INVESTOR-OWNED UTILITY EFFECTIVENESS OF ENHANCED CLEARANCES

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1 EXECUTIVE SUMMARY

Vegetation management is essential for maintaining the safety and reliability of electric power lines, particularly in wildfire-prone areas. By regularly clearing trees, shrubs, and other vegetation around power lines, utilities can reduce the probability of vegetation contact-caused outages ("outages"), consequently resulting in fewer ignitions.

California Public Utilities Commission (CPUC) General Order (GO) 95, Rule 35 mandates a minimum radial clearance of bare line conductors from vegetation, based on conductor voltage and whether facilities are located within the High Fire Threat District (HFTD). Rule 35, Appendix E recommends utilities establish greater clearances at time of pruning to ensure compliance with minimum clearances until the next scheduled maintenance. To reduce the risk of vegetation contact, utility tree pruning practices may exceed the recommended clearances at time of pruning, depending upon location, species, growth rate, tree health, and other site- and tree-specific conditions. To ensure the effectiveness of vegetation management activities in support of wildfire mitigation solutions, three electric investor-owned utilities (IOUs) in California: San Diego Gas & Electric Company (SDG&E), Pacific Gas and Electric Company (PG&E), and Southern California Edison Company (SCE) (collectively the "IOUs"), leverage both quantitative studies and expertise derived from field observations to better understand and improve vegetation management practices.

A study conducted by the third-party company, Electric Power Research Institute (EPRI),[1] evaluated the effectiveness of the clearance at the time of the pruning. This study standardized data from the three IOUs and compared the average duration from the time of inspection or pruning activity to the time of outage, based on the range of clearances at the time of inspection or pruning.

This white paper focuses on quantifying whether enhanced radial clearances are associated with a lower probability of vegetation contact. A machine learning technique, logistic regression model, was used to perform a sensitivity analysis comparing the differences in outage probabilities before and after modifying the targeted enhanced clearance levels. The result indicates enhanced clearances reduced approximately 20% of vegetation-caused outages. This white paper also addresses other factors, beyond radial clearances, that impact outage probabilities. Exploratory data analysis was also employed to identify the unique characteristics of three IOUs' land cover types, assess the impacts of weather conditions during and throughout the year, compare performance outcomes in the HFTD with other regions. Historical radial clearances of trees sampled from SDG&E were also analyzed to quantify the differences in the average outage rates for trees with enhanced clearances.

These different methods have shown that enhanced clearances reduce the probability of vegetation-caused outages by a measurable amount. This reduction in outage frequency can subsequently result in a lower incidence of ignitions in regions characterized by fire-prone vegetation.

However, the effectiveness of enhanced radial clearances in reducing the likelihood of ignitions is limited. Weather conditions can be a direct contributing factor to the probability of ignitions. For example, data has shown that the effectiveness of enhanced clearance diminishes during and after windy weather conditions. Additionally, the alteration of fuel loading along overhead conductors can

[1] This third-party study can be found in SDG&E's 2026-2028 Base WMP Appendix D.

provide additional risk-reduction benefits. Therefore, these may be considered as complementary risk control mechanisms.

2 INTRODUCTION

GO 95, Rule 35 mandates that "Where overhead conductors traverse trees and vegetation, safety and reliability of service demand that certain vegetation management activities be performed in order to establish necessary and reasonable clearances, the minimum clearances set forth in Table 1, Cases 13 and 14, measured between line conductors and vegetation under normal conditions shall be maintained." For conductors operating at 2,400 to 72,000 volts, GO 95, Rule 35, Appendix E recommends a minimum of 12 feet of clearance at time of pruning for facilities located in the HFTD and a minimum of 4 feet of clearance at time of trimming for facilities located outside of the HFTD.

The IOUs minimize vegetation contact risk through proactive vegetation management activities that catalog, audit, and prune or remove trees near electrical facilities. The terminology "enhanced clearance" has been misunderstood as a pruning practice that only takes the radial distance of vegetation from electric lines into consideration. In actuality, the three utilities follow a more balanced approach, considering what is necessary for safety, compliance, and reliability. In addition to the required minimum clearance, this balanced approach considers tree species, growth rate, site conditions, and tree health to determine the proper radial clearance for a tree. Additionally, industry pruning standards such as the American National Standards Institute (ANSI A300) guidelines factor into the determination of appropriate radial clearances.

This study focuses on quantifying the benefits of proactive pruning to 12 feet of clearance or greater at the time of pruning for primary distribution facilities. For the purposes of this study, clearances of 12 feet and above are defined as the “enhanced clearance”. Factors other than clearance can also contribute to the likelihood of vegetation contact-caused outages (“outages”), such as inspection frequency. However, these factors are not captured quantitatively in the data set nor considered in this study.

2.1 COMMONALITIES OF VEGETATION MANAGEMENT PRACTICES ACROSS UTILITIES

The IOUs’ vegetation management practices may differ based on the unique aspects of their respective service territories. However, there are practices that are common across the IOUs. First, the IOUs generally perform tree inspections twice per year in the HFTD portions of their respective service territory and at least once per year within the non-HFTD. Second, the primary inspection method is foot patrol. Third, a clearance of 12 feet or greater at time of pruning is defined as the threshold when quantifying whether an IOU has obtained enhanced clearance. In addition, each utility uses professional judgement based on training and arboricultural knowledge to make case-by-case determinations of which trees are appropriate candidates to receive expanded clearances. That is, the determination of how much clearance is obtained at time of pruning is not made arbitrarily. The goal of establishing proper clearance is predicated on ensuring safety and compliance for at least the annual pruning cycle. Indeed, in some instances the health of a tree may be adversely affected by expanded clearances.

3 DATA AND METHODS

3.1 DATA SAMPLE AND DATA VARIABLES

Vegetation-caused outage data from the three IOUs were collected from year 2015 to 2022 based on the Quarterly Data Reporting (QDR) files. To accurately reflect annual outage frequency in comparison to the outage data filtered in the third-party's assessment, this time period was used to conduct the exploratory analysis. Additional asset data, such as primary distribution overhead circuit miles, were sourced from the Q1 2024 Quarterly Data Report[2].

A table of data variables is available in Appendix A.

3.2 EXPLORATORY DATA ANALYSIS

3.2.1 BACKGROUND FOR DATA INTERPRETATION:

Public Safety Power Shutoffs (PSPSs) are the proactive de-energization of power lines during severe weather to reduce the likelihood of power lines causing an ignition. During elevated or severe weather conditions warranting a PSPS event, especially Red Flag Warnings (RFW)[3], vegetation-caused outages are not recorded on de-energized circuits. Therefore, weather conditions associated with vegetation outages used in this study (also reported as "risk-events" in the Wildfire Mitigation Plan (WMP) QDR) do not include this type of dry windy conditions. This indicates that the conclusions on the effectiveness of the enhanced clearance drawn from this analysis are not relevant to weather conditions that meet PSPS protocol.

Unless otherwise specified, outages mentioned in this white paper refer to vegetation-caused outages.

3.2.2 COMPARISON OF OVERHEAD CIRCUIT MILES AND LAND COVER ACROSS UTILITY SERVICE TERRITORIES

A comparison of the land cover[4] across California is informative when evaluating the effectiveness of vegetation-related mitigation methods and developing a utility-specific strategy.

California's land cover is highly diverse, reflecting its varied geography. Northern California features dense forests, fertile valleys like the Central Valley, and mountainous areas like the Sierra Nevada range. This region receives more rainfall, contributing to its lush vegetation. In contrast, Southern California is characterized by arid deserts, coastal plains, and extensive urban development. The landscape here includes chaparral, coastal sage scrub, and palm trees, with a generally warmer and drier climate. These

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[2] The % of total primary distribution overhead circuit miles that were added or removed is relatively small. To simplify the calculation, the circuit miles data from 2024 Q1 QDR in a utility company are used for all the years.

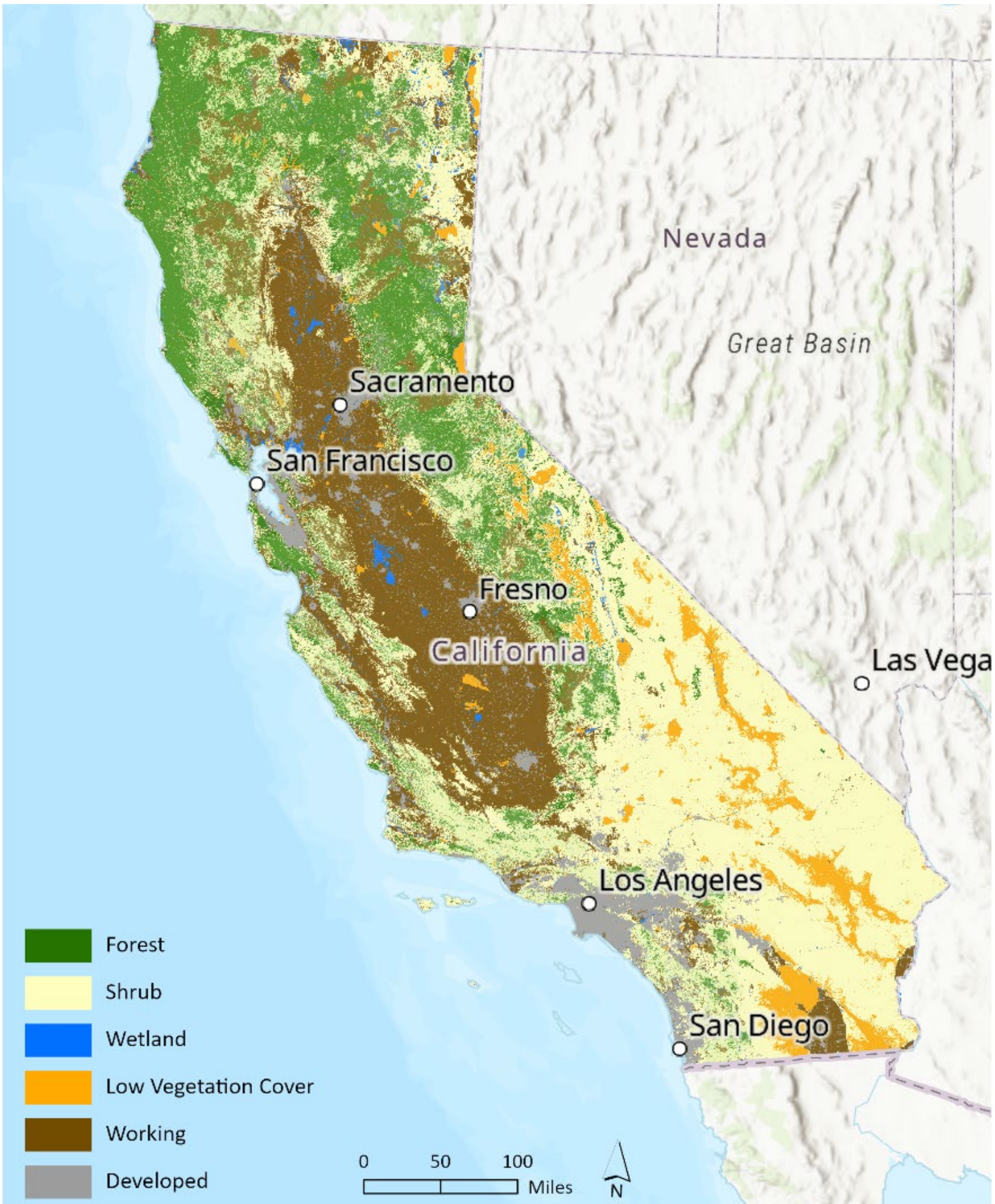
[3] RFW stands for Red Flag Warning issued by National Weather Service to alert areas of critical fire weather conditions, such as strong winds and low humidity, which could lead to extreme fire behavior.

[4] In the context of the National Land Cover Database (NLCD), land cover refers to the physical material at the surface of the earth. The NLCD provides detailed land cover data at a 30-meter spatial resolution, which is used for various environmental, land management, and modeling applications.

differences create distinct ecological zones and contribute to the unique identities of Northern and Southern California.

Figure 1 presents a land cover classification map of California, derived from the 2023 National Land Cover Database (NLCD). The map's land cover groups are categorized into stratified class bins based on the Anderson Level II Land Cover Classification System (Anderson, 1976).

Figure 1: California NLCD Land Cover map



Source: NLCD 2023 version. The grouping of the land cover types is included in Appendix A.

Table 1: Overheard Circuit Miles and Vegetation Outage Statistics by Land Cover

Utility Name and Sample Size	Metrics	Developed	Forest	Shrub	Wetland	Working	Low Veg Cover
PG&E HFTD miles = 25,293 non-HFTD miles = 54,485 HFTD outages = 16,245 non-HFTD outages = 13,183	Circuit miles % (HFTD)	42.0%	23.3%	18.6%	0.7%	15.2%	0.2%
	Circuit miles % (non-HFTD)	60.4%	0.5%	1.2%	0.8%	36.8%	0.3%
	Outages % (HFTD)	37.7%	49.0%	6.5%	0.6%	3.5%	0.3%
	Outage % in Non-HFTD	71.0%	10.4%	3.0%	1.1%	12.8%	0.3%
	Outages per mile (HFTD)	0.58	1.35	0.23	0.54	0.15	1.12
	Outages per mile (non-HFTD)	0.28	4.89	0.62	0.35	0.08	0.27
SCE HFTD miles = 13,743 non-HFTD miles = 36,787 HFTD outages = 987 non-HFTD outages = 2,354	Circuit miles % (HFTD)	46.4%	3.4%	34.5%	0.9%	14.6%	0.1%
	Circuit miles % (non-HFTD)	71.9%	0.02%	17.9%	0.2%	8.4%	1.6%
	Outages % (HFTD)	73.8%	12.7%	9.6%	0.5%	3.3%	0.1%
	Outage % in Non-HFTD	96.1%	0.1%	0.6%	0.0%	2.6%	0.6%
	Outages per mile (HFTD)	0.11	0.27	0.02	0.04	0.02	0.05
	Outages per mile (non-HFTD)	0.09	0.23	0.002	0	0.02	0.02
SDG&E HFTD miles = 3,378 non-HFTD miles = 2,950 HFTD outages = 134 non-HFTD outages = 341	Circuit miles % (HFTD)	39.6%	2.1%	47.6%	1.8%	8.8%	0.1%
	Circuit miles % (non-HFTD)	94.9%	0.05%	3.9%	0.3%	0.7%	0.2%
	Outages % (HFTD)	67.9%	4.5%	22.4%	3.7%	1.5%	n/a
	Outage % in Non-HFTD	99.7%	0.3%	0.0%	0.0%	0.0%	0.0%
	Outages per mile (HFTD)	0.07	0.08	0.02	0.08	0.01	n/a
	Outages per mile (non-HFTD)	0.12	0.72	0	0	0	0

** Outage data was collected from 2015 to 2022. A small portion of PG&E outage records (2.31%) are not spatially recorded; therefore, this table is a subset of all outages reported in the QDR.*

As shown in Table 1, PG&E has the highest proportion of service territory classified as "Forest" among the three utilities, with 23 percent of its overhead primary circuits (5,905 miles) located in forested areas. Consequently, nearly 50 percent of vegetation-caused outages in the HFTD portion of PG&E's service territory are associated with forests, which also have the highest outage rate per mile. In comparison, SCE and SDG&E have 3.4 percent and 2.1 percent of their service territories classified as

“Forest”, respectively. Despite these differences, forests exhibit the highest outage rate among all three IOUs. The ratio of forest outage percentage in HFTD to forest circuit miles percentage in HFTD is greater than 2 to 1 for all IOUs, indicating that outages are proportionally more likely to occur in forested areas.

SDG&E has the smallest service territory of the three utilities. In the HFTD portion of SDG&E's service territory, the largest land cover type is "Shrub," accounting for 47.6 percent, followed by "Developed," accounting for 39.6 percent. However, nearly 68 percent of vegetation-caused outages occur in developed regions, while 22.4 percent occur in shrub land areas. Similar patterns are observed for SCE’s HFTD territory, where “Developed” and “Shrub” land cover account for 46.4 percent and 34.5 percent of the circuit miles in HFTD respectively. These land covers are responsible for 73.8% and 9.6% of the outages in the HFTD."

Fuel types associated with forest and shrub land cover in California are generally easier to burn compared to developed and other land cover types. Forests and shrublands contain a significant amount of vegetation, including grasses, shrubs, and trees, which can serve as fuel for wildfires. These areas often have a high density of fine fuels, such as leaves, needles, and small branches, which can ignite easily and burn rapidly. Therefore, the ignition risks associated with “Forest” and “Shrub” are generally higher than with other land cover. From a vegetation management perspective, shrub lands are generally easier to manage than forests. Shrub lands typically have less biomass and a simpler structure compared to forests, making them more accessible for management activities such as controlled burns, mechanical removal, and herbicide application. Additionally, shrubs often grow in more open areas, which can facilitate easier access for equipment and personnel.

Forests, on the other hand, have a more complex structure with multiple layers of vegetation, including understory, midstory, and canopy layers. In addition to vegetation structure, forests are subject to stringent permitting requirements guiding vegetation management activities. This complexity can make management activities more challenging and labor-intensive. Forest management often requires more specialized techniques and equipment to address issues like tree thinning, invasive species control, and maintaining biodiversity. The forests in PG&E’s service territory are challenging to manage, which contributes to the high outage rate discussed in Section 3.2.3.

“Forest” and “Shrub” lands combined in HFTD account for 41.9 percent of PG&E’s primary overhead circuit miles, 49.7 percent of SDG&E’s circuit miles, and 37.9 percent of SCE’s circuit miles. Outage rate per circuit mile across three IOUs are not comparable given the variation in land cover, however, outage rate per circuit mile between HFTD and non-HFTD within one IOU offers insights on the outcome of vegetation management activities. The outage rate per circuit mile within the HFTD forest land cover is significantly lower than in non-HFTD areas in PG&E’s territory. For instance, PG&E's outage rate is 1.35 outages per circuit mile in the HFTD compared to 4.89 outages per circuit mile in the non-HFTD. A similar pattern is observed in shrubland. This lower outage rate highlights the results of PGE’s comprehensive mitigation effort in the HFTD, partially attributed to enhanced clearances. SCE and SDG&E have a relatively small percentage of overhead circuit miles in the non-HFTD forest areas, therefore a similar comparison between HFTD and non-HFTD is not meaningful in this case.

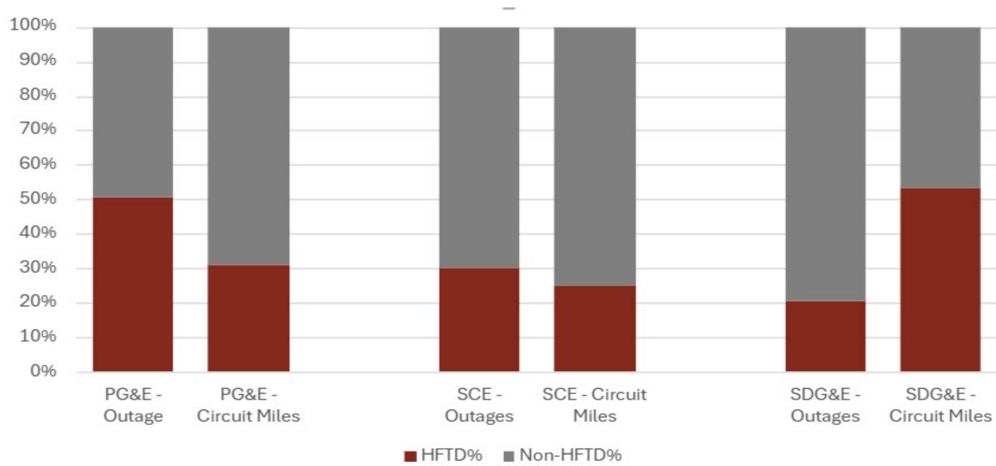
In conclusion, understanding the land cover types and their associated outage frequency and rate identifies factors beyond the radial clearance that impact the likelihood of vegetation-caused outages. This information can also guide utilities in researching and evaluating the minimum clearances based on land cover and in strategizing best practices.

3.2.3 STATISTICS ON VEGETATION CAUSED OUTAGES AND IGNITIONS

3.2.3.1 OUTAGE STATISTICS OUTSIDE OF RFW AND HWW[5] CONDITIONS

Figure 2 and Table 2 compare vegetation-caused outages in HFTD and non-HFTD portions of the service territories of each utility excluding RFW or HWW days. The comparison is shown by outage as well as by circuit miles.

Figure 2: Comparison of Vegetation Caused Outages Excluding RFW or HWW Days



Source: 2015-2022 WMP QDR

Table 2: Comparison of Vegetation Caused Outages Excluding RFW or HWW Days

Outages Outside of RFW or HWW Days	**PG&E (n=39,851)**	**SCE (n=2,737)**	**SDG&E (n=276)**
Annual actual frequency range (territory)	3,210 - 7,292	218 - 508	21 - 48
Percent of avg. outages in the HFTD	51%	30%	21%
Percent of circuit miles in the HFTD	31%	25%	53%
Range of annual percentage against all vegetation-related outages in HFTD	85.6% to 99.1%	65.3% to 91.3%	41.7% to 100%
Range of annualized frequency per 1000 miles in the HFTD**	51.1 - 174.0	6.6 - 17.8	0.9 - 4.5
Mean of annualized frequency per 1000 miles in HFTD*	101.0	10.8	2.1
Mean of annualized frequency per 1000 miles in non-HFTD*	45.0	8.4	7.5

Source: 2015-2022 WMP QDR Table 2 and Table 7

** Weather conditions vary greatly in each year; therefore the goal is to assess the outcome when such conditions do occur. Therefore, years when observations were 0 are not included when the mean is calculated.*

*** Circuit miles in HFTD are based on metrics in the Q1 2024 QDR.*

[5] HWW stands for high wind warning condition issued by the National Weather Service. A High Wind Warning is issued when sustained winds of 40 mph or higher are expected for at least an hour, or wind gusts of 58 mph or more are anticipated. "HWW" used in this paper are HWW conditions associated with winter storms and precipitation, without overlapped RFW conditions.

Over half (53 percent) of the primary overhead circuit miles in SDG&E's service territory are in the HFTD versus 31 percent in PG&E's service territory and 25 percent in SCE's service territory. This demonstrates the unique terrain of each utility's service territory.

When comparing the proportion of outages that occur outside of RFW or HWW days to the proportion of overhead circuit miles in the HFTD, the data shows utilities have distinctive results. For PG&E, outages in the HFTD are proportionally higher than the circuit miles percentage. SCE's percentage of outages in the HFTD is very close to its circuit miles proportion. SDG&E's percentage of outages in the HFTD is much less than the proportion of overhead circuit miles in the HFTD.

The percentage of forest land in the HFTD can be used to indicate the density of vegetation along overhead circuits. As shown in Table 1, the outage rate among land cover types varies significantly. PGE's higher annualized outage frequency in HFTD could be partially explained by much higher percentage of forest in the HFTD compared to other utilities.

In contrast, SDG&E's outage proportion in the HFTD is much lower than the circuit mile proportion, and annualized outage frequency is more than three times (2.1/7.5) lower in the HFTD compared to the non-HFTD. However, this observation is associated with very low forest land cover (2.14 percent, 76 miles). SCE has a similar outage rate in both the HFTD and the non-HFTD, which might be due to the smaller percentage of its territory in the HFTD.

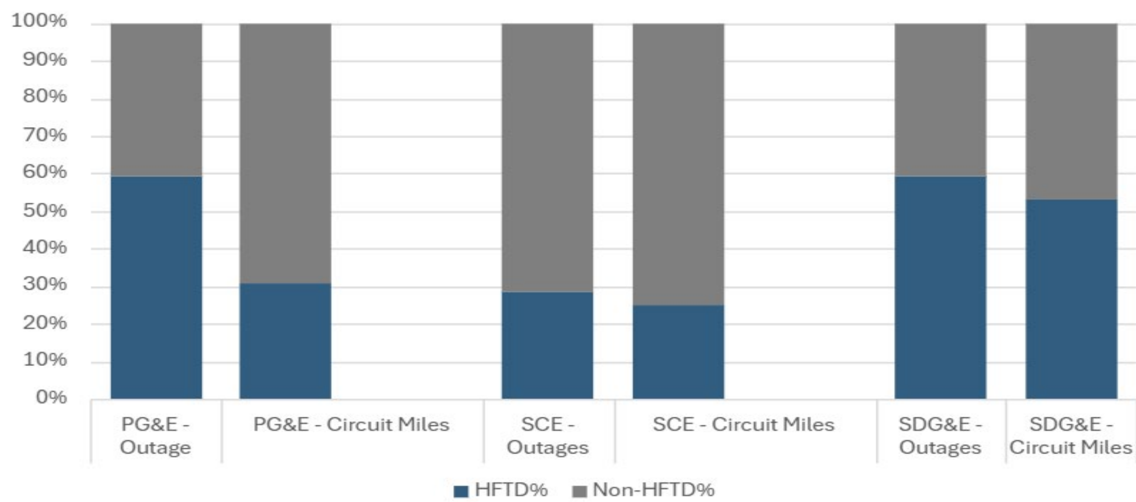
The effectiveness of enhanced clearances should be measured independently during wind events and non-wind events. The Annual Actual Outage Frequency range in Table 2 indicates that most vegetation contacts occurred outside of RFW and HWW conditions. While overall outage rates are higher in the HFTD compared to the non-HFTD for PG&E and SCE, Table 1 shows that the primary driver is likely due to the higher outage frequency in forest and shrubland compared to other land types. However, enhanced radial clearances in PG&E's HFTD forestland are associated with lower outage rates when compared to non-HFTD forestland. PG&E's outage rate in the forestland overall is still much higher than the rate in other land types. Therefore, further research is needed to determine the effective radial clearances required to reduce outage rates in forest and shrub regions to levels comparable to other land types.

3.2.3.2 OUTAGE STATISTICS DURING RFW CONDITIONS THAT DON'T TRIGGER PSPS PROTOCOLS

The impact of RFW and HWW weather conditions varies from event to event and across each service territory, and the pattern of these weather conditions is largely unpredictable. Understanding the influence of these weather conditions on vegetation-caused outages is crucial for evaluating the diminishing effectiveness of enhanced clearances. This also justifies the need for additional mitigation methods beyond enhanced clearances, thereby informing comprehensive mitigation strategies.

A small percentage of outages are observed during RFW weather conditions. The included RFW days do not meet the criteria to initiate PSPS protocols, possibly due to the moisture content of the fuel. RFW conditions vary from event to event, making comparison impossible due to spatial and temporal variations in weather factors. However, to compare outcomes across the utilities' service territories, overhead circuit mile days as a standardization method is used to generate the outage rate per 1,000 overhead circuit mile (OCM) days[6]. Additionally, the data sample used in this analysis does not include the RFW conditions that warrant PSPS protocols.

Figure 3: Comparison of Vegetation Caused Outages During RFW Conditions that do not Trigger PSPS Protocols



Source: 2015-2022 WMP Quarterly Data Report (QDR) Table 2 and Table 7

Table 33: Comparison of Vegetation Caused Outages during RFW Conditions that do not Trigger PSPS Protocols

Outages During RFW Days	PG&E (n=1,167)	SCE (n=381)	SDG&E (n=23)
Annual actual frequency range (territory)	2 - 297	0 - 117	0 - 12
Avg. outages % in HFTD*	59%	28%	59%
Circuit miles % in HFTD	31%	25%	53%
Range of annual percentage against all vegetation-related outages in HFTD	0.04% - 6.24%	0% - 26%	0% - 58.3%
Range of outage rate per 1000 OCM days (territory)	0.01 - 0.52	0 - 0.39	0 - 0.1
Mean of outage rate per 1000 OCM days (territory) **	0.27	0.22	0.05

Source: 2015-2022 WMP Quarterly Data Report (QDR)
** SCE's vegetation management mitigation scope also includes State Responsibility Area (SRA) in addition to HFTD. SRA is not used in the white paper. The statistical impact is negligible.*
*** Weather conditions vary greatly in each year, the goal is to assess the outcome when such conditions do occur. Therefore, years when observations were 0 are not included when the average is calculated. The outage rate is annualized*

Figure 3 indicates that the proportion of outages during RFW conditions closely matches the proportion of circuit miles in the HFTD. This impact is particularly evident in SDG&E's service territory, where the percentage of outage events in the HFTD during this type of RFW condition reaches 59 percent, a significant increase from 21 percent during no windy weather conditions. PG&E has a small increase,

[6] Overhead Circuit Mile (OCM) days is a metric collected in QDR Table 4. It measures the exposure of the overhead asset to a certain weather condition by using the product of time duration and circuit mile length. This can be used to understand some of the weather factors and general differences between each event or year.

from 51 to 59 percent; whereas outages percentage in the HFTD portion of SCE's service territory does not have a significant difference.

This difference highlights the vulnerability to windy conditions and the reduced effectiveness of enhanced vegetation pruning in the HFTD. The differences of the outage rate per 1,000 OCM days are smaller across the three utilities during such RFW conditions when compared to the outage rate outside of RFW or HWW conditions. SDG&E's sample size is relatively smaller, making it less comparable to the other two utilities.

3.2.3.3 OUTAGE STATISTICS DURING HWW ONLY CONDITIONS

The impact is even more pronounced during HWW conditions, as shown in Table 4. Although these wet, windy conditions differ significantly from dry, windy conditions like Santa Ana winds, HWW conditions can still serve as a stress test to evaluate the effectiveness of greater clearance during strong winds. Since wet, windy conditions do not pose an elevated wildfire risk, utilities typically do not need to de-energize the lines as they do during conditions that present a higher fire risk, such as RFW. Therefore, outage observations are available for comparison.

Table 4 presents statistics for observations during HWW conditions. PG&E experienced up to 54.49 outages per 1,000 OCM days annually during HWW conditions. To demonstrate the wind impact on vegetation-caused outages, the outage rate outside of RFW and HWW was standardized using OCM days and then compared to the rate during HWW. Since PG&E has a larger outage data sample size, its mean annualized outage rate of 45.0 from Table 2 was used as an example to extrapolate the outage rate per OCM days. Assuming 45.0 outages per 1,000 miles occurred in the non-HFTD for 365 days, this rate is normalized as follows:

$$
\begin{aligned}
x(\text{OCM days}) &= \frac{\text{number of outages}}{\text{OCM} \times 365 \text{ days}} \times 1000 \\
&= \frac{\text{number of outages}}{\text{OCM}} \times 1000 \times \frac{1}{365} \\
&= \text{number of outages per 1000 miles} \times \frac{1}{365} \\
&= 45 \times \frac{1}{365} \\
&= 0.12 \text{ per 1,000 OCM days per year}
\end{aligned}
$$

After the above conversion, 45.0 outages per 1,000 miles per year would be equivalent to 0.12 per 1,000 OCM days on average per year, whereas the outage rate during HWW condition is 54.49 per 1,000 OCM days per year in PG&E's service territory. This large difference highlights the magnitude of the weather impact.

This type of windy condition can also contribute to a significant portion of outages, as evidenced by the 51.7 percent recorded in 2022 for SDG&E's service territory. This indicates the reduced effectiveness of enhanced clearance, similar to RFW conditions. Additional findings regarding HWW are explained in Section 3.2.3.2.

Table 44: Comparison of Vegetation Caused Outages Observed during HWW conditions that do not Trigger PSPS Protocols

Outages Within Only HWW Days	PG&E (n=2,019)	SCE (n=265)	SDG&E (n=66)
Annual actual frequency range (territory)	3 to 647	6 to 97	0 to 35
Avg. outages % in HFTD	61%	31%	24%
Circuit miles % in HFTD	31%	25%	53%
Range of annual percentage against all vegetation-related outages in HFTD	0% to 12%	3% to 19%	0% to 51.7%
Range of outage rate per 1000 OCM days (territory)**	0.62 to 54.49	0.05 to 0.67	0 to 0.9
Mean of outage rate per 1000 OCM days (territory) *	11.1	0.3	0.3

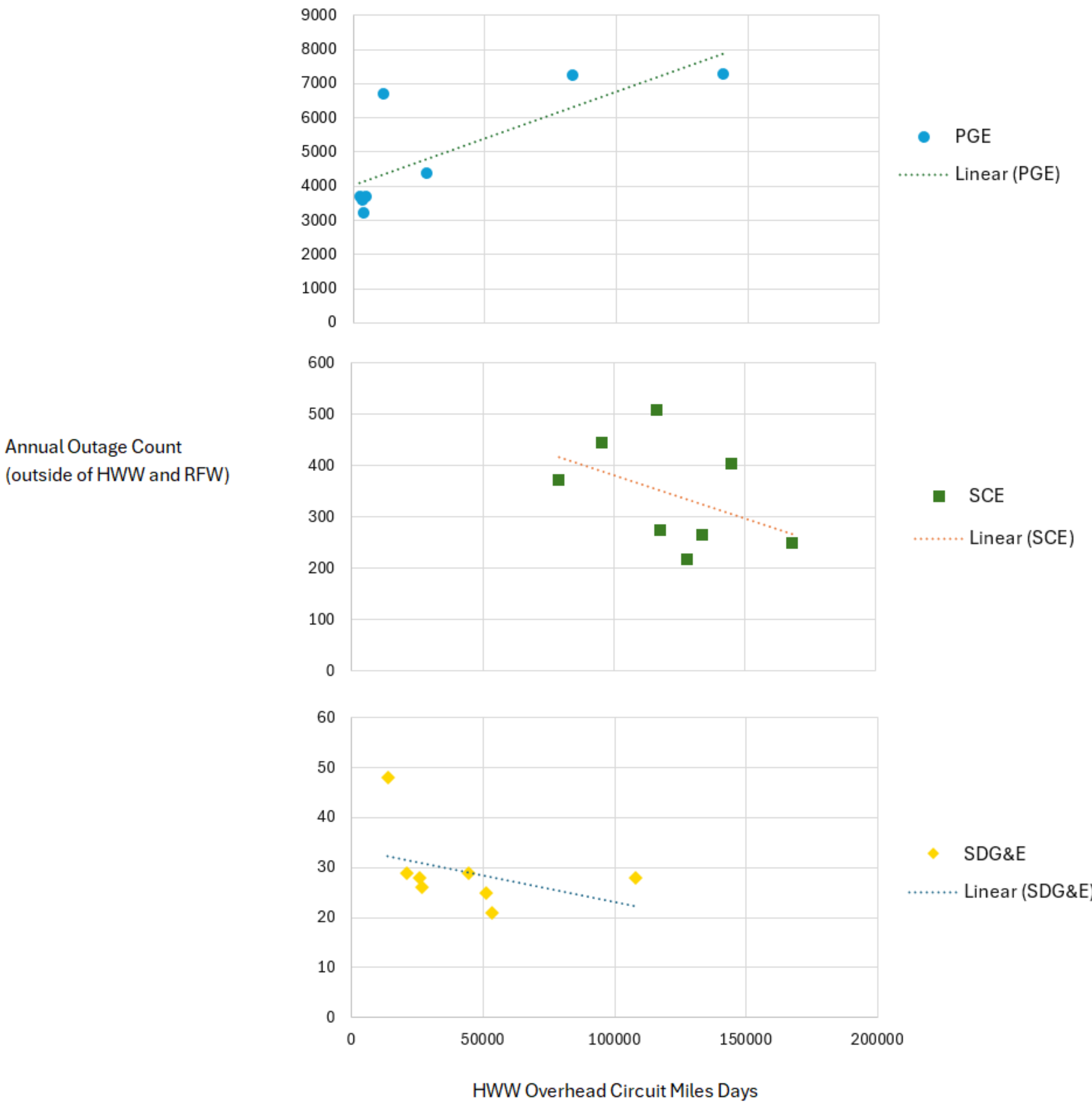
Source: 2015-2022 WMP QDR

** Weather conditions vary greatly in each year; the goal is to assess the outcome when such conditions do occur. Therefore, years when observations were 0 are not included when the average is calculated. The outage rate is annualized.*

*** OCM days is Overhead Circuit Mile days metric.*

3.2.3.4 THE IMPACT OF HWW WEATHER CONDITION ON THE OUTAGE FREQUENCY

Figure 4: Correlation between Outage Count Excluding HWW and RFW Conditions and Annual HWW Overhead Circuit Mile Days[7]



	PG&E	SCE	SDG&E
Pearson Correlation Coefficient	0.78	-0.45	-0.40

Source: QDR Table 2 and Table 4QDR

[7] HWW circuit mile days include some events that overlap with RFW conditions.

HWW conditions in Northern California are often associated with winter storms and atmospheric river events. These conditions typically occur during the winter months and bring strong winds, heavy rain, and sometimes snow to the region. In Southern California, HWW conditions are also common during winter storms.

As most HWW conditions bring rain to California during the winter season, they influence the annual outage frequency, not only during the HWW days but also for the rest of the year. However, this impact varies significantly between Northern and Southern California.

Figure 4 provides a compelling observation that a strong positive correlation (0.78) is evident for the year when PG&E's service territory experienced a higher frequency of HWW conditions. In contrast, moderate negative correlations (-0.45 and -0.4) were observed for the years when SCE's and SDG&E's service territories experienced more HWW conditions.

These observations may be attributed to the differences in vegetation type between Northern and Southern California. For Northern California, the data indicates that during years when greater HWW winter storms occur, higher outage frequency was observed.

This insight can inform utility strategies for effective vegetation management practices, particularly in regions where outages are more likely to occur following HWW days. Additionally, this correlation between HWW and outage frequency also highlights the cause of the variation in the effectiveness of enhanced clearances year over year.

3.2.3.5 VEGETATION CAUSED IGNITION FREQUENCY AND IGNITION PER OUTAGE

Ignition probability is directly influenced by factors such as fuel type, fuel moisture, wind, and heat sources. A heat source is derived from sparks generated when vegetation contacts bare conductors or when a tree strikes a covered conductor with enough force to break parts of the joints and other electrical devices. This can happen at a location with dry fuels or a location without any fuels. Therefore, not every vegetation contact (outage) has the same probability of causing an ignition.

Radial clearance as a treatment can reduce the probability of vegetation contact (outages) to a certain degree, as shown in Section 3.2.3 and Section 3.4. However, radial clearance on vegetation does not directly impact the probability of ignition. Statistically, assuming that ignition can happen randomly, reducing the probability of vegetation contacts through greater clearance logically leads to a reduction in the probability of vegetation contacts that result in ignitions.

The statistical relationship between clearance and ignition is that radial clearance can reduce the probability of vegetation contact with conductors, thereby reducing the overall number of outages. Radial clearance does not directly impact the probability of ignition once a contact occurs. The reduction in vegetation contacts indirectly reduces the number of potential ignition events.

Given that environmental factors vary greatly among utilities, ignitions per outage rate are not comparable among these regions. However, the differences between non-HFTD and HFTD areas within the same utility's service territory can offer some insights.

Table 5 shows that the average ignition frequency per 1,000 miles is higher in the HFTD than in the non-HFTD across all utilities, however, SDG&E has the smallest difference. Similarly, the ignition rate per outage in HFTD regions are higher than in non-HFTD regions, however, PG&E has the smallest difference.

Using SCE's rate as an example, the mean value in the HFTD is 0.0512, compared to 0.0321 in the non-HFTD. This means that on average, 100 outages would likely lead to 5 ignitions in the HFTD and 3 ignitions in the non-HFTD. In SDG&E's territory, the ignition rate is 2.8 times higher in the HFTD, but the outage rate in the HFTD is one third of the rate in the non-HFTD (see Table 2).

The higher rate in the HFTD might be attributed to more rural regions, such as the Wildland-Urban Interface (WUI), where fuel conditions are more prone to fire. This also indicates that enhanced clearance as a mitigation treatment alone is less likely to reduce ignitions if fuel conditions around the overhead assets remain unchanged.

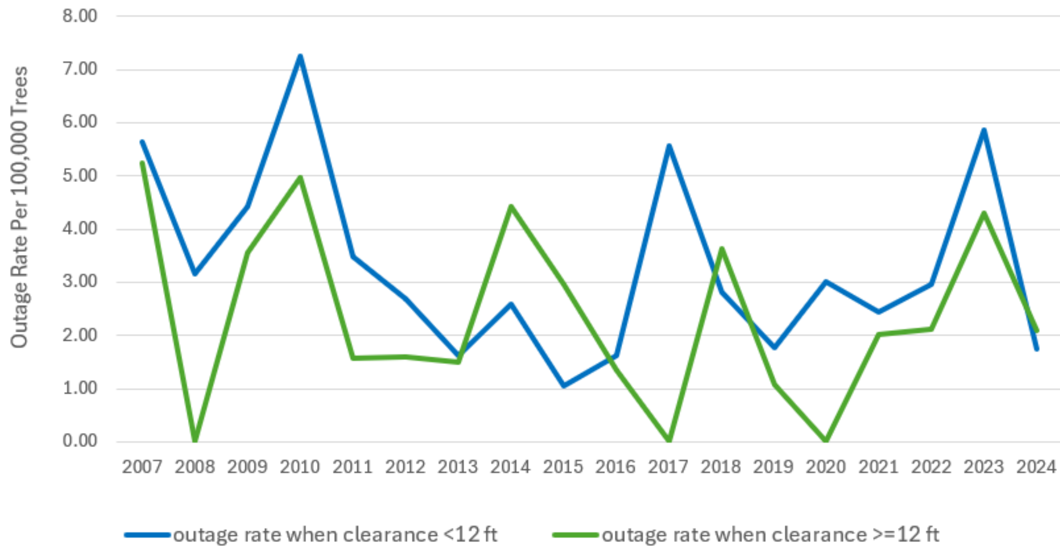
Table 5: Vegetation Caused Reportable Ignitions and Statistics (Annualized)

Mean ± Standard Deviation (μ±σ)	**PG&E (n=1025)**	**SCE (n=114)**	**SDG&E (n=18)**
Ignition per 1000 miles – HFTD	2.678 ± 0.658	0.570 ± 0.187	0.654 ± 0.501
Ignition per 1000 miles – non-HFTD	1.122 ± 0.234	0.313 ± 0.066	0.593 ± 0.382
Ignition rate per outage – HFTD	0.027 ± 0.013	0.051 ± 0.032	0.229 ± 0.206
Ignition rate per outage – non-HFTD	0.026 ± 0.008	0.032 ± 0.011	0.059 ± 0.045

Source: 2015-2022 WMP QDR

3.2.3.6 OUTAGE RATE COMPARISON BY CLEARANCE RANGE

Figure 5: Outage Rate per 100,000 Trees in the HFTD Portion of SDG&E's Service Territory from 2007 to 2024



	<12 ft	>=12 ft
average percentage of all trees inspected in HFTD (2007-2017)	73.3%	26.7%
average percentage of all trees inspected in HFTD (2018-2024)	64.6%	35.4%
outage sample	102	31
average outage rate (2007-2024)	3.3	2.4

Note: To evaluate the effectiveness of clearance, outages captured in this data sample only include trees that have been inspected and maintained prior to the outage events. The outage sample size is 133.

To effectively quantify the outage rate for trees that are either maintained[8] or pruned to an enhanced clearance, data collection must include the radial clearance at the time of inspection and pruning, as well as the estimated clearance when outages occurred. SDG&E has been collecting such data for over two decades; therefore, outage data were sampled from SDG&E's service territory to conduct this analysis.

As observed in Figure 5, in 16 out of the 18 years the outage rate for trees with enhanced clearances (>=12 ft) was lower than the trees with less clearances. This finding indicates that when vegetation clearance is maintained or pruned to enhanced clearances, it reduces the outage frequency by 27 percent on average (difference between 3.3 and 2.4).

[8] SDG&E tracks and records the radial clearance on every inventory tree at the time of routine inspections. When a tree does not require pruning in the annual inspection cycle, it means its radial clearance is maintained at a targeted sufficient distance. When a tree does require pruning after inspection, the radial clearance is pruned to a targeted sufficient distance for at least one annual cycle.

3.3 STATISTICAL ANALYSIS ON THE EFFECTIVENESS OF VEGETATION CLEARANCE

3.3.1 METHOD AND MACHINE LEARNING MODEL SELECTION FOR STATISTICAL INFERENCE

3.3.1.1 THE PURPOSE OF STATISTICAL INFERENCE AND LOGISTIC REGRESSION

The goal of this analysis is to quantify the probability of a vegetation caused outage event that could happen given the input variables, such as species or clearance and specifically how one input variable, clearance, impacts the probability of vegetation outages when holding other input variables consistent.

Logistic regression models the probability that a given input belongs to a particular class. It uses the logistic function (also known as the sigmoid function) to map predicted values to probabilities between 0 and 1. One of the strengths of logistic regression is its interpretability. The coefficients (weights) can be interpreted as the log odds of the outcome, making it easier to understand the influence of each feature (input variables).

Therefore, logistic regression was selected to quantify the influence of clearance on the probability of vegetation outages. Additionally, to understand the level of impact that clearance has on the probability of outages, a sensitivity analysis is used to answer the ‘what if’ question, namely, "if no trees were maintained with enhanced clearance, how many vegetation outages would have occurred?”.

A modified version of the test dataset was created by adjusting records with clearance values greater than 12 feet to have values of 11 feet. This modified test dataset was then used to generate new probabilities of vegetation related outages. Differences were then compared between the probability of outage based on the actual clearance and the probability of outage when enhanced clearances (values greater than 12 feet) are modified to 11 feet.

3.3.1.2 DATA SAMPLES AND DATA FRAME USED FOR MODELING

The data sample used for this statistical inference consisted of records captured throughout the SDG&E service territory. SDG&E is the first utility in California to track and record vegetation activities and tree-related variables at the tree level. This precise data collection enables advanced statistical inference by providing detailed information on tree features. Consequently, this data sample was selected for the analysis. Data recorded from 2006 to 2022 was used to train the logistic regression model, and data recorded from 2023 to 2024 was used to conduct the sensitivity analysis.

3.3.1.3 DATA VARIABLES

The response variable positive and negative observation were encoded for each Tree ID in each calendar year. If a Tree ID had an outage, then the output was classified as 1, otherwise, the output was classified as 0. Figure 6 shows the predictive variables that are important in this model. A logistic regression model was trained to predict the probability of a tree causing an outage. This step establishes a statistical algorithm using logistic regression, which can be used to conduct the sensitivity analysis.

Figure 6: Predictive Variables used in the Final Machine Learning model

	0	Coefs
0	species_grp_Ash	-0.986696
1	species_grp_Avocado	-1.058510
2	species_grp_Brush 5X5 Bamboo	-0.041978
3	species_grp_Century Plant	0.444559
4	species_grp_Cottonwood	-0.565706
5	species_grp_Eucalyptus	-0.123354
6	species_grp_Oak	-1.021837
7	species_grp_Other	-1.343835
8	species_grp_Palm-Date	-0.060114
9	species_grp_Palm-Fan	0.821419
10	species_grp_Palm-Feather	-0.426131
11	species_grp_Pepper (California)	-0.917737
12	species_grp_Pine	-0.111842
13	species_grp_Silk Oak	-0.174798
14	species_grp_Sycamore	-0.276343
15	species_grp_Willow	-0.932854
16	vma_grp_200	-0.663902
17	vma_grp_300	-1.894322
18	vma_grp_400	-1.443127
19	vma_grp_500	-0.608306
20	vma_grp_600	-1.319338
21	vma_grp_700	-0.846762
22	growthrate_FAST	-1.448301
23	growthrate_MED	-1.833513
24	growthrate_NR	-0.133987
25	growthrate_SLOW	-1.922541
26	growthrate_VFST	-1.437415
27	LINECLR_MID_scale	-2.277939
28	DBH_MID_scale	1.670327
29	TREEHEIGHT_MID_scale	3.663053
30	enhanced_clear_yes	-0.630047

3.3.2 MODEL OUTPUT AND INTERPRETATION

Table 6 presents the results from a model trained on data from 2006 to 2022 and tested on data from 2023 and 2024. Due to the significantly lower number of positive observations compared to negative ones, the model is imbalanced. However, the primary objective of this regression is to perform a sensitivity analysis, focusing on the predicted true positive outcomes.

More details on model performance can be found in Appendix B.

Table 66: Model Output with Actual Clearance Values (unit=outages in 2023 and 2024)

Confusion Matrix Using True Clearance Values		**Actual**		
		Outage	**No Outage**	**Total**
Predicted	Outage	47	162,971	163,018
	No Outage	15	610,267	610, 282
	Total	62	773,238	773,300

According to the model output shown in Table 6, 62 actual outages were observed from 2023 to 2024 and the model correctly predicted 47 out of 62. Based on the true positive and false positive ratio derived from this true test data, these ratios are then used to split the calculated true outages and calculated false outages in Table 7.

Table 77: Model Output after Altering Clearance Values (unit=outages in 2023 and 2024)

Confusion Matrix Using Altered Clearance Values		Calculated (used as actual)		
		Outage	**No Outage**	**Total From Model**
Predicted	Outage	62.8	217,955.2	218,018
	No Outage	13.9	555,237.1	555,251
	Total	76.7	773,192.3	773,300

The actual values for the variable "clearance" were adjusted to 11 if they exceed 11. After modifying the clearance values, the same algorithm was rerun to generate the performance output shown in Table 7. As a result, the calculated actual outage count increased from 62 to 76.7. The following formula illustrates the difference in outage counts between scenarios where some trees have enhanced clearances and where no trees have enhanced clearances. This method indicates that enhanced clearances reduced approximately 20% of vegetation-caused contacts.

$$(76.7 \times Sensitivity\ Analysis\ Outage\ Count) - (62 \times Actual\ Outage\ Count) \\ = Approximately\ 15\ Potential\ Mitigated\ Outage$$

3.3.3 CONCLUSION OF THE STATISTICAL INFERENCE

This sensitivity analysis provides further evidence that greater clearance reduces the probability of vegetation-caused outages, thereby resulting in fewer ignitions. This method helps quantify the impact by modifying one variable while holding other variables constant. However, it does not directly specify the clearance that should be adopted.

3.4 LIMITATION OF THE STATISTICAL INFERENCE

3.4.1 DATA VARIABLES NOT INCLUDED IN THE STATISTICAL INFERENCE.

The variation in the tree canopy is not considered in the model. Based on variables used in the third-party's analysis, the average of "Tree Canopy Cover" in PG&E's service territory is close to three times the average tree canopy cover in SCE's and SDG&E's service territories.

Additionally, variation in land cover is not captured in the regression model. The land cover identified at locations where outages are observed differs between Northern and Southern California.

Wind gust is not included as a variable. This model is not designed to make real-time predictions.

4 COMMENTS ON THE THIRD-PARTY MEMO REGARDING THE EFFECTIVENESS OF ENHANCED CLEARANCE

4.1 INTERPRETATION ON THE SAMPLE SIZE OF RESPONSE VARIABLE “TIME-TO-OUTAGE”

Time-to-Outage in the third-party analysis is defined as the days between the time when a tree received a pruning or inspection that recorded a clearance and the time when a tree caused an outage. This variable is used to measure the difference in duration among clearance categories to evaluate whether greater clearance is associated with longer duration.

Table 8 is interpreted as the sample size of the response variable “time-to-outage” collected from each utility and grouped by different radial clearance category. The sample size might not represent the ratio of the outage tree population for each clearance category.

For PG&E, it should be noted that there is not a direct connection between the outage records and the vegetation management database (inspection/tree work records). The data used in Table 8 was derived by geo-referencing location of outage tree and vegetation management records and filtering results based on multiple factors described in the third-party report. Because of the high variability in factors that influence this data, no direct conclusions should be drawn from PG&E data in Table 8.

Table 88: Response variable “Time-to-Outage” by clearance and its sample size

	“Time-to-Outage” Variable Sample Size (n=1,345)			Summary Stats			
Radial Clearance Category	**PG&E**	**SCE**	**SDG&E**	**Overall Mean (time-to-outage)**	**Median (time-to-outage)**	**Standard Error (time-to-outage)**	**Standard Deviation (time-to-outage)**
0-4 ft	8	13	6	287 days	121	85.5	444
4-12 ft	268	102	139	425 days	201	25.2	569
>12 ft	760	22	27	619 days	336	21.8	619

4.2 INTERPRETATION AND COMMENTS ON “OUTAGE VARIATIONS BETWEEN WORKED AND NON-WORKED TREES”

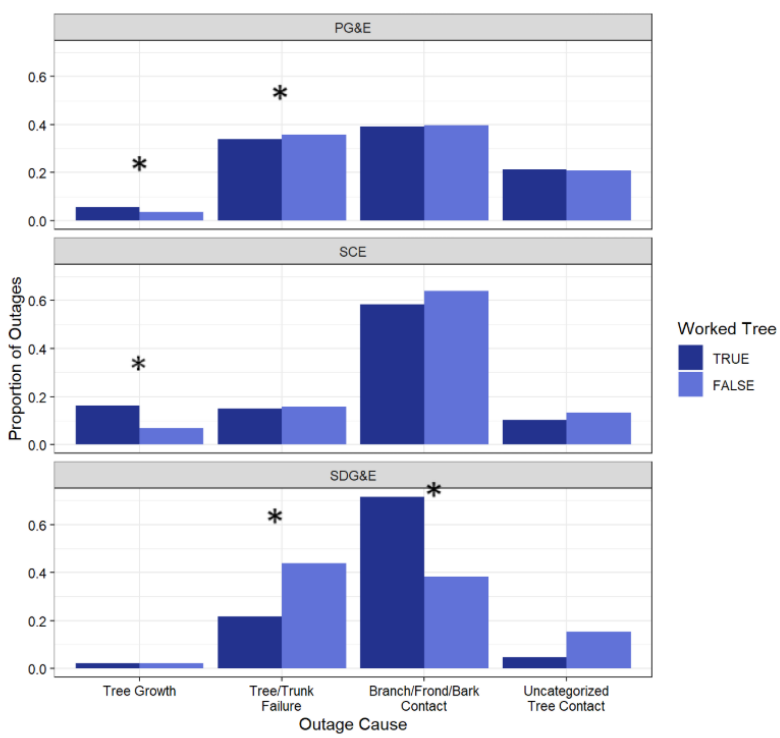
The third-party analysis stated that “IOUs differed in the proportion of outages caused by worked trees. Approximately two-thirds of SDG&E outages in the analysis subset were caused by worked trees (67.7 percent), whereas PG&E had 25.1 percent of outages caused by work trees, and SCE only had 5.0 percent of outages caused by worked trees”. This information indicates the proportion of trees that caused outages were previously recorded and maintained. The word “worked trees” is used to describe such observations.

However, the third-party analysis overlooks the differences in data collection practices across the three utilities when making related statements, meaning these percentages do not reflect the true ratio. For instance, PG&E does not record data when a tree is inspected but does not require follow-up, whereas SDG&E collects data on every tree at the time of its annual inspection, regardless of whether follow-up work is needed. This explains SDG&E's 67.7 percent figure. The correct interpretation of this number is that 67.7 percent of outages are caused by trees that have records and were inspected each year. This statement does not apply to PG&E, as not every tree inspection is recorded. Similarly, SCE did not historically collect data from every inspected tree, making the linkage between inspection activities and outages unclear. Therefore, no conclusions should be based on such data.

Additionally, this information has little relevance to the effectiveness of radial clearance. Based on data collected by SDG&E, when trees were not tracked and inspected prior to an outage event, their locations were much further from the conductors and thus not recorded. When evaluating the effectiveness of radial clearance, SDG&E excludes these tree records.

Work order data records are used to determine the date of previous inspection or tree pruning activities, allowing the duration between the previous clearance and the outage to be quantified. Figure 7 from third-party report is misleading given the flaws in data records.

Figure 4: EPRI assessment Figure 3-9

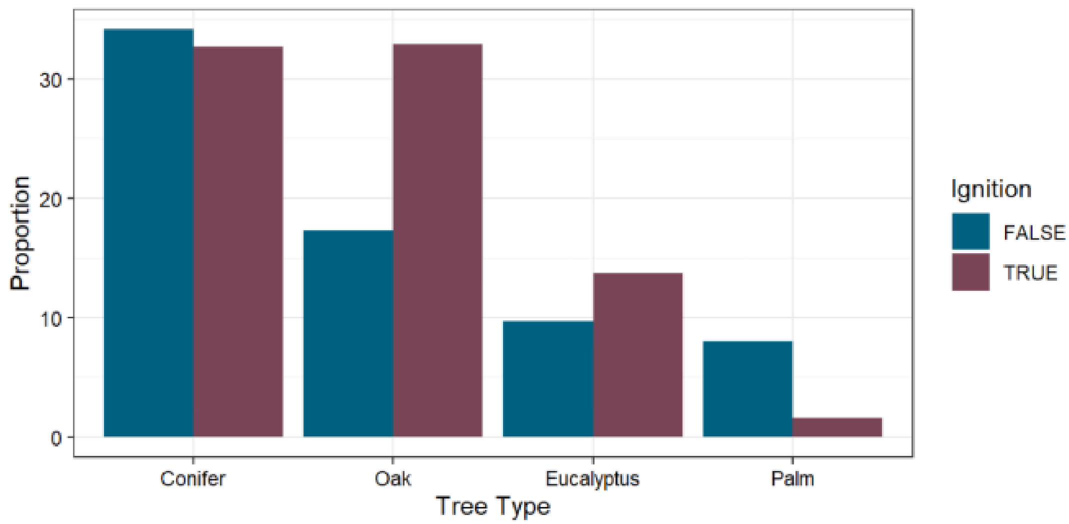


Source: Third-Party Report, Figure 3-9 The proportion of outages in each utility and outage cause based on work status (i.e., whether the tree was trimmed prior to an outage). When Worked Tree is TRUE, then the outage tree had been trimmed prior to causing an outage. Stars (*) indicate significant 2-sample proportion tests (p < 0.05) between worked-tree outages and non-worked-tree outages.

4.3 IGNITION SPECIES

The third-party analysis uses information in Figure 8 to suggest an association between tree species and ignitions. However, this graph is misleading as it may imply a direct causal relationship between species and ignition. The reality is that the likelihood of a tree species catching fire is not inherent to the species itself, but rather related to the type of fuels typically found in their vicinity. Therefore, it is the surrounding fuel types, not the tree species, that directly impact the probability of ignitions.

Figure 8: Variation in the Proportion of Outages without Ignitions and Outages Associated with Ignitions for the Top Genera Contributed to Outages.



Source: Third-Party Report, Figure 3-8 Variation in the proportion of outages without ignitions and outages associated with ignitions for the top genera contributing to outages. Conifers include Pinus spp., Sequoia spp., and Pseudotsuga spp. Oaks include Quercus spp. Eucalyptus includes Eucalyptus spp. Palms include Washingtonia spp. and unknown palms.

5 CONCLUSIONS AND RECOMMENDATIONS BASED ON ENHANCED CLEARANCE STUDY

As shown in this study, different methods have been used by the utilities and third parties to evaluate the effectiveness of enhanced clearance. Results demonstrate that greater clearance reduces the probability of outages by a measurable amount. A reduction in outage frequency can subsequently result in a lower incidence of ignitions in regions characterized by fire-prone vegetation.

However, the effectiveness of enhanced radial clearances alone in reducing the likelihood of ignitions is limited. Weather conditions can be a direct contributing factor to the probability of ignitions. For example, data has shown that the effectiveness of enhanced clearance diminishes during and after windy weather conditions. Additionally, the alteration of fuel loading under and adjacent to overhead conductors can provide additional risk-reduction benefits. Therefore, these may be considered as complementary risk control mechanisms.

Importantly, recognizing the differences between utility landscapes and land cover is crucial for effective risk management. As shown by the outage and ignition rates in this study, each utility has its own unique challenges related to risk due to differences in land cover. Utilities with significantly larger amounts of forested land face different and unique challenges compared to those with smaller service territories and less diverse land cover types. This study recommends utilities determine areas where historically higher wind gusts and drier fuel conditions may necessitate prioritization and frequency of inspection and tree pruning activities. Additional mitigation methods should be considered particularly in forest and shrubland areas. Such a strategy should consider location-specific treatments or enhanced clearance practices.

Establishing proper radial clearances at time of pruning is imperative to maintaining safety, compliance and reliability. The determination of proper clearance should take into account multiple factors including among others: species, growth rate, minimum clearance requirement, hazard abatement, line and tree movement, industry pruning standards, and tree health. There is a logical inference that increased clearances would result in reduced outages and, by association, ignitions. Indeed, recommendations set forth in General Order 95, Rule 35 state that radial clearances of 12 feet in the HFTD:

> *...are recommended minimum clearances that should be established, at time of trimming, between the vegetation and the energized conductors and associated live parts where practicable. Reasonable vegetation management practices may make it advantageous for the purposes of public safety or service reliability to obtain greater clearances than those listed below to ensure compliance until the next scheduled maintenance. Each utility may determine and apply additional appropriate clearances beyond clearances listed below, which take into consideration various factors, including: line operating voltage, length of span, line sag, planned maintenance cycles, location of vegetation within the span, species type, experience with particular species, vegetation growth rate and characteristics, vegetation management standards and best practices, local climate, elevation, fire risk, and vegetation trimming requirements that are applicable to State Responsibility Area lands pursuant to Public Resource Code Sections 4102 and 4293*.

The CPUC recommendation recognizes the establishment of enhanced clearances as a prudent method of preventing outages and ignitions that considers multiple and interrelated factors, and that this decision is made by professionals who understand and apply sound arboricultural practices. However, utility practices do not simply employ a radial clearance at time of pruning that is arbitrary or pre-determined. Rather, site-specific and tree-specific conditions should be considered to implement the most appropriate clearance to ensure compliance for the annual cycle.

This study also acknowledges the benefit of record keeping practices that connect tree related outage and ignition data to the work activity records to gain greater insight into clearance and trends in tree failure. By collecting higher frequency data over time utilities may identify patterns in vegetation growth and tree health. This will allow utilities to modify their clearance practices accordingly. Without sufficient data collection, opportunities for learning and improvement are reduced. It is recommended that each IOU make efforts to implement within their data records the ability to associate outage and ignition investigation information as part of their work activity history.

Finally, utilities, especially those with a large service territory, may benefit by leveraging remote sensing technologies such as LiDAR and satellite imagery to monitor clearance and tree health conditions. The evolution of vegetation management hinges on the development and effective use of data analytics, enabling a shift towards a more targeted and proactive vegetation mitigation strategy.

6 DISCUSSION ON COMBINED MITIGATIONS AND IMPLEMENTATIONS

The three IOUs' data sample, used in this study, does not holistically represent the effectiveness of combined mitigations. One of the main alternative mitigations is the use of covered conductor, which is used as an alternative to undergrounding and for the purpose of preventing ignitions caused by tree and power line contacts. Since covered conductor is a relatively recent engineering mitigation measure deployed by the IOUs, additional time will be required to further analyze its effectiveness combined with other mitigation measures.

Such mitigation strategies cannot be evaluated solely based on the cost-effectiveness of risk reduction. A key criterion is whether the combined mitigation can reduce the use of PSPS, enhance safety and reliability, and minimize impact to customers. Wildfires are one of the top risks facing Californians. However, a sustainable and reliable energy infrastructure is crucial for the future of electrification, social stability, economic growth, and long-term prosperity of the region.

The IOUs will explore further studies on alternative mitigations that involve enhanced tree pruning and associated lifecycle cost. The future implementation and milestones will depend on the effectiveness of this combined mitigation approach.

Appendix A: Supporting Data

Data Variables

Variable	Description
ANSI	American National Standards Institute
avg. ignition per 1000 miles	Total number of ignitions that occur over a given length of infrastructure and dividing it by the total miles of that infrastructure, multiplied by 1000.
avg. ignition rate per outage	Total number of ignitions divided by the total number of outages.
avg. outage rate per 1000 miles	Total number of outages that occur over a given length of infrastructure and dividing it by the total miles of that infrastructure, multiplied by 1000.
CPUC	California Public Utilities Commission
enhanced clearance	clearances of 12 feet and above
EPRI	Electric Power Research Institute
GO	General Order
HFTD	High Fire Threat District
HWW	high wind warning condition issued by the National Weather Service. A High Wind Warning is issued when sustained winds of 40 mph or higher are expected for at least an hour, or wind gusts of 58 mph or more are anticipated. "HWW" used in this paper are HWW conditions associated with winter storms and precipitation, without overlapped RFW conditions.
IOUs	investor-owned utilities: San Diego Gas & Electric Company (SDG&E), Pacific Gas and Electric Company (PG&E), and Southern California Edison Company (SCE)
land cover	In the context of the National Land Cover Database (NLCD), land cover refers to the physical material at the surface of the earth. The NLCD provides detailed land cover data at a 30-meter spatial resolution, which is used for various environmental, land management, and modeling applications.
NLCD	National Land Cover Database
Overhead Circuit Miles (OCM)	Overhead Circuit Mile (OCM) days is a metric collected in QDR Table 4. It measures the exposure of the overhead asset to a certain weather condition by using the product of time duration and circuit mile length. This can be used to understand some of the weather factors and general differences between each event or year.
PSPSs	Public Safety Power Shutoffs
QDR	Quarterly Data Reporting
RFW	Red Flag Warning issued by National Weather Service to alert areas of critical fire weather conditions, such as strong winds and low humidity, which could lead to extreme fire behavior.
SRA	State Responsibility Area
WUI	Wildland-Urban Interface

Supporting Data for Figure 1 and Table 1

Utility Name	Circuit Miles within the Service Territory	Developed	Forest	Shrub	Wetland	Working	Low Veg Cover	Unknown	Totals
PG&E	Circuit Miles (HFTD)	10,621	5,905	4,697	181	3,845	44		25,293
PG&E	Circuit Miles (non-HFTD)	32,911	279	649	411	20,069	166		54,485
Utility Name	**Outages (IOUs)**	**Developed**	**Forest**	**Shrub**	**Wetland**	**Working**	**Low Veg Cover**	**Unknown**	**Totals**
PG&E	Counts (HFTD)	6,128	7,968	1,064	97	563	49	376	16,245

PG&E	Counts (non-HFTD)	9,358	1,367	402	144	1,683	45	184	13,183
Utility Name	**Circuit Miles within the Service Territory**	**Developed**	**Forest**	**Shrub**	**Wetland**	**Working**	**Low Veg Cover**	**Unknown**	**Totals**
SCE	Circuit Miles (HFTD)	6,381	466	4,743	127	2,007	18		13,743
SCE	Circuit Miles (non-HFTD)	26,443	9	6,601	56	3,105	573		36,787
Utility Name	Outages (IOUs)	Developed	Forest	Shrub	Wetland	Working	Low Veg Cover	Unknown	total
SCE	Counts (HFTD)	728	125	95	5	33	1		987
SCE	Counts (non-HFTD)	2,262	2	14	0	62	14		2,354
Utility Name	**Circuit Miles within the Service Territory**	**Developed**	**Forest**	**Shrub**	**Wetland**	**Working**	**Low Veg Cover**	**Unknown**	**Totals**
SDG&E	Circuit Miles (HFTD)	1,338	72	1,607	61	296	3		3,378
SDG&E	Circuit Miles (non-HFTD)	2,799	1	115	9	22	5		2,950
Utility Name	**Outages (IOUs)**	**Developed**	**Forest**	**Shrub**	**Wetland**	**Working**	**Low Veg Cover**	**Unknown**	**Totals**
SDG&E	Counts (HFTD)	91	6	30	5	2	0		134
SDG&E	Counts (non-HFTD)	340	1	0	0	0	0		341

Supporting Data for Figure 2

Circuit Miles as of 2024Q1

SDG&E	HFTD	3,363
SDG&E	Non-HFTD	2,951
PG&E	HFTD	24,694
PG&E	Non-HFTD	55,243
SCE	HFTD	9,439
SCE	Non-HFTD	28,381

Distribution – No RFW or HWW

Outages	Tier	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
SDG&E	HFTD	7	15	11	5	6	4	6	3	0	0	57
SDG&E	Non-HFTD	18	33	17	16	20	24	23	68	51	0	219
PG&E	HFTD	2005	2310	3752	1714	4304	2134	2503	1263	2086		19985
PG&E	Non-HFTD	1695	2059	3540	1496	2954	1577	4221	2324	7548		19866
SCE	HFTD	85	153	127	84	168	66	74	63	112		820
SCE	Non-HFTD	287	355	277	182	276	152	201	187	0	240	1917

Distribution – No RFW or HWW

Outages	Tier	HFTD%	Non-HFTD%	Average	Annualized HFTD%	Annualized non-HFTD%
SDG&E	HFTD	0.21		7	0.21	
SDG&E	Non-HFTD		0.79	27		0.79
PG&E	HFTD	0.50		2498	0.50	
PG&E	Non-HFTD		0.50	2483		0.50
SCE	HFTD	0.30		103	0.30	
SCE	Non-HFTD		0.70	240		0.70

Supporting Data for Figure 3

Distribution – RFW Days

Outages	Tier	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
SDG&E	HFTD	0	0	4	7	0	1	0	0	0		12
SDG&E	Non-HFTD	0	0	3	5	2	1	0	0	0	0	11
PG&E	HFTD	4	1	118	51	21	142	64	4	2		405
PG&E	Non-HFTD	5	1	123	26	254	155	163	35	0	0	762
SCE	HFTD	0	5	50	19	9	16	9	0	2		108
SCE	Non-HFTD	0	14	67	92	35	41	24	0	3	0	273

Distribution – RFW Days

Outages	Tier	HFTD%	Non-HFTD%	Average if not 0	HFTD%	Non-HFTD%
SDG&E	HFTD	0.52		4	0.59	
SDG&E	Non-HFTD		0.48	3		0.41
PG&E	HFTD	0.35		51	0.35	
PG&E	Non-HFTD		0.65	95		0.65
SCE	HFTD	0.28		18	0.28	
SCE	Non-HFTD		0.72	46		0.72

Distribution – HWW Only Days

Outages	Tier	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
SDG&E	HFTD	1	2	7	0	0	1	1	4			16
SDG&E	Non-HFTD	1	11	28	2	0	0	7	1			50

Outages	Tier	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
PG&E	HFTD	22	37	402	1	341	0	358	7	0	167	1168
PG&E	Non-HFTD	13	23	245	2	291	3	267	7	0	106	851
SCE	HFTD	11	14	17	3	10	19	3	6			83
SCE	Non-HFTD	18	16	80	31	20	12	3	2			182

Distribution – HWW Only Days

Outages	Tier	HFTD%	Non-HFTD%	Average if not 0	HFTD%	Non-HFTD%
SDG&E	HFTD			3	0.24	
SDG&E	Non-HFTD			8		0.76
PG&E	HFTD	0.58		167	0.61	
PG&E	Non-HFTD		0.42	106		0.39
SCE	HFTD	0.31		10	0.31	
SCE	Non-HFTD		0.69	23		0.69

Supporting Data for Figure 4

Utility	Year	Outages – no HWW or RFW	Outages – HWW Only	HWW OCM Days
PG&E	2015	3700	35	2394
PG&E	2016	4369	60	28023
PG&E	2017	7292	647	140758
PG&E	2018	3210	3	3997
PG&E	2019	7258	632	83182
PG&E	2020	3711	3	4862
PG&E	2021	6724	625	11470
PG&E	2022	3587	14	3235
SCE	2015	372	29	78965
SCE	2016	508	30	116378
SCE	2017	404	97	144820
SCE	2018	266	34	133880
SCE	2019	444	30	95208
SCE	2020	218	31	127914
SCE	2021	275	6	117529
SCE	2022	250	8	168192
SDG&E	2015	25	2	51232
SDG&E	2016	48	13	13752
SDG&E	2017	28	35	107922
SDG&E	2018	21	2	53298

Utility	Year	Outages – no HWW or RFW	Outages – HWW Only	HWW OCM Days
SDG&E	2019	26	0	26852
SDG&E	2020	28	1	25667
SDG&E	2021	29	8	44509
SDG&E	2022	29	5	20708

Source: WMP QDR 2022 Q3 and Q4 Table 6 - High wind warning overhead circuit mile days

Supporting Data for Table 5

Utility			2015	2016	2017	2018	2019	2020	2021	2022
PG&E	Ignitions	Ignitions - HFTD	62	63	101	68	62	65	66	42
		Ignitions - non- HFTD	45	45	76	57	76	63	75	59
		avg. ignition per 1000 miles - HFTD	2.51	2.55	4.09	2.75	2.51	2.63	2.67	1.70
		avg. ignition per 1000 miles - non- HFTD	0.81	0.81	1.38	1.03	1.38	1.14	1.36	1.07
	Ignition rate per outage	avg. ignition rate per outage- HFTD	0.03	0.03	0.02	0.04	0.01	0.03	0.02	0.03
		avg. ignition per outage - non-hftd	0.03	0.02	0.02	0.04	0.02	0.04	0.02	0.02
SCE	Ignitions	Ignitions – HFTD	6	5	6	5	3	3	8	7
		Ignitions - non- HFTD	7	7	10	10	10	8	12	7
		avg. ignition per 1000 miles - HFTD	0.63	0.53	0.63	0.53	0.32	0.32	0.84	0.74
		avg. ignition per 1000 miles - non- HFTD	0.25	0.25	0.35	0.35	0.35	0.28	0.42	0.25
	Ignition rate per outage	avg. ignition rate per outage- HFTD	0.06	0.03	0.03	0.05	0.02	0.03	0.09	0.10
		avg. ignition per outage - non-HFTD	0.02	0.02	0.02	0.03	0.03	0.04	0.05	0.04
SDG&E	Ignitions	Ignitions - HFTD	5	2	2	0	1	0	0	1
		Ignitions - non- HFTD	0	2	1	3	0	1	0	0
		avg. ignition per 1000 miles - HFTD	1.49	0.59	0.59	0.00	0.30	0.00	0.00	0.30
		avg. ignition per 1000 miles - non- HFTD	0.00	0.68	0.34	1.02	0.00	0.34	0.00	0.00
	Ignition rate per outage	avg. ignition rate per outage- HFTD	0.63	0.12	0.09	0.00	0.17	0.00	0.00	0.14
		avg. ignition per outage - non-HFTD	0.00	0.05	0.02	0.13	0.00	0.04	0.00	0.00

Supporting Data for Figure 5

Year	Outage Rate* when Clearance is Less Than12 ft	Outage Rate* when Clearance is Greater Than or Equal to 12 ft
2007	5.63	5.25
2008	3.15	0
2009	4.43	3.56
2010	7.25	4.97
2011	3.48	1.56
2012	2.69	1.59
2013	1.62	1.49
2014	2.59	4.41
2015	1.04	2.95
2016	1.62	1.35
2017	5.55	0
2018	2.81	3.64
2019	1.78	1.07
2020	3.02	0
2021	2.43	2.02
2022	2.96	2.12
2023	5.87	4.29
2024	1.75	2.1

**Outages Rate per 100,000 trees*

Appendix B: Model Output and Interpretation

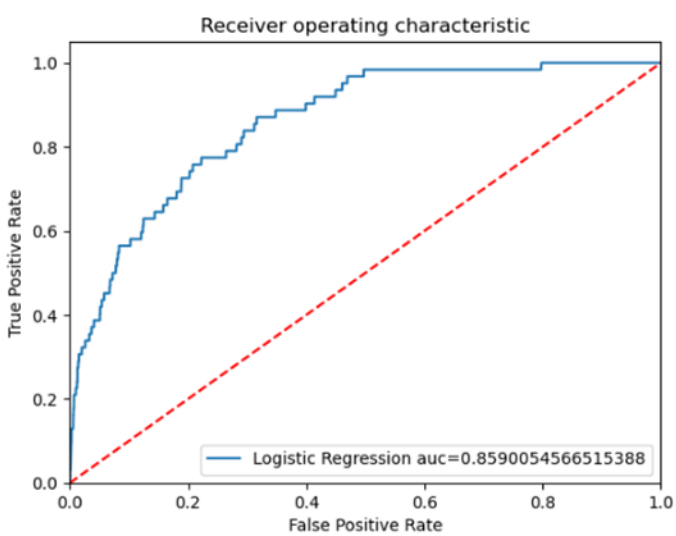
Sensitivity Analysis for Enhanced Clearance

The Vegetation Management Analytics repository contains three scripts essential for completing the dataset for sensitivity analysis. The first script retrieves and cleans vegetation management data from 2006 onwards, writing the output to S3. The second script separates outage data from other activities, linking outages to previous activities to analyze their impact on outage probability, and writes the processed data to S3. The third script prepares this data for modeling by correcting values, reducing features, and encoding variables, then generates a classification model to predict outcomes based on adjusted line clearance distances. The analysis uses Logistic Regression from scikit-learn package 1.2.0, considering factors like target species, vegetation management area, tree growth rate, Last Line Clearance Distance, Tree Diameter at Breast Height, Tree Height, Enhanced Clearance (Yes/No above 11 ft).

The sensitivity analysis examines the impact of changing line clearance distances for the test set (2023 & 2024). If the line clearance distance for a FacilityId was greater than 11 feet, it was reduced to 11 feet. The same threshold value was used to identify predicted outages versus no outages. The confusion matrix distribution from the actual test set was used to estimate potential mitigated vegetation-related outages.

Model Performance

AUC Curve



Threshold value was selected based on maximizing True Positives while also minimizing the False Positive rate (.0000700986). Used the Model that was generated from the Training dataset and Test performance on years not used for training (2023 & 2024).

2023 & 2024 Test

	Outage	No Outage	Total
Predicted Outage	47	162,971	163,018

	Outage	No Outage	Total
Predicted No Outage	15	610,267	610, 282
Total	62	773,238	773,300

Accuracy: 78.9%

Recall: 75.8%

Total Observations returned with positive prediction: 21.1%

Although this model is not perfect, it does appear it is capturing risk for the trees that did experience vegetation related outage in the following year. We can change underlying data values to understand the impact a variable may have on a FacilityId's risk probability. As data is changed, for this analysis it was assumed that the distribution of Outage and No Outage across Predicted Outage and Predicted Outage would be the same.

2023 & 2024 Distribution	Outage	No Outage	Total
Predicted Outage	0.000288	.999712	163,018
Predicted No Outage	0.000025	.999975	610,282

Sensitivity Analysis

The Sensitivity Analysis was done to understand Line Clearance distance's impact on a trees risk probability score. Line Clearance Distance was changed for the Test set (2023 & 2024). If FacilityId Line Clearance >11 (enhanced clearance) then it was reduced to 11. The same threshold value (0.0000700986) was used to identify if a FacilityId in the Test Set (changed data) was Predicted Outage vs Predicted No Outage. The Confusion matrix distribution from the actual test set was used to estimate potential mitigated Vegetation related outages.

Below is the estimated impact on outages by bringing observations with enhanced clearances down to 11 feet.

2023 & 2024 Changed Data	Outage	No Outage	Total
Predicted Outage	62.8 (calculated)	217,955.2 (calculated)	218,018 (from model)
Predicted No Outage	13.9 (calculated)	555,237.1 (calculated)	555,251 (from model)
Total	76.7	733,192.3	773,300

Difference in Outages: 76.7 (Sensitivity Analysis Outage count) - 62 (Actual Outage count) = ~15 (14.7) potential mitigated outages

The same analysis was done but separately by years of data as there was significant outage differences from 2023 to 2024.

2023 & 2024 Test Performance by Year

2023 Test Performance	Outage	No Outage	Total
Predicted Outage	35	78,263	78,298
Predicted No Outage	10	308,065	308,075
Total	45	386,328	386,373

2024 Test Performance	Outage	No Outage	Total
Predicted Outage	12	84,708	84,720
Predicted No Outage	5	302,202	302,207
Total	17	386,910	386,927

Below is the percentage distribution for each group calculated from performance of the machine learning model.

2023 % Distribution	Outage	No Outage	Total
Predicted Outage	0.0004470	.999553	78,298
Predicted No Outage	0.0000326	.999968	308,075

2024 % Distribution	Outage	No Outage	Total
Predicted Outage	0.0001416	.999858	84,720
Predicted No Outage	0.0000165	.999983	302,207

Same assumed performance distribution is used to understand potential mitigated outages.

2023 Changed Data	Outage	No Outage	Total
Predicted Outage	47.5	106,271.5	106,319
Predicted No Outage	9.1	280,044.9	280,054
Total	56.6	386,316.4	386,373

2024 Changed Data	Outage	No Outage	Total
Predicted Outage	15.8	111,714.2	111,730
Predicted No Outage	4.6	275,192.4	275,197
Total	20.4	386,906.6	38,6927

By year total Predicted outage = 77, actual outage count for the same period is 62, looking at it by year this analysis shows that potential outages mitigated by enhanced clearance over two years is 15. By year this would be a difference of 11.6 outages in 2023 and 3.4 outages in 2024.

Table 9

Plan for implementation of Results from Third-Party (TP) Study and White Paper (WP).

ID	Recommendation	Milestones	Timeline
TP01	Standardizing vegetation management data (e.g., inspection and trim records) would provide additional information about the clearances that are achieved more broadly for primary overhead circuits and would allow for more robust analyses of clearance effectiveness.	PG&E has updated its inspection records to now include the clearance that the inspector observes at time of inspection as well as the clearance that the tree crew observes before they perform the prescribed work.	N/A
TP02	Outage investigation reports did not include an estimate of radial clearance at the time of the outage for two of the three IOUs. Adding this estimate to the outage investigation report for all IOUs would provide valuable information to future analyses of clearance effectiveness.	PG&E has updated its outage investigation process to now include the estimated radial clearance at time of outage.	N/A
TP03	Implement a time-series, grid-type analysis. This analysis will leverage weather and landcover data, dividing utility service territories into grid cells for detailed evaluation over time.	PG&E already has a wildfire distribution risk model that incorporates fire science, meteorology, and satellite data into a grid type analysis this Is used to inform risk at the circuit protection segment level. PG&E will continue to explore any updated time-series data for future model versions of wildfire distribution risk models.	N/A
WP01	It is recommended that each IOU make efforts to implement within their data records the ability to associate outage and ignition investigation information as part of their work activity history.	PG&E has updated its incident investigation process to allow the individual performing the investigation to record if the tree associated with the incident has a previous work activity history.	Q1 2025
WP02	Utilities may also additionally benefit from the monitoring of vegetation conditions and clearance by leveraging remote sensing technologies, especially	PG&E has been developing its remote sensing capabilities over the last several years which includes pilots with satellite imagery. Satellite imagery has been	2025 Planned collection of satellite

ID	Recommendation	Milestones	Timeline
	those with larger service territories. By collecting higher frequency data over time utilities may identify patterns in vegetation growth and tree health and measure the minimal clearance based on outage and ignition rates associated with specific circuits or segments to enhance situational awareness. This will allow utilities to modify their clearance practices accordingly. Without data collection, opportunities for learning and improvement are reduced.	collected on all PG&E overhead electric assets within the HFTD to evaluate its capability to provide radial clearance distances, tree health, and other vegetation analytics. PG&E will continue to evaluate different remote sensing technology and to identify the optimal technology locations for its deployment.	on system wide overhead electric assets for Transmission and Distribution
WP03	This study recommends identifying locations with historically higher wind gusts and drier fuel conditions to inform of the risk and prioritization of inspection and clearance activities. The strategy should consider location-specific treatments or enhanced clearance practices. Additional mitigation methods should be considered particularly in forest and shrubland areas. Additionally, the establishment of radial clearance at time of pruning should consider multiple factors such as species, growth rate, hazard abatement, industry standards, and tree health.	PG&E already has a wildfire distribution risk model that incorporates meteorology data like wind direction and strike potential, as well as dead fuel moisture. Based on the wildfire distribution risk model, PG&E already targets locations for additional inspection and clearance activities. To maintain compliance with applicable regulation, trees are assessed on an individual basis and multiple factors are considered such as species, health, location, growth rate, etc. when determining if a tree requires mitigation and the subsequent prescription for work based on the need for mitigation.	N/A