMEDIST

Additional information was also collected regarding socio-economic factors within the area of study. To achieve the desired amount of granularity of analysis, the county and given distribution circuits were divided into census tracts. Census tracts are a subdivision of a county used in collecting data for the U.S. Census Bureau. These subdivisions are loosely equivalent to a neighborhood within the county. Within the area of study, there are approximately 50 separate census tracts. A reference map for the 2020 census tracts can be found on the US Census Bureau's website. This map was overlaid on the power system model in CYMEDIST to determine which census tracts were associated with which distribution circuits.

Along with census tract information, a measure of social vulnerability was also collected. The CDC has created a metric called the social vulnerability index (SVI) that is publicly available on their website. The SVI metric was created by the CDC to evaluate which communities are less likely to be able to recover from natural disasters on their own due to societal boundaries such as poverty or lack of transportation. SVI is calculated by considering 15 factors that are organized into the following four main themes: socioeconomic status, household composition/disability, minority status/language, and housing type/transportation. Each of these themes are rated on a scale from 0 to 1, 1 meaning most vulnerable and zero meaning not vulnerable at all. Figure 3.2 shows the summation of all 15 factors used in determining SVI metrics.

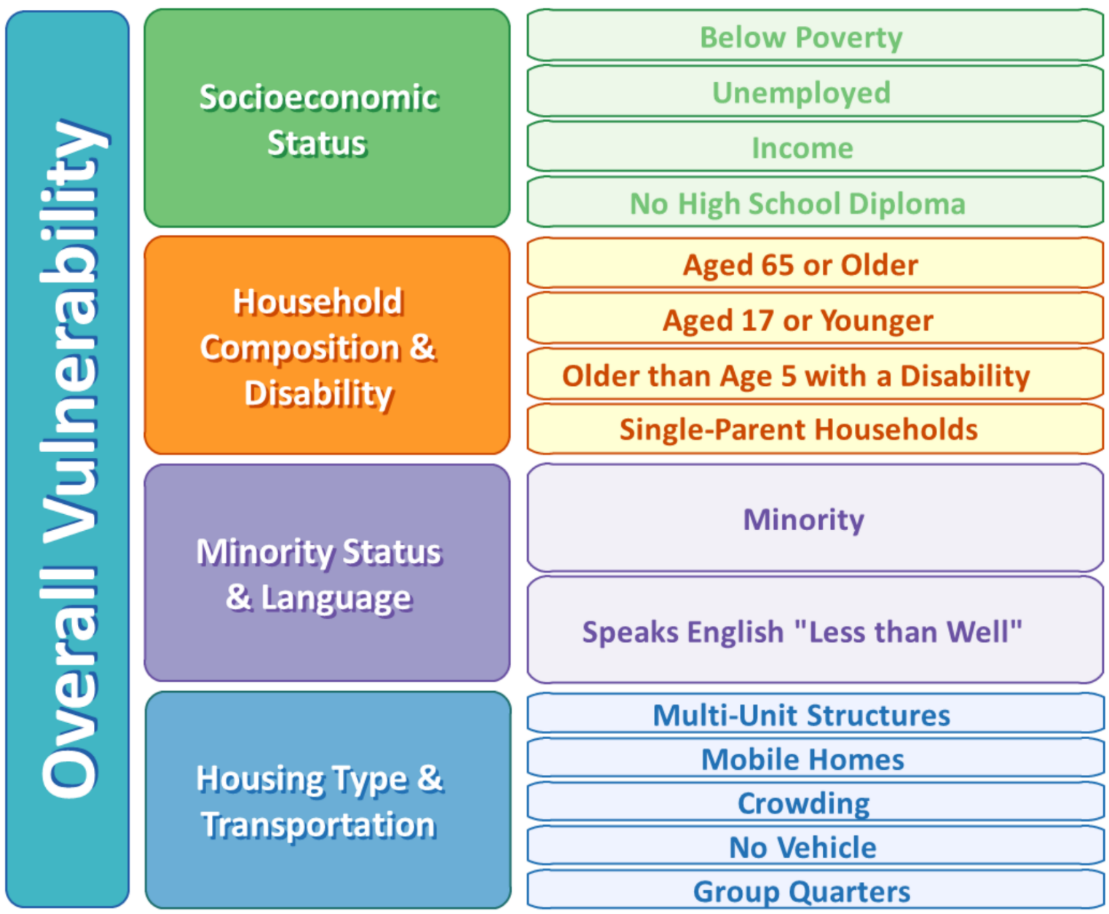

Figure 3.2: Summation of 15 Social Factors Used in SVI Calculations [29]

All four themes are then combined into an overall score denoting the vulnerability of a given area. These factors are collected from the annual American Community Survey conducted by the U.S. Census Bureau. The SVI metrics are updated every 5 years using current data and is calculated by census tract granularity.

3.2 Data Cleaning and Preparation

In any data analytics investigation, it is imperative to first perform data cleaning and processing before performing deeper analysis. In the following section, an explanation of all data cleaning methods performed prior to the analysis is provided.

Removing Fields of the Dataset

The original power outage data set had 88 columns and 50314 individual entries. A data set of this size can prove difficult to analyze effectively. Therefore, it was concluded that shrinking the size of the data set would be helpful. Various columns of the data set were removed reducing the overall field count to 57. The data fields that were removed contained information that were entirely blank for every data entry or contained the same information for every data entry. These fields did not contain unique information, and therefore would not help in distinguish individual outage events. Data fields containing sensitive customer information were also removed. These fields were removed because having access to that information was viewed as violating the privacy of the customer.

Reducing Outage Instances

Next, the number of individual outage instances were reduced. Several instances did not contain information of the location of the outage. It was determined that including these outage instances in analysis would prove difficult because there was no method that could be used to determine where the outages took place. Eliminating those individual outage instances reduced the row size from 50314 to 48994. Additionally, a large number of outage events were denoted as affecting one customer. Upon investigation, it was found that some of those events were truly describing a single household or business losing power. However, some of those events were describing certain electric co-operatives or municipalities losing power. It was decided to focus on an area that was entirely served by the local utility thereby eliminating those instances of false single customer outages.

Adding Data Fields for Improved Data Analytics

While certain information was removed to reduce the overall size of the data set, certain columns were added into the data set to also improve the ease at which data analytics could be performed. First, a column denoting the number of customer hours was added. This was calculated from the values of outage duration and customers affected that were already present within the data set. Second, coordinates for the location of the outage were given in the data set. However, those coordinates were in UTM17 format. All coordinate information was converted into GPS coordinates and added into the data set. This action was done because GPS coordinates were determined to be easier to use and understand than UTM17 coordinates.

3.2.1 Bucketing Outage Data into Major Events

After the necessary cleaning, the data set was bucketed into major weather events. The kinds of weather events considered for bucketing were hurricanes, ice storms, tornados, and tropical storms. Online resources were used to find a history of storms and weather events surrounding the area of study. These resources included weather.gov, National Weather Service, and local news articles. Using these resources, a time frame was established for the given storm. The data set was then filtered by the outage begin time field to the predetermined time frame for a given weather event. For certain events, a buffer of 24 hours was given when filtering the data. As a sanity check, the ‘lineman notes’ field in the selected data set was analyzed to see if any storm-like conditions were mentioned. Using the method described above, a total of 18 separate weather events were clearly identified and bucketed. Figure 3.3 shows a comprehensive list of all the events that were identified.

	Year	Extreme weather event	Event start time	Event end time
1	2010	2010 Winter Storm	2/13/2010 0:21	2/13/2010 23:18
2	2010	2010 Extreme Rainfall	9/26/2010 7:34	9/30/2010 22:18
3	2011	Hurricane Irene	8/26/11 8:33	8/30/2011 21:36
4	2012	Tropical Storm Beryl	5/29/2012 3:22	6/2/2012 22:26
5	2013	Tropical Storm Andrea	6/4/2013 8:39	6/10/13 22:15
6	2014	2014 Winter Storm	2/13/2014 0:07	2/16/2014 21:47
7	2014	Hurricane Arthur	7/2/2014 8:23	7/8/14 17:32
8	2015	2015 Winter Storm	2/23/2015 10:32	2/26/2015 19:52
9	2015	Tropical Storm Ana	5/9/2015 1:57	5/11/2015 21:42
10	2015	2015 Flooding	10/4/2015 1:45	10/6/2015 21:06
11	2016	September 2016 Event	9/2/2016 3:28	9/4/2016 23:55
12	2016	Hurricane Matthew	10/7/2016 1:50	10/11/2016 23:16
13	2017	2017 Tornado	5/23/2017 0:01	5/26/2017 23:14
14	2017	Tropical Storm Irma	9/11/2017 4:29	9/12/2017 21:47
15	2018	Hurricane Florence	9/13/2018 1:17	9/19/2018 23:57
16	2018	Hurricane Michael	10/11/2018 1:14	10/12/2018 19:56
17	2019	2019 Tornado	4/18/2019 5:54	4/19/2019 20:32
18	2019	Hurricane Dorian	9/5/2019 3:39	9/6/2019 23:28

Figure 3.3: Comprehensive List of All Weather Events Identified in the Data Set

After the weather events were identified, the next step in the data preparation was associating individual distribution circuits to a corresponding census tract. This action was taken so that the distribution circuits could be assigned a unique SVI value from the CDC’s data. The next subsection of this chapter will discuss the method used to achieve this goal.

3.2.2 Associating Census Tracts to Distribution Circuits

Before former data analysis was conducted, each individual distribution circuit was associated with a census tract or a combination of census tracts. This action was taken so that each distribution feeder could be assigned a corresponding SVI value. To begin this process, a map with census tract boundaries was downloaded from the United States Census Bureau's website. This map is in Google Earth file format and can be overlaid on top of the distribution circuits shown in CYMEDIST. Figure 3.5 shows the census tract map overlaid on the distribution circuits in CYMEDIST.

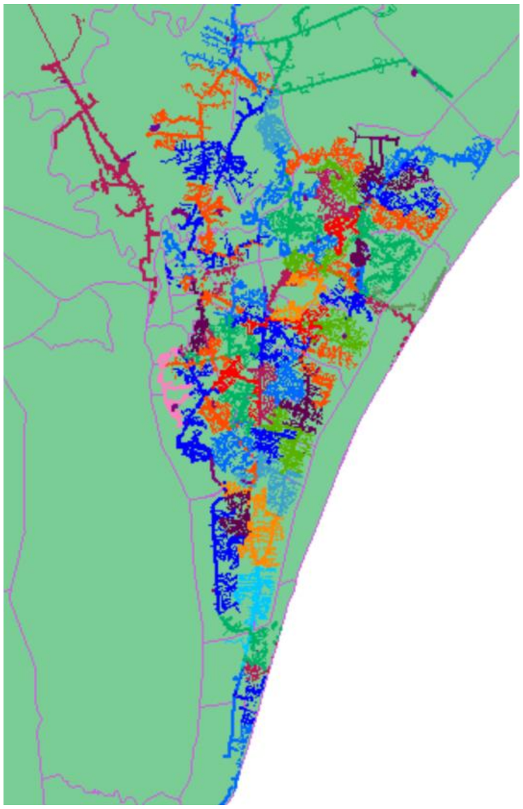

Figure 3.4: Map of Census Tract Boundaries and Distribution Circuits in CYMEDIST

Using the map in Figure 3.5, each distribution circuit's corresponding census tract was identified. By identifying this relationship, a unique SVI metric could now be assigned to each distribution circuit. In certain cases, a distribution feeder was in two or three census tracts. In calculating the SVI value for those circuits, the average value of the SVI metrics for every census tract the feeder was located in, was calculated. Figure 3.5 below showcases an illustrative example of the averaging method to determine SVI metrics for a given circuit.

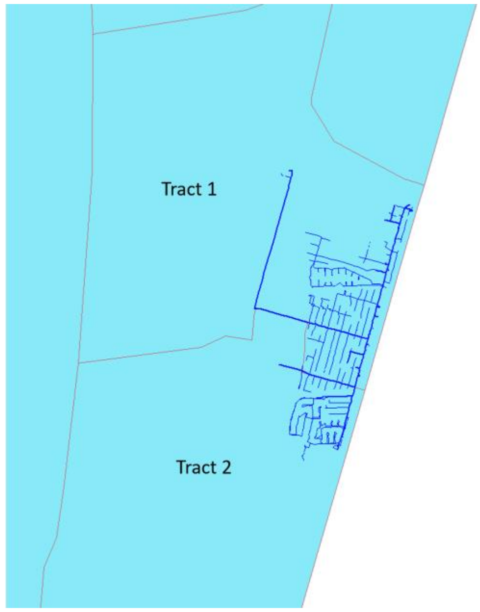

Figure 3.5: Illustrative Example of SVI Averaging

In figure 3.5, it can be seen that the given circuit is located in both census tracts 1 and 2. In order to calculate the feeder's unique SVI value the following equation is applied.

$$SVI\ of\ circuit = \frac{SVI\ of\ tract\ 1 + SVI\ of\ tract\ 2}{2}$$

By applying this equation, an unique SVI value is able to be calculated for every feeder in the area of study. After this process was finished, all distribution circuits were associated with a SVI value.

After all the data cleaning, filtering, and bucketing into events, data analytics was performed. In the remaining sections of this chapter, the data analytics applied to prove the disparity between socially vulnerable and other communities is discussed.

3.3 Reliability Analysis

Preliminary data analysis was performed to prove the initial assumption that a disparity among circuits of differing SVI values was not present in reliability analysis. The initial outage data set was filtered by "MED_TYPE" to non-MED days isolating the blue-sky outage days. From there, the SAIDI metrics for each circuit were calculated and compared against their SVI value. SAIDI metrics are calculated using the following formula. It is important to note that the industry typically calculates SAIDI metrics in terms of minutes of interruption. It was decided that hours of interruption would be used for this analysis due to the longer outage durations during extreme weather events investigated in later analysis.

$$SAIDI = \frac{customer\ hours}{total\ customers}$$

$$customer\ hours = \#\ of\ customers\ affected * duration\ of\ outage\ (hrs)$$

Using this equation, the SAIDI metrics were calculated for each circuit for every year between 2010 and 2019. Figures 3.6 to 3.15 illustrate the comparison between SAIDI values and SVI for each year between 2010 and 2019. It is industry practice to calculate SAIDI metrics in the unit of hours per year.

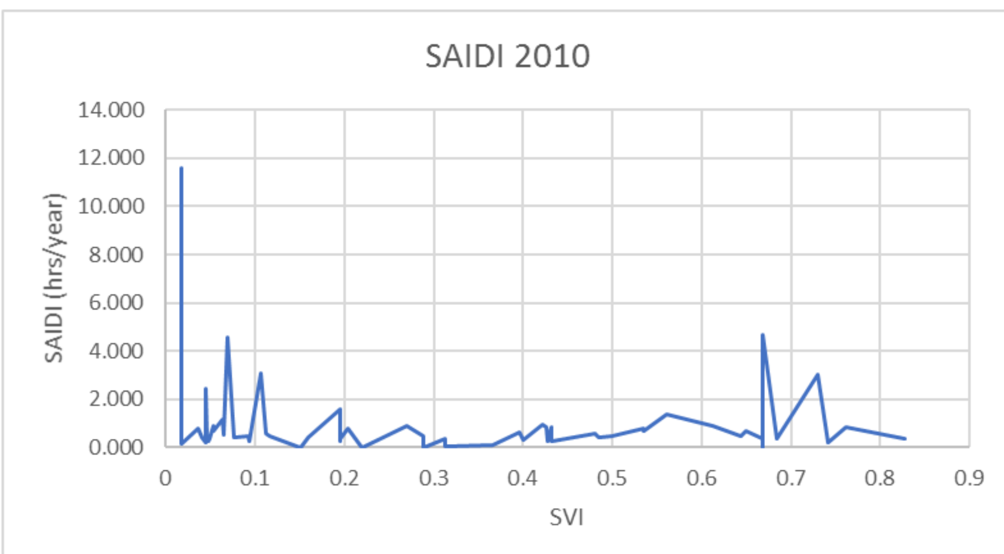

Figure 3.6: SAIDI 2010 Metrics vs. SVI

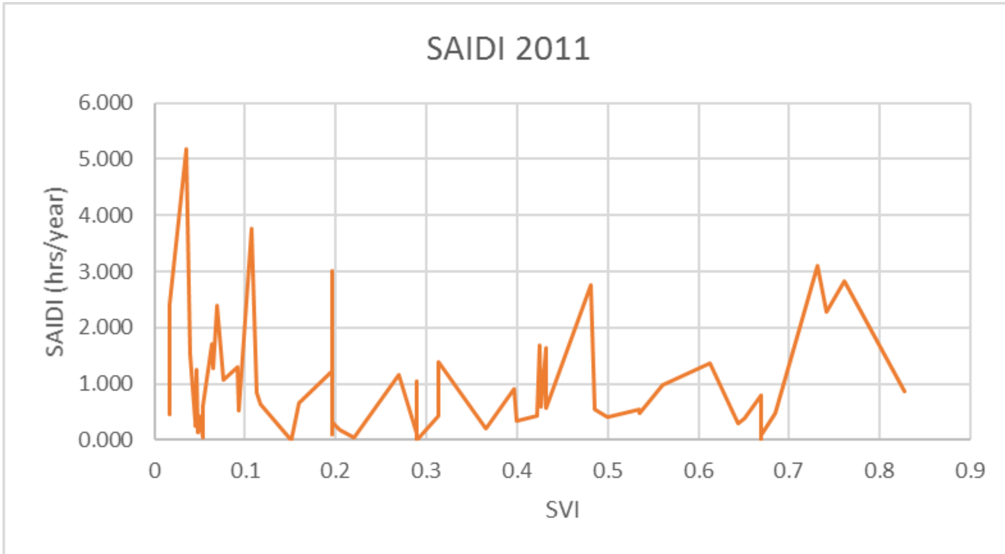

Figure 3.7: SAIDI 2011 vs. SVI

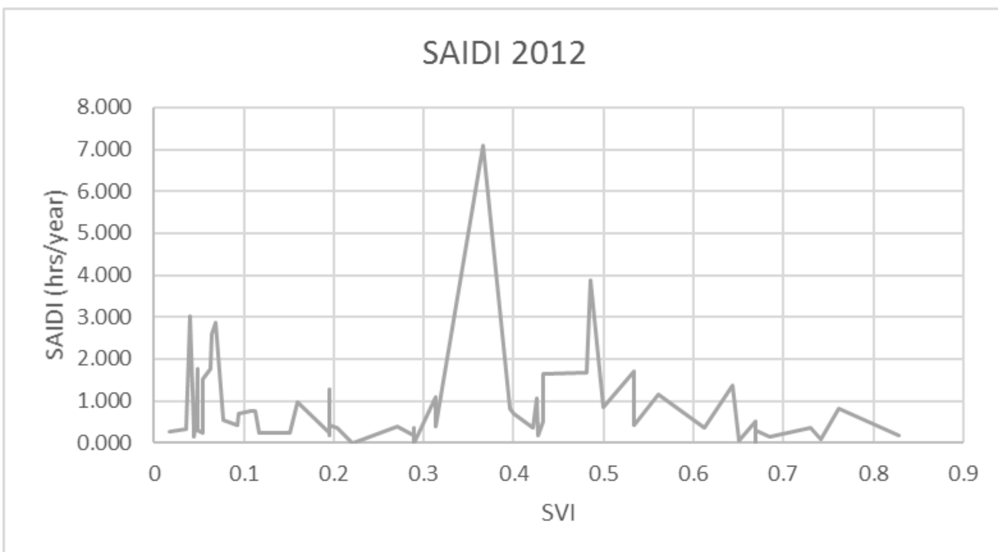

Figure 3.8: SAIDI 2012 vs. SVI

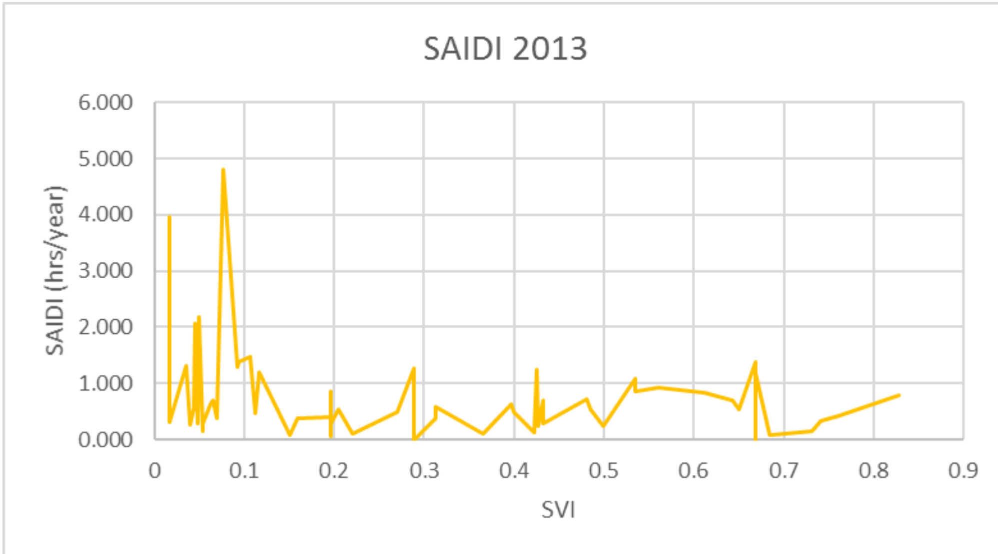

Figure 3.9: SAIDI 2013 vs. SVI

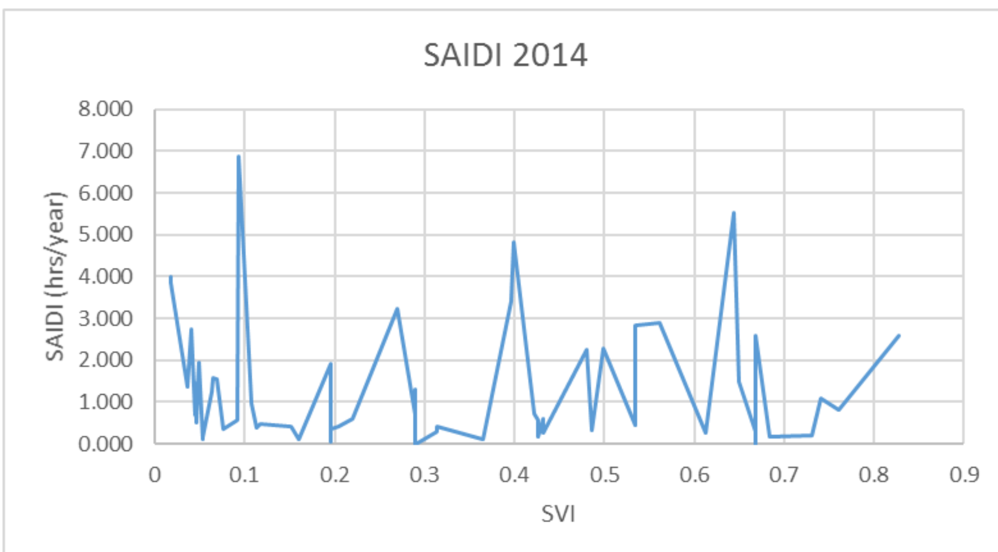

Figure 3.10: SAIDI 2014 vs. SVI

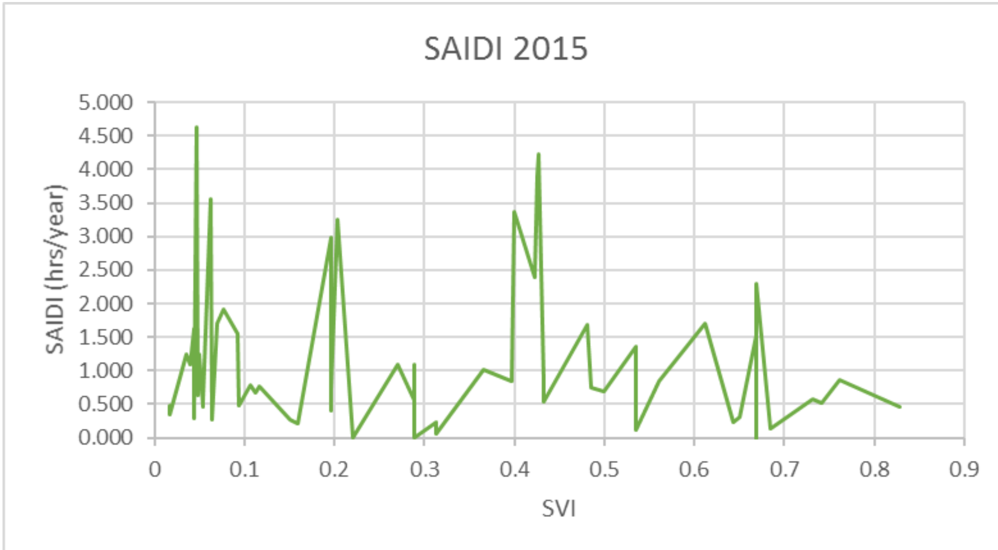

Figure 3.11: SAIDI 2015 vs. SVI

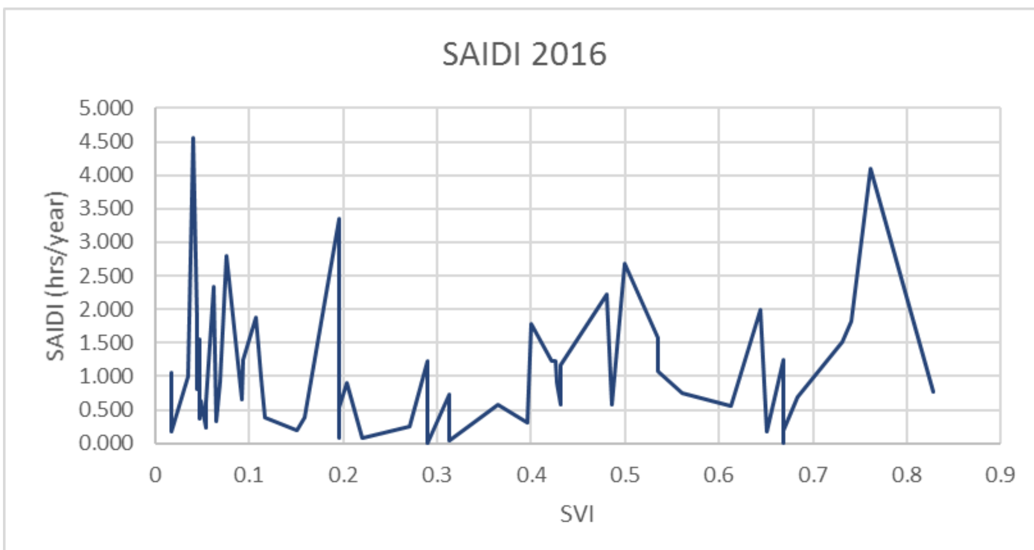

Figure 3.12: SAIDI 2016 vs. SVI

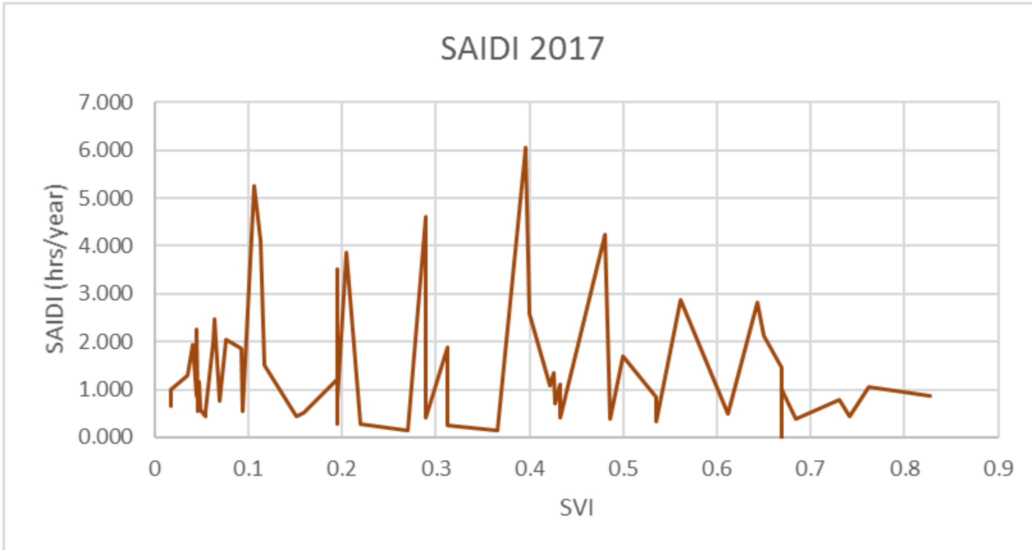

Figure 3.13: SAIDI 2017 vs. SVI

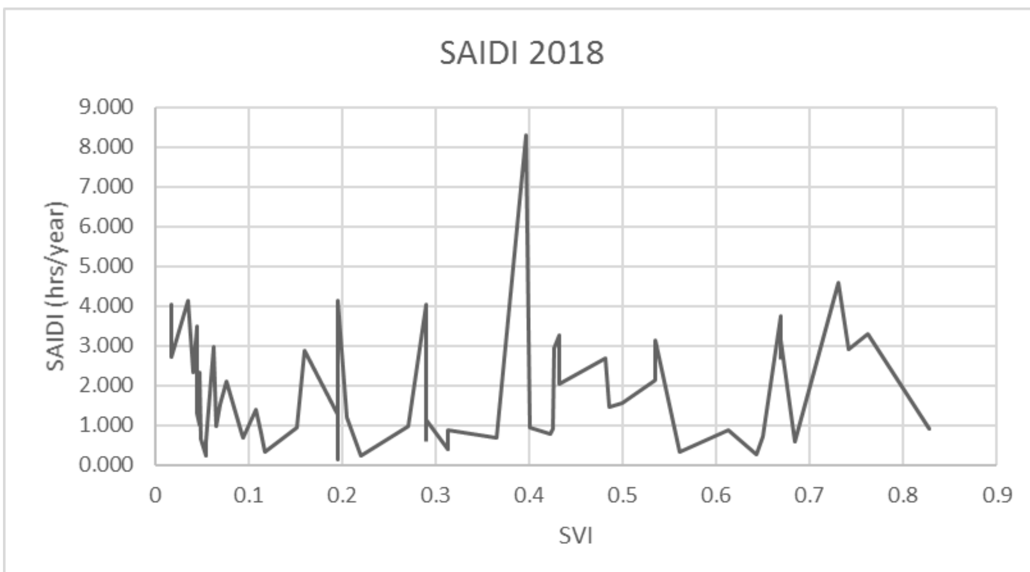

Figure 3.14: SAIDI 2018 vs. SVI

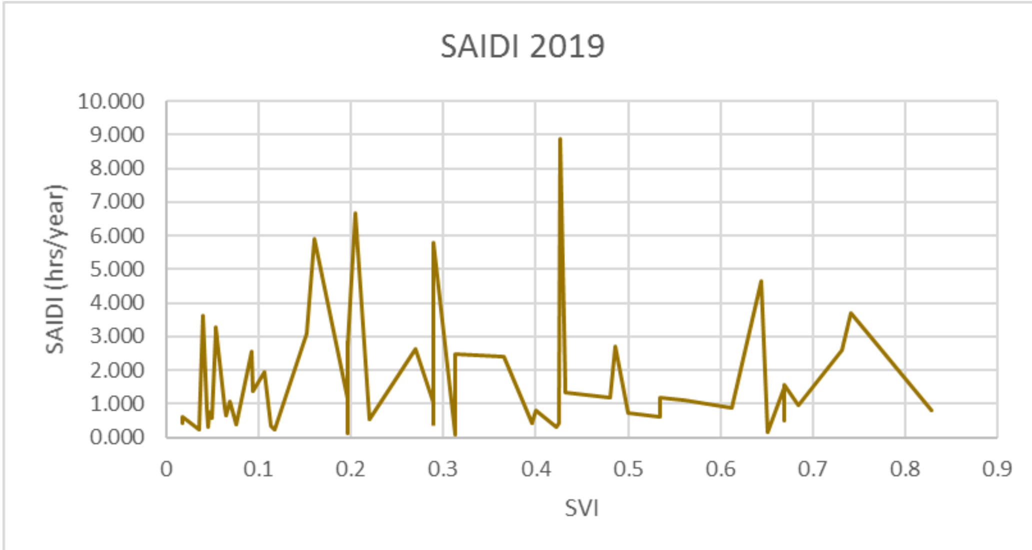

Figure 3.15: SAIDI 2019 vs. SVI

The SAIDI values for each circuit were averaged over the ten years present in the data set to create an average SAIDI value. The average SAIDI value was then compared to the SVI value for each circuit. The comparison between average SAIDI value and SVI is shown in Figure 3.16.

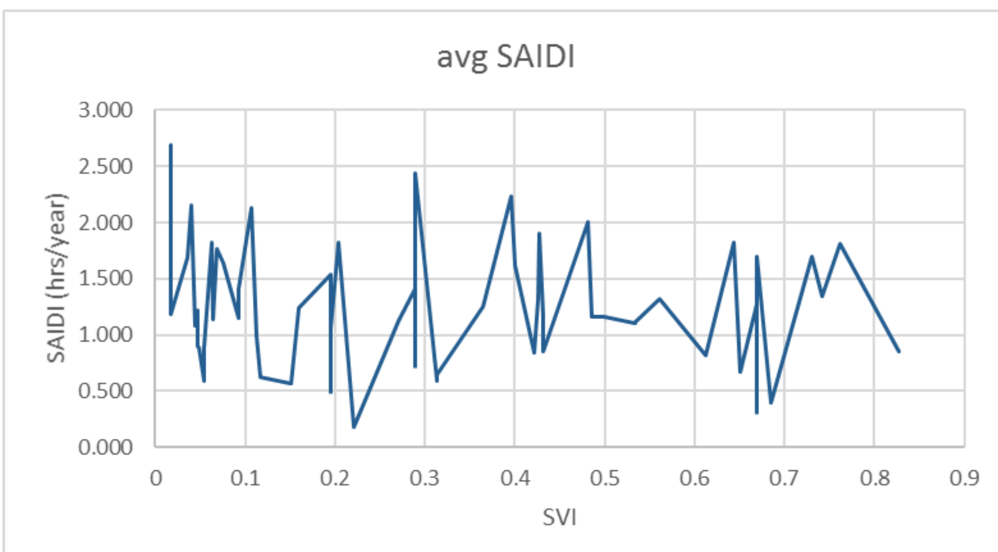

Figure 3.16: Average SAIDI 2010-2019 vs. SVI

From analyzing all of the graphs comparing SAIDI values against SVI metrics, it can be seen that there is no relationship between SAIDI and SVI. This finding suggests that socioeconomics do not affect electric service during a typical outage day. An additional reliability metric was also examined to solidify this argument. The Average Service Availability Index (ASAI) is defined by the following equation.

$$ASAI = \frac{\left(total\ customers * 8760\,\frac{hrs}{year}\right) - (customer\ hours)}{total\ customers * 8760\ hrs/year}$$

$$customer\ hours = \#\ of\ customers\ that\ power * duration\ of\ outage\ (hrs)$$

Using the formula illustrated above, the ASAI was calculated for every circuit in the area of study and was compared against the circuit's SVI value. Figures 3.18 to 3.27 illustrate the comparison between ASAI and SVI for the years 2010 through 2019. From these graphs it can be noted that no relationship exists between ASAI and SVI. Typical industry practice is to uphold a power system that has a ASAI value of 0.999 or better, colloquially referred to as 3 nines. In this data analysis, there were only two instances of circuits containing an ASAI value lower than 3 nines. The first instance was recorded for a circuit with an SVI value of 0.0171 where the ASAI value for 2010 was calculated to be 0.9987. The second instance was recorded for a circuit with an SVI value of 0.4269 where the ASAI value for 2019 was calculated to be 0.9989. In both instances, the ASAI value is only slightly below the industry standard.

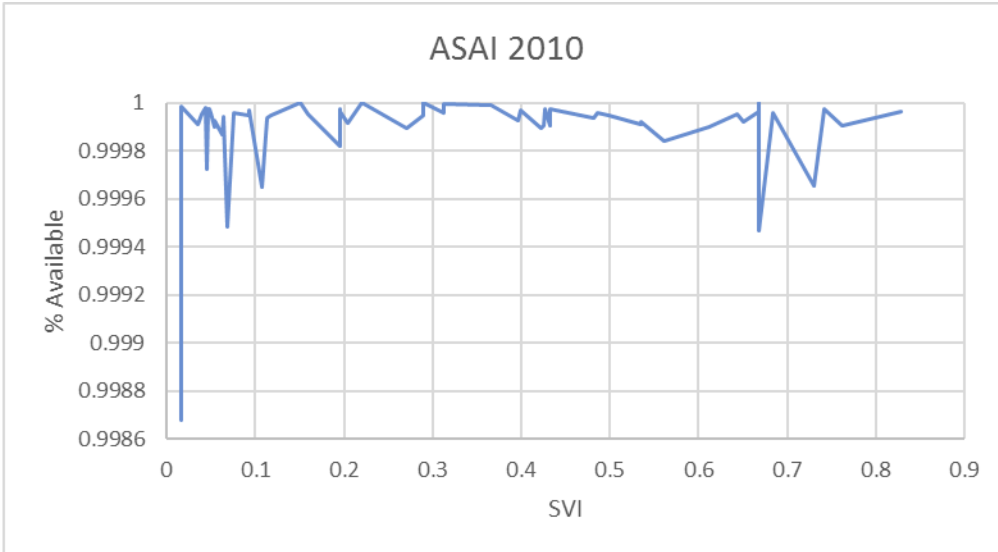

Figure 3.17: ASAI 2010 vs. SVI

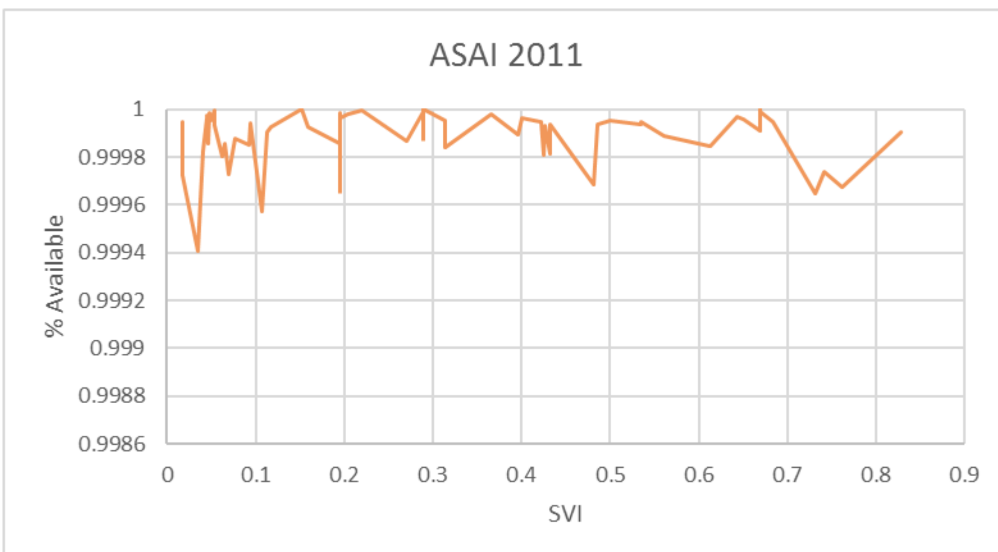

Figure 3.18: ASAI 2011 vs. SVI

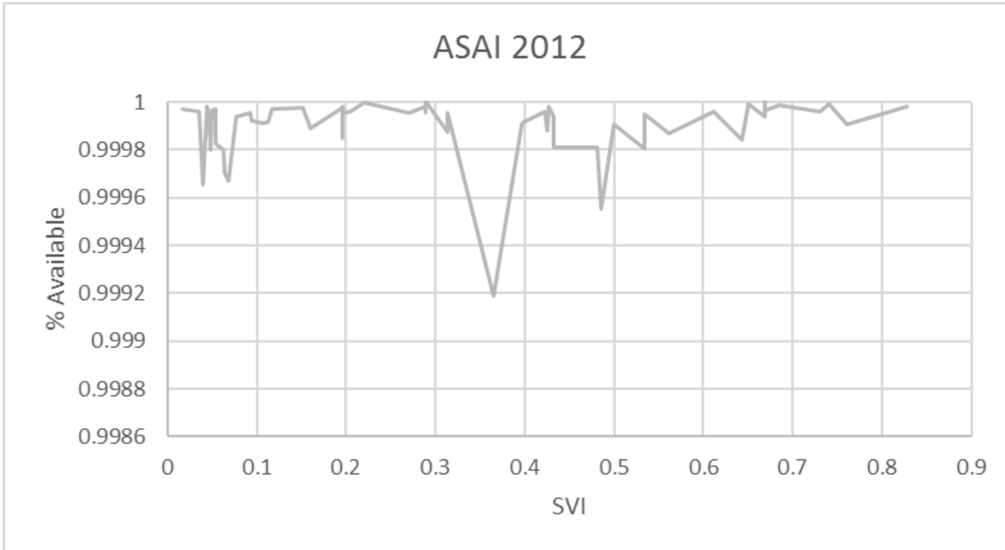

Figure 3.19: ASAI 2012 vs. SVI

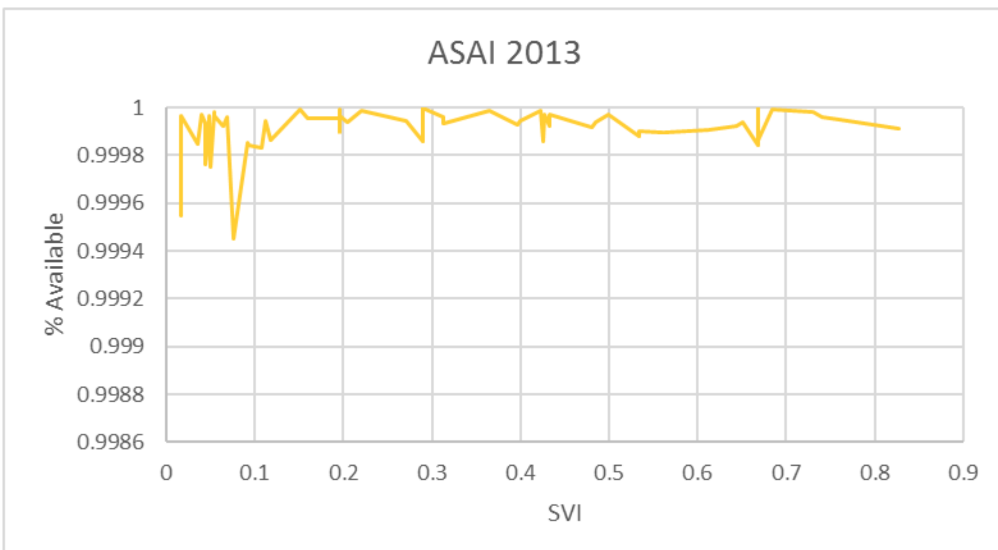

Figure 3.20: ASAI 2013 vs. SVI

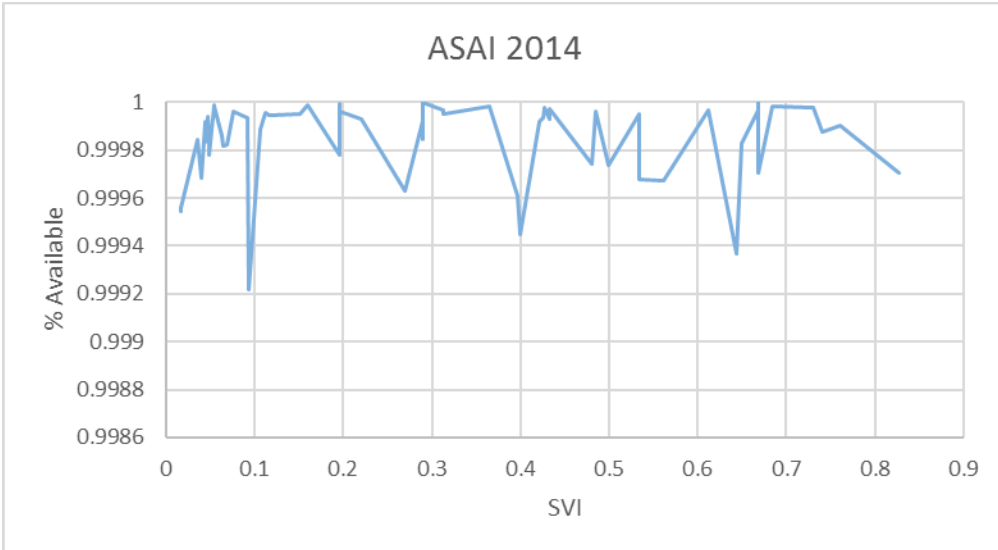

Figure 3.21: ASAI 2014 vs. SVI

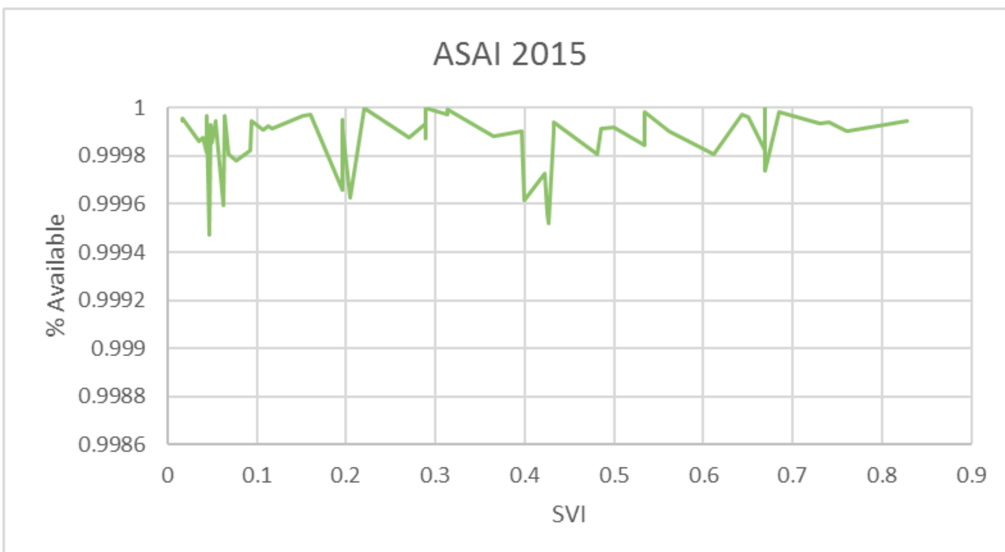

Figure 3.22: ASAI 2015 vs. SVI

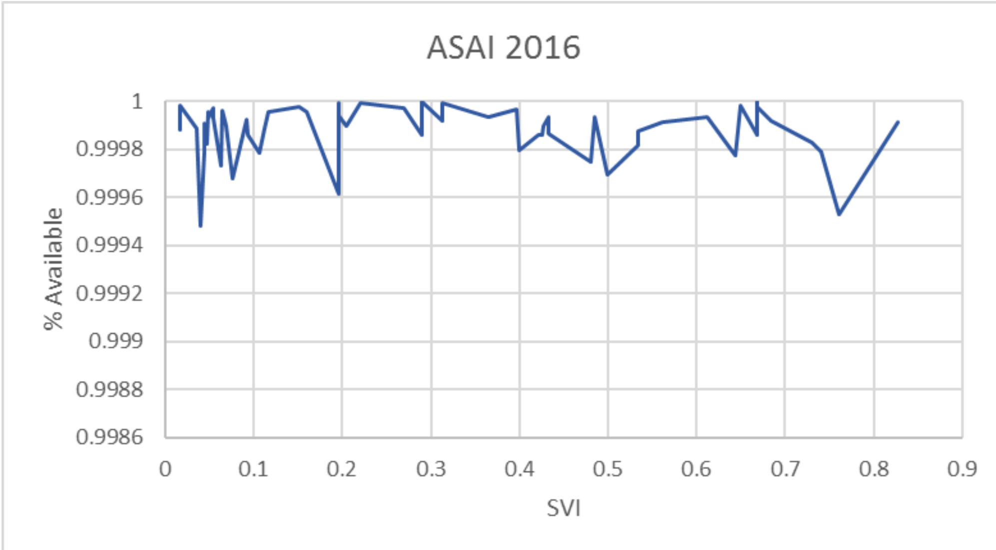

Figure 3.23: ASAI 2016 vs. SVI

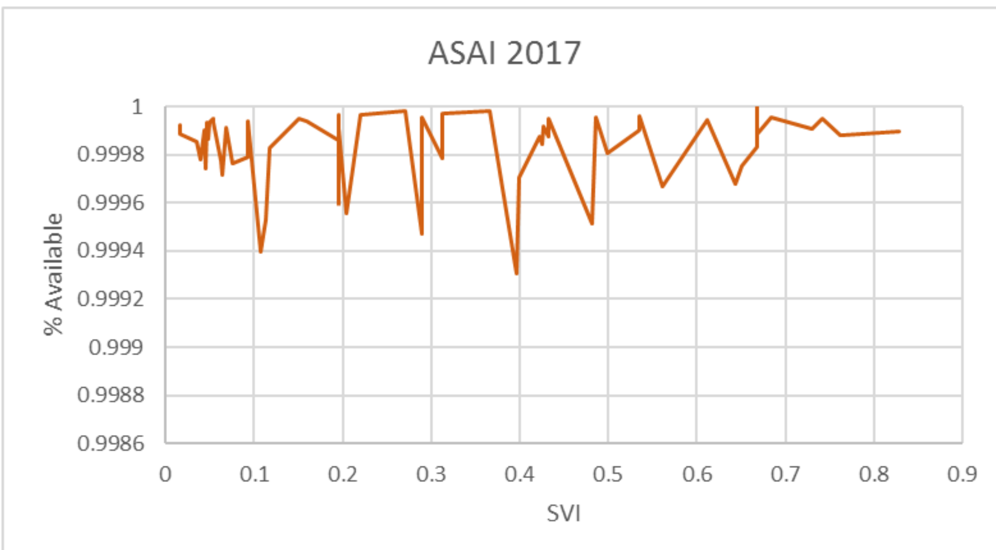

Figure 3.24: ASAI 2017 vs. SVI

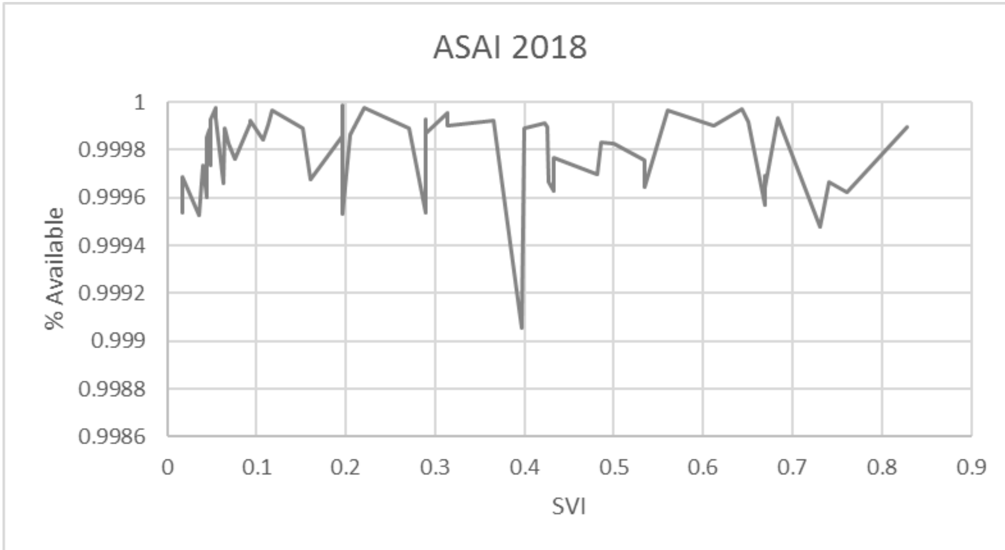

Figure 3.25: ASAI 2018 vs. SVI

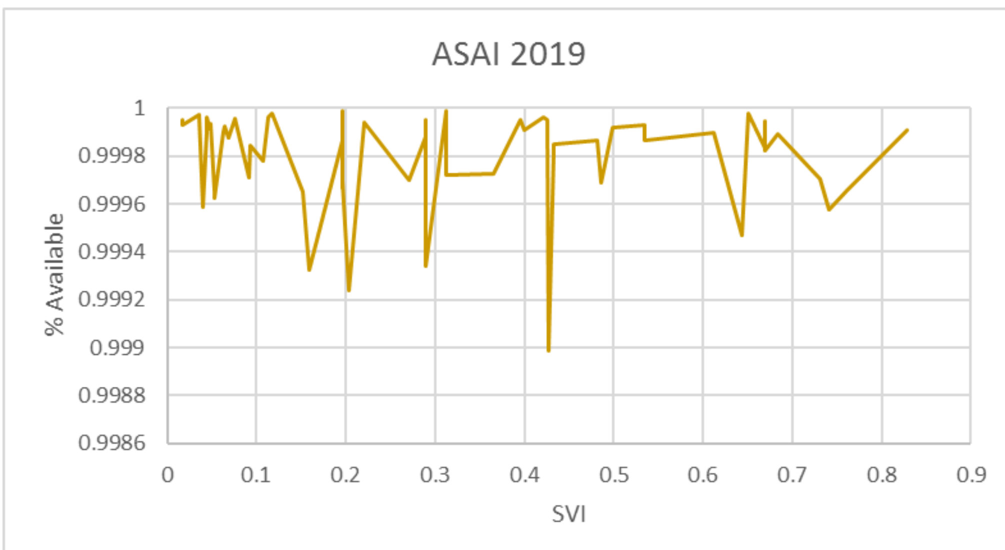

Figure 3.26: ASAI 2019 vs. SVI

In Figure 3.27, all the calculated ASAI values for the time period between 2010 and 2019 were averaged. The average ASAI values for each circuit were compared against the circuit's corresponding SVI value. No correlation can be found between these two values suggesting that social vulnerability does not affect the reliability of a circuit.

Additionally, the average ASAI values for all circuits are above the 3 nines criteria. This means no individual circuit appears to have diminished reliability.

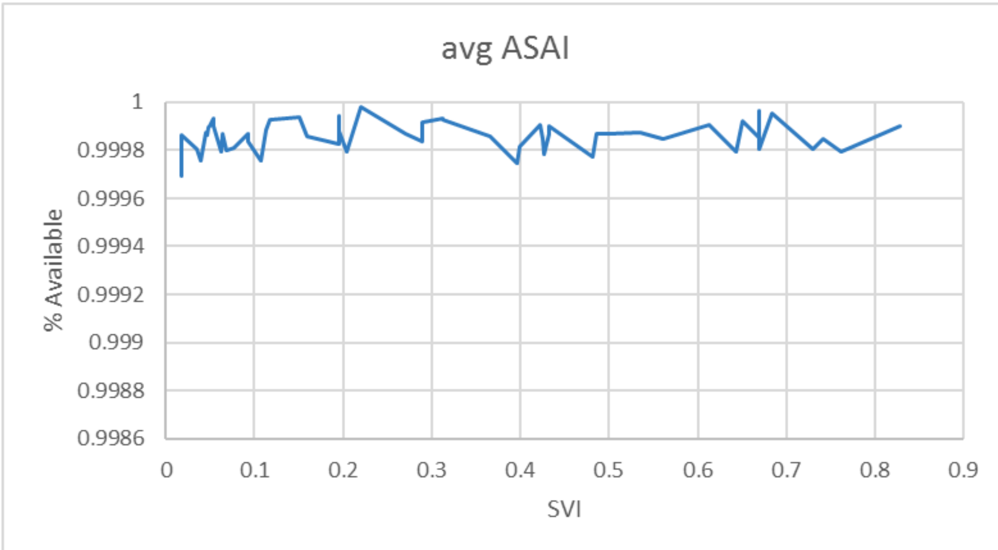

Figure 3.27: Average ASAI vs. SVI

The results in this section suggest that all circuits within the service area meet reliability standards. The data analysis method presented in this section is the current industry process to identify which circuits need additional infrastructure investment to improve performance. From analyzing the data gathered, the utility would conclude that none of the circuits in area of study need additional infrastructure investment. Additionally, no relationship can be found between SAIDI, ASAI, and SVI. This result suggests that social vulnerability has no effect on the performance of a feeder during ‘blue sky’, i.e., non-MED events. However, when the MED or black sky events are considered, the opposite conclusion can be found. The remaining sections of this chapter will showcase similar analysis expressed in this section specifically analyzing MED outage days that are not considered in standard reliability assessments.

3.4 Resiliency Curves and Dispatch Times

Resiliency curves were created for each distribution circuit during a few major storms. Resiliency curves are a tool typically used in the industry. These curves show the progression of outages combined with the restoration of outages over time. These curves illustrate the resiliency trapezoid or triangle for a given circuit as discussed in section 2.2. Python computer programming language was used to create a graphing algorithm to generate these curves. Figures 3.28 to 3.30 show the results of this analysis. The “x” mark on the figures denotes the first crews being dispatched to the circuit during the weather event.

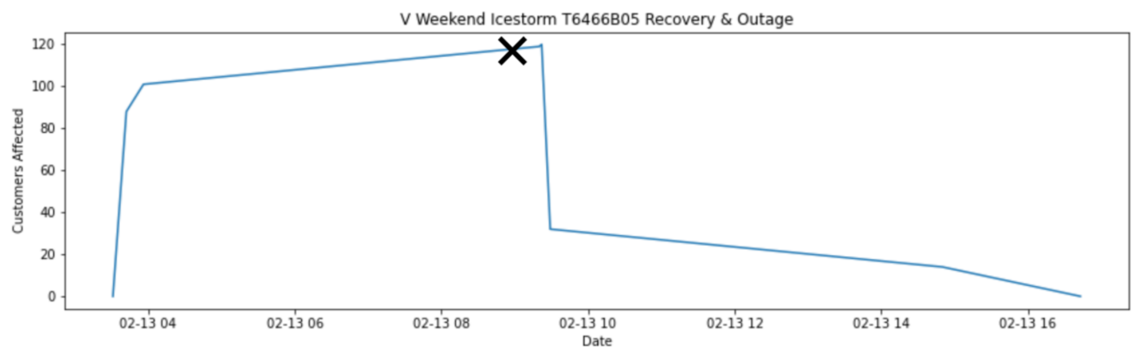

Figure 3.28: Curve for High SVI Circuit during Ice Storm

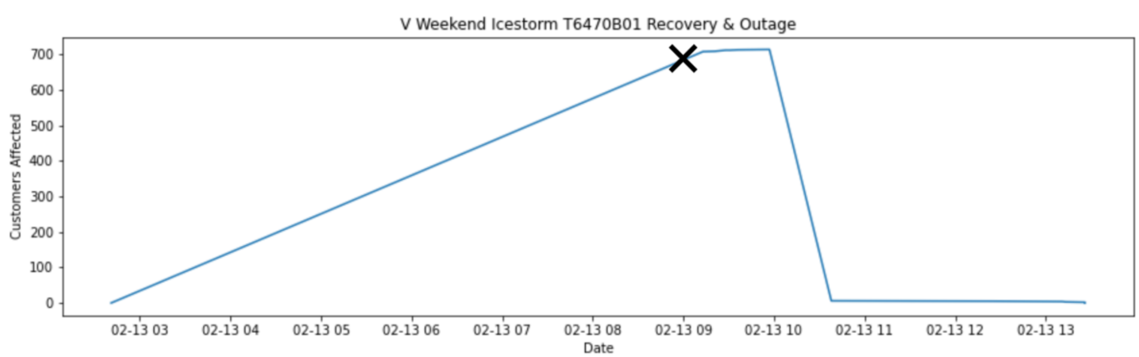

Figure 3.29: Curve for Low SVI Circuit during Ice Storm

From Figures 3.28 and 3.29, a delay between initial outages and first dispatch time can be noticed in the circuit with a high SVI value. The circuit with a low SVI value did not appear to have the same delay. This comparison between both figures suggests that there could be a possible bias when dispatching crews to more socially vulnerable areas. However, a similar approach was taken during Hurricane Michael and a possible bias was not noted.

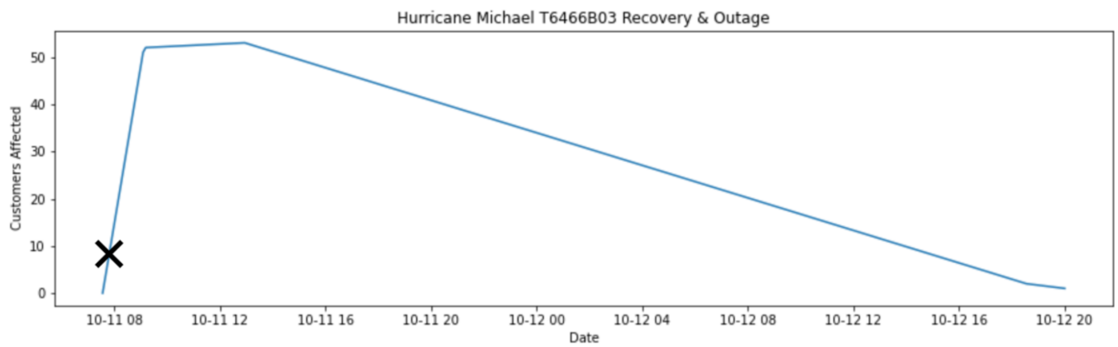

Figure 3.30: Curve for High SVI Circuit during Hurricane Michael

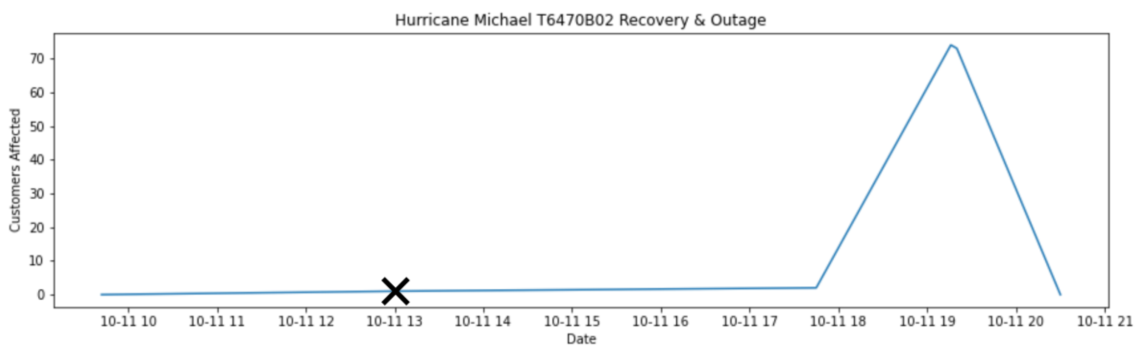

Figure 3.31: Curve for Low SVI Circuit during Hurricane Michael

As one can see from Figures 3.30 and 3.31, the first dispatch time for both circuits was shortly after the initial power outage. While a potential bias was apparent during the Ice Storm, there was not a bias shown during Hurricane Michael. To complete this analysis, Hurricane Dorian was also selected for analysis in a similar manner.

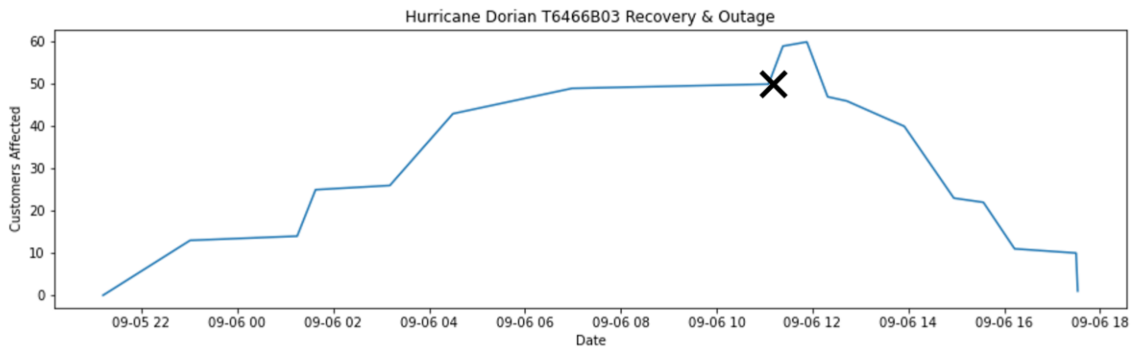

Figure 3.32: Curve for High SVI Circuit during Hurricane Dorian

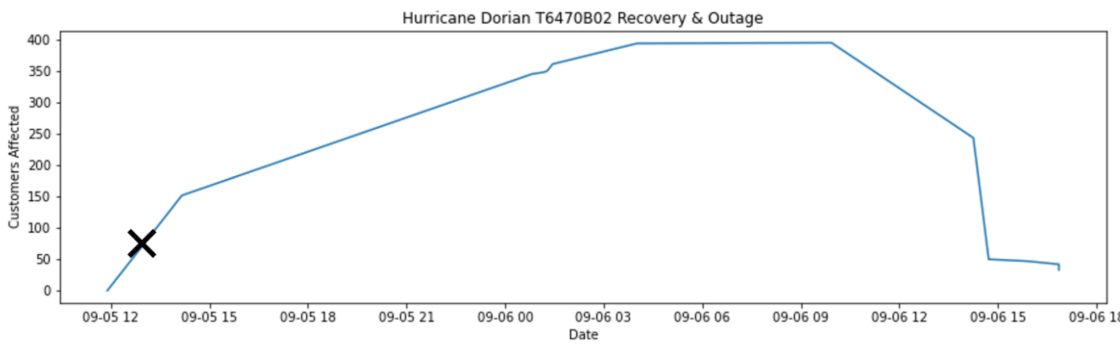

Figure 3.33: Curve for Low SVI Circuit during Hurricane Dorian

From Figures 3.32 and 3.32, a delay between initial outages and first dispatch time was noticed in the circuit with a high SVI value while the circuit with a low SVI value did not appear to have the same delay. From this analysis, two out of three storms that were analyzed showcased potential bias in promptly dispatching crews to more socially vulnerable areas.

While these results are compelling, additional data analysis was performed to find further evidence of a potential disparity with restoration practices among different communities during extreme storms. The next section of this chapter will discuss further investigation that was performed to discover additional evidence.

3.5 A Comparison of SVI with Outage Durations

For this portion of analysis, SVI values for each feeder were compared against the average outage durations for selected extreme weather scenarios. This section will discuss the methods employed in this analysis and conclusions drawn from this analysis.

3.5.1 Calculation of T-test Averages

To begin this analysis, the average duration for each storm (population average, μ) was calculated along with the standard deviation (σ) of outage durations during the entire storm. The sample size (n) for each storm was also recorded. Then, the average ($\bar{x}$) outage duration for each individual feeder was calculated. These feeder averages were compared to the population average using a t-distribution hypothesis test. The formula for this calculation is shown below along with the null and alternative hypothesis.

$$t - test\ value = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}}$$

H_0: This circuit does not have a higher outage duration than the rest of the system

H_a: This circuit does have a higher outage duration than the rest of the system

In this hypothesis test, a 95% confidence interval was chosen. While the critical test value for each storm varied depending on the sample size, on average, the critical value was 1.64. This means any t-test statistic above 1.64 was determined to have a higher outage duration than the rest of the distribution system.

3.5.2 Initial Results

The t-test values for each distribution circuit were compared with the feeder's SVI value. Figures 3.34 to 3.39 show preliminary results for each storm that was examined. The figures are organized in ascending order of storm severity. The relationship between these two variables was hypothesized to be linear. A linear relationship indicates that more socially vulnerable communities will have higher power outage durations on average than other circuits within the area. Hurricane Florence was excluded from analysis due to concerns over data quality. During the most extreme storms, crew members focus on restoring power rather than ensuring the quality of data reporting.

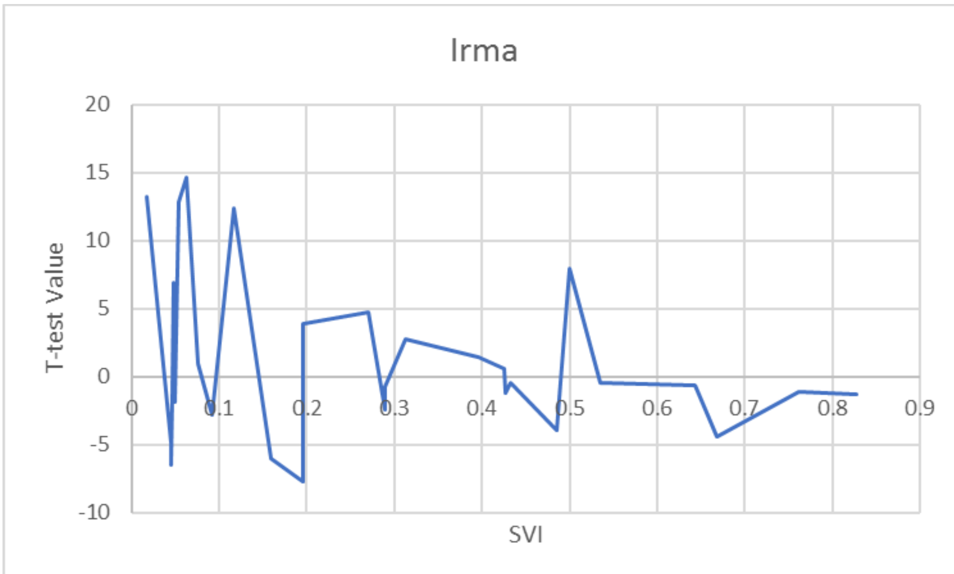

Figure 3.34: SVI vs. T-test Value for Tropical Storm Irma

In Figure 3.34, no apparent relationship between t-test values and SVI was noted. However, in the remaining figures, a relationship began to materialize.

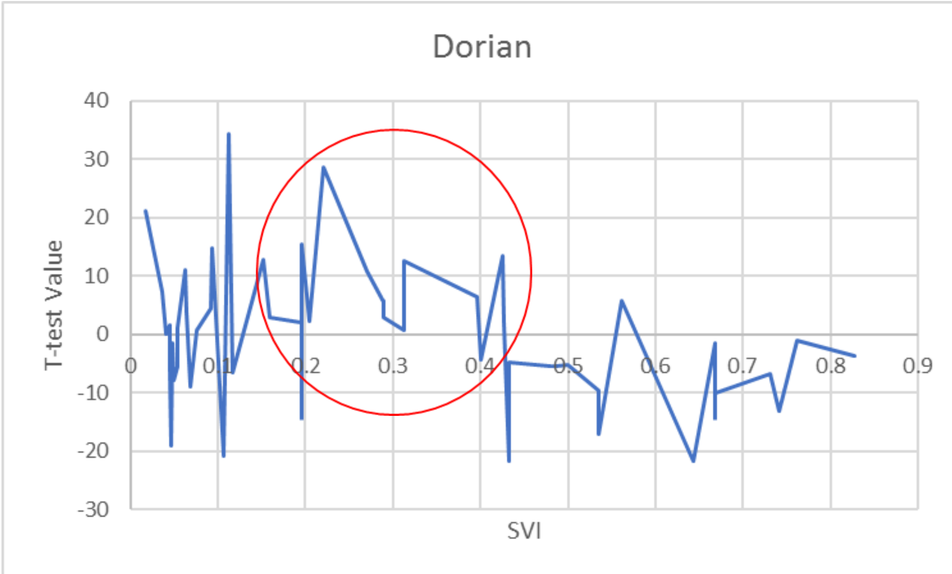

Figure 3.35: SVI vs. T-test Value for Hurricane Dorian

For Hurricane Dorian, a relationship between t-test values for average outage duration and SVI was noted. Circuits that had a SVI value between 0.2 and 0.4 had noticeably higher t-test values than the rest of the circuits affected by the storm. While Figure 3.35 shows a relationship, it did not present the hypothesized relationship. The analysis was extended to Hurricane Michael.

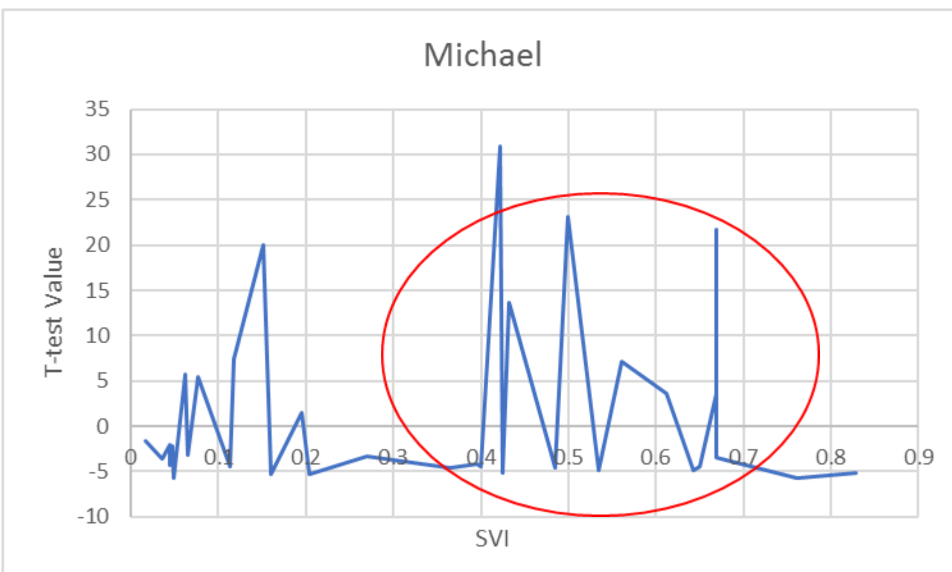

Figure 3.36: SVI vs. T-test Value for Hurricane Michael

Figure 3.36 shows a relationship between SVI values and T-test values again. Circuits with a SVI value between 0.4 and 0.7 appeared to have higher power outage durations on average during Hurricane Michael when compared to the entire distribution system. Again, this was not the result that was expected, and so, the analysis was extended to a more extreme weather event.

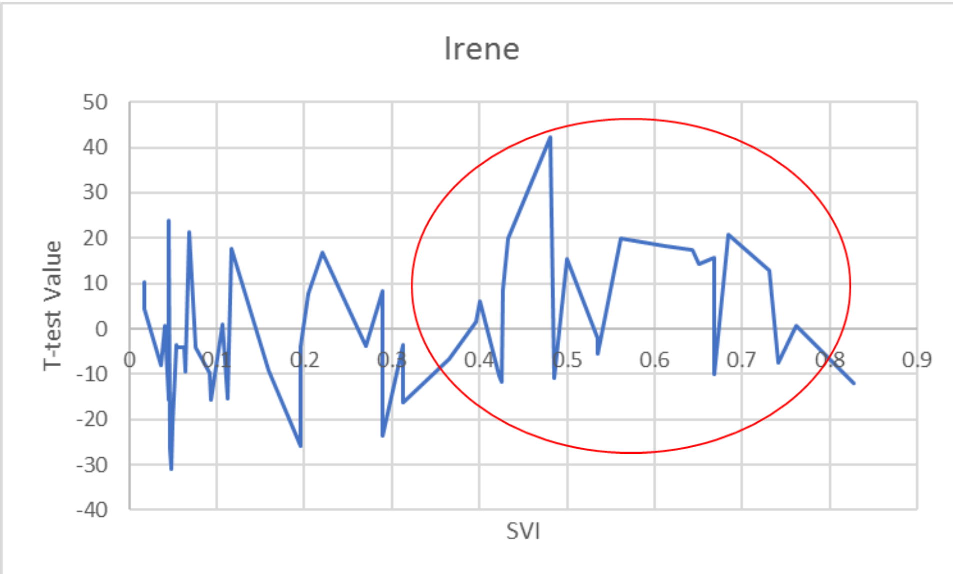

Figure 3.37: SVI vs. T-test Value for Hurricane Irene

Next, similar analysis was applied to Hurricane Irene. As seen in Figure 3.37, a similar relationship was noted as shown in Figure 3.36. To further extend analysis, an ice storm was selected for a similar analysis.

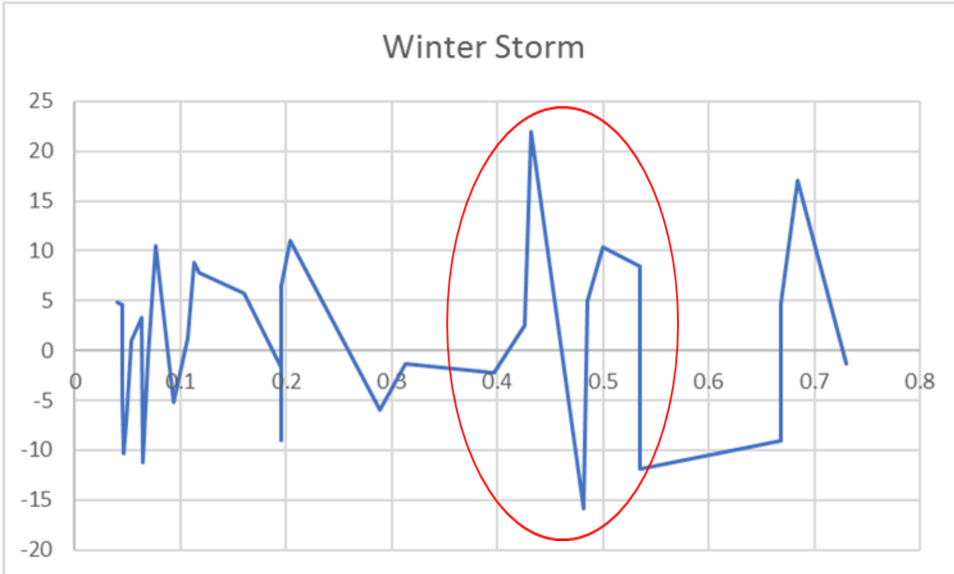

Figure 3.38: SVI vs. T-test Value for Ice Storm

Figure 3.38 did indicate a relationship between SVI values and T-test values for average outage duration. This relationship indicated that circuits with a SVI value between 0.4 and 0.55 had higher power outage durations on average than the rest of the distribution system during the winter storm. While this figure does present a relationship, it was not the expected relationship. Finally, a similar analysis was applied to Hurricane Matthew. This storm was the most severe of the storms examined during this analysis. The results are shown in Figure 3.39.

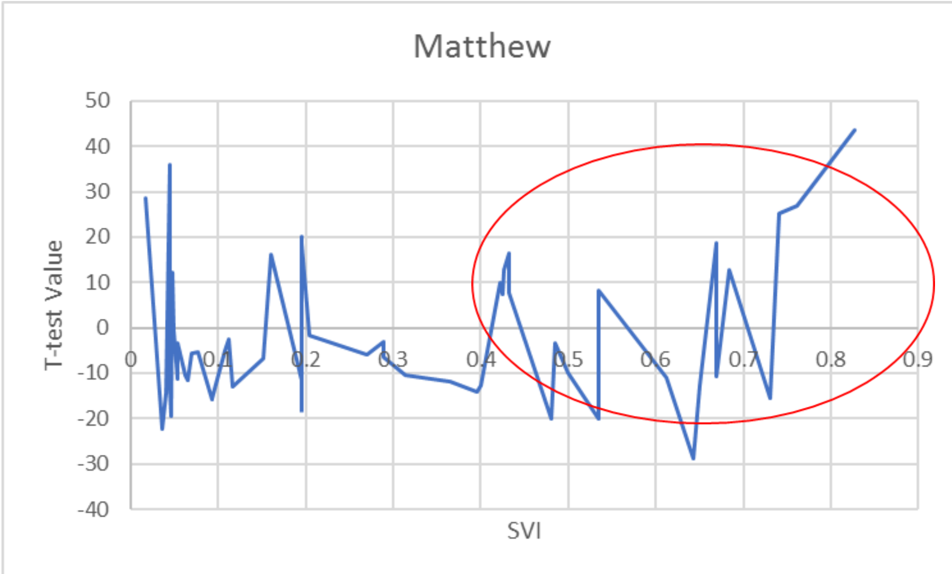

Figure 3.39: SVI vs. T-test Value Hurricane Matthew

From this figure, the circuits with SVI values higher than 0.4 appeared to have higher average power outage durations than the rest of the distribution system during Hurricane Matthew. This relationship was closer to the hypothesized results. These results suggested that the more socially vulnerable areas had higher power outage durations during Hurricane Matthew. However, a linear relationship was expected. Some additional data processing was applied, and the data analysis was repeated for Hurricanes Irene and Matthew. In the next subsection, these adjustments are discussed, and secondary results are shown.

3.5.3 Adjustments and Secondary Results

To discover a clearer relationship between social vulnerability and average outage duration, certain adjustments were made to the existing data set. These adjustments were applied based off of information provided by the utility partner regarding restoration practices. From this information, it was discovered that circuits with a substation related outage are given priority during extreme weather scenarios. Therefore, a fairer comparison of outage durations would be between circuits that all experienced substation outages during the same weather event.

A filter was applied to the data field “CLEARING_DEVICE_TYPE_DESCR” to only analyze outages marked as “00 Substation Device” or “01 Feeder Breaker/Recl in Substa”. The duration of each substation related outages was collected. This duration was graphed against each affected circuit’s SVI value. Figures 3.40 and 3.41 show the results for this portion of the analysis.

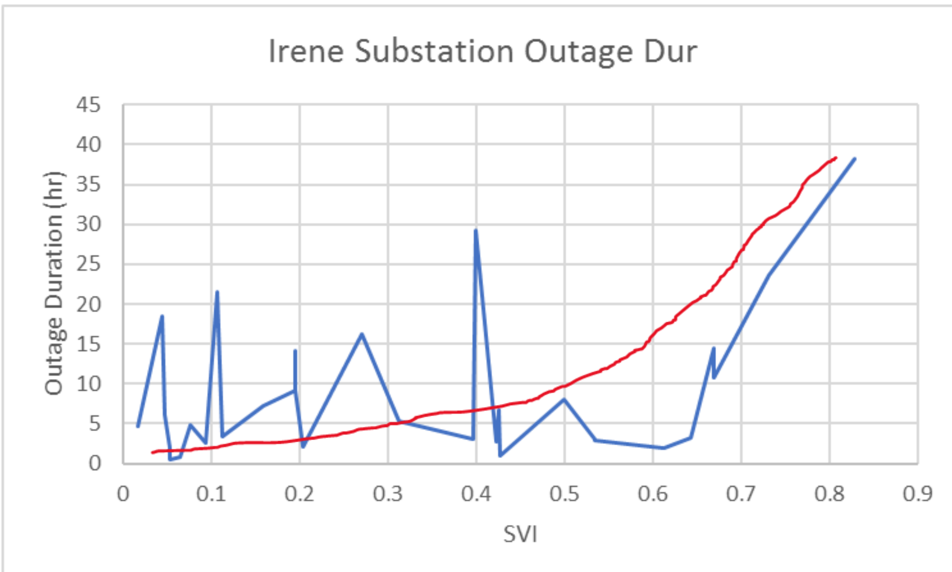

Figure 3.40: Substation Outage Duration vs. SVI during Hurricane Irene

By analyzing Figure 3.40, an exponential relationship between SVI and substation outage duration was noted. This relationship suggested that disadvantaged communities were more likely to have longer substation outages during Hurricane Irene. This relationship was more severe than the hypothesized relationship. Similar analysis was also applied to Hurricane Matthew. Figure 3.41 showcases the results of that analysis.

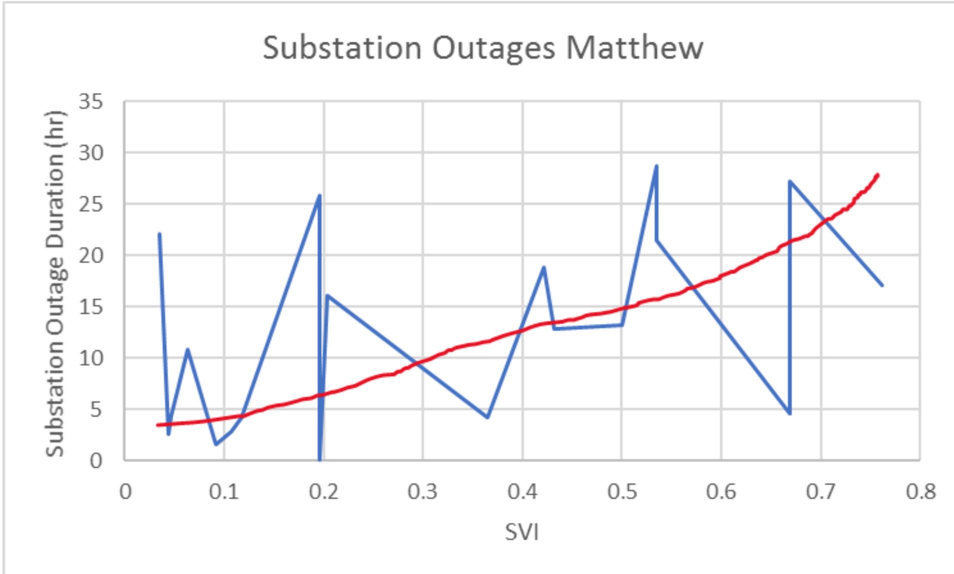

Figure 3.41: Substation Outage Durations vs. SVI during Hurricane Matthew

This figure indicates a linear relationship between SVI values and substation outage durations during Hurricane Matthew. This relationship was the hypothesized relationship stated earlier in this chapter. Again, this relationship suggested that impoverished communities were more likely to have longer substation outages when compared to the rest of the distribution system during Hurricane Matthew. From these two case studies, a clear bias was seen towards serving less socially vulnerable communities first in extreme storm scenarios. The other storms analyzed earlier were not included in this analysis because not enough circuits experienced substation related outages for the study to produce meaningful results.

Now, that a clear relationship was established, data analysis was extended to examine all power outages within a circuit during Hurricanes Irene and Matthew. This analysis followed the same method as described previously in Section 3.5.1, but only circuits that experienced a substation outage were considered in the analysis. The population mean, population standard deviation and sample size were kept the same value as the previous analysis. Figures 3.42 and 3.43 illustrate the results found from this analysis.

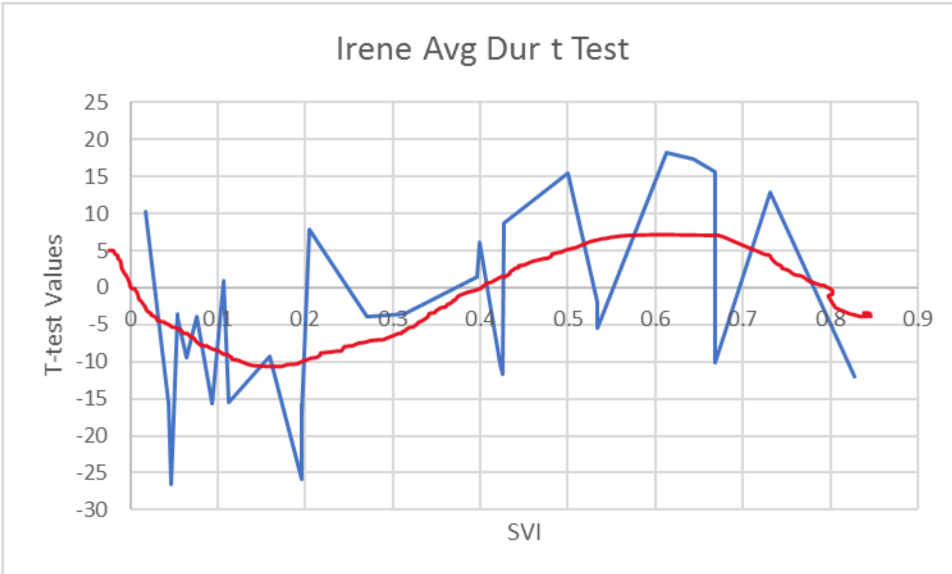

Figure 3.42: SVI vs. T-test Value for Circuits with Substation Outages during Hurricane Irene

By examining Figure 3.42, a sinusoidal relationship between SVI values and T-test values was noted. A collection of distribution circuits with SVI values between 0.4 and 0.8 appeared to have higher T-test values when compared to the average outage duration of the entire distribution system. These results suggested that circuits with a moderate to high SVI value had longer power outage duration on average during Hurricane Irene. While this was not the hypothesized relationship, these results presented a relationship between SVI and power outage duration. Similar analysis was also applied to Hurricane Matthew. The result of that analysis is shown in Figure 3.42.

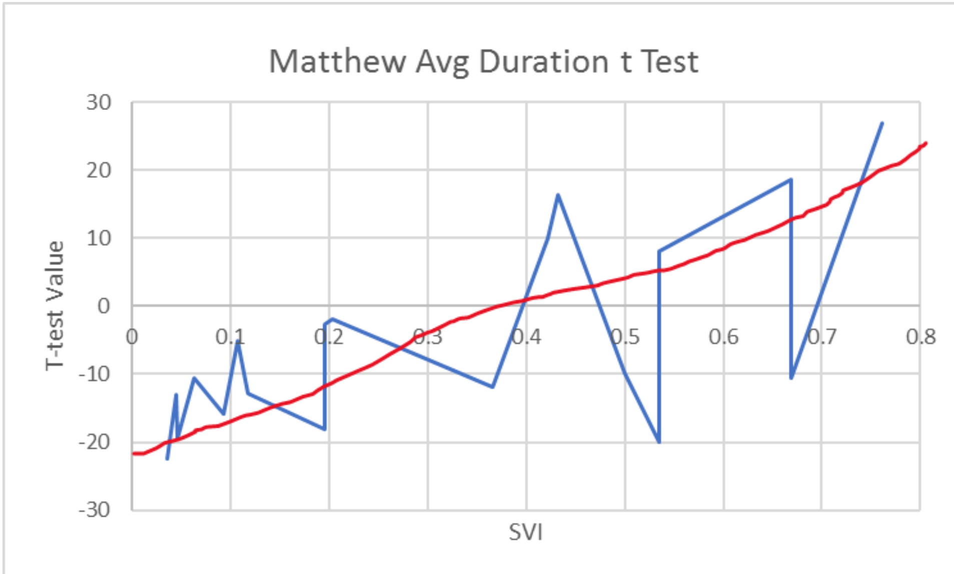

Figure 3.43: SVI vs. T-test Value for Circuits with Substation Outages during Hurricane Matthew

By examining Figure 3.43, a clear linear relationship between SVI values and T-test values was noted. This relationship suggested that disadvantaged communities had longer power outage durations on average than the rest of the distribution system during Hurricane Matthew. These results are evidence of a bias between restoration practices among different communities in the area of study.

For further due diligence, the lines of best fit were calculated for the data presented in the last four graphs. For this portion of analysis, a R^2 value higher than 0.1 was determined to be indicative of a correlation between the best fit model and the raw data. These results are presented in Figures 3.44 to 3.48 A strong linear relationship between outage time and SVI is noted for Hurricane Matthew. Hurricane Irene appears to have a stronger 5th order regression model correlation but is also able to be expressed as a linear model. It can be noted that both linear models for Hurricane Matthew and Hurricane Irene appear to be similar to one another in terms of slope and intercepting the x-axis around 0.45 SVI. In data analysis studies involving human behavior and social sciences, a R^2 value higher than 0.1 is indicative of a correlation between the raw data and the regression model. This number is a lower threshold than typical engineering studies because human behavior cannot be predicted as easily with mathematics.

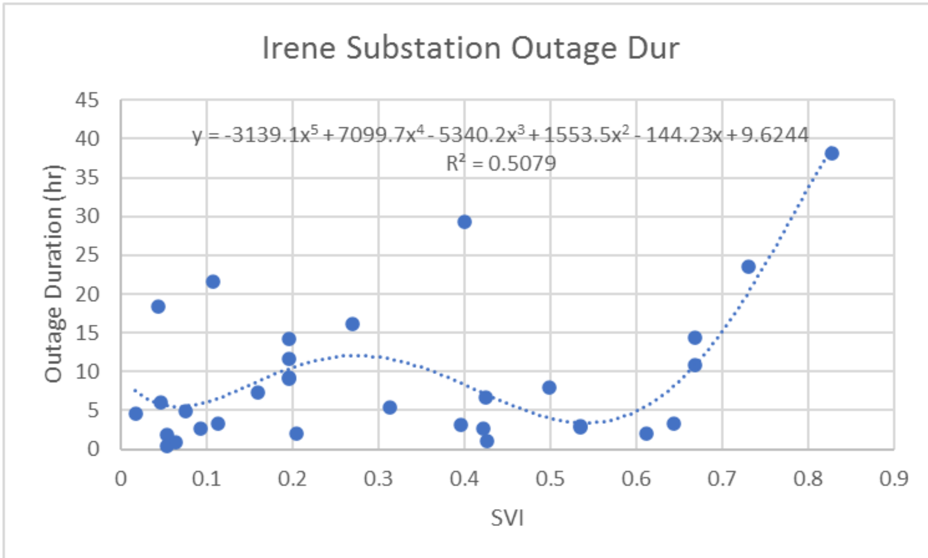

Figure 3.44: Substation Outage Duration vs. SVI during Hurricane Irene with 5th Order Regression Model

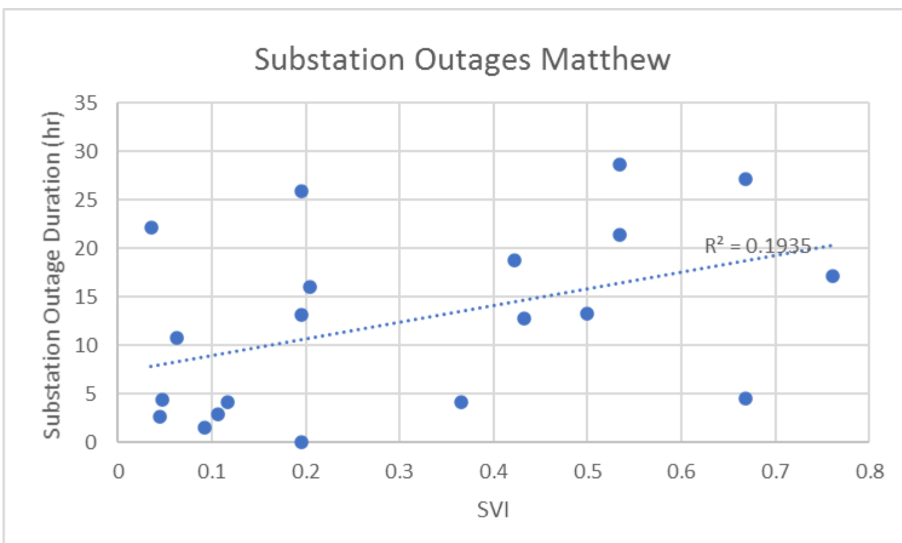

Figure 3.45: Substation Outage Durations vs. SVI during Hurricane Matthew with Linear Regression Model

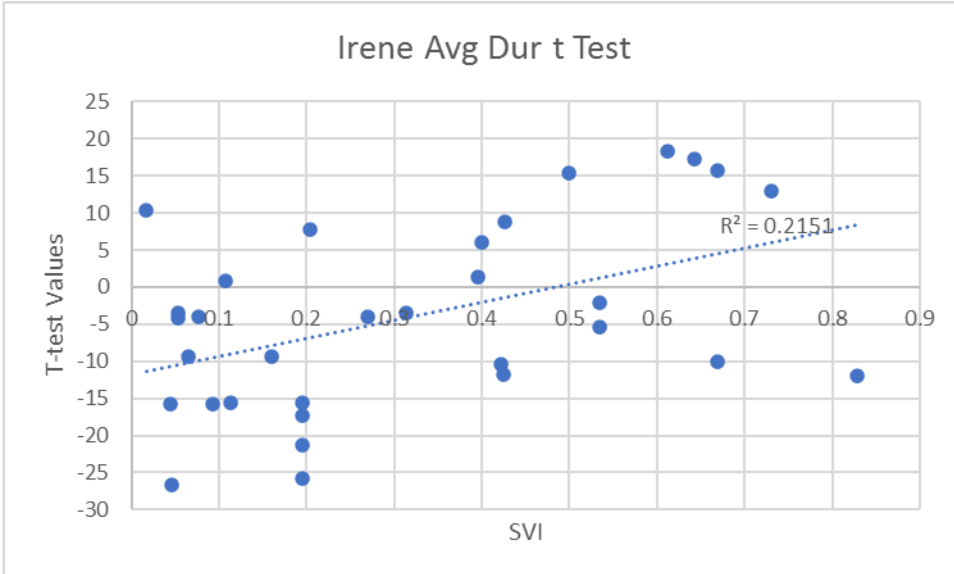

Figure 3.46: SVI vs. T-test Value for Circuits with Substation Outages during Hurricane Irene with Linear Regression Model

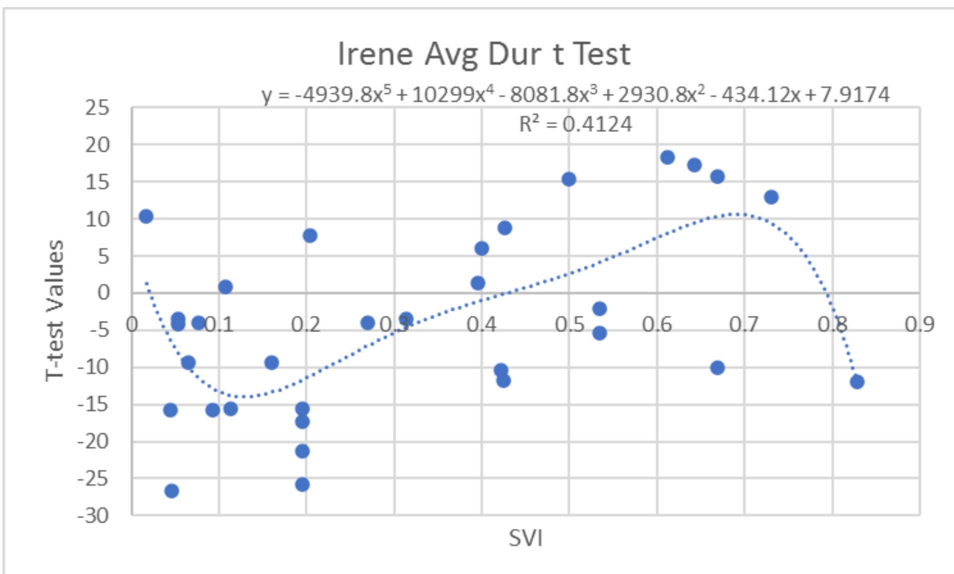

Figure 3.47: SVI vs. T-test Value for Circuits with Substation Outages during Hurricane Irene with 5^{th} Order Regression Model

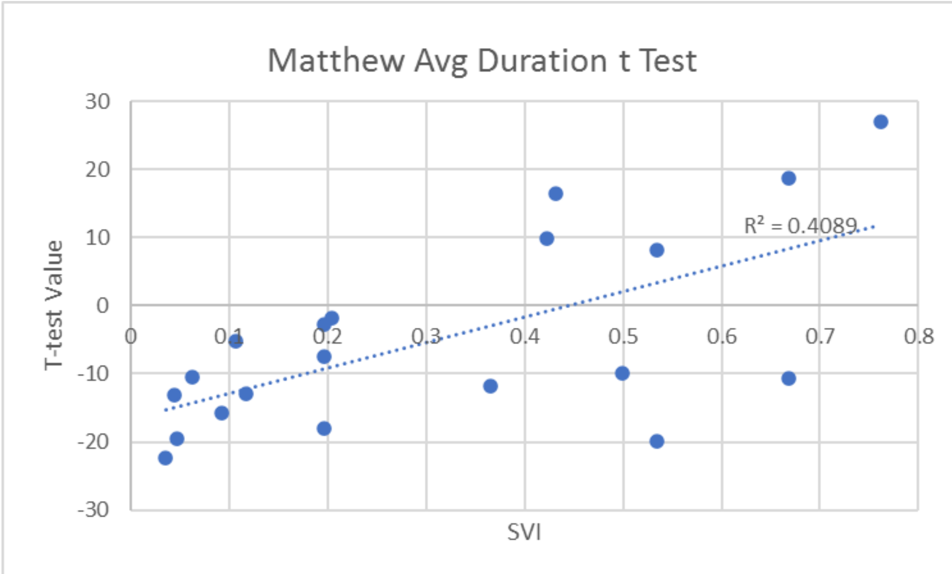

Figure 3.48: SVI vs. T-test Value for Circuits with Substation Outages during Hurricane Matthew with Linear Regression Model

Table 3.1 summarizes the regression model information shared in these figures.

Table 3.1: Regression Model Summary for Hurricane Irene and Hurricane Matthew

	Irene				Matthew			
	Substation Outages		Avg Duration		Substation Outages		Avg Duration	
	R2	Model	R2	Model	R2	Model	R2	Model
Linear	0.1138	12.659x + 4.992	0.2151	24.394x – 11.77	0.1935	17.11x +7.3183	0.4089	37.656x – 16.71
5th order	0.5079	$-3139.1x^5 + 7099.7x^4 - 5340.2x^3 + 1553.5x^2 - 144.23x + 9.6244$	0.4124	$-4939.8x^5 + 10299x^4 - 8081.8x^3 + 2930.8x^2 - 434.12x + 7.9174$				

3.5.4 Commentary

From the analysis presented in this chapter, a few conclusions can be drawn. First, a disparity does appear to exist between disadvantaged communities and other communities in the area of study. However, this relationship only becomes noticeable in more extreme weather scenarios. This conclusion is logical because in less extreme weather scenarios the local utility does not experience stress on their restoration capability. In less extreme weather scenarios, fewer power outages occur over a given area making it easier to restore the power system in a timely manner. Additionally, traditional reliability analysis methods do not capture a disparity either and no specific circuits appears to need additional infrastructure investment. This conclusion directly contradicts the conclusions drawn when examining Hurricanes Irene and Matthew. This direct contradiction highlights the need to consider both reliability and resiliency when determining area for future infrastructure investment.

Second, a disparity can only be noticed when comparing circuits of equal impact. All circuits experiencing a substation outage will have lower power outage durations on average than circuits that only experienced downstream outage events.

Third, distribution feeders located in more socially vulnerable communities appear to have a delay in initial dispatch times for restoration crews during the two weather events that were investigated out of three total. Given that restoration crews restore power from the substation out, this potential disparity should be investigated further to see if the dispatch delay is present for outages of similar clearing device type. Therefore, analysis attempting to prove unequal restoration practices is inconclusive.

Now that a disparity was clearly established, analysis on this investigation turned towards investigating social context behind these disparities. Chapter 4 applies the recognition justice tenet to the area of study.

CHAPTER 4: RECOGNITION JUSTICE- A HISTORY OF HURRICANE PRONE COASTAL AREAS IN NORTH CAROLINA

This chapter is an application of the second tenet of the energy justice framework. Recognition justice examines historical treatment of marginalized communities, instances of political domination, and specifies energy service needs for vulnerable communities. This chapter will begin by explaining why the southeastern coastal area of North Carolina is in need of resiliency improvements. Then, the chapter will discuss inequities between socioeconomic groups in terms of access to resources and representation. Finally, this chapter will discuss some historical events that contextualize the lives of minority communities and present possible explanation for the inequities between socioeconomic groups in the area.

4.1 History of Hurricanes Impacting Area

In this geographical area, it is common for hurricanes to make landfall off the coast. The North Carolina Department of Natural Resources has been tracking hurricanes and tropical storm landfalls since 1851. From 1851 to 2020, 84 tropical storms, including 52 hurricanes, have been recorded making landfall off the coast of North Carolina. This statistic suggest that a tropical storm is likely to make landfall on the North Carolina coast once every two years [30]. Figure 4.2 illustrates data collected by the North Carolina Department of Natural Resources.

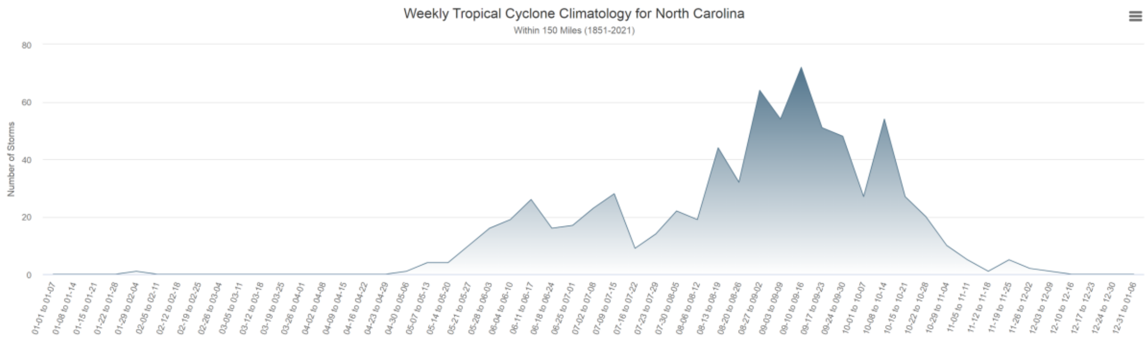

Figure 4.1: Historical Data of Tropical Storms Affecting North Carolina [31]

Among the storms recorded in the historical database, the most notable storms are named Diana (1984), Florence (2018), Floyd (1999), Hugo (1989), Gracie (1959), Matthew (2016), and Hazel (1954) [32]. Among the previous instances, Hurricane Matthew was investigated in detail. Hurricane Matthew made landfall in the Carolinas on October 8, 2016. This storm is directly responsible for 25 deaths in North Carolina along with $10.3 billion in damages. The damage caused by Matthew was so extensive that the name was officially retired from the list of Atlantic hurricane names [33].

From this discussion, it can be seen that North Carolina's coast is vulnerable to damage caused by tropical storms and hurricanes. From earlier discussions on the concept of resiliency, one can see that the area of study is in need of resiliency improvements to its power system. In terms of energy justice, focusing resiliency improvements to this specific area of North Carolina can be seen as a form of recognition justice because the unique energy needs, i.e., improved resiliency, are being addressed directly.

4.2 Socioeconomics of the Area

As with any geographical area, the southeastern coast of North Carolina has a diversity of socioeconomic classes. This diversity can be seen through investigating data collected by the United States Census Bureau. Table 4.1 presents some socioeconomic data for this area.

Table 4.1: Summary of Socioeconomic Factors in Area of Study

Percent of Black Population	13.4%
Poverty Rate	10.2%
Median Household Income	$54,891
Population	225,702

However, when these socioeconomic factors are analyzed on the census tract level, a wide range of values can be seen between communities. Figures 4.3, 4.4, and 4.5 showcase a mapping of percent of black population, poverty rate, and median household income over the entire county from a census tract granularity.

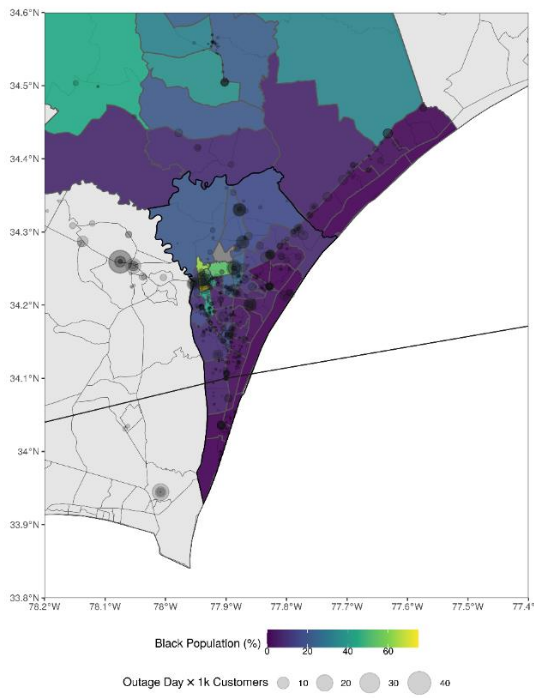

Figure 4.2: Map of Percent of Black Population over Area of Study [34]

From examining Figure 4.2, it can be seen that there is a concentration of a predominately black population located towards the western side of the map. In the next figure, poverty rate data is examined across the area of study.

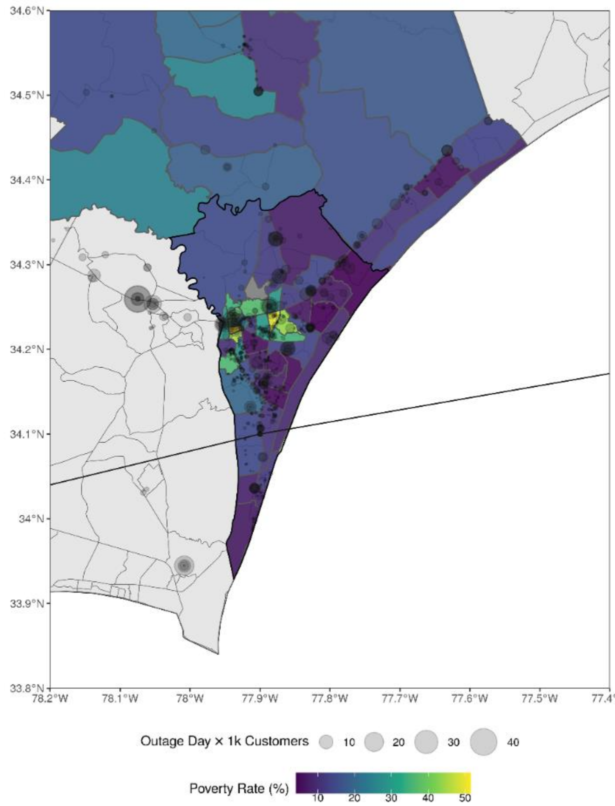

Figure 4.3: Map of Poverty Rate over Area of Study [34]

From examining Figure 4.3, a concentration of an elevated poverty rate can be seen in the western and central areas of the map. In the final figure, a similar relationship is seen for median household income.

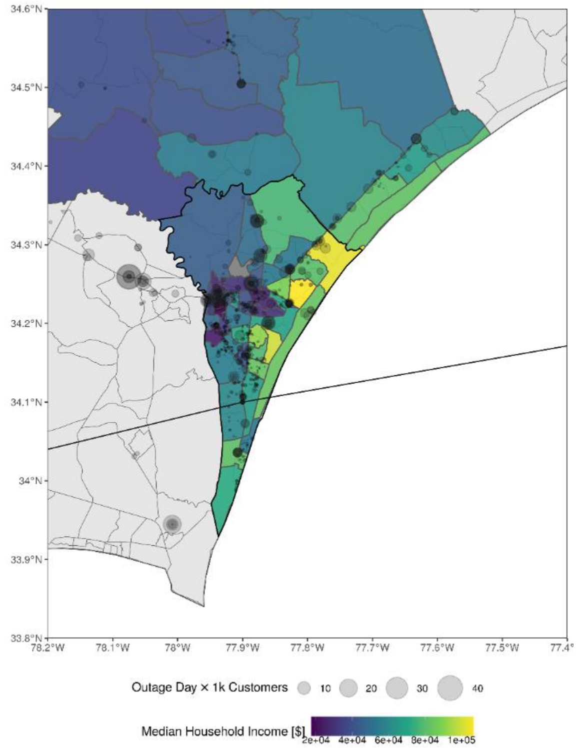

Figure 4.4: Map of Median Household Income over Area of Study [34]

From examining Figure 4.4, a concentration of lower median household income can be seen towards the western and center portions of the county. From examining all three figures, a pattern can be seen in this area of study. In this area, there are a collection of wealthier communities located along the coast with a collection of lower-income communities towards the western and center portion of the area of study. This disparity is easier to see by comparing two different census tracts directly. Table 4.2 shows this comparison.

Table 4.2: Comparison of Socioeconomic Data Between Two Census Tracts

	Census Tract 101	**Census Tract 123**
% of Black Population	54%	4%
Poverty Rate	36.1%	5%
Median Household Income	$31,172	$104,327

4.3 Perspectives through Interviews

While it is easy to note a disparity between different communities in this area of study, perspectives from people living in the area can help provide context behind the numbers. Throughout this study, various community members and locals were interviewed about their experience living in the area and living through extreme weather events. In this following section, one Denzel's perspective will be discussed. For privacy purposes, Denzel is an alias given for the community member who was interviewed.

Denzel is a 60-year-old, black male who grew up in the area of study and moved back ten years ago to become his mother's primary caretaker. Upon moving back, he became involved in local politics as an activist advocating for the community. He lives in a socially disadvantaged community located in the center portion of the area of study.

From examining the data analysis presented in the previous chapter, it can be seen that Denzel's neighborhood had a high t-distribution test value during Hurricane Matthew. Figure 4.7 illustrates where the neighborhood is in previous analysis.

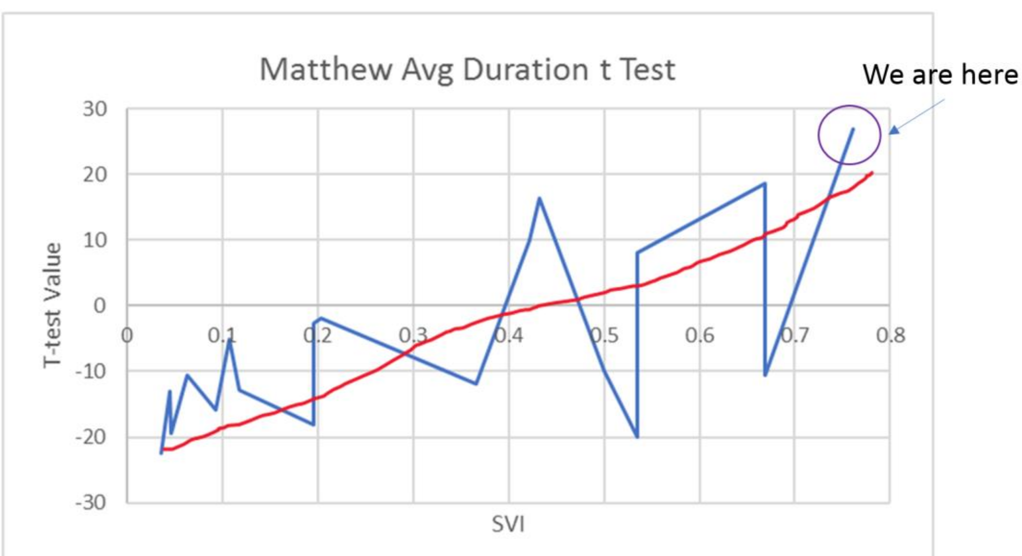

Figure 4.5: Disadvantaged Community Denoted on Disparity Analysis

This neighborhood is located within census tract 103. Table 4.3 presents the socioeconomic data for this area.

Table 4.3: Socioeconomic Data for Census Tract 103

Percent of Black Population	53%
Median Household Income	$37,538
Poverty Rate	34.5%

Given the data expressed in Table 4.3, it is clearly seen that this area and neighborhood are in a more socially vulnerable area, but the data only provides a part of the story. When interviewing Denzel, he described a community that had been neglected by society, exploited by local politicians, and historically persecuted. He also described a very resilient community. When asked why he became politically active, Denzel said, "I fight because my neighborhood is being bullied and I stand up to bullies." Throughout the interview, he described three injustices his community faces today.

4.3.1 Independence Blvd Expansion

The first injustice is the Independence Boulevard expansion project. This project, originally conceived in 1972, was created to improve traffic along major east to west routes in the city. The project proposed an extension of Independence Blvd by 1.7 miles and expanding the road from a two-lane road into a four-lane road [35]. The proposed expansion will directly go through a portion of the Denzel's neighborhood. According to eminent domain law and Kelo vs. City of New London, the United States government reserves the right to take ownership of private property and turn it into public use if the private property owner is fairly compensated [36]. In layman's terms, many residents living in this neighborhood will be forced out of their homes to “make way” for the expansion project.

To add insult to injury, many people in this community did not know about the project because the community was not consulted in the planning phases of the project. When Denzel first discovered these plans, he went door to door to people living in the neighborhood in a Paul Revere fashion screaming, “The DOT are coming. The DOT are coming.” Through educating his community on the DOT’s plans, the community fought back. However, despite his and his community’s efforts, the Department of Transportation (DOT) still plans on expanding Independence Blvd.

Denzel mentioned that the DOT has considered two other alternatives to expanding Independence Blvd. These options included expanding Forest Hills or connecting Princess Place Drive to 16th Street. Both options were considered, but the DOT ultimately decided on expanding Independence Blvd. Denzel feels this was done to intentionally hurt the predominantly black community because other options were available to the local politicians.

4.3.2 Local Transit Authority

The second injustice described was the local transit authority removing routes into the neighborhood. The local transit authority faced budget cuts in 2013 of up to $100,000. If the change would have been approved, over 40% of the transit budget would have been cut. In accordance, with the proposed budget cuts, the local transit authority elected to remove three bus routes from their system. Those three routes were 207 North, 107 College Road, and 301 Pleasure Island [37]. All three of those routes service Denzel’s neighborhood.

Thankfully, this plan was revised. As of February 2022, all three routes will still be removed. However, a portion of those routes will be replaced with a micro transit system. This change was made to the original plan thanks to new federal assistance money [38].

While this new plan is an improvement over the original plan of completely removing three routes, the proposed transit system will still leave a portion of Denzel's community without public transportation. Through examining additional socioeconomic data presented in Table 4.3, one can see the level of importance this community places on public transportation.

Table 4.3: Socioeconomic Data on Transportation in Census Tract 101 [39]

% of households with no car	6.04%
% of population that take public transit to work	0.56%
% of income from median income household spent on transportation	28.7%

It can be observed by the data presented in Table 4.3 that this community is highly dependent on public transportation as a large percentage of the population do not have access to private vehicles as a form of transportation. Additionally, this community already contributes a sizeable portion of their paycheck to paying for transportation needs. By removing public transit options in the area, residents will be forced to find alternative methods of transportation which will increase the overall percentage of income that is spent on transportation.

When speaking with Denzel, he highlighted the importance of public transportation to the community. He also presented alternative solutions to the current system. Among these suggestions were calls to rearrange the county budget and to receive financial compensation from the surrounding counties that also used the transit system. It was stressed that again the local politicians in the area of study selected a choice that directly, negatively impacted this community when other alternative decisions were available to them.

4.3.3 Diluting of the Black Vote

Finally, the black vote in this area has been diluted. Both the DOT and the transit authority are controlled by local politics. An easy way to prevent future injustices like the two previous examples is to have equitable representation of Denzel's community and the black community within local politics. Unfortunately, with the current structure of voting in this area, equitable representation is not present.

Under the current electoral system, the city council positions are at-large positions elected through a nonpartisan pluralistic process. City council members serve four-year terms [40]. For every election, voters select their top three candidates for city council [41]. The three candidates with the highest percentage of votes are declared winners. Currently, all city council member seats are at-large positions. At-large positions means all voters select every seat on the city council. While this might seem like a fair approach to elections, the majority population of the city ends up deciding all seat on the city council. Table 4.4 presents socioeconomic data to illustrate why this phenomenon may be detrimental.

Table 4.4: Racial Demographics of Entire Area of Study vs. Census Tract 103

	% of White Population	**% of Black Population**
Area Overall	76.5%	18.4%
Census Tract 103	44%	53%

Comparing the data presented in table 4.4, it is noted that the majority of the population in the area of study is white, while Denzel's neighborhood is predominantly black. During any city council election, the predominantly white population of the city will elect the new city council members. Those within predominantly black communities are not in the overall majority of the city so their votes are often drowned out by the majority white population. In the words of Denzel, "The black community has no political strength." Denzel and other community leaders argue that the city should create voting districts to elect city council members. With this approach to voting, predominantly black communities will be able to elect a leader that will directly represent their interests. The lack of political strength is a possible explanation behind the repeated neglect and exploitation of this community.

Recent efforts to enact this change were semi-successful. A public referendum was added to the ballot in 2019. The referendum contained multiple changes to the election system in this area Among these changes was an option of change the mode of election of city council from at-large to district based [42]. That portion of the referendum did not pass. Without a reform to the voting practices in this area, Denzel's community will continue to face injustices similar to the removal of public transportation or forced evictions.

4.4 Historical Roots: The Insurrection of 1898

Throughout Denzel's activism, he has strongly advocated for adjusting the mode of election of city council to district based. Local politicians from both parties, Democratic and Republican, has vehemently opposed his proposals. After a while, Denzel made the connection. "The people in power are the descendants of 1898."

The Confederacy was a collection of states in the United States that seceded from the country in response to mounting tensions from northern states to abolish the enslavement of black people in the southern portion of the United States. Their secession sparked a bloody Civil War that eventually ended with the Confederacy rejoining the country. This period following the Civil War is commonly referred to as the Reconstruction era because it marked a time of reconstructing cultural values and racial roles. The end of the Civil War marked the end of slavery. Black people were officially free and were given the right to vote.

The state of North Carolina was a crucial member of the Confederacy. In February of 1965, coastal cities in North Carolina were the last functioning seaports of the Confederacy and was a main source of weapons for their armies [43]. Being such an integral part of the Confederacy, North Carolina struggled to transition into a post-slavery world. It was common to not adequately pay black plantation workers, and physical abuse from policemen towards black men was common as well. The overall sentiment among white farmers was if they could reclaim black men as their slaves they would [43].

At the same time, the price of cotton began to plummet calling into question the ability to maintain the farmer lifestyle. Many people began to move into the cities looking for work. The black population, frustrated with the continual mistreatment by white plantation owners, decided to move to coastal cities, such as Wilmington, in search for a change. By 1897, 46% of the population in Wilmington was black, and this section of the population was thriving. Literacy rates among the black population were rising. There were black churches, black civic clubs, and all black fire departments. 13.6% of all business in Wilmington were black owned. Black men also held local political positions including recorder of deeds, corner, policeman, and the Port Customers Collector. In Wilmington, there was a new social class of elite black people [44].

This new social station of black people, within a large city, angered rural white farmers who still held racist beliefs and struggled with the plummeting prices of cotton. The black population had adjusted and thrived under the New South while rural white farmers were struggling economically. It became easy for the rural whites to blame the elite blacks for their falling economic standing. The Democratic Party, who had recently lost power in the city, capitalized on this anger in order to win the upcoming election. Various news articles began to be published inciting the growing disdain for elite blacks in Wilmington. Most of the articles mentioned a "negro domination" in Wilmington and growing concerns of "negro rule." Through the use of the media, the "negro domination" in Wilmington became the upcoming 1898 election's central issue.

Election day came and went. The Democrats won, but that was not enough for the growing white supremacist sentiment they had summoned. This new group of rural white, known as 'red shirts' for the clothing they adorned showing their support of white supremacy, believed that "blacks had no place in government and should be removed by force." On November 10, 1898, two days after the election, groups of armed red shirts flooded the streets of Wilmington. They had one goal, to "reclaim" their government. The rioting lasted three days resulting in at least 7 deaths, although, some reports have estimated the death toll in the hundreds. Notable black politicians were forced out of their homes by the mob including Daniel Wright, who was murdered by the red shirts. All the remaining Republican office holders were collected and forced to resign from office at gunpoint. At the end of the coup, no black office holders remained in power [44].

In immediate response to the riot, the black population fled Wilmington in a mass exodus. The black population decreased by 5.9% over the next two years. Over half of the black owned businesses were driven out of town by the rioters. Notable black leaders were exiled to the north at gunpoint. The black population was eliminated from all local and regional politics [44]. The elite black social class no longer existed in Wilmington, just as the white supremacists had hoped.

Those in power in the area of study today are the descendants of the red shirts of 1898. Through examining the historical roots of the insurrection of 1898, the continued neglect and discrimination of Denzel's neighborhood is contextualized.

4.5 Electric Utility's Role

When speaking with Denzel in regard to the local utility's treatment of his neighborhood, his tone notably changed. No favoritism in service was noted, and the utility was regarded as helpful and friendly. Denzel described his experience during Hurricane Florence and the local utility. Two or three days following Hurricane Florence, his mother's house still did not have power restored to it. He was able to locate the portion of the line that was down. A tree had fallen on the distribution line. He immediately called the local utility and requested they come out to fix the line. After some persuading, the problem was fixed within an hour.

This is a rarity for the people of this community. They complained and the governing body, in this case the local utility, listened and fixed their situation. When asked to comment on the utility's response, Denzel said the utility "did a good job." However, a disparity can still be seen between different communities and average outage duration during these major weather events. This dichotomy highlights the need for applying recognition justice to energy-based decisions. While the utility company is doing a good job with serving the community, additional work should be done to ensure equitable access to their services. All of the injustices described in this chapter, provide additional barriers for the community. These barriers impact everyday life including access to energy services. In order to achieve a truly just energy system, these barriers must be considered and weighed during extreme weather scenarios and during the infrastructure planning process.

4.6 Conclusion

The southeastern coast of North Carolina has a long and sordid history of its treatment of the black community. Many disparities still persist today and many in Denzel's community feel as though the local government does not care about them. Through all of this, the community feels the local utility at least tries to give them the best service possible. All disparities shown in the power outage data analysis are a result of these other disparities present in this area. This showcases why it's important that the utility places extra emphasis on helping Denzel's community. Even though, the community is treated equally in terms of service, a disparity is still present because of other barriers the community faces. Hence, an equitable approach is needed in which these more vulnerable communities are given extra attention and given priority during extreme storms.

In a perfect world, the additional barriers Denzel's community faces should be removed. This action would be considered justice. Denzel has dedicated a better portion of his life to achieving this goal. In the meantime, equitable treatment is needed to help this community.

CHAPTER 5: PROCEDURAL JUSTICE - SUGGESTED SOLUTIONS

This chapter will provide in-depth solutions to correcting the apparent disparity proven in the previous chapter. Along with these solutions, some data analytics is presented to prove a solution has a potential benefit to correcting the disparity. The presentation of these solutions is an application of the final tenet of energy justice, procedural justice, as discussed in Chapter 2. Procedural justice aims to derive solutions, in the form of infrastructure investment and community engagement, to correct injustices discovered in the first two tenets.

5.1 Additional Infrastructure Investment

During severe weather scenarios, the number one cause of outages is due to trees and vegetation falling on overhead lines. A combination of higher winds during hurricanes and a circuit that is primarily comprised of overhead lines will most likely results in longer outages when compared to the rest of the distribution system. Therefore, a simple solution to improve the outage durations within certain area is to replace existing overhead lines with underground cables. By doing so, this would prevent vegetation related outages in a given area during an extreme weather event.

Therefore, the first proposed solution is to invest in additional underground infrastructure in socially vulnerable communities. In this section, data analytics will prove that socially vulnerable communities are more likely to have less undergrounded conductor lines within its feeder circuit. Data analysis also suggests circuits will a lower percentage of underground cables are more likely to have longer duration outages on average.

5.1.1 Explanation of %UG Calculation

To begin this analysis, the percent of underground cables present within a distribution circuit was calculated. This calculation was performed first by gathering data from CYMEDIST. CYMEDIST contains information regarding all overhead and underground conductor cables within a circuit along with each cable's length in feet. In Figure 5.1, a portion of one distribution feeder in CYMEDIST is shown.

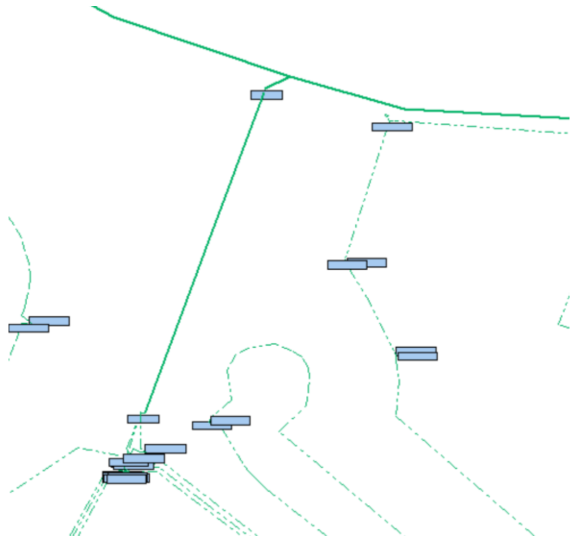

Figure 5.1: Distribution Circuit Shown in CYMEDIST

It can be noted that all underground conductors are marked with a dotted line in the model while overhead cables are marked with a solid line. Additionally, underground cables are denoted as device type 'cable' within the model's database while overhead conductors are denoted as 'Overhead Lines by Phase'.

To begin the process of calculating percent underground values for each circuit, all data for Overhead Lines by Phase and Cables were extracted from CYMEDIST and converted into excel files. The excel data files contain the length of each conductor cable segment in feet and also denotes which circuit every segment belongs to. To calculated percent underground all cable segment lengths were summed and then divided by the lengths of all segments both overhead and underground within a given circuit. The formula below shows a mathematical representation of this calculation.

$$\%UG = \frac{\sum Length\ of\ all\ cable\ segments}{\sum length\ of\ all\ cable\ segments + \sum length\ of\ all\ OverheadbyPhase\ segments}$$

This methodology was applied to every circuit within the area of study. Using these percent underground values and SVI values for every circuit, additional data analytics was performed.

5.1.2 Results of %UG Compared with SVI

Now that a percent underground value was calculated for every feeder circuit, the average T-test value calculated in Chapter 3 was compared with the percent underground value for every circuit. Figures 5.2 and 5.3 show the results obtained during this portion of analysis.

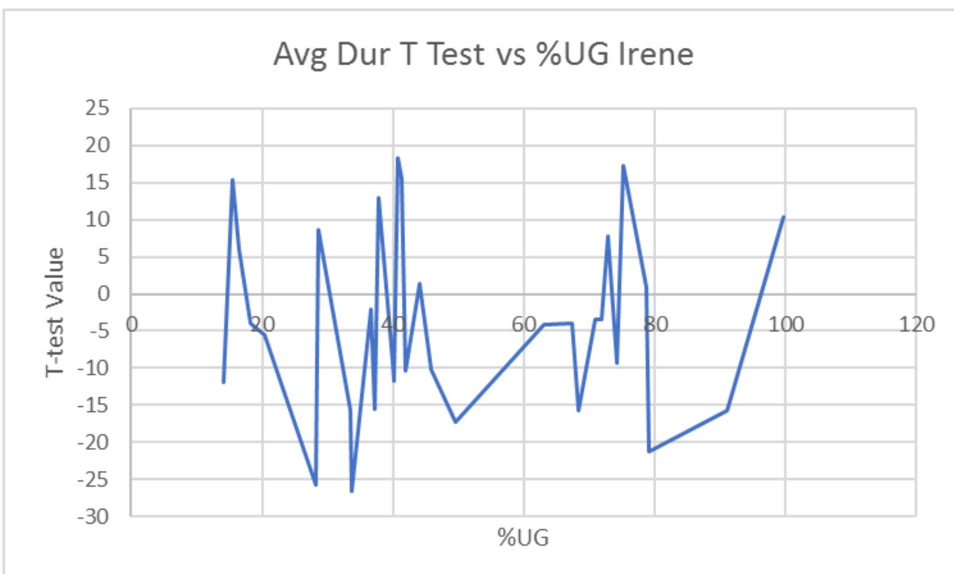

Figure 5.2: T-test vs. %UG during Hurricane Irene

From Figure 5.2, no relationship between percent underground and outage duration average t-test value is seen. However, in Figure 5.3, a relationship starts to form.

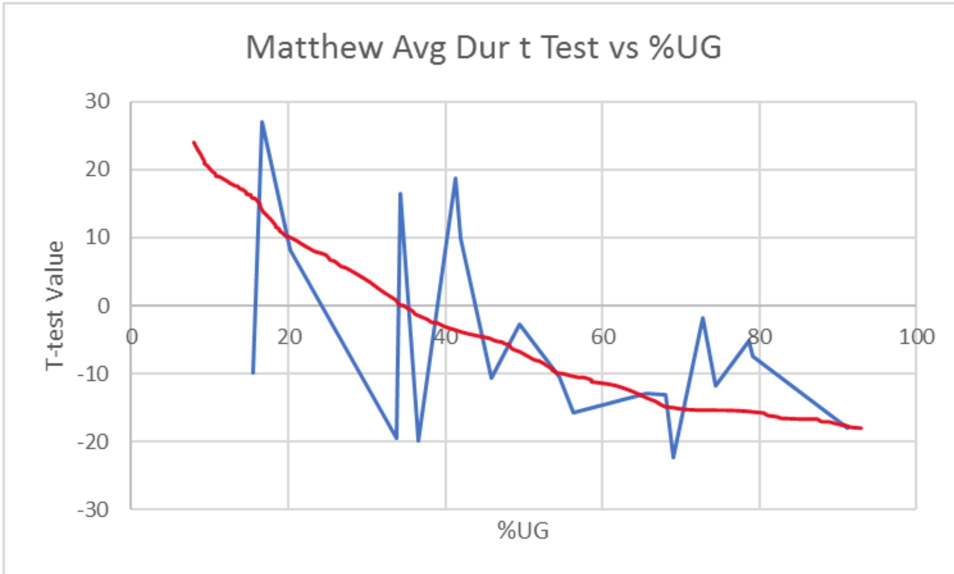

Figure 5.3: T-test vs. %UG during Hurricane Matthew

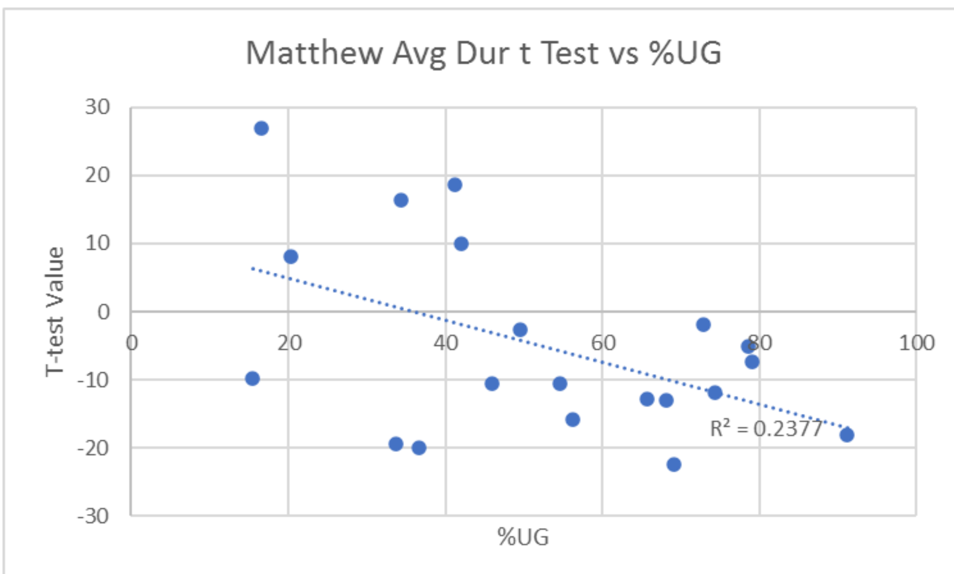

Figure 5.4: T-test vs. %UG during Hurricane Matthew with Linear Regression Model

By examining Figures 5.3 and 5.4, a slightly linear relationship is noted. This relationship suggests that circuits with less underground infrastructure were more likely to have longer duration outages on average during Hurricane Matthew.

A possible explanation for a relationship being present during Hurricane Matthew and not during Hurricane Irene can be seen by comparing the statistics of both storms. Hurricane Matthew was recorded as having a peak wind gust speed of 86 miles per hour when it made landfall on the coast of North Carolina. Hurricane Irene's peak wind gust was recorded at 66 miles per hour [33]. At higher wind speeds, more vegetation related outages are likely to occur. Therefore, it is possible that Hurricane Irene was not extreme enough of an event to lead to major vegetation related outages.

Further analysis was conducted directly comparing the percent underground values of each feeder to their corresponding SVI value. Figure 5.5 illustrates the results from this portion of the analysis.

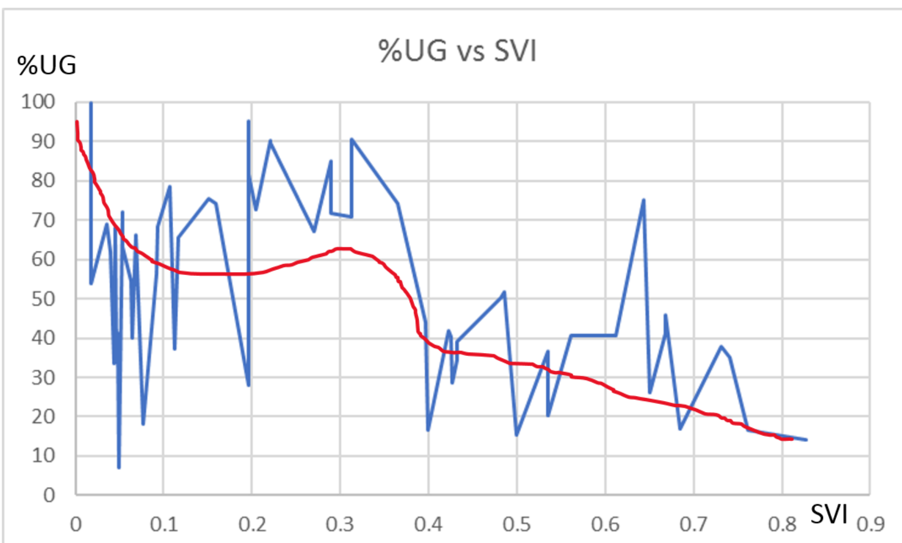

Figure 5.5: SVI vs. %UG

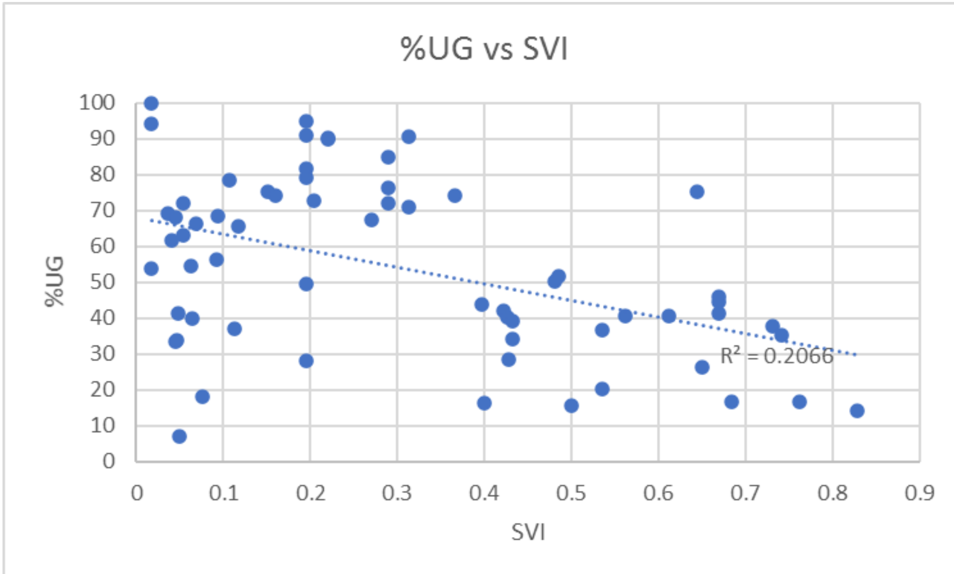

Figure 5.6: SVI vs. %UG with Linear Regression Model

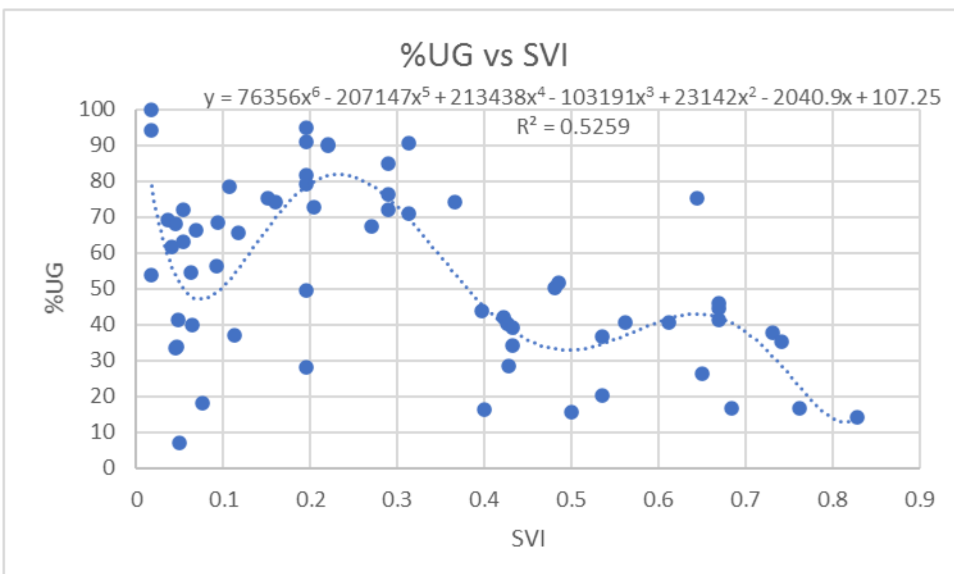

Figure 5.7: SVI vs. %UG with 6th Order Regression Model

By examining Figures 5.5 and 5.6, a negative linear relationship between percent underground and SVI value can be seen. Figure 5.7 illustrates the 6th order regression model that trends downward as well. These results suggest that more socially vulnerable communities are less likely to have underground infrastructure within their distribution circuit. That relationship also suggests that in extreme weather events more socially vulnerable communities will experience greater vegetation related outages and thereby will have longer duration outages on average when compared with the rest of the distribution system.

5.1.3 Discussion on Results

From the results shown in this section, a relationship between lack of underground infrastructure, longer outage durations on average, and more socially vulnerable communities was noted. By replacing existing overhead power lines with underground cables, an overall improvement in outage durations for more socially vulnerable communities could be realized.

5.1.4. Suggested Area for Undergrounding

Upon further investigation, three circuits were identified that had a high t-test value and a low percentage of underground lines. The statistics for these three circuits are shown in Table 5.1.

Table 5.1: T-test and %UG Metrics for Selected Circuits

Circuit Name	**SVI**	**T-test Value**	**%UG**
A	0.74	25.3	35.15
B	0.76	27.02	16.62
C	0.69	43.51	14.16

A portion of circuit B is located within Denzel’s community. Additionally, as mentioned in the previous chapter, Denzel’s mother lost power due to a tree falling on overhead distribution lines. By combining analysis from interviews and data analytics, circuit B becomes a good candidate for targeted undergrounding. Pacific Gas and Electric Company (PG&E) estimates that the cost to convert one mile of overhead lines into underground cables is about $3 million [45]. Table 5.2 provides cost estimates for undergrounding the remaining feeder or portion of the feeder.

Table 5.2: Cost Estimates for Undergrounding Circuit B

Resulting %UG	**Miles of Construction**	**Estimated Cost ($million)**
100	22.1	66.3
75	15.5	46.5
50	9	27

5.2 Microgrid Investments

Along with undergrounding investments, a microgrid could be constructed to service a certain area while the remainder of the system is down in an extreme weather event. The area for microgrid investment was selected by examining the work performed in the previous two chapters. By examining the comparison of t-hypothesis test values and SVI during Hurricane Matthew, a noticeable outlier is detected. Figure 5.5 illustrates the graph with the outlier marked.

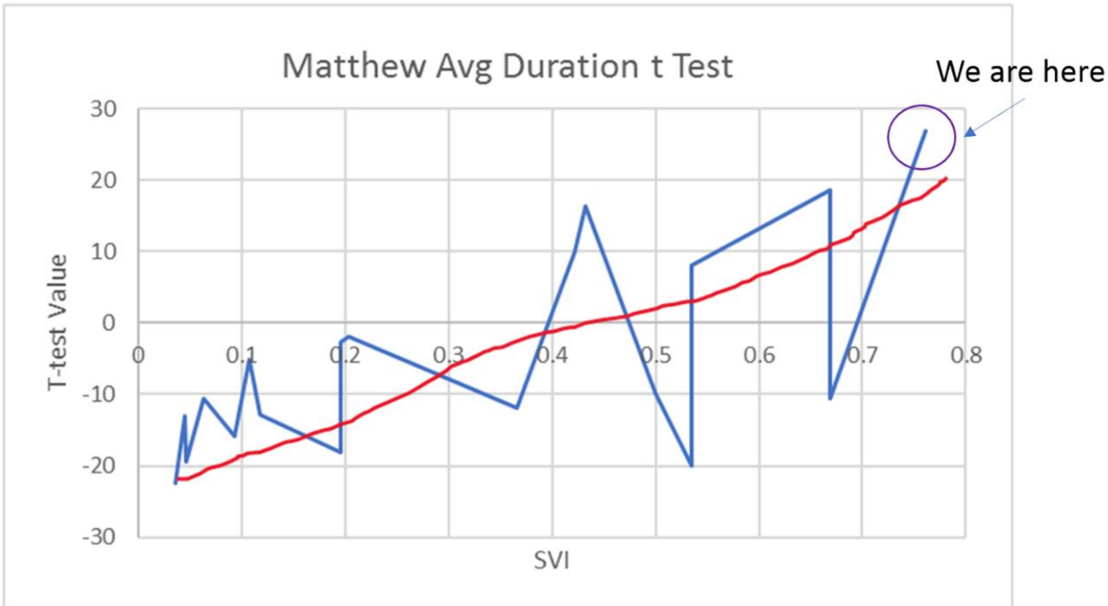

Figure 5.8: T-test Value vs. SVI During Hurricane Matthew with Outlier Marked

The outlier marked on Figure 5.5 refers to Circuit B, as discussed in section 5.1.4. Denzel's neighborhood is located within this circuit. Therefore, implementing a microgrid solution for this circuit is a logical solution derived from applying distributional and recognition justice tenets.

5.2.1 Initial Analysis

Initial analysis was conducted to determine the service area for a proposed microgrid. Initially, the entire feeder was considered as the service area. Customer information was obtained using CYMEDIST models. The information exported from CYMEDIST included load (expressed in kilowatt, kW, and kilo-volt-amps, kVA), and customer type (residential or commercial). The total customer load for the entire feeder was calculated to be 17.26 MW. From investigation of other microgrid projects, that capacity size for a microgrid was determined to be too large for a practical application.

The scope of the microgrid was limited to servicing customers within Denzel's neighborhood.

5.2.2 Proposed Microgrid Design

Figures 5.9 and 5.10 illustrate the proposed microgrid for the disadvantaged neighborhood. It is important to note that in order to successfully implement microgrids, additional investments in the distribution system may be required such as undergrounding portions of the circuit served by the potential microgrid. The microgrid will utilize PV generation rated at 4.5 MW with a battery energy storage system (BESS) rated at 110 MWh. The PV generation rating was selected from calculating the total load customers in the selected area utilizing CYMEDIST customer data. The BESS rating was calculated using the following formula [46].

$$BESS\ rating = customer\ load * hours\ of\ needed\ service$$

$$BESS\ rating = 4.5\ MW * 24\ hrs = 108\ MWh\ \approx 110\ MWh$$

The hours of needed service were determined through analyzing the historical outage data from Hurricane Matthew. Upon investigation, it was found that the area experienced a substation outage for 17 hours. The hours of needed service were selected to be 24 hours instead of 17 to provide a buffer in case a more extreme storm was to affect the area in the future. Essentially, implementing a microgrid of this size with the BESS included would allow the disadvantaged neighborhood to operate independently from the electric grid for a full 24 hours. In the best-case scenario, if this design were to be implemented, Denzel's neighborhood would not lose power at all during an extreme weather event.

Along with information on load requirements, CYMEDIST model also contained information designating each customer either residential or commercial. Commercial customers typically refer to businesses, hospitals, community centers while residential customers are homes or apartment buildings. Utilizing this information, the percentage of residential and commercial customers can be calculated using the following formulas.

$$\%\, residential = \frac{\#\, of\ customers\ marked\ as\ residential}{total\ customers\ within\ service\ area}$$

$$\%\, commercial = \frac{\#\, of\ customers\ marked\ as\ commercial}{total\ customers\ within\ service\ area}$$

Using the formulas described above, the customer profiles for the service area of the proposed microgrid was determined to be 98.3% residential and 1.6% commercial. The microgrid would service approximately 700 individual customers including the Derrick GS Davis Community Center which could serve as a potential safe haven or gathering place for the surrounding communities during an extreme weather event.

In order to better achieve funding for this project, the microgrid has been divided into three development stages. Table 5.3 describes the capacity of PV generation and BESS for each respective stage. It is important to note that implementing a BESS of this size could provide other benefits to the power systems, namely providing generation to offset peaks in generation during Winter months.

Table 5.3: Information for Each Stage of Proposed Microgrid

	PV Capacity	BESS Capacity	% Commercial Customers	% Residential Customers
Stage 1	1 MW	24 MWh	15	85
Stage 2	2 MW	48 MWh	5	95
Stage 3	1.5 MW	38 MWh	3	97

Figure 5.9 provides a map of the given service area for each stage of the microgrid, and Figure 5.10 overlays the given distribution network on top of a satellite map of the area.

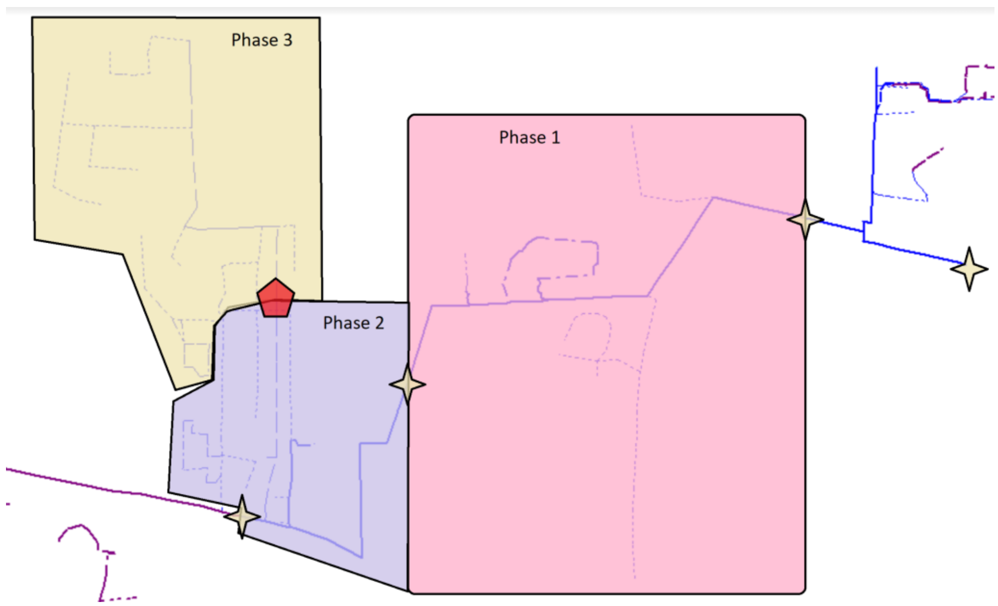

Figure 5.9: Map of Service Area for Proposed Microgrid

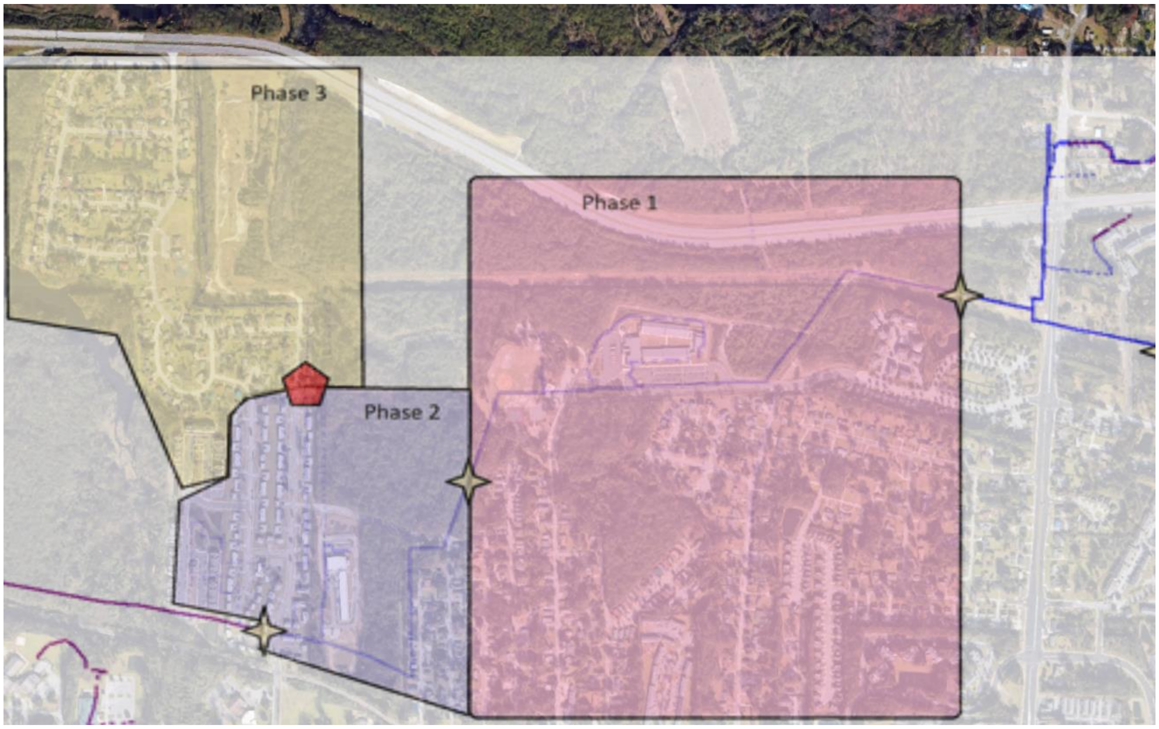

Figure 5.10: Service Map Overlaid onto Satellite Map

The star icon, in Figures 5.9 and 5.10, refer to existing protective devices that can be utilized for islanding the microgrid from the larger grid. The red pentagon icon refers to a protective device that would need to be added to the grid topology in order to effectively isolate the microgrid into its respective stages. The protective device, or isolating device, in this situation can be an automatic switch or recloser. In order to minimize costs, a switch was selected for this portion of the design.

Along with isolating device requirements, a microgrid requires equipment to connect the generation facility to the existing distribution system. In Figure 5.11, a schematic of the interconnecting devices for a typical microgrid system is shown. This figure was obtained from a product brochure from an international company that specializes in microgrid design.

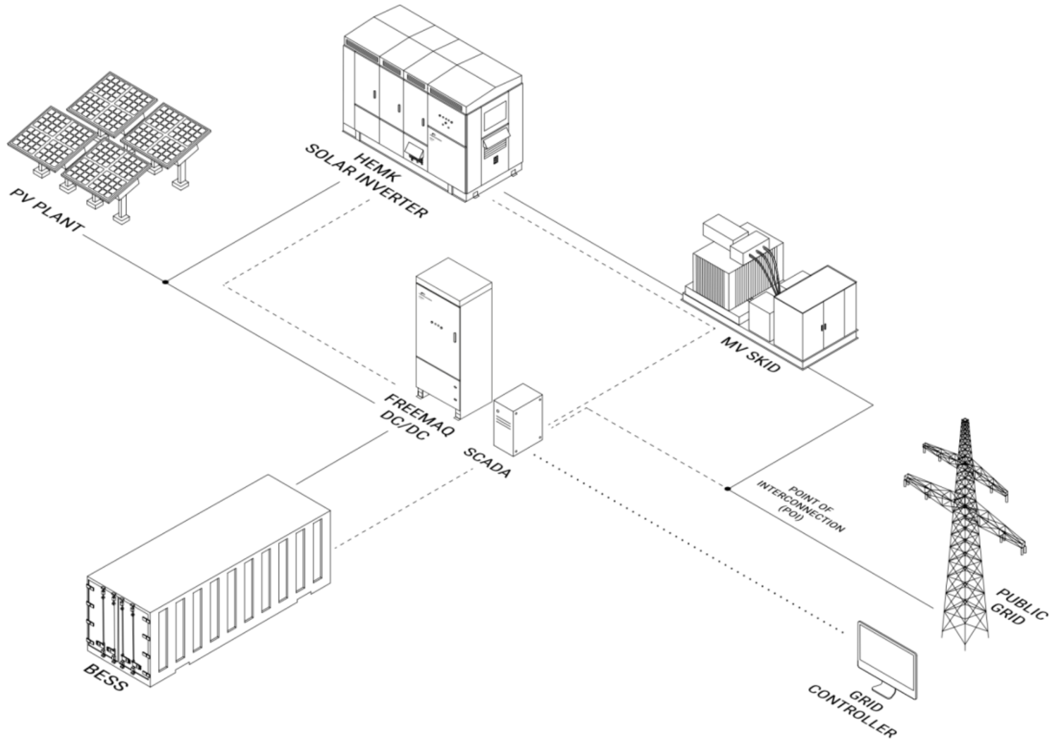

Figure 5.11: Schematic of Interconnecting Devices for a Typical Microgrid [47]

By examining Figure 5.11, it can be concluded that the proposed microgrid will need an inverter to convert DC (direct current) power into AC (alternating current) power. A DC to DC converter will be needed to convert DC power produced by the PV array to a level that can be stored in the BESS. The MV skid device is a transformer that steps up the voltage of any power produced to the primary distribution circuit level. The SCADA (supervisory control and data acquisition) box is a communications device that will allow system operators to control the dispatch on power produced while also gathering data on the performance of the system.

Additionally, a microgrid of this design requires land. PV arrays especially require a large amount of land. Land requirements for PV ranges from 2.5 to 10 acres per MW. According to the Great Plains Institute, a solar farm required 10 acres per MW [48].

For this design, 10 acres was chosen to ensure enough land is present in the service area to build the proposed microgrid. Figures 5.12 and 5.13 illustrate where the microgrid would be built and showcases that the land requirement is met. For stages 1 and 2, 20 acres would be required. These stages would be built in the area shown in Figure 5.12.

Figure 5.12: Proposed Land for Microgrid Stages 1 and 2

From examining Figure 5.12, it can be seen that there is enough land to construct microgrid stages 1 and 2. For stage 3, 15 acres would be required. Figure 5.13 showcases the area in which this microgrid stage could be constructed.

Figure 5.13: Proposed Land for Microgrid Stage 3

From examining Figure 5.13, it can be seen that there is enough land to construct microgrid stage 3.

As with any construction project, a cost estimate is needed to in order to obtain adequate funding. The following is a summary of the cost estimates for components of the microgrid:

1) Solar array installation is estimated to cost approximately $1/watt [49].
2) Battery storage cost is estimated at $345/kWh [50].
3) Clearing land for use in developing the microgrid is estimated to be $5000/acre [51].

By applying the above, a rough estimate for the overall cost to construct the proposed microgrid design is found. Table 5.4showcases the estimated cost for this project.

Table 5.4: Estimated Cost for Microgrid

	Cost per unit	Total Cost	Factor
PV Array	$1.01/W	$4.5 million	
BESS	$345/kWh	$38 million	
Land Clearing	$5k/acre	$50k	
		$42.55 million	1.2
		$51.06	

A factor of 1.2 was added to the cost estimate to account for interconnecting equipment and any additional labor costs that would be accrued during construction.

5.2.3 Operational Costs and Ownership

Along with initial capital costs described in Table 5.4, a microgrid project will also have operational costs associated with maintaining the facility. The ownership structure of the microgrid project will determine what entity is responsible for paying these operational costs. There are various different ownership structures a microgrid project can employ ranging from utility owned, privately owned, community owned, and any combination of the three [52]. In a utility owned structure, the local utility owns the facility outright. This means the utility is solely responsible for maintaining the facility and paying operational costs. The utility recoups the costs incurred through paying operational costs by increasing electricity rates on the consumer. Section 5.2.6 discusses rate cases in further detail. It is important to note that this ownership structure is not popular because electricity rates are raised for all customers on the system while only select communities will actually see the benefit of the microgrid project. This ownership structure is the traditional structure the power system has used in infrastructure development.

In recent years, community ownership of microgrids has become an attractive solution. In this business model, the local community owns the microgrid outright and is controlled through a community-based organization. The local community has a majority voice in voting decisions regarding the project, and all economic benefits are distributed throughout the local community [53]. With this ownership structure, various business models can be implemented to finance operational costs. One popular business model is referred to as the Energy-as-a-Service (EaaS) or Microgrid-as-a-Service (MaaS) model Under this model, electricity is seen as a societal good, like a fire department, rather than being treated as a product [54]. An EaaS agreement is similar in structure to a Power Purchase Agreement (PPA) in which users of the microgrid pay a monthly service fee as long as the microgrid is functional. The monthly service fee covers operational costs for the microgrid and is typically paid by residents of the community. Under this agreement, excess or unused power produced, can be sold to the local utility for a profit, and the local community can share in those profits the microgrid produces [55, 56]. The deployment of this business model will ensure operational costs for the microgrid are met while also enabling the local community to share in the project's economic benefits.

5.2.4 Funding Option: Grants

With every major construction project, the question of "who's going to pay for it" naturally is asked. The proposed microgrid described in the previous section has a budget of at least $51 million. There are two options to secure the funds to construct this project: grants and increasing rates on consumers. This section will discuss the grant options available. The Federal Emergency Management Agency (FEMA) has two grant programs that have funded the construction of microgrids. The first program is called the Hazard Mitigation Grant Program (HMGP). Under HMGP, FEMA allocates funding to state, local, and tribal governments to help develop mitigation plans for future extreme weather events. The program also provides funding to projects focused on rebuilding the power system to prevent damage from future weather events. This program also allows for local communities to apply [57]. With this program, Denzel's community could apply to this grant directly without having to seek the help of the local government. Considering the lack of representation and advocacy from the local government for this community, this grant could pose as a great option to obtain funding. In order to qualify for this grant, the project must complete the following steps: project scoping, mitigation planning, technical feasibility and effectiveness, cost effectiveness, and environmental and historic preservation considerations [57].

In the previous section, a portion of the project scoping has already been defined. The next steps in project scoping would include finding a vendor to supply equipment and contacting landowners to obtain permits to build on the required land. In mitigation planning, a mitigation plan is drafted that identifies the vulnerabilities of the system, the risks of not implementing the microgrid, and a explanation of how implementing a microgrid would improve the vulnerability and reduce the associated risk in the system. For technical feasibility and effectiveness, the project must prove that it is in compliance with industry standards and must be defined as either a stand-alone solution or a portion of a larger solution [57]. For this project, it can be considered a stand-alone project meaning funding will only be obtained to construct the microgrid, or it can be considered a portion of a larger project if the targeted undergrounding is included in the grant proposal. Under cost effectiveness, applicants must show that implementing the microgrid would reduce economic losses in the long run. This economic loss due to losing electricity is referred to as loss of function. The definition of loss of function can include the resulting risk of surrounding medical facilities losing power and the reduction of risk a microgrid would provide for the serviced community. Finally, under environmental and historic preservation considerations, the microgrid must prove that it is in compliance with federal laws and presidential executive orders (EO). Some of the laws included in this list are the Clean Water Act and EO 11988: Floodplain Management [57].

Along with the HMGP, FEMA has another grant program called the Building Resilient Infrastructure and Communities (BRIC) program. The purpose of the BRIC program is to shift federal spending on aftermath recovery towards proactive infrastructure investments and community lifelines to improve community resilience. The BRIC program focuses on funding projects that promote innovation [58]. A microgrid project would fall under the category of innovative solutions to improve community resilience.

The BRIC program has funded various microgrid projects over the years. The most notable projects that have been funded under this current administration are the Blue Lake Rancheria microgrid project, which received $6.3 million, and the Bronzeville microgrid project, which received $29.6 million under this program. The current administration has allocated an additional $3.5 billion to FEMA’s budget [59]. With this additional budget increase, FEMA has more ability to give grants towards building microgrids in disaster prone areas.

5.2.5 Funding Option: SGIP Equity Program and Equity Resiliency Program

Another possible funding resource for the proposed microgrid lies in incorporating regulatory incentive programs. From a regulatory perspective, microgrid projects can be seen as a Non-Wire Alternative (NWA) project. NWA projects are defined as any infrastructure investment for the power system that defers or avoids additional grid investments into transmission or distribution conductor cables [60]. This distinction is made because, as shown in previous sections, it is less expensive to build a microgrid to improve electric grid resiliency as opposed to constructing undergrounding lines.

In California, this NWA project classification approach has been taken to construct microgrids in response to the wildfires the state has experienced in recent years. Due to the increasing risk of wildfires, the use of transmission and distribution (T&D) lines must be limited. This results in service being disconnected on power lines located in high wildfire risk areas through a program called the Public Safety Power Shutoff (PSPS) program [61]. Unfortunately, implementing the PSPS program results in multiple communities losing access to electricity during wildfire season. The California Public Utilities Commission (CPUC) has developed a rebate program called the Self-Generation Incentive Program (SGIP) to encourage the construction of microgrid in low-income and disadvantaged communities that are affected by the PSPS program along with the Equity Resiliency Program. This SGIP program allocated $850/kWh for BESS serving residential area located in socially vulnerable communities. The Equity Resiliency

Program allocated $1000/kWh to funding microgrid project for low-income area with high wildfire risk [61].

A similar program could be implemented in North Carolina through the North Carolina Utilities Commission (NCUC) in partnership with the local utility to provide rebates for microgrids in area with high hurricane risk servicing socially vulnerable communities. If a similar program was implemented in North Carolina, the proposed microgrid project would qualify for tax incentives given that it services a socially vulnerable community in a high-risk area for hurricanes.

5.2.6 Funding Options: Rate Case

The final method of securing funding for this microgrid project is to increase the electricity rates that the customers pay in order to offset the initial investment required to construct the microgrid. This method of funding is not popular among customers, the NCUC, or the local utility because the cost will be pushed onto the customers. Additionally, any increase in electricity rates must be approved by the NCUC with sufficient documentation provided by the local utility proving that the infrastructure updates are needed. Rate cases are seldom approved because the focus of the NCUC, as it should be, is on maintaining low electricity rates for the consumer. However, there have been two rate cases approved in the past few years for constructing microgrids. In this section, those two rate cases will be discussed to determine appropriate arguments to make before the NCUC in order to gain funding the build the proposed microgrid.

The first successful rate case was for the Bronzeville microgrid project in the South Side of Chicago. As discussed previously, the Bronzeville microgrid did also receive grant funding through FEMA’s BRIC program. A rate case was pursued to recover additional funding required that the BRIC program was not able to allocate. In the proposed microgrid project, a similar approach is recommended.

The Bronzeville microgrid project was established in 2018 as a part of ComEd's Community of the Future program. This microgrid is located on the South Side of Chicago south of 38th street. Historically, this area of the United States is known as a migration destination for the black community fleeing the Jim Crow era south [57]. The site consists of 750 kW of PV generation, a 2 MWh BESS, and 5 MW of natural gas generation. The islanded operation time for this project is estimated to be 4 hours. The microgrid can interconnect with an existing microgrid located on the Illinois Institute of Technology's (IIT) campus [62]. The microgrid will service over 1,000 customers including 11 critical infrastructure customers [63]. ComEd petitioned the Illinois Commerce Commission (ICC) in rate case 17-0031to recover $25 million is costs. ComEd argued that a microgrid is a distribution resource that can improve unaccounted for energy (UFE) and line losses. Essentially, with a functioning microgrid in the area, less power would be lost through the transmission system which would reduce overall costs felt by the consumer. The microgrid would save operational costs in the long run [64]. This reasoning was their main argument. Additionally, ComEd argued that the microgrid would provide a safe haven during major power outages for surrounding communities. It was also argued that implementing this microgrid would further understanding of this technology's role in the power system. Finally, it was argued that the microgrid project would provide an opportunity to engage with the local community [65]. If the local utility in North Carolina were to petition the NCUC to build the proposed microgrid project, similar arguments could be used in the rate case and the

Bronzeville microgrid rate case can be referred to provide additional insight in project development.

The second successful rate case for securing funding to construct a microgrid project is local to North Carolina. The Hot Springs microgrid is located in Madison County, North Carolina [66]. This area is in a remote mountainous portion of the state. Figure 5.14 illustrates the location of the microgrid in relation to the state of North Carolina.

Figure 5.14: Madison County on North Carolina Map [67]

The Hot Springs microgrid is located at the service end of a 10-mile feeder that travels through the Great Smokey Mountains making it susceptible to frequent outages. The town of Hot Springs is a small rural town containing approximately 600 residents. The microgrid itself contains 2 MW of PV arrays, 4 MW BESS, and a microgrid controller [66, 68]. This microgrid topology is similar to the proposed microgrid topology presented in earlier sections.

As a part of due diligence on the local utility's part, two other alternatives to constructing the microgrid were investigated. The first alternative was a "do-nothing" scenario. In this scenario, the power outages of the current system were investigated to prove that the area was in need of infrastructure improvements. The second alternative was to build an additional distribution feeder to service the town [66]. As discussed in earlier sections, updating wire infrastructure within the power system is expensive. The Hot Springs microgrid was presented as a NWA project to avoid additional infrastructure investment in distribution cables in the form of constructing an additional feeder. A similar argument could be crafted for the proposed microgrid. By implementing the microgrid proposed in this thesis, additional undergrounding of the system could be avoided.

The Hot Springs microgrid was presented before the NCUC as a rate case. On October 8, 2018, the local utility filed a Certificate of Public Convenience and Necessity (CPCN) application in order to secure funding to construct the Holly Springs microgrid [69]. The NCUC later approved construction of the microgrid in May of 2019 [68]. A reason for the quick turnaround is due to a lack of community protest of the construction of the microgrid. The public witness hearing for this project was cancelled due to the overall support of the community which expedited this regulatory process [69]. This project serves as an illustrative example to the importance of proper community engagement. In 2016, the Energy Innovation Task Force (EITF) was formed comprised of local leaders and the local utility. The main focus of EITF was to help transition this area of North Carolina towards a "smarter, cleaner and affordable energy future" [70]. The success of EITF can be seen with the approval to construct the Holly Springs microgrid.

From investigating the above two successful rate cases, a few lessons can be gleaned for the proposed microgrid. First, a focus should be placed on the ancillary benefits a microgrid could provide to the larger power system in the form of improving lines losses. Second, a microgrid is considered to be a NWA project, and so, cost analysis comparing wire alternatives with the microgrid provides a coherent argument for constructing the microgrid when compared to a more costly alternative. Third, community engagement is the most important aspect of obtaining approval from the NCUC. A further discussion of how to implement a community engagement program will be discussed in the next section. All three of these lessons could be applied in the case of the proposed microgrid should the local utility wish to apply for a rate case with the NCUC.

5.3 Community Engagement

As highlighted in the previous section, community engagement is critical to gain a thorough understanding of the affected community and to prevent any conflicts between the local community and the local utility. Community engagement builds trust between the community and power structures. Once trust is built, all entities involved in the project are able to work together to create a better project [71]. Projects with a community engagement program also are better designed with the community in mind and provide services needed by the community.

Community engagement programs are relatively new to the power system industry, but a few examples of successful community engagement can be seen in Latin American countries. The microgrids built in Huatacondo, Chile, Ollagüe, Chile; and Puertecitos. Mexico all cited local community engagement as critical to the overall sustainability of these projects [72]. The University of Puerto Rico- Mayagüez (UPRM) applied a community engagement program in the development of a microgrid to mitigate the impact of hurricanes within the region. These engineering students consulted students from social science fields to determine ethical dilemmas associated with constructing the microgrid. By considering the ethical implications of the project, a microgrid was designed that would reduce harm to all affected parties. The UPRM team also held three workshops educating the community on the proposed microgrid and its benefits the microgrid would give to the community [73]. By considering the community impacts, the designed microgrid better served the community it was meant to help.

While the benefits of community engagement have been sufficiently discussed, a formal understanding of what community engagement is and how to apply it correctly, is needed. Community engagement is defined as the building of institutional bridges between local government, business groups, and local citizenry. Community engagement has become popular over the last decade due to rising cases of democratic deficit. Under a democratic deficit, a gap is present between ideals and the reality of managing the outcomes of those ideals [74]. Community engagement seeks to reduce this gap through providing outlets for the local community to participate. There are different levels of community participation that ranges from informing to empowerment. Table 5.5 illustrates the different levels of community participation.

Table 5.5: Levels of Community Participation [74]

Inform	Consult	Involve	Collaborate	Empower
Public participation goal To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, opportunities and/or solutions.	*Public participation goal* To obtain public feedback on analysis, alternatives and/or decisions.	*Public participation goal* To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	*Public participation goal* To partner with the public in each aspect of the decision, including the development of alternatives and the identification of the preferred solution.	*Public participation goal* To place final decision-making in the hands of the public.
Promise to the public We will keep you informed.	*Promise to the public* We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision.	*Promise to the public* We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	*Promise to the public* We will look to you for direct advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	*Promise to the public* We will implement what you decide.
Example techniques to consider Fact sheets Web sites Open houses	*Example techniques to consider* Public comment Focus groups Surveys Public meetings	*Example techniques to consider* Workshops Deliberative polling	*Example techniques to consider* Citizen advisory committees Consensus-building Participatory decision making	*Example techniques to consider* Citizens' juries Ballots Delegated decisions

For our application of community engagement, informing will serve as a baseline while consulting, involving, and collaborating will be where majority of the effort is focused. With any community engagement program, the motives of all identified parties must be taken into account. A focus on enacting equity is usually the main objective of local communities while a business entity might want to uphold social responsibilities [74]. These motives tend to be aligned but require communication across all stakeholders to understand.

A standard methodology for community engagement has been described in literature as a four-stage process. The stages are defined as follows: formation of development group, building trust, co-construction, and ensuring sustainability [71]. In the initial stage, an energy service need for a community is identified [71]. In the area of study, the community is in need of a more resilient power grid that can survive during extreme weather events. From the identification of the community need, an interdisciplinary team must be formed. For the area of study, this team should include representatives from the local utility, project contractors, the local government, and members of the local community.

In the next stage, denoted as stage one in the literature, trust must be built between all affected stakeholders, or entities and people that are directly affected by the construction of the projects [71]. For Denzel's community, this step will require enormous amounts of time and effort due to the community's negative interactions with other power structures in the area. Trust can be built by gathering information interviews, questionnaires, and direct observations of the local community [71]. Interviews with affected stakeholders is especially important in this stage to gather information on visions for the project. All visions are carefully considered and consolidated to create a unique shared vision that all stakeholders agree to [71]. In this stage, community members should be presented with an opportunity to learn about the proposed project and express concerns [71]. For the area of study, hosting a town hall is recommended as an avenue to initiate this conversation. From the information gathered at this stage, three criteria must be evaluated before continuing forward. First, identification of any opposition to the project. Second, the evaluation of any ecological impacts or impacts of cultural value to the community. Third, the disagreement in vision between stakeholders must be assessed and resolved [71]. By evaluating these three criteria, the usefulness to the community can be measured, and it can be determined if construction of the project should continue. Within this stage and the remainder of the project, all stakeholders and the interdisciplinary team must focus on the benefits the project will bring to the community [71].

In the co-construction stage, two forms of engagement are initiated. First, the local community is educated on the technical aspects of the project [69]. In the case of the area of study, this can be achieved through workshops lead by the local utility. Second, the local utility must develop context on the area and the social implications the project would impose [71]. The interview presented in this thesis is a start to that work. For this step of community engagement, additional interviews with local residents are recommended to gain context. By performing these interviews, the utility will gain perspective on challenges the community faces while also learning how to communicate effectively with the community. This action also builds further trust the community will feel towards the local utility. This stage must stress the importance of empowering the local community with the technical knowledge of the project and cooperation between the local utility and the community through building context on the affected area [71].

In the final stage, ensuring sustainability, potential impacts to the community are identified through informal interviews and questionnaires [71]. The information gathered from these questionnaires provide indicators are developed to monitor the evolution of the project and its use after construction [71]. At this stage, trust between the community and additional stakeholders should be built and communication channels should be officially formed. Through communication channels or questionnaires, the community will be able to present any concerns which will be evaluated and incorporated into the project. Figure 5.15 provides a graphical summary of the stages of community engagement described in this section.

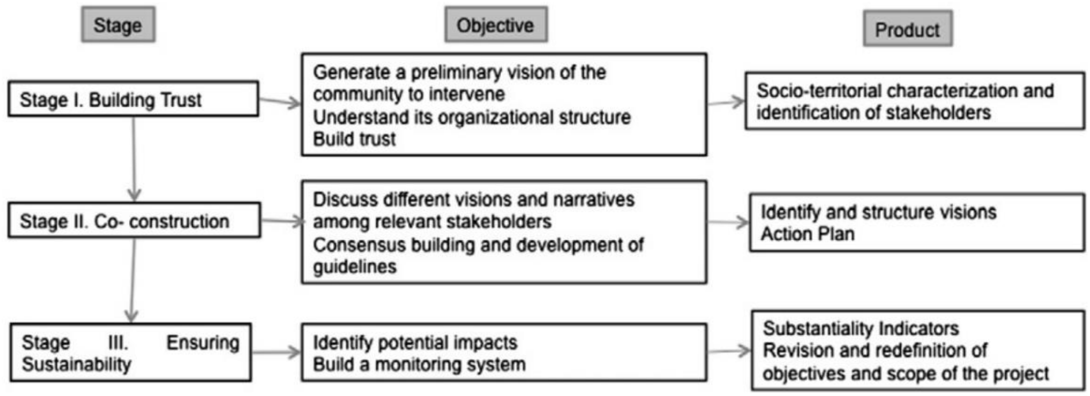

Figure 5.15: Stages of Community Engagement [71]

To apply the framework of community engagement in coastal North Carolina the following actions are recommended.

Stage 0: form team comprised of representatives from the local utility, project contractors, the local government, and members of the local community

Stage 1: Interviews with community members and stakeholders; town hall presenting project idea to community

Stage 2: Workshops educating public on technical aspects of the project; interviews of local members of the community to build social context

Stage 3: Questionaries for community; formation of official channels of communication between local utility and community

Through implementing this framework of community engagement, Denzel's community will feel empowered to engage in dialogue with the utility and will feel that they were a part of the decision-making process. Additionally, through the process of community engagement, more solutions to improve resiliency of the system may be discovered.

CHAPTER 6: CONCLUSIONS AND FUTURE WORK

6.1 Completed Work

In this thesis, the three-tenet framework of energy justice was applied to a resiliency study for the southeastern coastal region of North Carolina. A comprehensive literature review was conducted examining energy justice, resiliency, and the role microgrids play in improving both areas. The first tenet, distributional justice, was applied to the area of study using a data-driven approach. In this tenet, the power system was analyzed during extreme weather events to determine if any physical inequities existed. The following data was used for this purpose:

(a) social vulnerability index (SVI) collected from the CDC,

(b) historical outage data provided by the local utility,

(c) CYMEDIST models of the circuits in the given area provided by the local utility.

Initially, all data underwent a pre-processing stage. Through analyzing the outage data set and weather reports, the outage data was bucketed into 18 major weather events. SVI metrics were collected on a census tract granularity. The CYMEDIST models were compared to a map of census tracts in the area to assign a unique SVI value to several feeders in the county. Additionally, single customer outage was excluded along with data entries lacking coordinate information. After the pre-processing operations, the average outage duration for the entire system during particular events was compared to the average outage duration for each individual feeder. A t-distribution hypothesis test was applied to quantify the comparison. To ensure a fair comparison, only circuits that experienced a substation related outage were considered because circuits with substation outages are given priority in the restoration process. The t-test values calculated for each feeder were then compared against the SVI metric determined for each feeder. Graphs were created measuring the t-test value versus the SVI value for each feeder. For two storms, a relationship was found between the SVI and the t-test value. From the data collected, it can be concluded that more socially vulnerable communities experienced longer power outages on average during Hurricanes Irene and Matthew when compared to the rest of the system. In essence, there is a physical disparity and inequity present in the current topology of the power system.

The second tenet applied is called recognition justice. This tenet involves investigating the area for historical treatment of marginalized communities, instances of political domination, and specifies energy services needs for the given community. This tenet provides the needed context to provide explanations, from a socioeconomics perspective, for the possible disparity showcased above. For this portion of work, a community member was interviewed on his experience living in a disadvantaged neighborhood on the southeastern coast of North Carolina. This neighborhood receives electricity from a feeder with an SVI score of 0.76 and a t-test score for Hurricane Matthew of 27.02. The community members interviewed described a resilient community that continues to face neglect and exploitation by the local government. This community currently faces the threat of forceful eviction to “make way” for the Independence Blvd expansion project. Public transportation routes into the neighborhood have been systematically cut in a community that is highly reliant on public transportation. Additionally, the city council in this area are at-large positions. This means all residents vote for all positions in the city council. While this may seem fair at first glance, the majority wins in this structure of voting and the minority population of this neighborhood does not have any political power to change these obstacles they currently face. Additionally, the inequities in this community contain a racial component with historical roots. The area of study has a majority white population at 76.5% while Denzel's neighborhood has a majority black population of 53%. During any city council election, the white majority ends up winning their selected seats limiting the number of representatives the black community is able to elect for their community. There are historical roots to this inequity. In 1898, a murderous coup led by red shirts, percussor to the KKK, marched on Wilmington killing at least seven black residents and forcibly removing all black representatives from office at gunpoint. The stain of this historical event is still present in how the black community today is treated by local government. When asked about the community member's interaction with the local utility, a tone shift was noted. The restoration efforts described were deemed to be equal and summarized by saying "[the local utility] did a good job". However, despite the local utility doing its best, a disparity was still seen in earlier data analysis. This fact highlights the need for additional work to be done by the utility to ensure this community receives truly equal access to energy services. The interview conducted shines a light on the living conditions for socially disadvantaged communities in the area of study. It showcases that additional socioeconomic barriers and distrust of power structures could be affecting the electric service during storms. The current population in this neighborhood have a natural distrust of power structures due to their negative experiences interacting with the DOT, public transportation, and the local government. Therefore, when the power goes out, the community is less likely to call. In our current system, power restoration is highly dependent on customers calling to report outages. An entire community expressing reluctance in calling could be a possible explanation for the disparity discovered in the distributional justice tenet. This portion of work highlights the importance of equitable service the utility should provide. This community faces additional barriers that other communities do not face when it comes to receiving electric power service. Therefore, the utility must provide additional services to correct the disparities found namely in the form of community engagement.

The third and final tenet of energy justice is called procedural justice. This tenet combines the knowledge acquired during the distributional and recognition portions of analysis to determine solutions the local utility can implement to correct these disparities. The first suggestion is to conduct targeted undergrounding of socially vulnerable neighborhoods. Currently, the leading cause of power outages during major hurricanes is trees falling on overhead lines. By undergrounding these lines, the system can avoid this risk altogether. Additional data analysis was conducted to prove that more socially vulnerable communities currently have less of their system undergrounded. Information regarding overhead and underground conductor cables was collected from CYMEDIST. The %UG value was calculated for each individual feeder and compared to the t-test value and the SVI values of each feeder collected for previous analysis. For Hurricane Irene, a relationship was not found between t-test value and %UG. However, for Hurricane Matthew, a linear relationship was found with a R^2 value of 0.2377. Additionally, SVI values and %UG values were compared directly and a linear relationship, with an R^2 value of 0.2066, was found between the two along with a descending 5th order relationship, with an R^2 value of 0.5259. These results suggest that more socially vulnerable communities have less of their circuit undergrounded. This provides a possible explanation for the disparity recorded earlier. Essentially, undergrounding these additional circuits would improve the equity of the power system. The second suggestion is to construct a microgrid to serve Denzel's community. The proposed microgrid would be implemented in three stages and would serve 700 customers including the GS Davis Community Center which could serve as a community safe haven during extreme weather events. For this design, a solar plus storage generation method was selected. For this solution, land requirements and funding opportunities have also been investigated. The final recommendation is to implement greater community engagement with Denzel's community. First, this action will ensure that the community feels represented in the decision-making process and will build trust between the community and the local utility. Second, this action will serve as a medium to educate the community on the services the local utility provides and highlight the importance of calling to report outages. Third, the local utility can learn more about the specific needs of the community to create more solutions to correct the disparities highlighted through this investigation.

6.2 Future Work

The following actions could be taken to expand the work conducted in this thesis.

- Create a weighted average methodology instead of using a straight averaging methodology to calculate SVI metrics for each feeder
- Expand similar framework to other coastal areas in North Carolina
    - Compare and contrast the performance of co-operatives and municipalities against the local utility

  - Compare and contrast social barriers faced by those living in rural communities
- Expand the framework to analyze other areas of the United States that face extreme weather scenarios not captured in this analysis (i.e. winter storms, wildfires)
- Engage the local utility and the local community in implementing the solutions presented in this thesis
- Derive social inclusion metrics for the NCUC to utilize in creating goals for energy justice and providing incentive for utilities to enact the solutions presented in this thesis

REFERENCES

[1] "Code of Ethics", *National Society of Professional Engineers*, July 2019, https://www.nspe.org/resources/ethics/code-ethics#:~:text=Engineers%20shall%20be%20guided%20in,project%20will%20not%20be%20successful.

[2] L. Kanger, and B. Sovacool, "Towards a Multi-Scalar and Multi-Horizon Framework of Energy Injustice: A Whole Systems Analysis of Estonian Energy Transition", *Political Geography*, vol. 93, March 2022.

[3] R. Heffron, and D. McCauley, "The Concept of Energy Justice Across Disciplines", *Energy Policy*, vol. 105, pp. 658-667, June 2017.

[4] S. Baker, S. DeVar, and S. Prakash, "The Energy Justice Workbook", *Initiative for Energy Justice*, Dec 2019.

[5] K. Jenkins, D. McCauley, R. Heffron, H. Stephan, and R. Rehner, "Energy Justice: A Conceptual Framework", *Energy Research & Social Science*, vol. 11, pp. 174-182, Jan 2016.

[6] B. Tarekegne, R. O'Neil, and J. Twitchell, "Energy Storage as an Equity Asset", *Current Sustainable/Renewable Energy Report*, vol. 8, pp. 149-155, May 2021.

[7] B. Sovacool, M. Burke, L, Baker, C. Kumar Kotikalapudi, and H. Wlokas, "New Frontiers and Conceptual Frameworks for Energy Justice", *Energy Policy*, vol. 105, pp. 677-691, June 2017.

[8] B. Sovacool, and M. Dworkin, "Energy Justice: Conceptual Insights and Practical Applications", *Applied Energy*, vol. 142, pp. 435-444, March 2015.

[9] S. Fuller, and D. McCauley, "Framing Energy Justice: Perspectives from Activism and Advocacy", *Energy Research & Social Science*, vol. 11, pp. 1-8, Jan 2016.

[10] M. Bergman, "'They chose us because we were rural and poor': when environmental racism and climate change collide", *The Guardian*, March 8 2019, https://www.theguardian.com/environment/2019/mar/08/climate-changed-racism-environment-south.

[11] S. Mufson, "Keystone pipeline's path cuts across Native American land, history", *The Washington Post*, July 14 2012, https://www.washingtonpost.com/blogs/keystone-down-the-line/wp/2012/09/17/pipelines-path-cuts-across-indian-country-and-history/

[12] "IEEE Guide for Electric Power Distribution Reliability Indices," in IEEE Std 1366-2012 (Revision of IEEE Std 1366-2003) , vol., no., pp.1-43, 31 May 2012, doi: 10.1109/IEEESTD.2012.6209381.

[13] F. Jufri, V. Widiputra, and J. Jung, "State-of-the-art review on power grid resilience to extreme weather events: Definitions, frameworks, quantitative assessment methodologies, and enhancement strategies", Applied Energy, vol. 293, pp. 1049-1065, April 1, 2019.

[14] "Electric Power System Resiliency: Challenges and Opportunities", Electric Power Research Institute, Feb 2016.

[15] C. Chen, J. Wang, and D. Ton, "Modernizing Distribution System Restoration to Achieve Grid Resiliency Against Extreme Weather Events: An Integrated Solution", in Proceedings of the IEEE, vol. 105, no. 7, pp. 1267-1288, July 2017, doi: 10.1109/JPROC.2017.2684780.

[16] "Economic Benefits of Increasing Electric Grid Resilience to Weather Outages", The Executive Office of the President, Aug 2013.

[17] B. Preston et al, "Resilience of the U.S. Electricity System: A Multi-Hazard Perspective", U.S. Department of Energy, Aug 18, 2016.

[18] Y. Wang, C. Chen, J. Wang and R. Baldick, "Research on Resilience of Power Systems Under Natural Disasters—A Review," in IEEE Transactions on Power Systems, vol. 31, no. 2, pp. 1604-1613, March 2016, doi: 10.1109/TPWRS.2015.2429656.

[19] "Electric Power System Resiliency: Challenges and Opportunities", Electric Power Research Institute, White paper, Feb 25, 2014.

[20] Committee on Enhancing the Resilience of the Nation's Electric Power Transmission and Distribution System, Board on Energy and Environmental Systems, and Division on Engineering and Physical Sciences, "Enhancing the Resilience of the Nation's Electricity System", Washington, DC: The National Academies Press, 2017.

[21] M. Ulak, A. Yazici, and E. Ozguven, "A prescriptive model to assess the socio-demographics impacts of resilience improvements on power networks", International Journal of Disaster Risk Reduction, vol. 55, Dec 2020.

[22] A. Nejat, L. Solitare, E. Pettitt, and H. Mohsenian-Rad, "Equitable Community Resilience: The Case of Winter Storm Uri in Texas", Cornell University, Jan 2022.

[23] P. Temino, “Understanding the Difference Between Distributed and Centralized Generation,” *EE Power*, technical article, Jan 2021.
[24] H. Farhangi, "The path of the smart grid," in *IEEE Power and Energy Magazine*, vol. 8, no. 1, pp. 18-28, January-February 2010, doi: 10.1109/MPE.2009.934876.

[25] X. Zhou, T. Guo and Y. Ma, "An overview on microgrid technology," *2015 IEEE International Conference on Mechatronics and Automation (ICMA)*, 2015, pp. 76-81, doi: 10.1109/ICMA.2015.7237460.

[26] M.S. Mahmoud, S. Hussain, and M.A. Abido, “Modeling and control of microgrid: An overview”, *Journal of the Franklin Institute*, vol. 351, issue 5, pp. 2822-2859, May 2014.

[27] C. Marnay *et al*., "Microgrid Evolution Roadmap," *2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST)*, 2015, pp. 139-144, doi: 10.1109/SEDST.2015.7315197.

[28] C. Alvial-Palavicino, N. Garrido-Echeverria, G. Estevez, L. Reyes, and R. Palma-Behnke, “A methodology for community engagement in the introduction of renewable based smart micrgrid”, *Energy for Sustainable Development*, vol. 15, issue 3, pp. 314-323, Sept 2011.

[29] “CDC SVI 2018 Documentation”, Agency for Toxic Substances and Disease Registry, Jan, 1, 2020. https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/SVI_documentation_2018.html

[30] D. Reynolds and J. Melrose, “How often do hurricanes make landfall in North Carolina on average?”, *Fox 8 News*, Sept 2021, https://myfox8.com/weather-stories/how-often-do-hurricanes-make-landfall-in-north-carolina-on-average/.

[31] “Hurricane Database”, *North Carolina State Climate Office*, https://products.climate.ncsu.edu/weather/hurricanes/statistics/.

[32] C. Mulcahy, “This is when the Carolinas historically see the worst hurricanes”, *WCNC News*, Sept 2020, https://www.wcnc.com/article/weather/historic-carolina-hurricanes-stats-history-list-dates/275-71c546b7-3ef9-45c2-84e9-e33b8559a90f.

[33] T. Armstrong, “Hurricane Matthew in the Carolinas: October 8, 2016”, *National Weather Service*, Sept 2017, https://www.weather.gov/ilm/Matthew.

[34] P. Jung, “Energy Resiliency: Duke Energy Outage Data – Data Processing & Coordinate Issues”, *University of North Carolina at Charlotte Planning an Affordable and Resilient Grid (PARSG) Project,* [internal document], April 2020.

[35] "Project History", *North Carolina Department of Transportation*, Nov 25, 2020, https://www.ncdot.gov/projects/independence-boulevard/Pages/project-history.aspx.

[36] "Eminent Domain", *Legal Information Institute: Cornell Law School*, 2022, https://www.law.cornell.edu/wex/eminent_domain.\

[37] "Budget cuts could cost several bus routes", *WECT 6 NEWS*, Oct 12, 2013, https://www.wect.com/story/23381949/budget-cuts-could-cut-bus-routes/.

[38] K. Kenoyer, "Wave Transit set to replace some routes with RideMicro, double the frequency of others", *WHQR Public Radio*, Feb 10, 2022, https://www.whqr.org/local/2022-02-10/wave-transit-set-to-replace-some-routes-with-ridemicro-double-the-frequency-of-others.

[39] "Policy Map", *United States Department of Housing and Urban Development*, [database], 2022, https://www.policymap.com/newmaps#/.

[40] "Code of Ordinances of the City of Wilmington, North Carolina", *Municode.com*, part 1, subpart A, article VI, Dec 30, 2021, https://library.municode.com/nc/wilmington/codes/code_of_ordinances?nodeId=PTICHRELA_SPATHCH_ARTIVEL.

[41] "2021 Wilmington Election: Mayor & City Council", *Disability Rights North Carolina*, Oct 3, 2021, https://disabilityrightsnc.org/archive/2021-wilmington-election-mayor-city-council.

[42] B. Schachtman, "Wilmington could radically change its city council, here's how 5,000 residents could start the process", *Port City Daily*, July 28, 2019, https://portcitydaily.com/local-news/2019/07/28/wilmington-could-radically-change-its-city-council-heres-how-5000-residents-could-start-the-process/.

[43] D. Zucchino, "Wilmington's Lies", *Atlantic Monthly Press*, Jan 2020.

[44] S. Willard Bell, "Enigmatic Anger: Populism, Status Anxiety, and the Wilmington Race Riot of 1898", *University of North Carolina at Charlotte*, 1999.

[45] "Facts About Undergrounding Electric Lines", *PG&E Currents*, Oct 31, 2017, https://www.pgecurrents.com/2017/10/31/facts-about-undergrounding-electric-lines/.

[46] "Solar-Plus-Storage 101", *Department of Energy Solar Energy Technology Office*, March 11, 2019, https://www.energy.gov/eere/solar/articles/solar-plus-storage-101.

[47] "FreeMaq DC/DC: Bi-Directional DC/DC Converter", *Power Electronics,* [brochure], https://power-electronics.com/en/.

[48] J. Wyatt and M. Kristian, "The True Land Footprint of Solar Energy", *Great Plains Institute,* Sept 14, 2021, https://betterenergy.org/blog/the-true-land-footprint-of-solar-energy/#:~:text=Estimating%20the%20land%20footprint%20of,for%20maintenance%20and%20site%20access.

[49] "NREL Marks Ongoing Cost Reductions for Installed Photovoltaic Systems, While Also Establishing Benchmark of PV-Plus-Storage Systems", National Renewable Energy Labs, Feb. 10 2021, https://www.nrel.gov/news/program/2021/documenting-a-decade-of-cost-declines-for-pv-systems.html.

[50] W. Cole, A. Will Frazier, and C. Augustine, "Cost Projections for Utility-Scale Battery Storage: 2021 Update", *National Renewable Energy Labs*, June 2021, https://www.nrel.gov/docs/fy21osti/79236.pdf.

[51] "What Does it Cost to Clear Land in NC?", EricAndrewsRelator.com, March, 19 2019, https://www.ericandrewsrealtor.com/cost-to-clear-land/#:~:text=Clearing%20wooded%20land%20in%20North,costs%20%243%2C000%20%E2%80%93%20%245%2C000%20per%20acre.

[52] B. Blair and P. De Martini, "Community Microgrid Ownership Models", *Pacific Energy Institute,* Dec 2020, https://pacificenergyinstitute.org/wp-content/uploads/2020/12/Community-Microgrid-Ownership-Models-Paper-final.pdf.

[53] "Community Ownership Models: Innovation Landscape Brief", *International Renewable Energy Agency*, 2020, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Community_ownership_2020.

[54] M. Warnery, M. Håkanssona, and K. Karltorpad, "Unpacking the complexity of community microgrids: A review of institutions' roles for development of microgrids", *Renewable and Sustainable Energy Reviews,* vol. 121, April 2020, https://doi.org/10.1016/j.rser.2019.109690.

[55] "Understanding the Energy-as-a-Service Model for Microgrids", *Microgrid Knowledge*, Feb 18, 2019, https://microgridknowledge.com/energy-as-a-service-model-microgrids/#:~:text=An%20energy%2Das%2Da%2D,may%20no%20longer%20meet%20code..

[56] C. Metelitsa, "New Business Models Gain Strength With Renewed Interest in Microgrids", Jan 18, 2018, https://www.greentechmedia.com/articles/read/new-business-models-gain-strength-with-renewed-interest-in-microgrids.

[57] "Hazard Mitigation Assistance Grant Funding for Microgrid Projects", FEMA, June 25, 2021, https://www.fema.gov/grants/mitigation.

[58] "Building Resilient Infrastructure and Communities", FEMA, April 25, 2022, https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities.

[59] E. Howland, "FEMA Seeks Microgrids as Biden Channels $3.5 Billion to Agency for Disaster Relief", *Microgrid Knowledge,* Aug 6, 2021, https://microgridknowledge.com/fema-disaster-recovery-microgrids/#:~:text=According%20to%20the%20agency%2C%20FEMA,Bronzeville%20microgrid%20project%20in%20Illinois.

[60] K. Mahani, and F. Farzan, "Unwiring the Country", *IEEE Power & Energy Magazine*, vol. 20, no. 2, pp. 14-22, March/April 2022.

[61] B. Reid, J. Bourg, and D. Schmidt, "Let's Make a Deal", *IEEE Power & Energy Magazine*, vol. 20, no. 2, pp. 23-31, March/April 2022.

[62] A. Henderson, "Chicago microgrid project attempts to balance corporate, community needs", *Energy News Network*, Feb 17, 2021, https://energynews.us/2021/02/17/chicago-microgrid-project-attempts-to-balance-corporate-community-needs/.

[63] L. Cohn, "Here comes the future: Bronzeville 'microgrid cluster' set to begin operating this year", *Microgrid Knowledge*, Jan 24, 2022, https://microgridknowledge.com/bronzeville-microgrid-cluster-lessons-comed/.

[64] "ComEd Helps Historic Bronzeville Neighborhood Build Brighter Future", *ComEd*, July 29, 2021, https://poweringlives.comed.com/comed-helps-historic-bronzeville-neighborhood-build-brighter-future/.

[65] E. Wood, "Commonwealth Edison Makes the Case for its Bronzeville Microgrid Cluster", *Microgrid Knowledge*, Aug 3, 2017, https://microgridknowledge.com/bronzeville-microgrid-cluster/.

[66] P. Maloney, "Duke Energy and the No Controversy Microgrid: Hot Springs", *Microgrid Knowledge*, May 27, 2019, https://microgridknowledge.com/hot-springs-microgrid-approved/.

[67] "North Carolina County Map", *GIS Geography*, April 13, 2022, https://gisgeography.com/north-carolina-county-map/.

[68] "North Carolina regulators approve Duke Energy's innovative microgrid project in Madison County", *Duke Energy News*, May 21, 2019, https://news.duke-energy.com/releases/north-carolina-regulators-approve-duke-energys-innovative-microgrid-project-in-madison-county.

[69] State of North Carolina Utilities Commission Raleigh, "DOCKET NO. E-2, SUB 1185", updated: Oct 2018, https://starw1.ncuc.gov/NCUC/ViewFile.aspx?Id=751a240b-9a68-4970-89cc-b9c85f289607.

[70] L. Somers, "Duke Energy Progress, LLC Western Carolinas Modernization Project Final Progress Report and Annual Community Engagement Report Docket No. E-2, Sub 1089", *report to North Carolina Utilities Commission*, March 29, 2021, https://starw1.ncuc.gov/NCUC/ViewFile.aspx?Id=85486fb3-99a9-47f7-8a50-2db4dffb560a.

[71] C. Palavicino, N. Garrido-Echeverría, G. Jiménez -Estévez, L. Reyes, and R. Palma-Behnke, "A methodology for community engagement in the introduction of renewable based smart microgrid", *Energy for Sustainable Development*, vol. 15, issue 3, pp. 314-323, Sept 2011, https://doi.org/10.1016/j.esd.2011.06.007.

[72] G. Jiménez-Estévez, A. Navarro-Espinosa, R. Palma-Behnke, L. Lanuzza and N. Velázquez, "Achieving Resilience at Distribution Level: Learning from Isolated Community Microgrids," in *IEEE Power and Energy Magazine*, vol. 15, no. 3, pp. 64-73, May-June 2017, doi: 10.1109/MPE.2017.2662328.

[73] G. A. Carrión, R. A. Cintrón, M. A. Rodríguez, W. E. Sanabria, R. Reyes and E. O'Neill-Carrillo, "Community Microgrids to Increase Local Resiliency," *2018 IEEE International Symposium on Technology and Society (ISTAS), 2018*, pp. 1-7, doi: 10.1109/ISTAS.2018.8638269.

[74] B. Head, "Community Engagement: Participation on Whose Terms?", *Australian Journal of Political Science*, vol. 42, issue 3, pp. 441-454, doi: 10.1080/10361140701513570.

Vita

Emily A. Abbate was born in Concord, NC on May 25, 1998. She graduated from Northwest Cabarrus High School in June 2016 with Summa Cum Laude honors. In May 2021, she received a Bachelor's of Science in Electrical Engineering with a concentration in Power and Energy Systems with Summa Cum Laude honors. On August 2022, she will receive a Master's of Science in Electrical Engineering with a concentration in Power Systems with Summa Cum Laude honors.

Emily worked for Duke Energy Renewable in the Renewable Control Center as a part of their co-op student program throughout her undergraduate years. She also has experience working for Power Engineers as a summer intern in their Power Delivery Services Group. Additionally, she has worked as a Research Assistant with the PARSG and SETO projects which partnered with the Department of Energy and Duke Energy. Upon completion of her master's, Emily will be joining Schweitzer Engineering Labs as an Associate Engineer working in the Engineering Services department. She currently has an Engineering Intern license with the state of North Carolina and hopes to receive her Professional Engineering license within a few years.

She has received various awards and recognitions including an academic scholarship through the Duke Energy Distinguish EPIC Scholars program, 8-time Chancellor's List student, the Benjamin A. Hood Service Award, and the Outstanding Student Leadership Award. Her most prized recognition was being selected to speak at her undergraduate commencement ceremony where she discovered her love of public speaking.

A humanitarian at heart, Emily hopes her master's thesis titled "Applying Energy Justice Framework to Resiliency Studies in Power Systems" will inspire change within the power industry.