ILLNESS, An Alternative Way To Assess Wildfire Risk

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Abstract

Wildfires pose a significant environmental threat in Southern California, particularly in regions serviced by San Diego Gas & Electric (SDG&E). Currently, SDG&E uses Public Safety Power Shutoffs (PSPS) primarily based on wind-speed thresholds to mitigate wildfire risks. However, this approach may lead to unnecessary power outages, adversely impacting communities. In response, we propose the **ILLNESS Score**—*Insight on Life, Living, Nature, Energy, Service, and Season*—a comprehensive metric incorporating diverse environmental and social factors, including temperature, humidity, vegetation conditions, energy vulnerabilities, and community impacts. By balancing these risk factors (weather conditions, vegetation, and electrical infrastructure) against societal costs (impact on critical services and residents), our approach provides a nuanced and justified framework for PSPS decisions. The ILLNESS Score thus enables more precise, transparent, and community-conscious wildfire risk management, effectively minimizing unnecessary disruptions while maintaining public safety.

1 Introduction

1.1 Background on Public Safety Power Shutoffs

Public Safety Power Shutoffs (PSPS) are preventive measures employed by utilities, such as San Diego Gas & Electric (SDG&E), designed to mitigate wildfire risks. During extreme weather conditions—characterized by high winds, dryness, and increased fire danger—utilities proactively shut off electricity to high-risk areas to prevent power lines from igniting wildfires. While effective in reducing wildfire occurrences, PSPS events often result in considerable inconvenience and safety concerns for local communities due to extended periods without power.

1.2 Broad Problem Statement

SDG&E currently triggers PSPS primarily based on windspeed thresholds, an approach that is often too simplistic, resulting in unnecessary disruptions and significant inconvenience for communities. Wildfire risks, however, are multidimensional, involving complex interactions between weather conditions, vegetation characteristics, energy / infrastructure vulnerabilities, and community life impact. To address these limitations, we introduce the **ILLNESS Score**—*Insight on Life, Living, Nature, Energy, Service, and Season*—a comprehensive, data-driven metric designed to balance safety needs against community impacts, minimizing unnecessary power outages and enhancing public confidence in wildfire safety measures.

1.3 Specific Problem Statement

We propose the ILLNESS Score, calculated from factors across various dimensions—including weather, vegetation, energy / infrastructure, and community life impact—to provide a comprehensive and interpretable risk metric. This facilitates more informed and nuanced PSPS decisions, aiming to optimize wildfire prevention while minimizing negative impacts on affected communities.

1.4 Literature Review

1.4.1 Electricity Distribution in Southern California

Southern California is served by a complex electricity distribution network managed by investor-owned utilities like SDG&E. Covering a service area of approximately 4,100 square miles and supplying electricity to 3.7 million people, SDG&E operates extensive infrastructure that includes both high-voltage transmission lines and local distribution systems (Electricity Forum (2024)). The distribution network must adapt to various challenges, including the risk of conductor breaks and faults due to external factors like vehicle collisions, weather events, and vegetation interference. In recent years, climate change has intensified these risks, leading to higher frequencies of wildfires and more unpredictable weather patterns, including the notorious Santa Ana winds, which exacerbate fire dangers.

Figure 1: The Bond Fire, driven by high winds, burns near Silverado Canyon in 2020

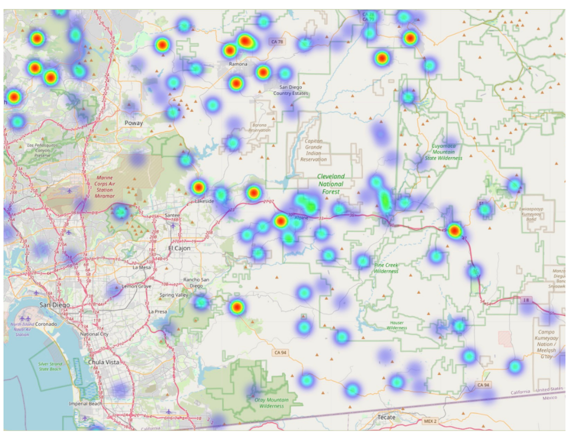
To safeguard public safety and infrastructure, SDG&E has incorporated advanced technologies such as phasor measurement units (PMUs) that capture high-resolution data on phase angles, voltages, and currents across the grid (Schweitzer Engineering Laboratories (2024)). This real-time data, synchronized across multiple points, allows for rapid detection and response to anomalies like conductor breaks, reducing the time it takes to cut power in case of a fault. SDG&E's Falling Conductor Protection (FCP) solution, developed in collaboration with Schweitzer Engineering Laboratories (SEL), is one example of such innovation. The FCP system uses PMUs to detect potential conductor breaks and isolate affected circuit sections within milliseconds, preventing potential ignition sources from reaching the ground and minimizing the risk of wildfire.

1.4.2 Previous Actions on Wildfire Mitigation

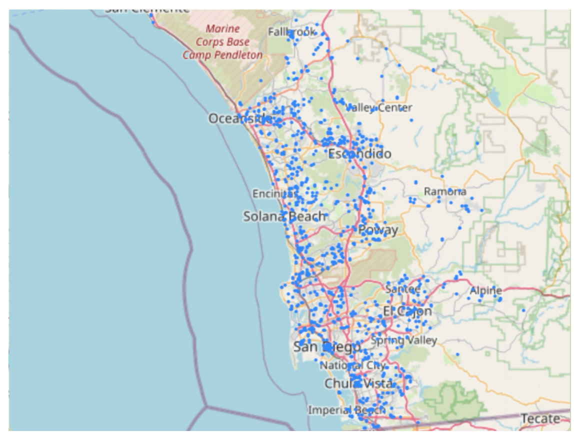
California's utilities have taken proactive measures in recent years to mitigate the risks posed by wildfires. The 2019 California Public Safety Power Shutoffs (PSPS) highlighted the severity of the wildfire threat (Wikipedia contributors (2024)), as utilities like PG&E,

SCE, and SDG&E preemptively cut power to millions of residents to prevent fires from igniting due to downed power lines. These widespread PSPS events, while effective in reducing fire risks, drew public backlash due to their impact on communities, especially those dependent on electricity for medical needs and critical services. The challenges faced during these events underscored the need for more sophisticated solutions beyond broad shutoffs.

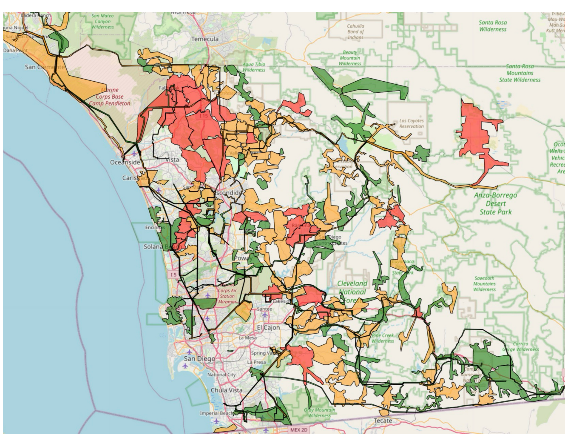
SDG&E, in particular, has implemented a series of targeted programs to address wildfire risks. The utility's Fire Threat Reduction model, developed following major fire events, uses fire history, ignition data, and environmental conditions to map high-risk areas (San Diego Gas Electric (2016)). Additionally, SDG&E's Fire Potential Index (FPI) and the Santa Ana Wildfire Threat Index (SAWTI) provide predictive insights into fire risks based on wind conditions, fuel moisture, and temperature. These indices help SDG&E prioritize de-energizing high-risk circuits and guide operational decisions on power restoration during dangerous conditions. Furthermore, SDG&E has adopted advanced vegetation management practices and improved system protection settings to minimize fire hazards associated with its distribution lines. These efforts illustrate the utility's commitment to reducing wildfire risks through data-driven approaches and continuous innovation.



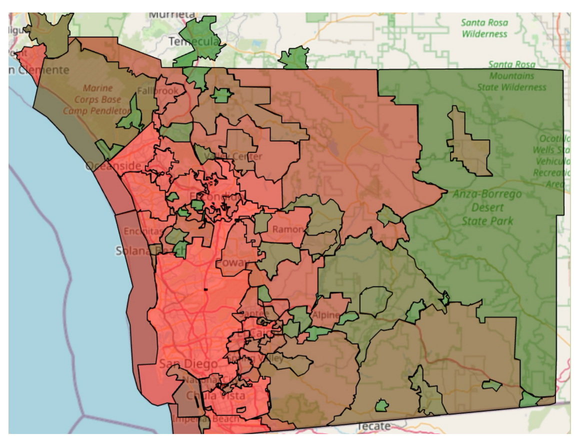
(a) Weather Identified Risk Areas



(b) Conductor Identified Risk Areas



(c) Vegetation Identified Risk Areas



(d) Community Impact of PSPS

Figure 2: Visualization of key datasets used in the wildfire risk assessment.

2 Data

The data utilized in this project was provided by San Diego Gas & Electric (SDG&E). It encompasses key categories crucial to accurately assessing wildfire risk:

- **Weather Data**: Forecasted and observed meteorological data, such as temperature, dryness, and windspeed.
- **Vegetation Data**: Metrics on tree density and Vegetation Risk Index (VRI).
- **Geographic Data**: Geographic parameters, including elevation and High Fire Threat Districts (HFTD).
- **Energy / Infrastructure Data**: Information on electrical conductors, including material type, age, and maintenance history.
- **Community Impact Data**: Population density, critical facility locations, and medically vulnerable customer distribution.

To better illustrate these datasets, we provide visualizations highlighting key risk areas (Figure 2).

All datasets were securely provided and maintained by SDG&E, ensuring data privacy and security.

3 Methodology

Our methodology involves developing a comprehensive composite model—the **ILLNESS Score**—integrating insights from multiple specialized sub-models. We opted to train separate models for distinct variable categories to optimize computational efficiency, ensure model-specific fit, and manage large, complex datasets effectively. This approach enables each model to leverage the strengths of different algorithms, thereby enhancing overall predictive accuracy.

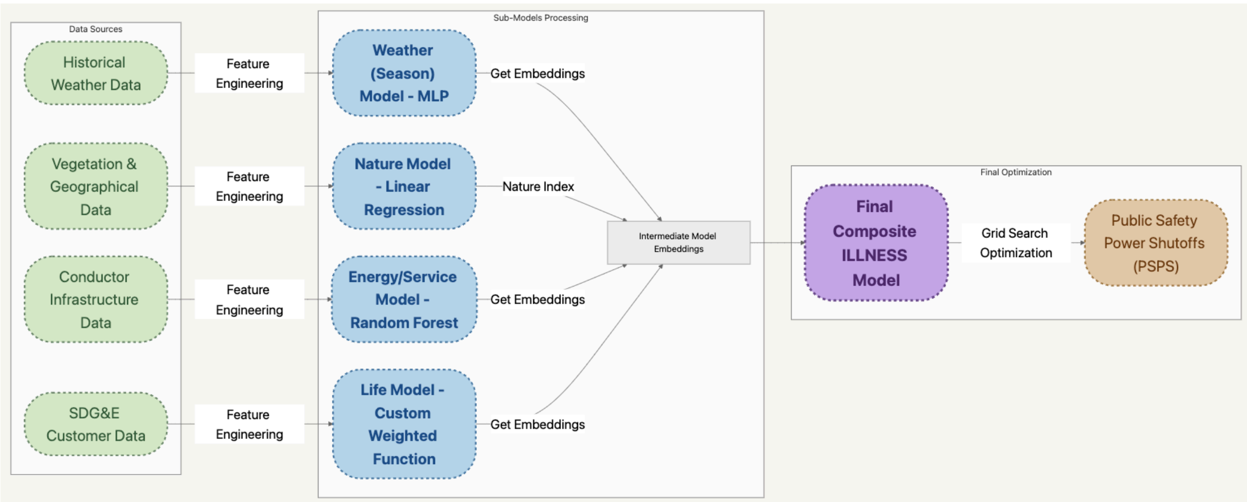


Figure 3: Flowchart illustrating the integration of sub-models into the final ILLNESS Score.

3.1 Weather Risk Model (W)

We selected a Multilayer Perceptron (MLP) neural network for the Weather Risk Model due to several advantages:

- **Flexibility**: Supports both regression and classification, facilitating easy adaptation as project requirements evolve.
- **Ease of Implementation & Interpretation**: Simpler architecture relative to deeper neural networks, thus easier to configure, tune, and interpret.
- **Attention Mechanism**: Can be modified to prioritize critical variables, aiding in identifying key environmental factors driving wildfire risk.
- **Debugging & Transparency**: Facilitates error tracing and straightforward debugging, increasing reliability.

The Weather Risk Model is trained on historical observed and forecasted data, including temperature, dryness, and windspeed, producing a score indicative of weather-driven wildfire risk.

The model's target variable is an overall fire-risk score derived from multiple wildfire-related features. The most heavily weighted factors include the fire's rate of spread and the ignition component. The ignition component measures the likelihood that a fire, once started in a given area, will require suppression.

3.2 Nature Risk Model (N)

The Nature Risk Model employs linear regression for simplicity and interpretability, using vegetation characteristics (Vegetation Risk Index, VRI), geographic parameters (latitude, longitude, elevation), and vegetation-related features. The Nature Index (NI) is calculated as:

$$NI(Nature\ Index) = \frac{\sum_{i=1}^{n} w_i x_i - min(S)}{max(S) - min(S)} \times 9 + 1$$

3.2.1 Weighted Features

Table 1: Feature Weights

Rank	**Feature**	**Weight**
1	longitude	0.453783
2	latitude	0.198523
3	vri_numeric	0.183907
4	num_strike_trees	0.163351
5	elevation	0.000436

Using these weighted features, this index quantifies natural wildfire risks across geographical regions effectively.

3.3 Energy Risk Model (E)

The conductor data includes a large span of data, including the length, structure material, upstream/downstream spans, work order dates, and more. We focus on the structure material, age, type, wire risk, and days since the last work order of each conductor span, then correlate them to a wildfire risk value. From our exploratory data analysis, we can infer that steel structures and overhead powerlines correlate to the highest public safety power shutoff (PSPS) probability, which is defined as:

$$Probability(\%) = \frac{Count\ of\ High\ Windspeed\ Events}{Total\ Windspeed\ Records} \times 100$$

Some of these variables are categorical, so we one-hot encoded them, and then applied a machine learning algorithm.

A Logistic Regression model would have been suitable for categorical data, but we want our model to calculate a scalable performance score, not predict a binary category. Thus, we tested Linear Regression and Random Forest models, which showed similar results in terms of accuracy. However, Random Forest has a slightly lower error than the other two models, and after finetuning, we recorded the below accuracy scores:

Table 2: Random Forest Model Performance Metrics

Metric	Value
MAE	1.498273167365387
MSE	9.764269329112558
R2 score	0.5368583080336017

3.3.1 Key Features in Energy Risk Model

The most significant features of the Random Forest model are upstream structure HFTD, upstream/downstream days since work order, and span length in miles. High fire threat district (HFTD) is the index for assessing fire threats, so it is logical that high HFTD correlates to high PSPS probability. The number of days since the work order tells how long ago it has been since the last inspection or maintenance, and we know that well-maintained, sturdy electricity poles are less likely to fall over and ignite a wildfire. Lastly, the span length, which could correlate with the number of customers related to a conductor span, therefore with more customers mean higher risk and higher probability of PSPS.

3.4 Life Impact Model (L)

A custom-developed weighted scoring system evaluates the societal impact of potential power shutoffs, prioritizing regions with higher population density, critical services, and medically vulnerable populations. This model explicitly quantifies the community "cost" associated with power outages, thereby balancing wildfire prevention with public welfare.

3.5 Composite ILLNESS Score

The final composite **ILLNESS Score** mathematically integrates the outputs from the Weather (W), Nature (N), Energy (E), and Community Impact (L) sub-models. It balances the wildfire risks (W, N, E) against community impacts (L), using the formula:

$$Composite = \left(\frac{W_W exp[\alpha(W - W_{min})] + W_N exp[\alpha(N - N_{min})] + W_E exp[\alpha(E - E_{min})] - \lambda p(N, E)}{[W_W exp[\alpha(W - W_{min})] + W_N exp[\alpha(N - N_{min})] + W_E exp[\alpha(E - E_{min})] - \lambda p(N, E)] + \beta L^\gamma} \right)$$

Where:

- $W_{min}, N_{min}, E_{min}$: Minimum historical risk scores for normalization.
- W_W, W_N, W_E: Weighting factors scaling each risk type.
- α: Exponential parameter emphasizing severe conditions.
- β: Weighting factor adjusting the influence of community impact.
- γ: Exponent determining the nonlinear effect of community impact.
- λ: Parameter capturing synergy or overlap between different risk factors.
- $p(N, E)$: Function representing the combined effect of nature and energy risks.

This structured and integrated methodology ensures nuanced, transparent, and actionable insights, enabling SDG&E to make well-informed and justified decisions regarding Public Safety Power Shutoffs.

4 Result

The final output of our project is a comprehensive visualization of wildfire risk and the corresponding Public Safety Power Shutoff (PSPS) recommendations using the ILLNESS score. Figure 4 illustrates the integrated result, presented as a map-based visualization accessible through our interactive web application at our GitHub page.

Areas marked in red indicate regions where the societal and service impacts from shutting off power outweigh wildfire risks, suggesting PSPS is not advisable. In contrast, areas shown in green highlight regions where the wildfire risks significantly exceed societal costs, supporting PSPS activation as a justified preventive measure.

The composite visualization highlights meaningful changes from the intermediate risk assessments to the final result. For example, certain inland communities initially indicated as high community impact (red), such as Ramona, shift toward green in the final result, signifying wildfire risks are severe enough to justify power shutoffs despite high societal costs. Conversely, northern areas such

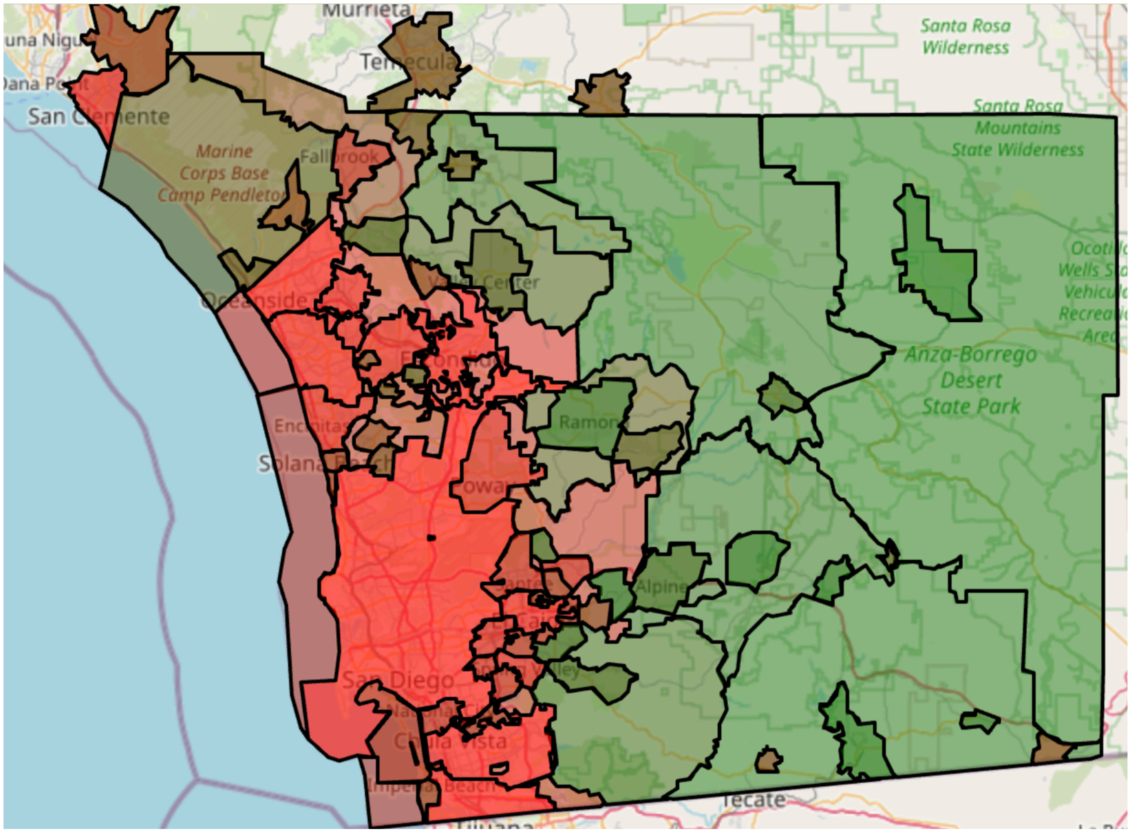


Figure 4: Final visualization of wildfire risk assessment using the ILLNESS Score. Red indicates regions where PSPS activation is not recommended; green indicates where PSPS is advisable.

as Rancho Mission Viejo transition from initially moderate wildfire risk (greenish areas) to red, reflecting that the societal impact of power disruptions in these locations outweighs the calculated wildfire risk.

These nuanced transitions clearly demonstrate the strength of the ILLNESS Score in balancing complex risk factors against community impacts, offering transparent and informed guidance on PSPS activation decisions.

5 Discussion

5.1 Our Achievement

The development of the ILLNESS Score represents a significant advancement in wildfire risk assessment and Public Safety Power Shutoff (PSPS) decision-making for San Diego Gas & Electric (SDG&E). The core achievement of our project is the introduction of a comprehensive, data-driven metric that effectively balances wildfire risks with community impacts. Unlike existing systems employed by SDG&E and other utility companies, which predominantly emphasize wind conditions, humidity, vegetation status, and ground dryness, our approach uniquely integrates a strong emphasis on community impact, especially on medically vulnerable customers and densely populated areas.

The table below summarizes the most important features considered by each specialized sub-model, highlighting the comprehensive and nuanced approach of our ILLNESS model:

Table 3: Key Features by Sub-model

Sub-model	**Most Important Features**
Weather (MLP)	Dryness, Temperature, Windspeed
Nature (Linear Regression)	Longitude, Latitude, Vegetation Risk Index (VRI)
Infrastructure (Random Forest)	Upstream HFTD, Upstream/Downstream Days Since Work Order, Miles of Conductor
Community Impact (Custom Score)	Population Density, Critical Facilities, Medically Vulnerable Customers

Compared to existing PSPS systems used by SDG&E and other utilities—which primarily focus on high winds, humidity, vegetation conditions, and dry ground materials—the ILLNESS Score integrates a vital additional dimension: explicit consideration of community impact. This innovation significantly reduces unnecessary disruptions and provides a transparent and justifiable foundation for PSPS decisions, especially evident in cases such as Ramona, where wildfire risk notably outweighs community impacts, and Rancho Mission Viejo, where the societal cost outweighs wildfire risk.

5.2 Future Work

Challenges encountered during the development process included limitations in real-time data acquisition, accuracy of predictive inputs, and computational complexity. Looking forward, incorporating real-time satellite imagery, advanced fire detection sensors, and more detailed demographic data is expected to further improve the precision of our predictions. Although our current geographical heatmaps are static, we could improve them by creating a live dashboard that updates the score periodically. It would again include the tooltip details with score breakdowns, as we want to provide transparency to people who consumes energy from SDG&E so they are aware of possible PSPS events and the reasons.

Future work will also prioritize validating and updating the ILLNESS Score model using actual outcomes from implemented PSPS events, continuously refining the score to enhance reliability and applicability. Ultimately, we aim for the ILLNESS Score to become a trusted standard in wildfire risk assessment and management, effectively balancing safety with minimal disruption to essential community services.

6 Acknowledgment

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7 Contributions Statement

Neil Sharma: 34% (code + report writing)

Gloria Kao: 33% (code + report writing)

Shentong Li: 33% (code + report writing)

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