Determining Expected Number Of Customers Affected By Public Safety Power Shutoffs In The Next Decade

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Abstract

Recent weather concerns of wildfires have become a problem that utility companies have to solve so that another large scale fire such as the San Diego Witch Creek Fire does not happen again. In lieu of these concerns, utility companies such as SDGE have implemented the usage of PSPS (Public safety power shutoffs) but customers of SDGE have had concerns regarding the uncertain nature of these shutoffs. Prior research indicates that measures are being taken to minimize the uncertainty of these power shut offs with techniques such as sectionalizing devices, community microgrids, and individual backup/temporary generators. However, these results don't delve into the estimating the annual number of customers affected by these PSPS events. In this paper, we present an approach to estimate the total number of customers affected by Public Safety Power Shutoff (PSPS) events over the next ten years. We calculate the expected customer impact by combining PSPS probabilities at the span level with customer count data, including both direct and downstream connections. This analysis is performed at three granularities: individual spans, segments, and circuits. By incorporating both the frequency of shutoffs and the number of affected customers, we provide a comprehensive assessment of PSPS impact that can help utilities prioritize grid hardening efforts and improve resilience planning. Our methodology enables a scalable, data-driven approach to quantifying customer impact across diverse power distribution networks.

Code: https://github.com/Bharath-Sathappan/OptimizingPSPS

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1 Introduction

In recent years, California has faced a surge of devastating wildfires, largely influenced by the overlap between urban development and wildfire-prone environments. To mitigate these risks, several utility companies, including San Diego Gas & Electric (SDG&E), have implemented Public Safety Power Shutoffs (PSPS) to reduce the likelihood of electrical infrastructure starting fires during high-risk weather conditions. While PSPS is effective in reducing wildfire incidents, these shutoffs have a significant impact ranging from economic downturns to health risks for people living on life-support machines. This study explores a data-driven approach estimating the expected number of customers that will be shut off over the next decade at span, segment, and circuit granularity.

In the Article, A Review of Public Safety Power Shutoffs (PSPS) for Wildfire Mitigation: Policies, Practices, Models and Data Sources, we can see that one of the most effective ways to prevent wildfires is to turn off power which are also known as public safety power shutoffs. This procedure increasingly gained significance as fire severity increased in recent years. The drawback to PSPS is that vulnerable communities will be at risk when these PSPS events occur. The PSPS problem is essentially one balancing the risk of wildfires and the risk of these vulnerable communities. A few recommendations the paper recommended to consider were "energy innovation, energy equity, and PSPS uncertainties". Our study will also include many of these conditions and approaches from this paper, and will be more specific to SDGE's data. We will also look to mitigate wildfire risk further and focus on the impacts on communities these actions may have.

The datasets that we are using contain information about weather stations, wind speed data, geospatial data about these stations, VRI (vegetation risk index) data, and conductor span data. The weather station dataset provides geospatial data per weather station providing us the appropriate information to visualize these stations on a map. These visualizations will be useful for risk assessment as well as displaying PSPS probability. Furthermore, we also have data regarding recorded wind speeds and alert speeds by weather stations contributing further towards risk assessment. Risk assessment is the premise of this paper as we are finding the impact PSPS events have on local communities. In addition, we are also given vegetation risk index data based on weather stations which further assess the risk of a wildfire given a location. Lastly, we were given conductor data which will also allow us to visualize conductors as well as track downstream effects of spans within each feeder.

2 Methodology

Our study involved a comprehensive approach to estimate the expected amount of customers that'll be shut-off over the next 10 years at the span,segment, and circuit granularity. Our methodology comprised of several key steps. We began by conducting an Exploratory Data Analysis (EDA) of weather station data, wind data collected by these stations through multiple years, and alert speed data per weather station. We cleaned and merged these datasets to create a preliminary database used for our subsequent analysis.

Using the merged dataset we calculated the Public Safety Power Shutoff (PSPS) probability for each weather station by counting the number of days where the wind speed recorded was higher than the alert threshold and then aggregating by weather station and dividing by total records per station to obtain PSPS probabilities per weather station. We then merged our merged dataset comprising of weather station data, wind data, and alert data with our vegetation risk index (VRI) dataset, merging on weather station codes. Following that we then conducted a geospatial join with our conductor span dataset by converting both datasets into a geopandas dataset, ensuring both datasets' coordinate reference system (CRS) were the same resulting in our final merged data frame. We set predicate to intersects to ensure that all conductor spans within the vri boundary of a weather station would be correctly merged. A crucial step in our methodology was the creation of a graph network object representing the spans of the electrical grid, This network enabled us to trace upstream connections within the grid, allowing us to identify potential stations that could trigger a shutoff for any given span. Utilizing the network analysis results, we computed the PSPS probability for every conductor span in the grid by utilizing span tracing to identify upstream spans and then compiling a set of associated weather stations based off of these upstream spans. Once we had our associated weather stations, we calculated the probability of a PSPS shutoff utilizing union probability derived by

$$P(\text{at least one}) = 1 - P(\text{none}) = 1 - \prod_{i=1}^{n}(1 - P_i)$$

We used the union probability because it was the best choice to determine the probability that a span will experience a shutdown based on any of its associated stations. To estimate the expected customers that will be shutoff over the next 10 years at the span/segment/circuit granularity we took an expected value approach where we calculated the average annual high fire days per station and multiplied it by the PSPS probability and a factor of ten resulting in the the expected rate of shutoffs for the next ten years.

$$R_s = A_s \times P_s \times 10$$

Where:

- R_s is the expected rate of shutoffs for station s
- A_s is the average count of annual high fire days for station s
- P_s is the PSPS probability for station s

The total number of shutoffs for the following ten years per span was calculated by summing the annual rates for each associated station.

$$S_i = \sum_{s \in S_i} R_s$$

Where:

- S_i is the total number of shutoffs for span i
- S_i is the set of stations associated with span i

To answer our question of estimating the number of customers affected for the next 10 years per span we had to add the total amount of customers as well as the total amount of downstream customers, resulting in the total amount of customers affected per shutoff.

$$C_i = T_i + D_i$$

Where:

- C_i is the total customers affected per shutoff for span i
- T_i is the total customers directly connected to span i
- D_i is the total downstream customers of span i

To obtain the expected number of customers affected by PSPS shut offs in the next 10 years per span, we multiplied the total affected customers by the total number of expected shutoffs.

$$E_i = C_i \times S_i$$

Where:

- E_i is the expected number of customers affected for span i

Since we already had our estimate at the span level we simply had to group by feederid and upstreamardfacilityid and sum the total number of shutoffs over the next ten yeasts to obtain our respective results at the circuit and segment granularity.

$$E_g = \sum_{i \in G} E_i$$

Where:

- E_g is the expected number of customers affected for granularity g (circuit or segment)
- G is the set of spans belonging to the specific circuit or segment

3 Results

3.1 PSPS Probability Distribution

The distribution of PSPS shutdown probabilities across weather stations shows significant variation in risk levels. Figure 1 displays a right-skewed distribution, indicating that while most weather stations have relatively low probabilities of PSPS shutdowns, there are some stations with notably higher risk levels. The probabilities range from 0 to 0.843575, with most stations concentrated in the lower range (0-0.2). The mean probability is indicated by the red dashed line in the histogram, showing the central tendency of PSPS shutdown risk across the network. This distribution helps identify high-risk areas that may require additional attention for risk mitigation strategies.

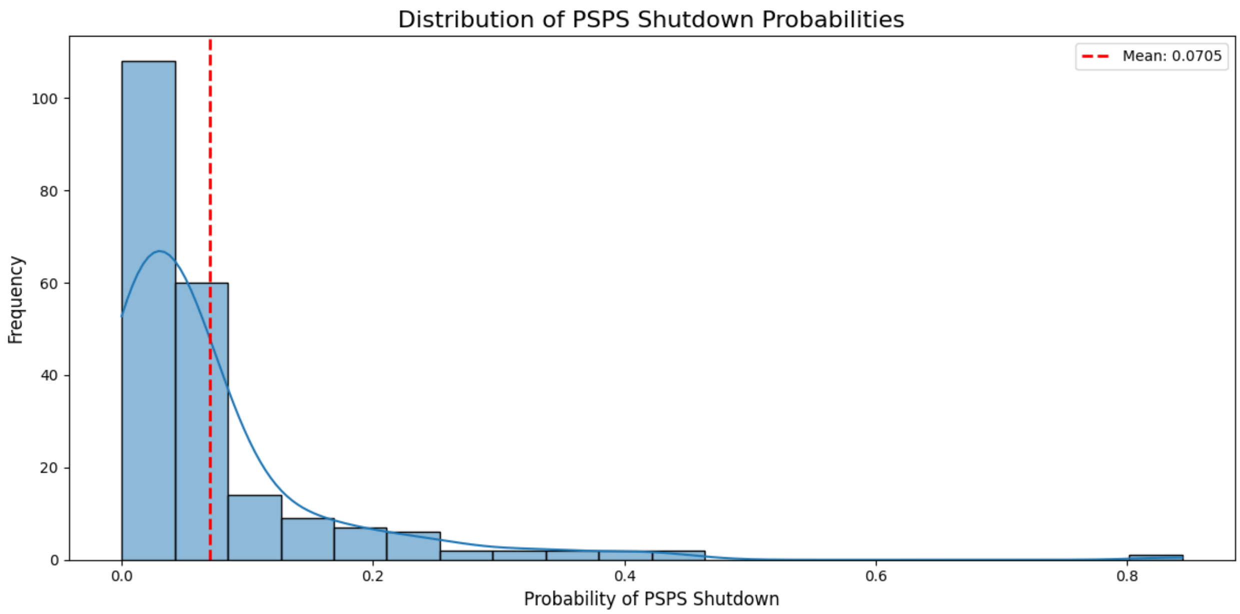

Figure 1: Distribution of PSPS Shutdown Probabilities across Weather Stations

3.2 Annual Shutoff Rates

The three graphs in Figure 2 reveal key patterns in the PSPS (Public Safety Power Shutoff) system's operation. The leftmost histogram shows a highly right-skewed distribution of annual shutoff rates, with most locations experiencing relatively few shutoffs and a long tail extending toward higher frequencies. The middle graph demonstrates a stepped pattern in the number of associated stations, indicating that most grid segments are connected to 1-2 stations, with decreasing frequency as the number of stations increases. The rightmost graph illustrates a relationship between shutoffs and customer impact, suggesting an inverse correlation where higher shutoff frequencies tend to affect fewer customers. The circuit and segment level analysis in Figure 5 further reinforces these findings through two detailed histograms. Both distributions exhibit strong right-skewed patterns, with the circuit level showing approximately 250 occurrences at low customer impact levels, while the segment level displays about 400 occurrences. This consistent pattern across both hierarchical levels suggests that the grid's design effectively contains most disruptions to smaller service areas, minimizing widespread customer impact during PSPS events.

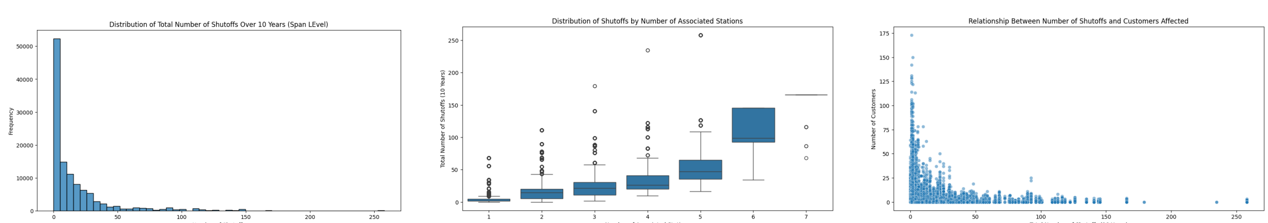

Figure 2: Overall caption for all three images

3.3 Spatial Distribution of PSPS Risk

The spatial distribution of PSPS risk across the service territory reveals distinct geographical patterns in shutdown probabilities. Figure 4 displays the VRI (Vegetation Risk Index) shapes colored by their associated PSPS shutdown probabilities. The map shows significant spatial variation in PSPS risk, with probabilities ranging from 0 to approximately 0.84. Areas in green indicate lower PSPS probabilities, while yellow and red areas represent regions with higher shutdown risks. The spatial pattern reveals that higher-risk areas tend to be concentrated in the eastern regions and mountainous terrain, particularly in Tier 2 and Tier 3 High Fire Threat Districts (HFTD). This visualization helps identify geographical clusters of high-risk areas that may require prioritized attention for risk mitigation efforts.

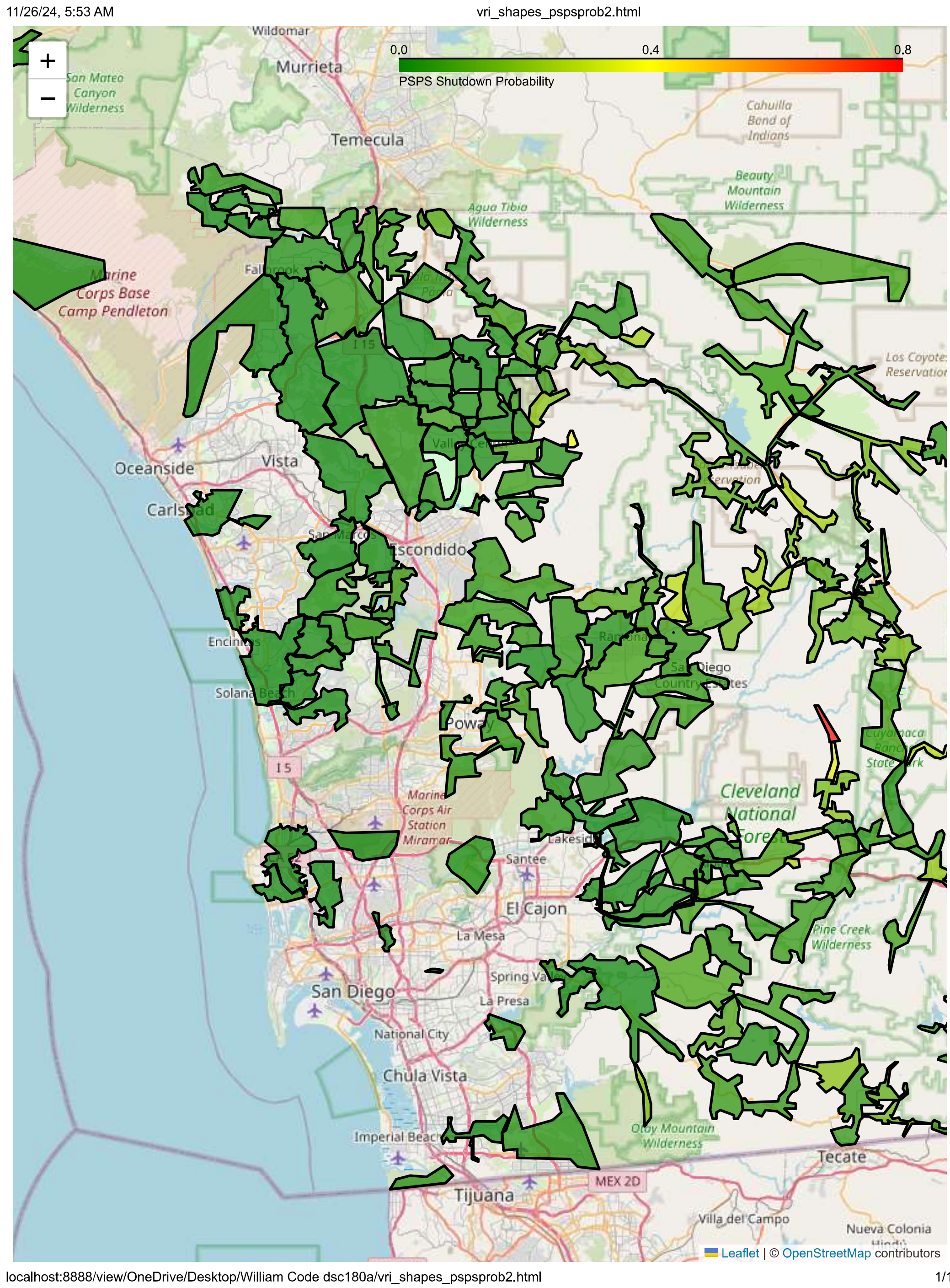

Figure 3: Spatial Distribution of PSPS Shutdown Probabilities across VRI Shapes

3.4 Customer Impact Span Level

The data shows a highly right-skewed (positively skewed) distribution, with the majority of incidents affecting a relatively small number of customers. The highest frequency bar appears near zero, indicating that most events impact fewer than 20,000 customers. The peak frequency is approximately 100,000 occurrences at the lowest customer impact range

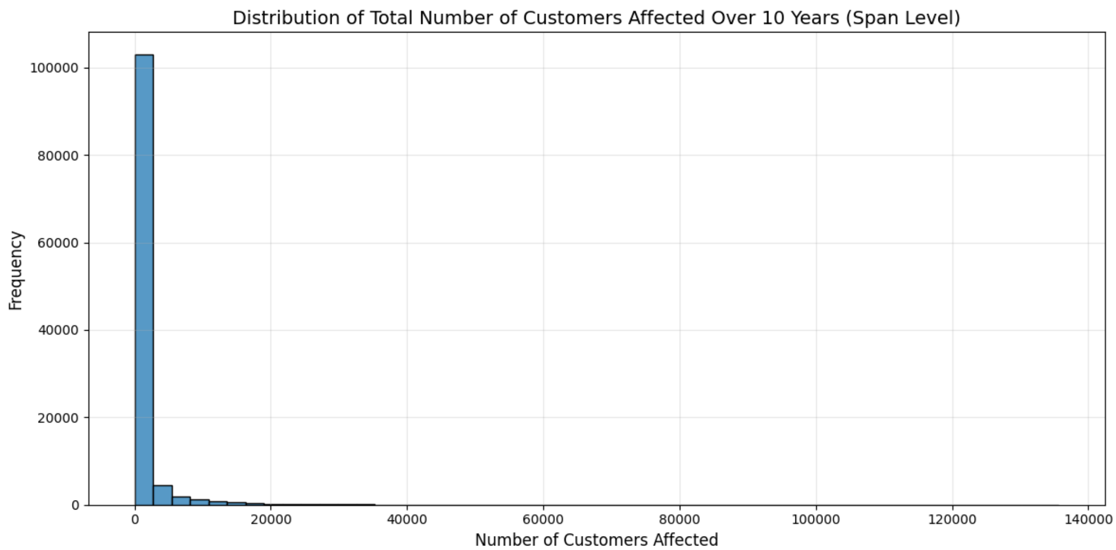

Figure 4: Spatial Distribution of PSPS Shutdown Probabilities across VRI Shapes

3.5 Circuit and Segment Level Analysis

The two histograms reveal important patterns in customer impact at both circuit and segment levels over a 10-year period. Both distributions exhibit strong right-skewed characteristics, with the majority of events concentrated at the lower end of the customer impact scale. At the circuit level, the frequency peaks at around 250 occurrences for minimal customer impacts, with a long tail extending to higher impact events. Similarly, the segment level analysis shows an even more pronounced skew, with approximately 400 occurrences at the lowest impact level. This parallel pattern between circuit and segment levels suggests that the grid's hierarchical structure effectively contains most disruptions to smaller service areas, while large-scale outages affecting many customers remain relatively rare events. The consistency between both levels of analysis indicates that the current grid segmentation strategy helps limit the spread of power shutoffs across the network.

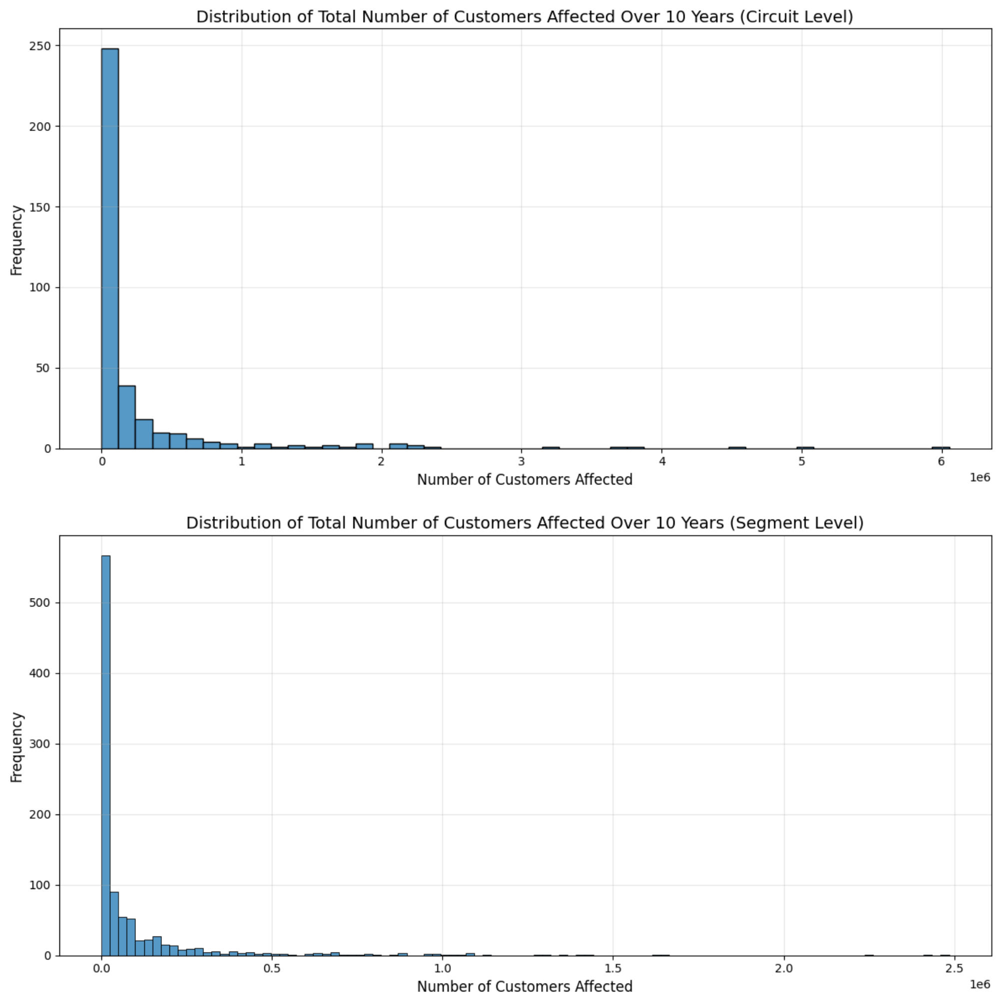

Figure 5: Segment and Circuit Customer Affected over 10 Years Distribution

4 Discussion

4.1 Comparison With Prior Work

There has been some work related to the impact of PSPS events so far. In the paper on, Economic Consequences of Wildfire Adaptation: Public Safety Power Shutoffs in California, the authors attempt to describe the economic impacts these shut offs have on local economies, and its effect on vulnerable populations. Our study differs from these prior papers because it observes the impact of turning off power to spans, segments, and/or circuits specific to SDGE.

4.2 Implication of Results

Our analysis reveals patterns that have significant implications for grid management and PSPS implementation. The strong correlation between the number of associated stations and shutoff frequency suggests that complex grid interconnections may increase vulnerability to PSPS events. The inverse relationship between customer shutoff frequency and customer impact indicates that the current rid effectively isolates high frequency shutoffs to smaller service area. This finding suggests that existing switch allocations and segmentation strategies are partially successful in minimizing widespread customer impact, though there is more room for optimization.

4.3 Limitations

There are several constraints that may affect the comprehensiveness of this analysis. Our study relies solely on historical wind data to project future PSPS events and its effects and do not take into account other factors such as conductor condition, vegetation data, and other climate factors. The methodology also assumes static customer distribution and grid structure over the ten year projection period. Additionally, the analysis doesn't cover the full effects of power shutoffs on critical infrastructure or consider socioeconomic impact of prolonged outages. The model also excludes current hardening factors as well as future hardening initiatives.

4.4 Future Work

Several promising directions that could build upon our research include switch optimizations to lower annual PSPS expected shutoffs as well as integrating vegetation data, hardening data, climate/seasonal patterns. In addition investigations of micro grid implementation opportunities in high risk areas and assessment of emerging technologies that could provide more granular control over grid segments.