OFFICE OF ENERGY INFRASTRUCTURE SAFETY

WILDFIRE SAFETY ADVISORY BOARD

STAFF DRAFT: RECOMMENDATIONS TO THE OFFICE OF ENERGY INFRASTRUCTURE SAFETY

APRIL 2025

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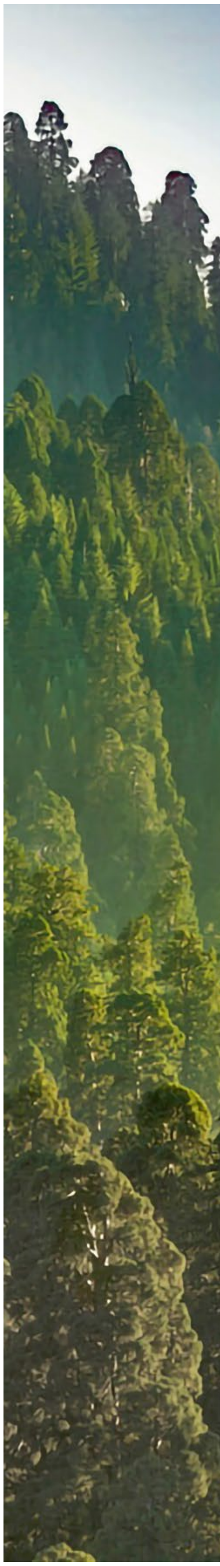
Under California Public Utilities Code (PUC) sections 326.2 and 8389, the Wildfire Safety Advisory Board (WSAB or the Board) must make annual recommendations to the Office of Energy Infrastructure Safety (Energy Safety) by June 30. WSAB responds to that legal requirement with this report. The report explores measures of effectiveness of utility wildfire risk mitigation practices, examines investor-owned utilities' (IOUs) wildfire risk models, and briefly describes developments in safety culture assessment. The recommendations included in this report were developed based upon literature reviews, data analysis, IOU submissions, and expert interviews.

Board staff explored measures of effectiveness of utility wildfire risk mitigation including overall effectiveness (trends in fires and ignitions) and the effectiveness of specific mitigation measures. Board staff analyzed data on power generation/transmission/distribution-caused wildfires from the California Department of Forestry and Fire Protection and utility ignitions submitted by IOUs. The data show no strong trend in fires or in ignitions overall, but a decline in ignitions within high fire-threat district. Key challenges to independent analysis of effectiveness include data limitations, weather variability, overlapping implementation of multiple mitigations, and variation in program design and data reporting. To improve transparency, WSAB recommends that Energy Safety require the IOUs to include additional reporting of fire weather indices and provide a clearer tracking of mitigation outcomes. WSAB also recommends that Energy Safety establish consistent metrics for comparing initiatives across utilities.

Utilities use wildfire risk modeling for operational and mitigation planning. Although they continue to develop and advance these models, uncertainty is intrinsic to modeling. Therefore, WSAB recommends that the next advancements in these models more explicitly acknowledge and report their uncertainty. WSAB recommends that Energy Safety require IOUs to test and compare multiple wildfire spread models, including open-source alternatives; report risk distributions, rather than single values; and provide data and risk model results with the appropriate levels of precision.

The California Public Utilities Commission recently adopted a Safety Culture Assessment Framework and established a Utility Safety Culture Working Group. The Board recommends that Energy Safety work with California Public Utilities Commission staff to include Board staff in the Utility Safety Culture Working Group.



2 INTRODUCTION

WSAB is required by PUC sections 326.2 and 8389 to make recommendations to Energy Safety on appropriate performance metrics and processes for determining electrical corporation compliance with its wildfire mitigation plan, appropriate requirements for wildfire mitigation plans, and the appropriate scope and process for assessing the safety culture of an electrical corporation by June 30 annually. This document is a report to meet that legal requirement.

The devastating Palisades and Eaton fires of January 2025 occurred while Board staff was preparing this report. At present, investigators have not made a determination of the cause of either fire. Nonetheless, the recurrence of catastrophic wildfires in California reinforces the importance of the Board's mission, "to advise and make recommendations to reduce the risk of utility related wildfires."[1]

2.1 About the Wildfire Safety Advisory Board

PUC section 326.1 established WSAB, a seven-member body of wildfire and utility policy experts appointed by the Governor, Speaker of the Assembly, and Senate Committee on Rules. PUC sections 326.2 and 8389 mandate that WSAB develop and make annual recommendations to Energy Safety as described above. The Board also reviews and provides comments and advisory opinions to each local publicly owned electric utility (POU) and electrical cooperative regarding the content and sufficiency of its wildfire mitigation plan and recommendations on how to mitigate wildfire risk. Each member of the Board brings a unique perspective and their own expertise. Additional information about the Board, its members, and its prior recommendations, advisory opinions, and meetings can be found on the Board website: https://energysafety.ca.gov/what-we-do/wildfire-safety-advisory-board/.

The current members of the Wildfire Safety Advisory Board are:

- Ralph Armstrong
- Marybel Batjer
- Jessica Block, Chair
- Timothy Haines
- John Mader
- Chris Porter, Vice Chair
- Dr. Alexandra Syphard

2.2 Wildfire Safety Advisory Board Workstreams

[1] Wildfire Safety Advisory Board, "2024–2027 Strategic Plan," 2024, https://energysafety.ca.gov/wp-content/uploads/2024/06/2024-2027-wsab-strategic-plan-1.pdf.

Board staff presented a prioritized Work Plan to the Board at its September 4, 2024, meeting.[2] The Work Plan described seven workstreams. Among those workstreams were the development of this report, as well as workstreams on the effectiveness of grid hardening and vegetation management and on risk modeling. The workstreams on effectiveness of grid hardening and vegetation management and risk modeling resulted in sections 3 and 4 of this report.

2.3 Wildfire Risk

Wildfire risk can be divided into components. For example, the United States Forest Service (USFS) uses a framework that risk equals hazard times vulnerability.[3] In Energy Safety's Wildfire Mitigation Plan (WMP) Guidelines[4] risk is decomposed into likelihood and consequence, where consequence combines hazard intensity, exposure potential, and vulnerability. For consistency with IOU-submitted WMPs, in this report Board staff uses the WMP Guidelines' decomposition.

Wildfire likelihood and consequence are not independent, but can have common drivers. For example, strong winds can simultaneously increase the potential consequence of an ignition by accelerating fire spread and increase the likelihood of some ignitions, e.g., by moving vegetation into contact with conductors.

2.4 Structure of This Report

Following this introduction are sections explaining the process, findings, and recommendations for the workstreams on effectiveness (Section 3) and on risk modeling (Section 4). Section 5 updates the Board's activity on safety culture assessment.

3 EFFECTIVENESS OF RISK MITIGATION

An era of utility wildfire risk mitigation began in California after catastrophic utility-caused wildfires in 2017 and 2018. Utilities wrote the first wildfire mitigation plans in 2019 and began implementation in 2020. Utilities have spent billions of ratepayer dollars on mitigation activities. The Board, along with many others, wants to know whether the mitigation activities implemented by the IOUs have been effective, in order to prioritize and shape future recommendations. In particular, Board members asked Board staff to examine grid hardening and vegetation management. Board staff reviewed IOU WMPs and academic studies and also conducted interviews with subject matter experts.

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[2] Wildfire Safety Advisory Board, "*Draft Work Plan and Implementation Plan*," (2024), https://energysafety.ca.gov/wp-content/uploads/2024/11//work-plan-and-implementation-plan-1.pdf.

[3] USDA Forest Service, "Understand Risk," https://wildfirerisk.org/understand-risk/.

[4] Office of Energy Infrastructure Safety, *Wildfire Mitigation Plan Guidelines*, (2025), https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=58026&shareable=true

Board staff considered several ways to measure effectiveness. Reduction in wildfire risk is impossible to measure directly. Wildfire risk modeling is an important tool but provides calculated results rather than a measurement. Metrics for overall effectiveness include:

- The number of utility-caused fires
- Utility-related ignitions, statewide and in the high fire-threat district
- Consequence metrics for utility-caused fires, including casualties, number of structures burned, acres burned, and value of losses

Utilities also measure and report metrics on overall effectiveness, as well as the effectiveness of specific mitigation activities, e.g., replacing bare conductor with covered conductor.

One way to measure effectiveness, either overall or for a specific mitigation activity, would be to compare the number of events before and after the activity. For a variety of reasons, discussed more in Section 3.2, it is challenging to measure utility wildfire mitigation effectiveness in that way.

Whether mitigation has been *sufficiently* effective is a question beyond the scope of this report. Even if there has been progress in risk mitigation, the remaining level of risk may still be higher than is acceptable. The California Public Utilities Commission (CPUC) is among those to recognize this issue; it is currently reviewing and seeking comment on "risk tolerance" in an open proceeding.[5]

3.1 Definitions of Effectiveness

Reducing utility-related wildfire risk could include reducing both likelihood and consequence. In practice, most attention and investment has been directed to reducing the likelihood of ignition, e.g., through vegetation management, grid hardening, and operational mitigations such as public safety power shutoffs (PSPS) and protective equipment and device settings (PEDS). Utilities do consider potential consequence when deciding under what circumstances to reduce ignitions through PSPS and PEDS, and when deciding the type and priority of planning mitigations such as grid hardening. Further, there are also utility initiatives that reduce consequence post-ignition. Examples include funding wildfire-spotting camera networks, coordinating with firefighting agencies, community outreach and awareness efforts, and in some cases, fuels management. For example, Liberty Utilities collaborates with the USFS on powerline "resilience corridors"[6] to reduce fuels along its infrastructure beyond its right-of-way.

In the development of this report, Board staff also focused its attention on the likelihood of an event, by measuring how many events occur rather than measures of consequence, such as the size (acreage) or impact of events. This is for two major reasons. First, consequence

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[5] California Public Utilities Commission, Risk-Based Decision-Making Framework (RDF): R 20-07-013, https://www.cpuc.ca.gov/about-cpuc/divisions/safety-policy-division/risk-assessment-and-safety-analytics/r-20-07-013.

[6] Lake Tahoe Info, Project 02.01.02.0014 - Liberty Utilities Resilience Corridors Project, https://www.laketahoeinfo.org/Project/Detail/4192.

depends on variables including weather and climate conditions, suppression, and community and individual actions to limit spread and harden structures. Reducing ignitions is more within the primary historical role of utilities in constructing, operating, and maintaining infrastructure than reducing consequences. Second, smaller, lower consequence fires are more common while high-consequence fires are rarer. Consequence measures are dominated by the impacts of a few high-consequence events. This can obscure trends. For example, a year with one high-consequence event followed by a few years without any could look like a decline in wildfire consequence. Such a "decline" may not represent a real change in risk.

3.2 Effectiveness Metric: Fires Caused by Power Generation/Transmission/Distribution

One way to measure the effectiveness of utility wildfire risk mitigation is by analyzing annual wildfire data. The California Department of Forestry and Fire Protection (CAL FIRE) publishes data about California wildfires in annual Wildfire Activity Statistics reports, commonly called Redbooks.[7] The Redbooks are "primarily a statistical record of wildfire incidents responded to by CAL FIRE personnel and resources."[8]

Redbook data are divided by wildfire cause. The fire cause categories are arson, campfire, debris burning (commercial/residential use), power generation/transmission/distribution, equipment use, lightning, playing with fire, railroads, smoking, vehicles, miscellaneous (explosive devices, fireworks, glass refraction, shooting, spontaneous combustion), and undetermined.

The cause attribution allows Board staff to look at trends in the number of "power generation/transmission/distribution" fires. It also allows for the comparison of fires caused by utilities and those from other causes. In theory, this could be a simple weather normalization. For example, if years with higher precipitation have fewer fires overall, then a reduction in power generation/transmission/distribution fires may be more an effect of fire season length, fuel moisture, etc., than of utility mitigations.

Redbook data has limitations. One is that the Redbooks include only data on incidents that CAL FIRE responded to in the State Responsibility Area (SRA). This leaves out data for ignitions that federal and local agencies responded to. A second is that Redbook numbers covering utility ignitions also include other electrical power ignitions, including residential ignitions. From 2008–2012, the category of "Power Lines" represented power

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[7] California Department of Forestry and Fire Protection, "Statistics," last modified February 24, 2025, https://www.fire.ca.gov/our-impact/statistics.

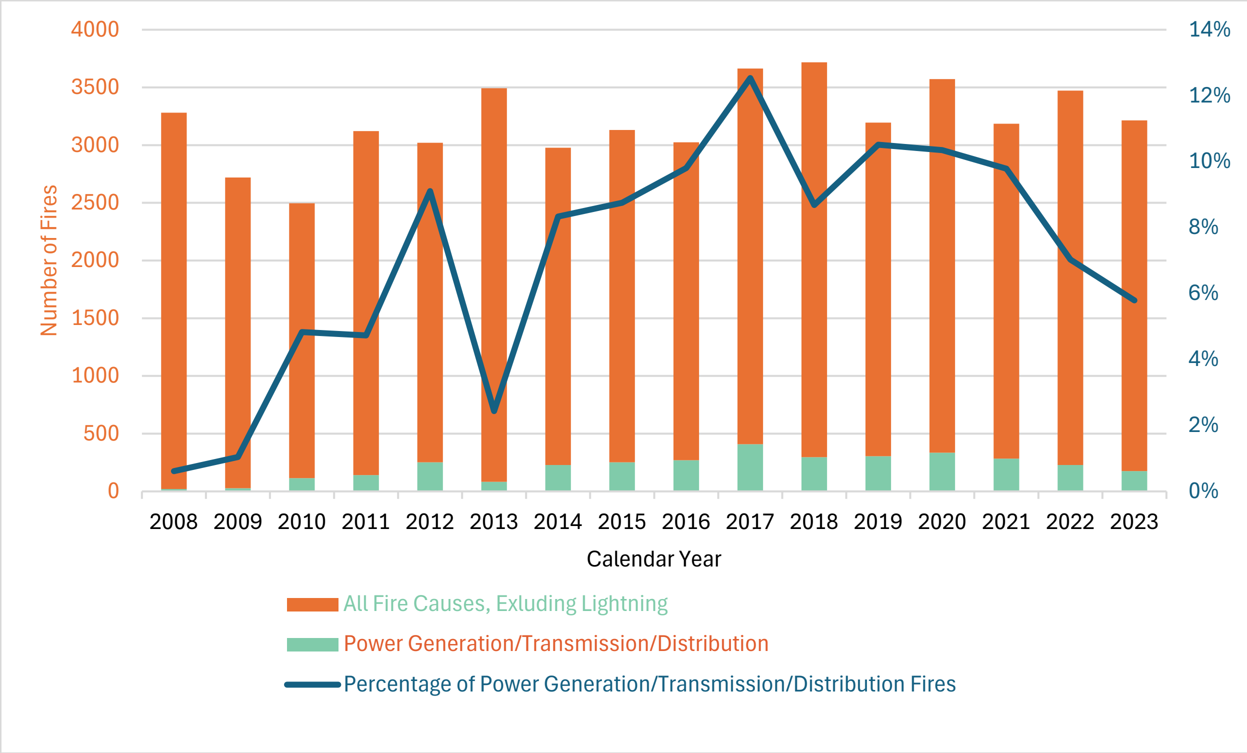
[8] California Department of Forestry and Fire Protection, *2022 Redbook: Wildfire Activity Statistics* (Sacramento: California Department of Forestry and Fire Protection, 2022), https://34c031f8-c9fd-4018-8c5a-4159cdff6b0d-cdn-endpoint.azureedge.net/-/media/calfire-website/misc-doc/2022-redbook---wildfire-activity-statistics.pdf?rev=1c2ac22a02b24a66b42d638024e3c0e5&hash=77EE5093000CF6BF793B703BF951CC26.

generation/transmission/distribution fires in the Redbooks. The category name was changed to "Electrical Power" for 2013–2022. The category name was changed again in the 2023 Redbook to "Power Generation/Transmission/Distribution." This was part of an effort to better identify electric utility ignitions in the back-end data, but this broader category still included other electrical ignitions, including some residential ignitions (e.g., malfunctioning extension cords, yard lights, pumps, etc.). The Redbook numbers are helpful in that they can provide an idea of electric utility ignitions that occurred for a given year, but they are still somewhat higher than the number of electric utility ignitions in the underlying source data used to create the Redbooks and should be treated as only approximate.

Figure 1 shows the annual number of power generation/transmission/distribution fires and all fires excluding lightning. Board staff excluded lightning as a fire cause in this study because it is naturally occurring and highly variable, and because of this, may obscure any signal in human-caused fires. There was a general increase in the number and percentage of power generation/transmission/distribution fires from 2008–2017, before the first wildfire mitigation plans. In 2022 and 2023, the data show lower numbers and percentages of power generation/transmission/distribution fires.

Perhaps surprisingly, the total number of fires per year generally stays the same. It does not correlate with precipitation. Therefore, any discussion of weather's impact on ignitions and fires must be in greater depth than whether a year was wet or dry.

Figure 1. Fires from Power Generation/Transmission/Distribution



3.3 Effectiveness Metric: Ignitions

Both the CPUC and Energy Safety require utilities to report ignitions data. The CPUC requires utilities to report "all equipment-related ignitions that meet the following criteria:

1. A self-propagating fire of material other than electrical and/or communication facilities, and
2. The resulting fire traveled greater than one linear meter from the ignition point, and
3. The utility has knowledge that the fire occurred." [9]

Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric Company (SGD&E) have reported ignition data to the CPUC annually since 2014. The data include the ignition date, time, location, and material at origin, land use at origin, size, suppressor/suppressing agency, utility facility information, outage, and field observations.

Utilities are also required to report to Energy Safety ignitions that meet the following criteria:

1. An electrical-corporation caused fire that requires fire suppression or

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[9] California Public Utilities Commission, *Decision Approving the California Advanced Services Fund 2021-2022 Program*, Decision 21-06-036 (San Francisco: California Public Utilities Commission, 2021), https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M087/K892/87892306.PDF.

2. If a government investigation is determining if an electrical-corporation's infrastructure caused a fire[10]

The IOUs report ignitions data to Energy Safety in quarterly data reports (QDRs) and include the year, quarter, HTFD tier, risk driver, and relevant details. The data reported to Energy Safety cover 2015–present. Figure 2 shows the ignitions data from both the CPUC and Energy Safety. Despite the differences in reporting criteria from the CPUC and Energy Safety, the patterns and trends are similar in the two data sets. Subsequent figures show data IOUs reported to Energy Safety.

Figure 2. Comparison of Ignition Data Reported to CPUC and Energy Safety

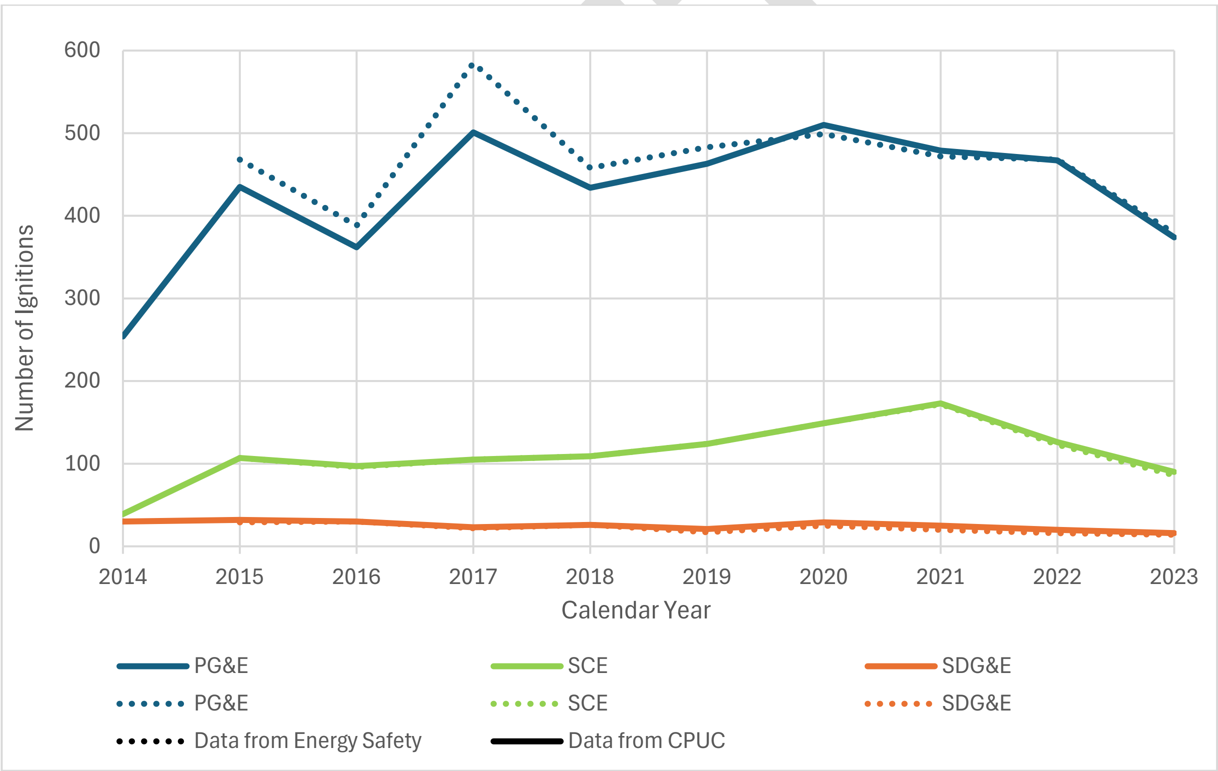
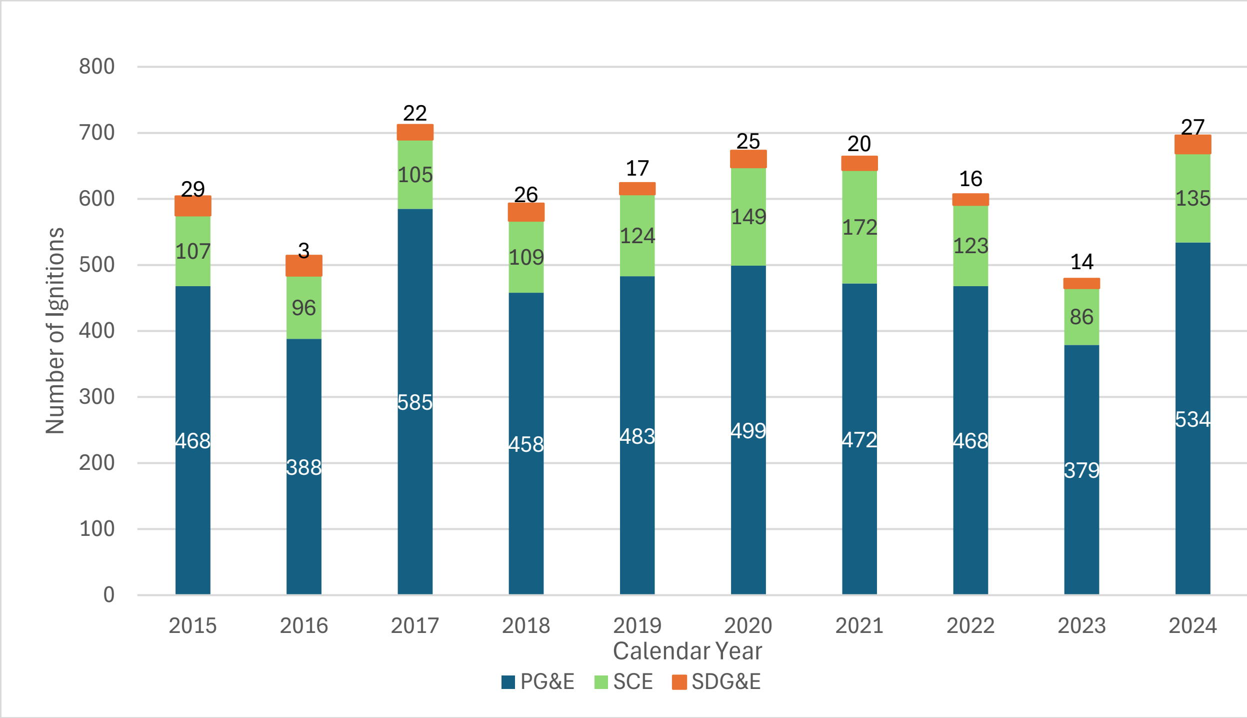


Figure 3 shows the number of ignitions for PG&E, SCE, and SDG&E from 2015–2024. As in the fire data, the ignitions data show lower ignitions in 2022 and 2023. However, the data show a large increase in ignitions in 2024 for all large IOUs.

[10] California Code of Regulations, Title 14, Section 29300.

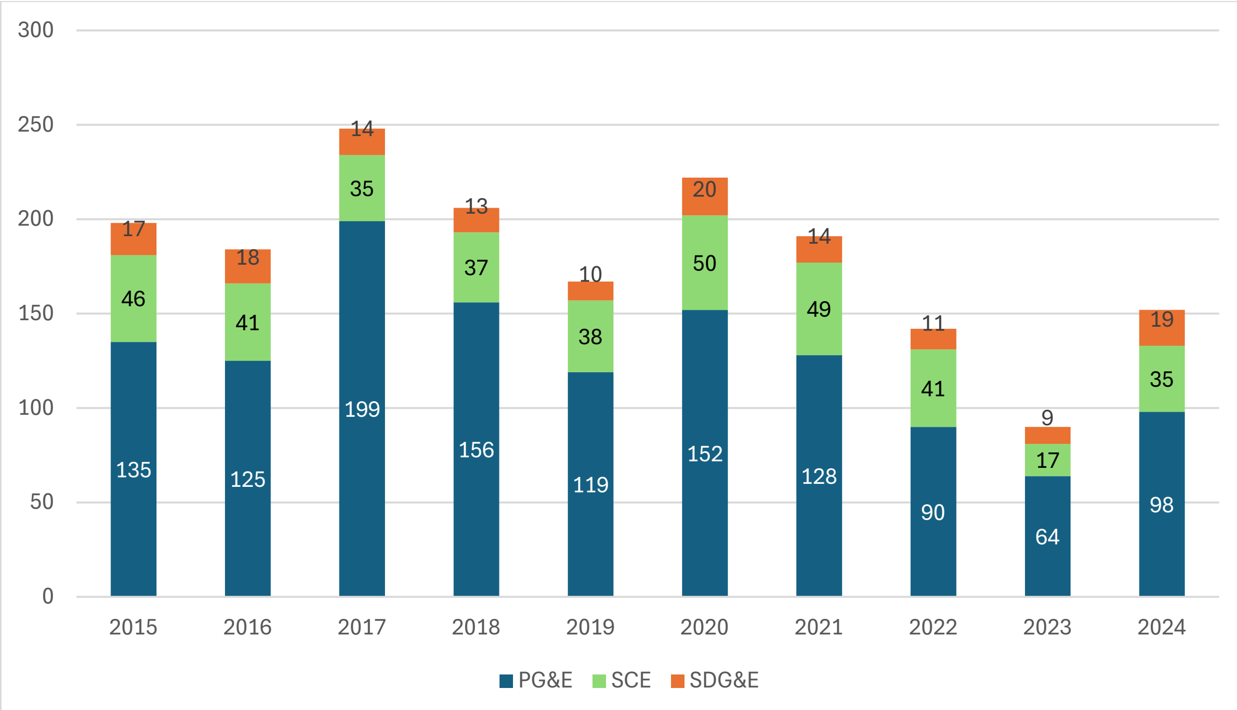
Figure 3. Large IOU Ignitions



The CPUC delineated the High Fire Threat District (HFTD) "that encompasses (a) areas where there is an elevated hazard for utility-associated wildfires occurring and spreading rapidly, and (b) communities that face elevated risks from utility-associated wildfires."[11] Given the higher risk, utilities, regulators, and other stakeholders often focus more attention on actions within the HFTD. For example, certain CPUC regulations on wildfire safety apply only within the HFTD. As noted above, the ignitions data provided to Energy Safety include whether each ignition is withing the HFTD. Figure 4 shows the number of ignitions reported by the three large IOUs in the HFTD. Board staff observes a trend in the decline of ignition incidents of IOUs in the HFTD from 2020–2023, with 2023 recording the lowest number of incidents in the last 9 years. However, the number of ignitions within the HFTD rebounded in 2024.

[11] California Public Utilities Commission, "Decision Adopting a Work Plan for the Development of Fire Map 2," Decision 17-01-009, January 19, 2017, https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M172/K762/172762082.PDF, 62.

Figure 4. Large IOU Ignitions in the High Fire-Threat District



3.3 Challenges in Evaluating Mitigation-Specific Effectiveness

Board staff identified several challenges in independently evaluating the effectiveness of grid hardening and vegetation management strategies.

3.3.1 Data Limitations

The number of reported ignitions is several hundred per year. This is a reasonable though not large sample size for effectiveness. However, once the ignitions are further divided, for example, by mitigation activity (grid hardening, enhanced vegetation management, etc.) and time (pre- and post-implementation), the numbers of ignitions before and after a mitigation quickly become too small for simple comparisons. Fluctuations in ignition data before and after implementation may not reflect the actual risk reduction achieved.

Utilities track and analyze outage data, using the reduction in outage numbers to measure the effectiveness of wildfire mitigation strategies. However, there are limitations in using outage data to measure the effectiveness of mitigation efforts. First among them is that there are multiple potential causes for outage events, not all of which are associated with wildfire risk. For example, a weather-related outage during a winter storm may have a low fire risk. Conversely, grid hardening against wildfire risk should sometimes, but not always, reduce outages, further obscuring a signal. An example would be replacing non-exempt fuses with exempt fuses of the same rating. Utilities work to account for these in their analysis. However, a completely independent review and evaluation would require significant resources, exceeding those available to Board staff at this time.

3.3.2 Weather Variability

Weather plays a crucial role in the ignition of wildfires. Wind speed and direction, humidity, and fuel moisture can significantly impact fire risk. Many groups have developed fire weather indices to condense multiple sources of information into simpler forms. For example, the Fire Weather Indices Wiki collects "some twenty of the most well-known" fire weather indices. [12] The USFS provides Wildland Fire Potential Index, Wildland Large Fire Probability, and Wildland Fire Spread Possibility forecasts.[13] The WMP Guidelines state that, "[t]he electrical corporation must describe its process for calculating its fire potential index (FPI) or a similar a landscape scale index used as a proxy for assessing real-time risk of a wildfire under current and forecasted weather conditions."[14]

To account for weather in measuring effectiveness in reducing ignitions would require an evaluator to test whether the mitigation made a difference in ignition on days with similar weather and fuel conditions before and after a mitigation. Fire weather indices are one potentially attractive way to simplify a comparison between ignitions on days when conditions were "similar." However, "[m]ost fire indices are empirical models. Therefore, their validity is often limited to the specific type of climate or vegetation where they were developed… transferring fire indices from one region to another should only be performed with caution."[15] An independent review of normalizing for weather based on an FPI would require endorsing the development and use of an FPI, which itself requires a deep understanding of regional weather and fire patterns. Measuring effectiveness in reducing *risk* would also mean addressing consequence: identifying whether ignitions were being reduced on the days when the weather implied the highest consequences for an event. These measurements are possible to make, but challenging, requiring both significant data and expertise.

One example of measuring effectiveness by comparing ignitions before and after mitigations under similar weather conditions was reported in Warner et al. (2024).[16] The authors trained a machine learning model "to predict a circuit's daily ignition risk using time-varying factors like wind speed, fuel moisture, and relative humidity as well as fixed circuit characteristics," based on ignition data from 2015–2019.[17] They then predicted ignition risk for each circuit for

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[12] Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Fire Weather Indices Wiki, https://wikifire.wsl.ch/tiki-index515f.html.

[13] US Geological Survey, Fire Danger Forecast, https://www.usgs.gov/fire-danger-forecast.

[14] Energy Safety, "WMP Guidelines," 136–137.

[15] WSL, Fire Weather Indices Wiki, "Introduction."

[16] Warner, C., Callaway, D., & Fowlie, M., "Risk-Cost Tradeoffs in Power Sector Wildfire Prevention," (Energy Institute at Haas Working Paper 347, 2024), https://haas.berkeley.edu/wp-content/uploads/WP347.pdf.

[17] Warner et al., Risk-Cost Tradeoffs, 9.

every day from 2015–2022, and "use[d] a matching algorithm to identify circuits that would have faced the same risk probability over our time period, but received different risk mitigation treatments." Their results are described briefly in sections 3.5.1 on enhanced vegetation management and 3.5.4 on protective equipment and device settings.

Simple methods for accounting for weather variability are not meaningful (see Section 3.2), and meaningful methods are not simple.

3.3.3 Combinations of Mitigation Measures

Utilities often implement multiple mitigation efforts in a single location. This combination of strategies makes it difficult to isolate the impact of any single measure on the reduction of wildfire risk. Utilities may also use PSPS and/or PEDS on a circuit segment in addition to longer-term mitigations, which confounds attempts to separate out ignition and outage data.

3.3.4 Variation in Program Design and Data Reporting

Enhanced vegetation management (EVM) programs (clearing vegetation beyond minimum requirements) vary significantly between utilities. The effectiveness of enhanced vegetation management depends on program design and geography. Further, reporting on impact has varied: PG&E formerly had an EVM program,[18] while SCE and SDG&E combined reporting on their EVM with other routine vegetation management activities. Even the unit of activity for vegetation management varies: circuit miles for PG&E and SCE versus tree units for SDG&E. These reporting differences make it more challenging both to review effectiveness within an IOU's portfolio and to compare effectiveness across utilities.

3.4 Effectiveness of Mitigation Initiatives

As part of risk modeling, utilities assume that a mitigation results in a specific reduction in risk. For example, replacing bare conductor with covered conductor reduces the risk of ignition by vegetation contact. Utilities have studied the reduction in risk for a number of common mitigation initiatives. Energy Safety requested that utilities conduct joint studies and report on the effectiveness of EVM and covered conductors. SDG&E additionally reported completing efficacy studies on recloser protocols, impact of overhead distribution hardening at reducing overhead faults, CAL FIRE-approved expulsion fuses vs. other expulsion fuses, impact of sensitive relay settings at reducing ignitions from risk events, and rapid earth fault current limiter control and protection systems.

[18] Pacific Gas and Electric Company, *2023-2025 Wildfire Mitigation Plan R 8*, https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=57976&shareable=true, 4.

3.4.1 Enhanced Vegetation Management

Utilities practice enhanced vegetation management by exceeding standard clearance requirements in removing vegetation around power lines and infrastructure, targeting high fire risk areas to reduce the chance of trees, limbs, and branches coming into contact with power lines. The effectiveness of enhanced vegetation clearance can vary among utilities due to differing program designs, geography, and approaches.

The three large IOUs highlighted significant improvements in outage numbers due to enhanced vegetation clearances, in the "Progression of Effectiveness of Enhanced Clearances Joint Study."[19] The study reported that SDG&E achieved an approximate 20% improvement in vegetation-related outages, while SCE's annual average of the number of tree-caused circuit interruptions reduced by approximately 48% in the post-enhanced clearance period compared to the pre-enhanced clearance period. Utilities will update the results of the "Effectiveness of Enhanced Clearances Joint Study" in their 2026–2028 WMP submissions.

The authors of "Risk-Cost Tradeoffs" found that for their sample of PG&E's mitigation, "circuits with high levels of [enhanced] vegetation management caused 57% fewer ignitions than similarly risky circuits with zero to minimal amounts of vegetation management."[20]

3.4.2 Covered Conductor

Covered conductors (CC) are equipped with an external polymer sheath to prevent accidental contact with other conductors and grounded objects, like tree branches. The composition and layering of CC vary with voltage ratings. For example, multi-layer options provide higher protection against conductor-to-conductor and conductor-to-ground contact and also have higher impulse strength, often featuring a semiconducting conductor shield. [21] Utilities have recently been replacing bare conductors with CC to reduce wildfire risks.

All six IOUs, led by SCE, "contracted with Exponent [, Inc.] to independently investigate the effectiveness of CC for overhead distribution systems… Exponent conducted several testing scenarios that covered various contact-from-object, wire down, system strength, flammability, and water ingress scenarios. PG&E developed an additional test plan to ensure coverage of failure modes and additional CC types. SDG&E also performed additional test plans including environmental, service life, UV exposure, degradation, and mechanical strength tests."[22]

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[19] PG&E, *"2023-2025 Wildfire Mitigation Plan R 8,"* 1109.

[20] Warner et al. (2024), *"Risk-Cost Tradeoffs,"* 13.

[21] Exponent, *Effectiveness of Covered Conductors: Failure Mode Identification and Literature Review*," 2021, https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=52749&shareable=true.

[22] Southern California Edison, "*2023-2025 Wildfire Mitigation Plan R 3.1*," 2024, https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=57620&shareable=true, 879.

Incorporating the results of these tests, SCE updated its overall estimated mitigation effectiveness for CC from approximately 67% to 72%.[23] Using SCE data, the Mussey Grade Road Alliance estimates effectiveness at 85%.[24] PG&E updated its overall estimated effectiveness to 64%.[25] The authors of "Risk-Cost Tradeoffs" could not "estimate the effectiveness of this measure empirically given the low deployment levels" in PG&E territory.[26] SDG&E reported that this approach has resulted in an effectiveness estimate for its Wildfire Covered Conductor Program of 65.7%.[27]

3.4.3 Undergrounding

In their 2023–2025 WMPs, PG&E and SDG&E reported that undergrounding lines has a 97.7% and 98% effectiveness in mitigating wildfire risk.[28, 29]

3.4.4 Protective Equipment and Device Settings

PEDS, commonly known as "fast trip," "fast curve," or "enhanced powerline safety settings (EPSS)," are advanced safety measures implemented by electric utilities on powerlines to reduce wildfire risk. These settings increase the sensitivity of protective devices, triggering automatic outages within as little as less than one-tenth of a second when a fault is detected. If a hazard, such as a tree branch, contacts a powerline, devices like circuit breakers and line reclosers quickly shut off power. This rapid response helps prevent potential fire ignitions.

SCE began its fast curve program in 2018. "To measure fast curve wildfire ignition risk reduction, SCE evaluated fault-to-ignition ratios from June to October in 2021 and 2022 with the analysis indicating approximately a ~54% reduction between circuits with fast curve enabled… versus circuits with without fast curve…."[30]

SDG&E indicated that data for this mitigation are too limited to be statistically significant. However, from 2015–2021, there were 90 fault events downstream of devices with sensitive

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[23] SCE, "*2023-2025 Wildfire Mitigation Plan*,"907.

[24] Mussey Grade Road Alliance, "Mussey Grade Road Alliance Opening Brief on Southern California Edison's 2025 General Rate Case," https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M536/K087/536087274.PDF, 2024: 50.

[25] SCE, "*2023-2025 Wildfire Mitigation Plan R 3.1*,"910.

[26] Warner et al. "Risk-Cost Tradeoffs," 9.

[27] SCE, "*2023-2025 Wildfire Mitigation Plan R 3.1*,"911.

[28] PG&E, *"2023-25 Wildfire Mitigation Plan R 8,"423.*

[29] San Diego Gas & Electric Company, "*2023-2025 Wildfire Mitigation Plan (Revision 5)*" https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=56957&shareable=true, 2024, 159.

[30] SCE, "*2023-2025 Wildfire Mitigation Plan R 3.1*,"778.

relay settings enabled, on days with extreme FPI or a red flag warning. Zero of these fault events led to ignitions.[31]

PG&E reported that in 2022 there was "a 68 percent reduction in CPUC-reportable ignitions on EPSS-enabled lines in HFTD-areas (compared to weather-normalized 2018-2020 average ignitions)." [32] Warner et al., 2024 showed that PG&E's enabling fast-trip settings on a given high-risk circuit-day reduces the circuit's probability of sparking an ignition by 72% on average circuits. Critically, they also found that combining enhanced vegetation management with fast-trip settings reduces ignition risk by 92% on average.[33]

3.5 Conclusion

Board staff reviewed data on effectiveness measured by the number of power generation/transmission/distribution-caused fires and utility-reported ignitions. Given the rebound in ignitions in 2024, it is too soon to say whether the decrease in power generation/transmission/distribution fires is a trend. There is no trend in the total number of utility-reported ignitions; however, even with a rebound in 2024 there appears to be a decreasing trend in ignitions in the HFTD. The decrease of reported ignitions in the HFTD may indicate the effectiveness of utilities' wildfire mitigation efforts.

Board staff also reviewed existing studies of the effectiveness of individual mitigation strategies. Data limitations and weather variability make the analysis of effectiveness highly complex. Independent review of the effectiveness of mitigation strategies is beyond the resources available to Board staff. The recommendations below are designed to bring transparency to utilities' analysis and assumptions of effectiveness. These recommendations are also meant to aid Energy Safety in its review of the IOUs' WMPs.

3.6 Recommendations on Effectiveness

1. Energy Safety should require IOUs to include in their WMPs, or other submission (as appropriate), the details of any fire weather indices. Details should include specific calculation methods, data sources, and methods of development. These indices may be specific to ecological regions (or pyromes) or to a service territory as a whole. The input data should be clearly defined, the methods should be published, and details should include a comparison to other indices and a rationale for unique and/or customized elements.
2. Energy Safety should require IOUs to report in their performance metrics clear annual tracking of effectiveness, measured by ignitions and fires in addition to other metrics Energy Safety allows, and include both raw data and data normalized by weather.

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[31] SDG&E, *"2023-2025 Wildfire Mitigation Plan (Revision 5),"*241.

[32] PG&E, *"2023-25 Wildfire Mitigation Plan R 7,"573.*

[33] Warner et al., *"Risk-Cost Tradeoffs."*

3. Building on required joint studies of the effectiveness of enhanced vegetation clearances and CCs, Energy Safety should require utilities to report in their WMPs on the effectiveness of at least four other mitigation efforts, such as specific equipment upgrade initiatives. These evaluations may include laboratory or other controlled-environment testing but should also include pre- and post-implementation data, clear descriptions of the methods for evaluating each mitigation effort, and the assumptions and variations in their models that may influence results. IOUs should be required in their WMPs to clearly demonstrate the impact of PEDS in isolation and in combination with other activities.
4. Energy Safety should require utilities to report initiatives in standard units of measurement, identified by Energy Safety, for the same mitigation type (e.g., circuit miles vs. trees).

4 RISK MODELING

Utilities use models to calculate the risk of wildfires. These risk models are used to make operational decisions, such as implementing PSPS or PEDS, as well as planning decisions that determine how investments are prioritized. It is essential for regulators and other stakeholders to understand the capabilities and limitations of these risk models as utilities continue to develop and advance their risk models.

The Board asked staff to develop a better understanding of IOU risk models in order to make recommendations to Energy Safety. To accomplish this goal, Board staff conducted a review of the IOU wildfire risk models, as described in the IOUs' WMPs, and held meetings with PG&E, SCE and SDG&E. Energy Safety's requirements for WMPs[34] include specific requirements for IOUs' reporting on their wildfire risk models. This provided an understanding of the individual model processes. Board staff met with Energy Safety experts. These meetings helped Board staff to understand the regulatory landscape and learn from accomplishments of the Risk Model Working Group. Board staff also performed a literature review and met with academics to understand previous and current research focused on risk model advancement. Finally, to gain an additional perspective on wildfire risk and analysis, Board staff met with insurance and financial risk modelers to learn about their techniques in calculating current and future wildfire risk in California.

4.1 Use of Wildfire Spread Models

IOUs use wildfire spread models as part of the calculation of potential consequences of hypothetical utility-caused wildfires. Wildfire spread models simulate wildfires starting from ignition points under utility assets. Modelers vary weather and fuel conditions, generating a distribution of outputs. Most IOUs intersect those outputs with asset layers, including structures, to estimate a distribution of consequences. PG&E, on the other hand, uses a "Destructive Potential Classifier" which evaluates wildfire spread model outputs along with FPI values to calculate consequence values. IOUs aggregate their consequence distributions

[34] Energy Safety, *Wildfire Mitigation Plan Guidelines 2026-2028,* 29-50.

into single consequence values. Consequence multiplied by the ignition likelihood equals wildfire risk.

4.2 Risk Models and Uncertainty

Models are simplified representations of more complex real-world phenomena. Uncertainty is a measure of the range of likely differences between model outputs and real-world outcomes. Uncertainty is intrinsic to modeling and is not *per se* a failing or flaw in any modeling approach. However, understanding the uncertainty in models is essential to making decisions using those models. Uncertainties can provide areas for improvement and a better understanding of where to place confidence in model results.

Modelers identify and represent uncertainty by verifying, validating, and performing sensitivity analysis on models. Verification is ensuring that a model produces the anticipated outcome. Validation is a measure of how closely the models represent the real world. Currently, wildfire spread models "lack… systematic methods for model validation."[35] Individual models may contain unique uncertainties even if they model the same thing (i.e. wildfire spread) or are based on the same equations. Sensitivity analysis measures the extent to which varying input variables changes model outputs. Understanding the range of inputs entered and the distribution of outputs is important. Intermediate calculations that contain uncertainty compound throughout the modeling process.

Cardil et al., 2023 published a study on the uncertainty of Technosylva's wildfire spread model, Wildfire Analyst Enterprise (WFA-e), which is based on the Rothermel fire spread equations.[36] This study determined the mean absolute percentage error (MAPE), a measure of prediction accuracy, of WFA-e to initially average 47% in a sensitivity analysis of fuel types. The error varied from 26% error in areas with shrub fuel class assignments to approximately 67% error in timber fuel class assignments. These fuel classes are inputs selected by model developers. The authors find an overall average MAPE decrease to 37% after adjusting a timber understory fuel type for California-specific timber species. This paper defines model accuracy via one benchmark, rate of spread; additional metrics for uncertainty including acreage and perimeter directions could also be quantified.

In other research, Benalli et al.'s (2016) study shows that wind speed (WSpd) and direction (WDir), ignition location (IgnSp) and timing (IgnTmp), as well as fuel class and typology have similar uncertainties that impact a model's accuracy.[37] This study conducted a sensitivity analysis on the FARSITE wildfire spread model, which is also Rothermel-based. Figure 5 shows the results of the sensitivity analysis on FARSITE using spatial discrepancy and fire growth rate (rate of spread) as benchmarks. The sensitivity of models is important to

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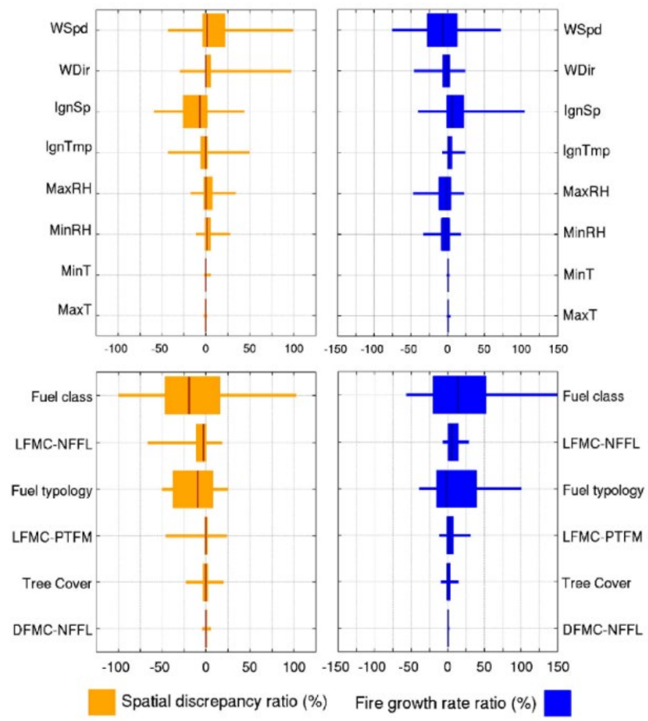
[35] Benali, Akli, et al., "Deciphering the Impact of Uncertainty on the Accuracy of Large Wildfire Spread Simulations," *Science of the Total Environment, Volumes 569–570,* 2016: 73-85, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2016.06.112.

[36] Cardil, Adrián, et al., "Performance of Operational Fire Spread Models in California," *International Journal of Wildland Fire 32*, no. 11 (July 7, 2023): 1492–1502, https://doi.org/10.1071/wf22128.

[37]Benali, et al., "Deciphering the Impact of Uncertainty."

understand because the quality of highly sensitive input data could drastically affect the model's reliability.

Figure 5. Overall Impact of Uncertainty on the Accuracy of Wildfire Spread Models



Reporting in the IOUs' WMPs does not fully explain and account for the uncertainty within IOUs' wildfire risk models. Therefore, utilities do not appear to be incorporating uncertainty as fully as it could be into decision making.

4.3 Use of a Single Wildfire Spread Model

All six IOUs use a single wildfire spread model in their consequence calculations. Moreover, all six IOUs use the same wildfire spread model provided by Technosylva. Multiple wildfire spread models are available, including some that are open source.[38] Board staff have not evaluated the Technosylva wildfire spread model, but every model includes simplifications that produce uncertainty. Comparing the results of multiple models, applied to similar inputs, would give a fuller representation of the range of uncertainties inherent in contemporary wildfire spread models. This comparison would also allow for a more robust analysis of the underlying reasons for similarities and differences in outputs.

There are examples of other applications that compare multiple models to better understand uncertainty and gain a more accurate result. Modelers compare projections from multiple models to analyze similarities, differences, and the range of variability between model

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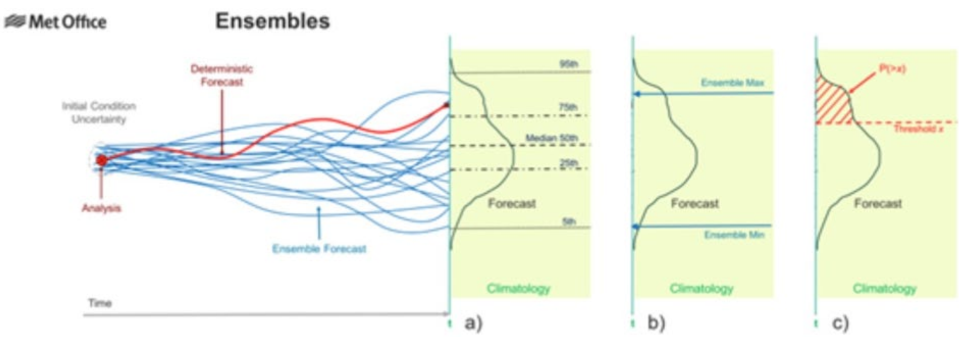
[38] Electric Power Research Institute, "Wildfire Risk Tool Inventory: Wildfire Tool Inventory and Evaluation," Last modified June 14, 2024, https://apps.epri.com/wildfire-tool-inventory/en/inventory-risk-tools.html.

results. One example is the use of an ensemble model in global climate modeling. "[A]n ensemble model combines multiple models to create a stronger, more accurate prediction than any single model could achieve on its own."[39] In global climate modeling, it is well understood that the models contain uncertainty and are parameterized differently. As illustrated in Figure 6, results can be interpreted in different ways depending on the goals of the analysis. Figure 6 shows using quantiles (a), minimum and/or maximum values (b), or the probability of exceeding a threshold value (c). An ensemble approach may or may not be appropriate for use in wildfire spread modeling, however, a comparison of available models is a necessary step forward.

Figure 6. Diagram of Different Interpretations of Model Predictions Using the Ensemble Approach



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A second example is outlined by Heinrich et al. (2022). In their study on building resilience in the insurance industry, the authors argue that since risk models are inaccurate, tending to underestimate risk in some areas and overestimate in others, using a multi-model, rather than single model, approach can make a significance difference in performance.[40] Further, they state, "[i]f everyone in the industry bets on the same model then everyone runs the risk of being wrong at the same time, creating high levels of systemic fragility."[41] IOUs' reliance on one wildfire spread model to drive mitigation may be a potential vulnerability in calculating risk throughout the state.

4.4 Collapsing of Consequence Distributions

As described in Section 4.1, IOUs calculate distributions of consequence for ignitions at a specific location. They then historically have collapsed those distributions into a single value that is used in decision making. Reporting a single value from a distribution of simulations is

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[39] International Business Machines Corporation, "What is ensemble learning?" Last modified March 18, 2024, https://www.ibm.com/think/topics/ensemble-learning.

[40] Heinrich, Torsten, Juan Sabuco, and J. Doyne Farmer, "A simulation of the insurance industry: the problem of risk model homogeneity," *Journal of Economic Interaction and Coordination 17,* 2022: 535–576, https://doi.org/10.1007/s11403-021-00319-4.

[41] Artemis, "Multi-risk model approach can build stronger catastrophe insurance industry," Last modified March 12, 2021, https://www.artemis.bm/news/multi-risk-model-approach-can-build-stronger-catastrophe-insurance-industry/.

an incomplete representation of the results. Illustrating this point, Figure 7 provides an example of how distributions with large variation could result in equal mean values. Effective decision making and oversight both require a better understanding of the distribution of risk, especially "tail risk" of the most extreme events. Tail risk in this application refers to ignition events that may have low probability of occurring, but high consequence. Energy Safety has presented IOUs with "areas for continued improvement" (ACIs) to transition to using probability distributions when aggregating risk scores in their WMPs.[42,43,44,45] SDGE reports in its 2025 WMP Update that moves in this direction "will continue to be explored."[46] SCE declined to change its approach. [47] The CPUC's Safety Policy Division also makes a similar argument in a staff proposal on risk tolerance in Phase 4 of the Risk-Based Decision-Making Framework Proceeding.[48]

[42] Energy Safety, "SCE-23-02," *Decision for Southern California Edison Company 2023-2025 Wildfire Mitigation Plan*, 2023: 84, https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=55556&shareable=true.

[43] Energy Safety, "SCE-25U-01," *Decision for Southern California Edison Company 2025 Wildfire Mitigation Plan Update*, 2024: 50-51. https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=57548&shareable=true.

[44] Energy Safety, "SDGE-23-02," *Decision for San Diego Gas & Electric Company 2023-2025 Wildfire Mitigation Plan.* 2023: 78. https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=55555&shareable=true

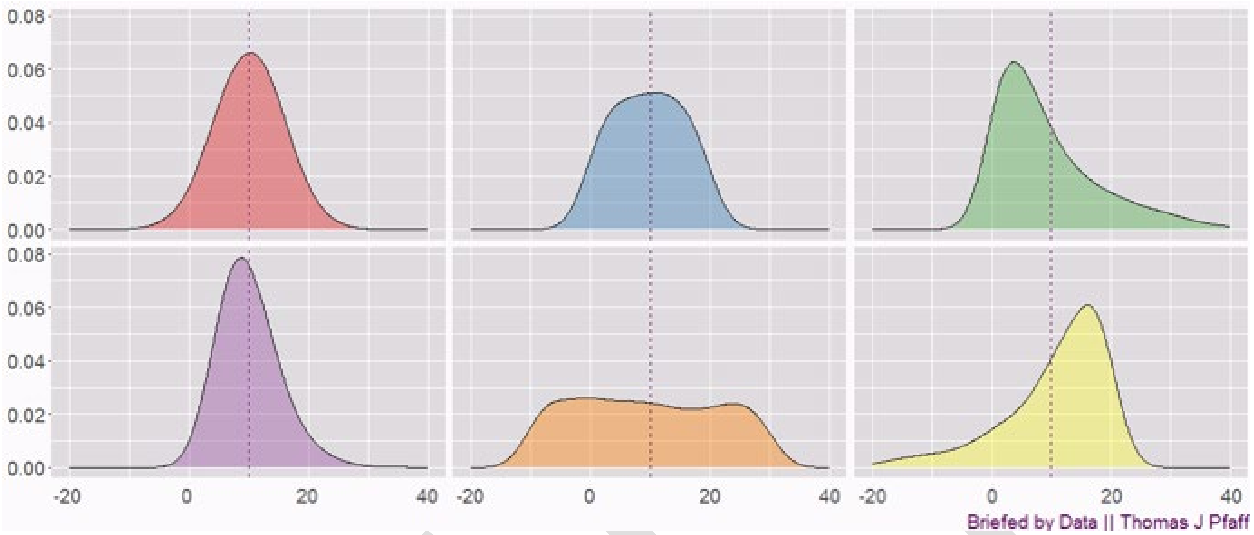
[45] Energy Safety, "SDGE-25U-01," *Decision for San Diego Gas & Electric Company 2025 Wildfire Mitigation Plan Update, 2024*: 67. https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=57541&shareable=true

[46] SDGE, *2025 Wildfire Mitigation Plan Update,* 2024: 43. https://www.sdge.com/sites/default/files/regulatory/2024-07-05_SDGE_2025_WMP-Update_R2.pdf.

[47] SCE, *2025 Wildfire Mitigation Plan Update,* 2024: 35-43. https://www.sce.com/sites/default/files/AEM/Wildfire%20Mitigation%20Plan/2023-2025/SCE%202025%20WMP%20Update%20R1.pdf

[48] CPUC, *R.20-07-013, Phase 4, Safety Policy Division, Staff Proposal on Overall Residual Risk, Risk Tolerance and Simple Optimization*, 2024: 17. https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M548/K361/548361460.PDF

Figure 7. Different Distributions with the Same Mean Value[49]



4.5 Uncertainty in Ignition Likelihood

Uncertainties also exist in the ignition likelihood models, including the three large IOUs algorithms used to calculate their ignition likelihoods. These three models all use machine learning. Machine learning algorithms, as in all models, contain uncertainties.[50, 51] "Uncertainty almost automatically occurs in any application of machine learning."[52] Utilities also do not fully describe the uncertainties in this component of the modeling.

4.6 Improbable Levels of Precision

The number of significant figures in a number represents a degree of precision, or the number of figures known to some degree of reliability, within a calculated output.[53] Federal agencies have developed standards for use and reporting of significant digits established as well as industry specific standards set by state agencies.

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[49] Modified from Pfaff, Thomas J., *Briefed by Data,* "Same Mean Different Distribution,*"* Last modified November 25, 2023. https://briefedbydata.substack.com/p/same-mean-different-distribution.

[50] Kläs, Michael, and Anna Maria Vollmer, "Uncertainty in Machine Learning Applications: A Practice-Driven Classification of Uncertainty," *Lecture Notes in Computer Science*, 2018: 431–38. https://doi.org/10.1007/978-3-319-99229-7_36.

[51] Hüllermeier, Eyke, and Willem Waegeman, "Aleatoric and Epistemic Uncertainty in Machine Learning: An Introduction to Concepts and Methods," *Machine Learning 110*, 2021: 457–506, https://doi.org/10.1007/s10994-021-05946-3.

[52] Hammer, Barbara and Thomas Villmann, "How to process uncertainty in machine learning?" *European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning,* 2007, https://www.esann.org/sites/default/files/proceedings/legacy/es2007-7.pdf.

[53] Stewart, K, "Significant Figures," *Encyclopedia Britannica*, last updated February 11, 2025, https://www.britannica.com/science/significant-figures.

In their WMP submissions, IOUs provide four significant digits in both Table 6-5, "Summary of Top-Risk Circuits, Segments, or Spans" and Table 7-4, "Summary of Risk Reduction for Top-Risk Circuits." Within their QDRs, some model outputs are reported to 15 significant digits. Even without a full acknowledgement of and accounting for uncertainty in IOUs' risk models, it is improbable that the outputs are precise to one part in one-quadrillion. In particular, the multiplication of likelihood and consequence compounds the uncertainties in each contributing model. When carrying out calculations the result is limited by the figure with the least significant figures, or least accurate measurement.[54] Reporting to these levels misrepresents the level of uncertainty throughout the risk modeling process and provides a false level of confidence in model results.

4.7 Conclusion

Uncertainty is intrinsic to modeling. The IOUs' current reporting of risk modeling methods and results does not adequately account for uncertainties in individual models and the compounding uncertainty of combining multiple models. Informed decision-making requires understanding the uncertainty and sensitivities of risk models and distributions of their outputs.

WSAB recognizes the challenges of continuous development of wildfire risk models, often at the frontier of knowledge. It acknowledges the efforts of many dedicated individuals at IOUs and other organizations to advance modeling in the service of public safety. These recommendations are offered in the same spirit of continued improvement to serve the public interest. Decision makers are not fully informed if uncertainty is not considered. The Board believes the next step to take as these models evolve is a fuller and more transparent accounting of the uncertainty. This would lead to greater confidence in reported results, a better understanding of the data that feeds decisions, and more fully informed decision making.

4.8 Recommendations

1. Energy Safety should require each IOU in its 2029–2031 WMP to test and compare multiple wildfire spread models when calculating wildfire consequence. Each IOU should test and compare at least three models, at least one of which should be open-source and peer-reviewed, across a representative sample of its territory. Energy Safety should require comparison of model outputs, along with a justification of why the model or ensemble of models to be used in decision-making is the most appropriate.
2. Energy Safety should establish clear standards for WMP reporting of wildfire spread model verification, validation, and sensitivity analysis. Energy Safety should develop standards for input data and a method to identify and compare standardized outputs.

[54] Stewart, K, "Significant Figures," *Encyclopedia Britannica*.

3. Energy Safety should continue to press IOUs to report uncertainties, including probability distributions and their dependencies where appropriate, for each "risk driver" (as defined in the WMPs) of ignition. Energy Safety should also require IOUs to report distributions of risk values for a representative sample, in geography and risk values, of circuits or circuit segments, clearly explaining the variation due to changes in ignition likelihood, consequence, or correlation of both, in each WMP and WMP update.
4. Energy Safety should require that, as soon as practicable in base WMPs, WMP updates, and performance metrics, IOUs report data and model results with an appropriate number of significant digits to represent the degree of precision in their risk models.

5 SAFETY CULTURE ASSESSMENT

PUC section 8389(d)(4) requires Energy Safety to assess electrical corporation wildfire safety culture annually. PUC section 8386.2 states that the CPUC must require third-party evaluations of safety culture at least every five years. In January 2025, the CPUC adopted a decision[55] establishing its Safety Culture Assessment Framework for the large IOUs. The decision noted that CPUC "strives to achieve regulatory alignment and continuity with Energy Safety" and encouraged a coordination plan between Commission staff and Energy Safety. It also created a Utility Safety Culture Working Group consisting of "the Safety Policy Division, Energy Safety, the Joint IOUs, and other interested entities."

The Board recommends that Energy Safety work with CPUC staff to include Board staff in the meetings with the Utility Safety Working Group as an "interested entity," to understand the latest developments in safety culture assessment and inform potential future Board recommendations.

[55] California Public Utilities Commission, "Decision Adopting Safety Culture Assessment Framework for the Large Investor-Owned Utilities," https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M555/K500/555500176.PDF.

OFFICE OF ENERGY INFRASTRUCTURE SAFETY
CALIFORNIA WILDFIRE SAFETY ADVISORY BOARD
www.energysafety.ca.gov

715 P Street
20th Floor
Sacramento, CA 95814
wsab@energysafety.ca.gov