E3 Review of PG&E's Wildfire Risk Model Version 4

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Energy+Environmental Economics

Jessie Knapstein, Associate Director
Andrew DeBenedictis, Director
Jen Cardona, Managing Consultant
Dyami Andrews, Managing Consultant
Disha Trivedi, Consultant
Ren Orans, Founding Partner

Energy and Environmental Economics, Inc. (E3)
44 Montgomery Street, Suite 1500
San Francisco, CA 94104

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1 Executive Summary

1.1 Introduction

Energy and Environmental Economics (E3) was hired by PG&E to provide an independent peer review of Version 4 of its Wildfire Risk Model (v4). E3 produced a similar review and report for Version 2 (v2) and Version 3 (v3) of this model. These reports were filed as part of PG&E's Wildfire Mitigation Plan (WMP) submission to the California Public Utilities Commission (CPUC) Wildfire Safety Division in 2021 and 2022, respectively. [1,2] The previous reviews focused solely on the Wildfire Distribution Risk Model (WDRM). The current review is expanded to cover both the WDRM and the analogous transmission risk model known as the Transmission Composite Model (TCM).

In addition to a review of the most recent updates to PG&E's wildfire risk models, the scope of this work has also been extended to include a review of wildfire risk modeling best-practices across relevant fields including academia, the regulatory and insurance spaces, and the private sector. E3 assembled and interviewed a technical advisory committee of wildfire risk modeling experts spanning these various fields. The process of interviewing the technical advisory committee members brought several recurring themes to the surface that were echoed across interviews. Section 3 details the best practices and learnings from the technical advisory committee interviews.

This report is structured as follows:

- **Executive Summary:** overview of the key findings and recommendations from this review
- **Background:** relevant context surrounding PG&E's models and use cases
- **Wildfire Risk Modeling Best Practices:** summary of learnings from interviews with the technical advisory committee and independent research into the field
- **PG&E Wildfire Risk Model Evaluation:** summary of E3's review of PG&E's v4 model including recommendations for the modeling teams
- **Conclusions:** concluding remarks following E3's evaluation of PG&E's v4 model

While this review's primary audience is the PG&E risk decision-makers, we believe that wildfire mitigation must be considered holistically across jurisdictions to be most effective. Our recommendations are actionable for PG&E, but full implementation would require action from the regulators and possibly legislators as well.

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[1] E3 Review of PG&E's 2021 Wildfire Distribution Risk Model <https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=51801&shareable=true>

[2] E3 Review of PG&E's 2022 Wildfire Risk Model Version 3 <https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=53553&shareable=true>

1.2 Summary of findings

In the previous 2022 review of PG&E's v3 model, E3 noted that PG&E had "made substantial progress in transforming its model from one that was primarily used to validate mitigation measures chosen by its subject matter experts (SME) within high fire zone areas to a model that can be used to supplement and prioritize the targeting of mitigation measures across its entire service territory." E3 commented that although the model was being used to support mitigation plans *within* priority business units, the model was not being used to set budgets or mitigation strategies *amongst* the business units across the entire company. The model was mainly being used to prioritize where to focus mitigations, but not to determine *which* mitigation measures to deploy. A major shortcoming of this approach is that there was no line of sight between the risk model and decisions on which mitigations to pursue (e.g. large amounts of undergrounding).

We introduced the "crawl, walk, run, fly" framework (Figure 1), emphasizing that the next step for PG&E would be to expand the use of its model to develop transparent and effective mitigation plans. In the current review, E3 found that although PG&E continued to make considerable improvements to their technical modeling framework, the use of the model is still limited to prioritizing mitigations within each business unit rather than to determine the comprehensive mitigation plan and allocating budgets across business units accordingly.

Crawl	Walk	Run	Fly
Targeted & granular use with limited application. Data quality & transparency issues. Little to no process or standardization. (v2)	Broadened use with application in key areas of risk planning (ignition, consequence, & mitigations). Temporally limited and siloed from other risk models. Reliance on SME input. Some data quality improvements & standardization. (v3)	Use across the entire risk planning decision space (budgeting, ignition, consequence, & mitigations) for short & long-term planning. Full collaboration across risk models. Process for continuous data improvements & standardization.	Compliance with state-led planning process for full cycle long and short-term planning. Standardization of processes, full transparency, & data quality control and sharing practices for continuous improvement.

Figure 1 v3 E3 Review Summary: Crawl, walk, run, fly trajectory for PG&E wildfire risk planning

After reviewing the v4 model and conducting interviews with the technical advisory committee, E3 has developed several technical recommendations for PG&E's modeling teams (see Section 1.4 and Section 4). However, we believe these technical recommendations to be secondary to our core recommendation that: **PG&E should continue development of the model to inform the entire risk planning decision space, building on v4 to produce transparent and justifiable company-wide mitigation budgets for short- and long-term planning. While we continue to believe that the combination of informed risk modeling and experienced SME's provides a robust risk management framework, we also believe that the models, as they become more informative, should have an increasing role in the decision-making process. The expanded modeling role will require more feedback and trust in the results from the SMEs.**

1.3 Fit for purpose

Over the last several years, PG&E has continued to improve upon their wildfire risk modeling framework and has built a suite of models that is capable of systematically quantifying the wildfire risk across their system, frequently going above and beyond requirements. Although there is always room for improvement in developing these models further (see Section 1.4 for technical recommendations), E3's primary recommendation is that PG&E should focus more strongly on using the models to drive planning decisions around mitigations based on quantitative findings, and to improve transparency in justifying their proposed mitigation plans. E3 believes that although PG&E's models are fit for their current purpose, as defined by PG&E and the CPUC, they are not currently being used to their full potential in determining the investments that PG&E should ultimately make in risk mitigation. The State continues to take strides toward standardizing a transparent process for the investor-owned utilities (IOUs) to justify their proposed mitigations, and some amount of burden falls to the State to create processes that use the utilities' modeling capabilities to their full potential. However, **we hope to see PG&E lead by example in utilizing their models to transparently justify the costs of the mitigations they are pursuing.**

PG&E continues to strive for solutions on how to balance the pressing need for wildfire risk mitigation with the numerous other system needs including reliability. To this end, PG&E's nascent Integrated Grid Planning (IGP) team aims to develop strategic plans to address these needs systematically. To summarize the Integrated Grid Planning initiative, PG&E has stated:

> "PG&E is embarking on an effort to redefine the Electric planning process and strategy across Transmission and Distribution. The goal of this work is to create an integrated planning process that evaluates all risks across the electric system and prioritizes capital effectively among varying needs (e.g., wildfire, asset health, capacity, reliability, climate resilience). Redefining our planning process will require changes to the way capital projects are identified, planned, and prioritized to bundle projects and address all present needs in a more efficient manner."

PG&E's IGP team has a crucial role to play in filling the gap in utilizing wildfire risk modeling outputs in a systematic framework to justify and balance mitigation costs relative to other system needs. The IGP team has set out to build on PG&E's current approach to planning, citing goals including:

- solving for multiple system needs (pursuing wildfire risk mitigation alongside other objectives);
- building stable plans with long-term visibility into the timeline for planned work; and
- efficiently using resources to maximize the impact of every dollar spent.

The primary recommendation presented in the present review is highly relevant to many of the IGP team goals including those listed above. Successful execution of these goals will require PG&E to improve upon the current framework for utilizing wildfire risk modeling outputs to develop stable and efficient plans. We provide further recommendations for the IGP team to approach this challenge in Section 1.3.1.

It is also important to recognize that PG&E's WDRM and TCM models do not live in isolation, but rather are part of the CPUC's "Risk-Based Decision-Making Framework", which has been developed and improved over the course of the last decade. A need for transparent and sound justifications for proposed actions has been at the heart of the regulatory process around this framework from its inception (see Section 2 for additional background information). E3's recommendation is aligned with the needs identified in the ongoing regulatory process surrounding these models, but aims to further refine some of the ways IOUs meet these needs.

The subsequent section describes a framework that PG&E could use towards satisfying E3's recommendation to improve upon the ultimate application of their models towards transparent justification of their mitigation plans.

1.3.1 Informing mitigation budgets using the risk modeling framework

In E3's prior review of the v3 WDRM model, E3 identified the lack of a comprehensive Statewide wildfire risk mitigation planning process as a key hurdle in PG&E's planning process. E3 suggested that although PG&E cannot undertake such a planning process on its own without coordination amongst other key stakeholders in the state, such a process would allow PG&E to:

+ More optimally allocate effort and resources across potential risk reduction measures
+ Provide additional transparency on decision-making regarding risk mitigation spending, and a quantitative view of how proposed efforts will contribute to risk buy-down and public safety.

Currently, PG&E is setting total wildfire mitigation budgets for business units using a top-down approach that starts from a total budget and is allocated to business units based on their relative wildfire risk as measured by number of ignitions. PG&E is then using model outputs from the WDRM within business units to prioritize mitigation efforts that will impact the highest risk circuit segments to mitigate the top 20% of risk. With this framework, the rich insights into the system-wide wildfire risk are not being used in determining the total proposed mitigation budgets amongst business units which could limit funding to the most effective mitigation measures. **E3 recommends that PG&E take steps towards using outputs from its risk models to inform the total budgets for risk mitigation, justify proposed mitigation measures, and to more optimally allocate funds based on findings**.

To illustrate the potential for PG&E's wildfire risk models to further inform the budget and mitigation strategies, we look to existing practices in reliability planning for the electricity system in California. Resource adequacy in California relies in part on models that estimate the relationship between investing in more resources (marginal costs) and the impact that those resources would have on improving reliability (marginal benefit). Energy consumer's benefits are maximized when the estimated value of lost load and the cost of marginal capacity additions are equal. An economically optimal planning reserve margin can be determined by adding capacity until the marginal reduction in the value of lost load equals the marginal cost of new capacity.

A similar process could be employed to determine the appropriate level of mitigation spending relative to the wildfire risk on the system. For example, the cost associated with wildfire risk could be viewed as the expected wildfire damages plus the value of lost load incurred during Public Safety Power Shutoff (PSPS) and Enhanced Powerline Safety Settings (EPSS) events. Without investing in mitigation, these costs are expected to increase. PG&E's modeling framework could be used to determine the marginal reduction in wildfire damages + PSPS/EPSS costs associated with incremental mitigation spending. This would allow for a quantitative way to justify the total amount of mitigation spending based on the risk buy-down. Figure 2 shows an illustrative example of these parallel planning frameworks, with the target level of total mitigation investment being set to minimize the sum of total customer costs.

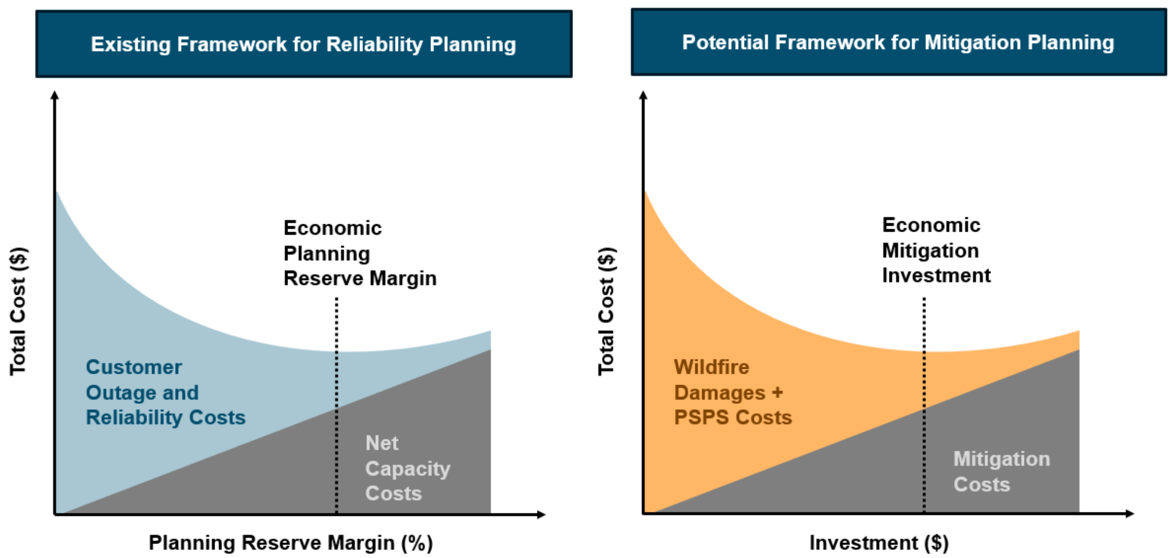

Figure 2 Illustrative example of reliability planning framework (left), and example of potential analogous framework for mitigation budget planning (right)

We acknowledge that no other jurisdiction has implemented a comprehensive least-cost planning framework like this for wildfire mitigation and to do so would come with its own set of challenges. Setting an overall risk mitigation budget this way would require a risk tolerance or wildfire risk planning standard to be accepted. The CPUC has discussed the potential for a standard risk tolerance to be set across all IOUs in the ongoing Rulemaking centered on improving the risk-based decision-making framework. However, to-date, no such explicit statewide standard exits.[3] This was discussed in detail in E3's 2022 review of PG&E's v3 of the WDRM. While regulatory approval is needed to set a statewide standard for this risk tolerance, we still see benefits for PG&E in applying a planning framework like this to justify their proposed costs in the meantime. For instance, a natural threshold to look at for an intuitive understanding of how costs and benefits stack up is the economic threshold as shown in Figure 2 above. With such a high

[3] An implicit standard is promulgated through budget limits and regulatory approvals of spending plans. The existence of this implicit standard for risk tolerance, with no thorough understanding or justification, is cause enough to at least attempt to quantify the complex variables at play in this potential framework for mitigation planning.

amount of existing risk on PG&E's system today, it's possible that mitigations that seem expensive in absolute terms are economic when accounting for the counterfactual costs of wildfire damages and PSPS/EPSS events that would occur in their absence. Conversely, relatively low-cost measures might not be cost effective if the risk is low in that application and time period.

Although challenging to achieve, a framework like the one described here has the potential to improve the effectiveness and transparency of PG&E's system-wide planning efforts. This framework could be particularly useful for PG&E's Integrated Grid Planning (IGP) team, which is working to develop the process through which PG&E will evaluate tradeoffs across the system for asset investments. While wildfire is one component that the IGP team will consider, they are focused on balancing tradeoffs across several other categories including capacity to serve new load, asset health, and reliability. Although the IGP team does not set the capital envelope for funding, they will produce capital deployment plans to allocate funds across competing priorities. In today's planning paradigm, wildfire mitigation budgets are set in a top-down fashion and plans are constructed in relative isolation from other competing priorities. Over the past several years since wildfire has become a top priority, this planning paradigm has made it challenging to maintain the level of funding for competing system needs. The formation of the IGP team is an important step from PG&E to attempt to rebalance. However, ultimately **balancing wildfire mitigations against other critical system needs will remain impossible absent guidance on acceptable levels of wildfire risk from the regulator that will drive clarity on the budget envelope**. A least-cost framework like the one proposed here could be used by the IGP team to more clearly assess the proposed wildfire mitigation plans and more easily compare the outcomes against other system needs based on quantitative costs and benefits.

1.3.2 Adapting cost recovery for effective planning

An overall wildfire risk planning standard would go a long way towards allowing for comparison of wildfire mitigation budgets and plans across system needs. However, **given the unique nature of wildfire risk and mitigations, another key consideration should be adopting a cost recovery mechanism outside of the traditional General Rate Case (GRC) to consider wildfire risk**. In the several years that E3 has been conducting this evaluation for PG&E, we have come to understand that the magnitude of this issue is not balanced with the processes used to address it. The stand-alone WMP and inclusion of OEIS partially address this problem, but more is needed. Some of the distinguishing features of wildfire risk are:

(1) the critical need for equity to be considered;

(2) the need for early collaboration given several agencies and jurisdictions in proposing, designing and improving mitigations;

(3) a more holistic planning and evaluation process capable of developing both more permanent, and inherently costly, mitigation plans to be considered in tandem with shorter term solutions to quell immediate risk.

There is precedence for this tailored approach to risk mitigation and cost recovery, as detailed in Section 2.2.2. For example, separate approaches to cost recovery have been developed for construction costs and eventual decommissioning of Diablo Canyon Power Plant. [4,5] The new Electric Undergrounding Expediting program (SB 884) is another example of a funding approval process separate from the GRC, but this pertains specifically to undergrounding plans and does not extend to other mitigation efforts.[6] In 2018, California also considered legislation that would have created a separate avenue for funding risk mitigation for major events including wildfires, but the bill did not become a law.[7] The apt concerns related to this option have been the potential for substantial rate increases and the risk of allowing cost recovery for PG&E negligence. E3 agrees that these concerns are of the utmost importance but thinks that the current structure does not fully protect against them, and where it is disallowing wildfire risk mitigation spending to limit rate impacts, it is not clear if that is in the best interests of ratepayers overall.[8] As was the case for Diablo Canyon, a discovery period to determine whether there was PG&E negligence could be instituted and a performance-based approach to cost recovery could be instituted.

Short-term measures like tree-trimming and long-term measures like undergrounding or system hardening are vastly different in how quickly they can be accomplished and how large and permanent a risk buy-down they achieve. A wildfire risk planning standard could be adaptable to both short- and long-term planning and could start to highlight and internalize some key tradeoffs in the temporal permanence of different mitigation options. However, given concerns over growing rates and wildfire mitigation being a substantial rate component, transparent and quantitative analysis that shows the true, holistic economic benefits of the chosen mitigations could help building confidence that the proposed mitigations by the utility and approved the CPUC are justified. Especially for the costly and more permanent wildfire solutions, in order for this analysis to be appropriately considered, it needs a dedicated venue that can consider how to:

- define, and continuously evolve, a wildfire risk threshold;
- define wildfire mitigation cost responsibility;
- incorporate and collaborate with other wildfire mitigations happening through state or federal initiatives;
- align with various parties around best practices, especially pertaining to wildfire spread modeling and risk modeling;
- incorporate equity in risk mitigations; and
- balance investments across short-term risk buy-downs that have immediate impact and more permanent wildfire solutions.

As noted, equity is another important consideration that wouldn't be accounted for by evaluating mitigations purely on a cost basis. Future evaluation processes must ensure that mitigation dollars do not produce unacceptable levels of wealth transfers. Decision D.22-12-027 requires each IOU to conduct an

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4 Diablo Canyon Memorandum Account Recorded Costs True-Up Review Report https://www.pge.com/tariffs/assets/pdf/adviceletter/ELEC_7068-E.pdf
5 Diablo Canyon Decommissioning Funding. https://diablocanyonpanel.org/decom-topics/decom-funding/
6 SB-884 Electricity: expedited utility distribution infrastructure undergrounding program. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB884
7 SB-1088 Safety, reliability, and resiliency planning: general rate case cycle. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1088
8 The feasibility of construction timelines to underground 2,000 miles of line was one of the discussion points that led the CPUC to reduce the number of miles that were ultimately approved in PG&E's most recent rate case.

environmental and social justice (ESJ) pilot study on how to incorporate ESJ concerns into the risk-based decision-making framework. Many of the considerations in PG&E's proposed ESJ pilot study are aligned with E3's recommendations regarding the quantification of consequences (e.g. considering the impact of wildfire smoke and how mitigations can benefit local air quality).[9] To-date, we are unaware of any updates to the v4 model that specifically account for equity. We look forward to PG&E's incorporation of the ESJ pilot study in the 2024 Risk Assessment and Mitigation Phase (RAMP) filing.

1.4 Technical modeling recommendations

This section presents a series of structured recommendations, tailored to enhance PG&E's wildfire risk models. These recommendations are organized in alignment with the framework used in PG&E's existing models, specifically focusing on overarching strategies. While this section provides high level summaries of E3's priority technical modeling recommendations, more detail is provided around these recommendations as well as additional model-specific recommendations in Sections 4.3-4.6. The goal of this approach is to provide a clear and systematic pathway for integrating these recommendations into PG&E's risk model.

1.4.1 Right-size development efforts based on importance and impact

As PG&E continues to develop and improve their wildfire risk modeling ecosystem, E3 recommends that strong consideration be given to which of the planned modeling updates are imperative and will have meaningful impact before they are implemented. PG&E should seek to prioritize efforts that are deemed important for correctly assessing the wildfire risk across their system. The time and effort spent on various development efforts should be roughly proportional to the estimated impact of the updates to be made. This right-sizing of development efforts should be considered across the overarching suite of models (i.e. WDRM, TCM, and consequence model), as well as for the efforts within each branch of models. Right-sizing efforts should also consider the importance of each model component as it relates to the overall picture of wildfire risk company-wide. For instance, the TCM may not require the same level of model detail as the WDRM given the much higher wildfire risk on the distribution system relative to the transmission system. Similarly, the simplicity of the modeling process to translate wildfire simulation results into consequence values seems incongruent with the disproportionately large impact of consequence in the final risk scores.

1.4.2 Justify and seek improvements for model approaches that dilute valuable upstream detail: consequence binning and conservative age logic

In determining wildfire consequence, the consequence model coarsely bins its inputs, placing simulated fires into High and Low impact buckets. This binning approach inherently reduces the level of resolution available within the modeling results, blurring the significant amount of upstream detail available.

[9] Presentation on "PG&E's Proposed Environmental and Social Justice Pilot Study Plan" https://efiling.energy.ca.gov/GetDocument.aspx?tn=250647&DocumentContentId=85425

Alongside this binning, E3 has learned that the main driver for consequence is the FPI score which further reduces the impacts of the in-depth simulations coming from the Technosylva analysis. Through this binning approach, the current implementation of PG&E's risk model simplifies down a diverse and detailed set of inputs. This simplification was an intentional choice by PG&E's modeling team in order to anchor the outcomes to historical data and avoid false precision due to limited data and a lack of real-world validation of the detailed simulations. However, this approach also leads to point estimates of consequence that represent a large range of possible outcomes. E3 recommends that PG&E take steps to quantify and communicate the uncertainty around the consequence scores given the high-bias nature of this modeling approach. Additional public documentation on PG&E's rationale behind these modeling choices were made may also be beneficial. Finally, we recommend that PG&E continue to seek improvements to this approach, especially given that the consequence score is the key driver of the final risk tranches. Notably, although Technosylva simulations are being used across the IOUs in California, there is no standardization of how these simulations should be used to generate final consequence scores. This may be an area ripe for discussion and collaboration within the State.

E3's discussions with the TCM team have revealed that the model produces very conservative estimates of wildfire risk. Currently this is being addressed on the outputs of the TCM through what is called their Bayesian Updating process, along with efforts to reduce overall conservatism through data cleanup and the incorporation of new modeling results. Alongside this general trend of conservatism, in cases where asset age is missing or invalid, PG&E utilizes "Conservative Age Logic" to determine what value to utilize within downstream models. As its name suggests, this approach places a very conservative estimate on asset age, which significantly impacts many model calculations. E3 recommends that PG&E re-evaluate this approach to handling missing data, as this could be a leading cause of some of the relatively high risk estimates that the TCM model is producing. Alongside this re-evaluation, E3 suggests that the downstream impacts of these conservative assumptions be tested such that the entire PG&E team can be aware of the significance of its effects.

This recommendation should be considered in the context of our overall comment on right-sizing. It is our opinion that the current approaches to these calculations have the potential to reduce the value of results enough that they should be addressed, but the extent to which they are addressed should consider the level of effort and expected improvement.

1.4.3 Report risk + uncertainty in outputs and develop a process to understand how individual modeling updates impact results

E3 recommends that PG&E and the CPUC shift the focus of model outputs to quantify absolute risk with uncertainty for each circuit instead of circuit ranks or tranches based on rank. This reporting would avoid loss of risk score information that occurs when outputs focus on ranks. Risk + uncertainty reporting has many advantages: impacts of changes between model versions would be easier to understand, cost benefit analysis and comparison to a risk planning standard would be enabled, need for improved methods and data would be highlighted by large uncertainties, and more robust planning priorities could be developed around high and low confidence results.

The current CPUC-defined tranche-based risk reporting framework provides no vehicle for interpreting and using uncertainty in risk scores. However, this lack of a vehicle may be the result of the State not realizing the potential value or availability of uncertainty quantification. We encourage PG&E to lead this worthwhile exploration with the CPUC by making this information available, and we hope to see further discussion of these uncertainties as the State continues to refine its processes.

Alongside the change in output reporting, PG&E should develop a standardized process to determine the granular impacts of future modeling updates. The results of this standardized process should not only reveal how the results have changed, but also why they have changed at a particular modeling step. Incorporation of this improved reporting and version tracking will help ease the tensions between a long-term planning need for stability and the overall need for accuracy in risk quantification.

1.4.4 Incorporate air quality and health impacts

Wildfire smoke has the potential to spread far beyond the initial burn area, carrying with it myriad pollutants that impact air quality and downstream human health. PG&E does not currently consider the consequences of wildfire smoke within their risk and consequence modeling. E3 recommends that future iterations of PG&E's modeling consider utility-caused wildfire smoke's consequences, particularly those incremental to smoke and consequences from wildfires that result from other causes, as well as factors that contribute to concentrated smoke conditions. Measurements of such factors may require assessing appropriate counterfactual smoke conditions to smoke created by utility-caused wildfires, as well as additional sub-models that analyze vegetation for indicators of smoke-producing fuels. E3 recommends that PG&E, in collaboration with the State and other IOUs, develop a simple, standardized model to assess utility-caused wildfire smoke dispersal and downstream health impacts. While detailed and computationally-expensive modeling options exist for simulating individual wildfire smoke dispersal and health impacts, developing a simple, standardized model may provide a reasonable assessment of health consequences from utility-caused wildfire smoke. Despite the potential uncertainties associated with modeling wildfire smoke impacts, E3 still believes it to be an important part of a holistic view on wildfire risk. This uncertainty should be captured, potentially as an additional sensitivity, in line with the recommendations above.

2 Background

This section provides additional context surrounding the regulatory process through which PG&E's wildfire risk modeling framework was born (Section 2.1). In addition to the regulatory background, this section also provides background on the various avenues through which PG&E is able to secure mitigation funding (Section 2.2). This context underscores the importance of E3's primary recommendation that PG&E should work towards better-using their models to transparently justify the costs of the mitigations they are pursuing.

2.1 Background on the Risk-Based Decision-Making Framework

PG&E's WDRM and TCM models are a part of a broader "Risk-Based Decision-Making Framework", which is a regulatorily mandated framework through which utilities quantify their top safety risks and establish costs for mitigation programs as part of the General Rate Case (GRC) process in the rate case plan (RCP). The California Public Utility Commission (CPUC) first set out to establish this framework in 2013 with Rulemaking R.13-11-006. This Rulemaking set the stage for the ultimate purpose of PG&E's wildfire risk models, stating:

"GRCs are at the heart of our regulatory oversight. As part of our deliberate efforts to change our culture and organization in order to elevate safety, we should determine how the RCP should be revised to explicitly include a showing and scrutiny of programs to ensure appropriate safety, reliability and security of the utility's physical and cyber systems, and not just a presentation of claimed costs."[10]

From the very outset, this rulemaking made clear that at its core, this framework was meant to provide clarity and transparency to the regulator regarding the funds required to ensure safety and reliability at justifiable costs. Several regulatory Decisions have guided the IOUs on how this framework should be set up and applied to meet these goals. With each Decision, the CPUC has been marching toward a more uniform and transparent quantitative framework across the utilities. In 2018, Decision D.18-12-014 approved a settlement agreement that "achieves steps toward a more uniform and quantitative risk-based decision-making framework."[11] This Decision laid out new minimum requirements for the risk-based decision-making framework, including requiring utilities to use a multi-attribute value function (MAVF) such that the quantification of consequence could be more easily compared and understood. The Decision also approved a long-term roadmap that outlined steps to continue to migrate from relative risk scoring to more quantitative methods for optimized risk mitigation.

Now, more than a decade after that original Rulemaking R.13-11-006 established the need for a "Risk-Based Decision-Making Framework", the CPUC is still continually iterating and improving on the guidance for how the framework should be carried out for its intended purposes. Rulemaking R.20-07-013 is currently in progress, with the objective to "consider ways to strengthen the risk-based decision-making framework that regulated energy utilities use to assess, manage, mitigate, and minimize safety risks."[12] In December 2022, Decision D.22-12-027 adopted a new approach to the risk-based decision-making framework. Once again, the CPUC highlighted that a core purpose of these revisions was to succinctly justify the mitigation efforts in accordance with Rulemaking R.20-07-013, stating: "The main objectives of the … Proceeding are to further guide and ensure electric and gas utilities prioritize safety consistent with California Public Utilities Code (Pub. Util. Code) § 451 requirements to ensure just and reasonable rates."[13] Significant revisions in this decision include:

+ replacing the MAVF framework with a cost-benefit approach where risk consequence is expressed in dollar values;
+ specified methodologies and sources to be used to determine standard dollar values of each risk; and

[10] Rulemaking 13-11-006. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K856/81856126.PDF
[11] Decision 18-12-014. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M250/K266/250266979.PDF
[12] Rulemaking 20-07-013. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M344/K081/344081678.PDF
[13] Decision 22-12-027. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M500/K014/500014668.PDF

- requiring a cost-benefit ratio calculation for mitigations, where dollar values of mitigation benefits will be divided by dollar values of mitigation costs, resulting in comparable cost-benefit metrics for proposed mitigations.

Notably, these revisions to the risk-based decision-making framework are all aimed toward standardization that will allow the CPUC to more easily assess whether proposed mitigation costs are justified. This highlights the continued need for utilities including PG&E to improve upon the transparency and justification of mitigation plans so that informed decisions can be made to ensure both safety and just costs to ratepayers. We look forward to PG&E's continued progress toward satisfying these revised requirements. In particular, the newly required cost-benefit analysis may resolve some of E3's top concerns regarding the transparency in the chosen mitigation strategies and using the model to quantitatively justify the plans (see Section 1.3.1 for more details on our recommended approach).

2.2 Cost recovery mechanisms for wildfire mitigation efforts and the growing need to justify mitigation costs

2.2.1 Current cost recovery mechanisms

The successful mitigation of wildfire risk in PG&E's service territory is reliant on the approval of funding towards highly effective mitigation activities. Currently, there are several avenues through which PG&E may gain approval from the CPUC to spend money on mitigation activities or recover such funds after the fact. All of these avenues require PG&E to clearly and transparently justify their mitigation costs and articulate the benefits of their plans. This requirement is reasonable as all stakeholders serve to benefit if PG&E is able to clearly justify effective mitigation plans: the CPUC will be able to make more informed decisions, PG&E will be able to follow through with more of their plans without hinderances, PG&E ratepayers can be assured that the mitigation plans represent cost-effective pathways that will lessen the impact on rates, and most importantly, the general public will benefit from increased levels of safety and reliability.

The primary path through which PG&E can gain funding approval for wildfire mitigation activities is the General Rate Case (GRC). As detailed above, the "risk-based decision-making framework" that necessitated PG&E's wildfire models was born out of a need for the IOUs to be able to quantitatively justify safety and reliability measures as part of the GRC process so that the CPUC can make informed decisions on whether to approve or deny the rate case plans. In the most recent rate case, the CPUC approved 1,230 miles of undergrounding out of PG&E's proposed 2,000 miles, favoring a covered conductor alternative approach for the remaining 773 miles.[14] Costs and construction feasibility on the timeline both factored into the ultimate decision. PG&E also faced a great deal of public backlash to their proposed undergrounding plan due to the perceived cost impact on ratepayers.[15] PG&E responded to the

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[14] CPUC Prioritizes Safety, Reliability, and Affordability in PG&E Rate Case. https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-prioritizes-safety-reliability-and-affordability-in-pge-rate-case-2023

[15] "PG&E's plan to bury power lines and prevent wildfires faces opposition because of high rates." ABC10, 2023. https://www.abc10.com/article/news/local/california/pge-bury-power-lines-prevent-wildfires-high-rates/103-24f7453c-75aa-474d-8670-32cd9d11fd99

backlash claiming that the news stories did "not tell the complete story of how undergrounding reduces wildfire risk for our customers and communities."[16] PG&E can better support their proposed mitigation plans if they can present evidence from their models to clearly show the benefits to both the CPUC and the general public of their preferred mitigation methods relative to other potential mitigations.

A second avenue for PG&E to fund wildfire mitigation efforts is through an application to the CPUC to recover recorded expenditures related to wildfires that are tracked in a memorandum account.[17] Once again, the CPUC can either approve or deny these applications. These applications rely on the reasonableness review by the CPUC. Thus, it is once again necessary for PG&E to be able to clearly and transparently justify why their costs exceed previously approved funds.

Recently, a new avenue has opened for PG&E to apply for wildfire mitigation funding approval following SB 884, the Electric Undergrounding Expediting Program.[18] This law allows for expedited approval of undergrounding plans. Plans are required to show a comparison of undergrounding versus alternative mitigation strategies, and an evaluation of project costs and projected benefits over the lifetime of the assets. Plans are first approved by the Office of Energy Infrastructure Safety (OEIS), and then by the CPUC. Crucially, the law states that "the office may only approve the plan if the large electrical corporation has shown that the plan will substantially increase electrical reliability by reducing the use of public safety power shutoffs, enhanced powerline safety settings, de-energization events, and any other outage programs, and substantially reduce the risk of wildfire." Proving that a plan meets these requirements would necessitate an approach similar to what we recommend in the current review where the benefits of the proposed mitigation strategy over other options are borne out through the detailed modeling results.

2.2.2 Additional considerations on cost recovery mechanisms for wildfire risk mitigation

Currently, the primary cost recovery mechanism for PG&E's wildfire risk mitigation efforts is through the GRC along with all other proposed costs for PG&E's system. The nature of mitigating wildfire risk is inherently different from PG&E's other needs related to its electrical system. Given the unique nature of the challenge around wildfire risk, it is worth considering whether separate cost recovery mechanisms for wildfire risk mitigation would alleviate the challenge that PG&E currently faces where wildfire mitigation costs are competing directly with other system needs.

The new Electric Undergrounding Expediting Program (SB 884) is one example of a separate avenue for the approval of wildfire mitigation funds (funds for undergrounding in particular) independent of the GRC

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[16] PG&E Responds to Inaccurate Claims About the Cost and Effectiveness of its Powerline Undergrounding Program in Reducing Wildfire Risk. https://www.pgecurrents.com/articles/3806-pg-e-responds-inaccurate-claims-cost-effectiveness-powerline-undergrounding-program-reducing-wildfire-risk

[17] The memorandum account cost recovery mechanism is described in Pub. Util. Code § 8386.4. https://casetext.com/statute/california-codes/california-public-utilities-code/division-41-provisions-applicable-to-privately-owned-and-publicly-owned-public-utilities/chapter-6-wildfire-mitigation/section-83864-memorandum-account-to-track-costs

[18] SB-884 Electricity: expedited utility distribution infrastructure undergrounding program. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220SB884

process, as discussed in Section 2.2.1. At the time of writing the present report, the CPUC has only recently released the guidelines to address the requirements of this new law.

The notion that wildfire mitigation costs may be better addressed with a separate approval process has been explored in California in recent history. In 2018, Senate Bill 1088, "Safety, reliability, and resiliency planning: general rate case cycle," was introduced.[19] The bill ultimately died and did not become a law. The bill would have required each IOU to submit a safety, reliability, and resiliency plan to the CPUC every 2 years that would have encompassed a range of major events including wildfires, floods, earthquakes, and others. The CPUC would have been required to approve the submitted plans within 18 months and authorize cost recovery through rates.[20] Major arguments in opposition to the bill included:

- concerns that it would provide a "blank check" to IOUs for cost recovery related to their plans, which would in turn increase rates; and
- concerns that ratepayers would be obligated to pay for a utility's negligence or items not addressed in their plan.

E3 suggests that these concerns could be alleviated by a statewide risk tolerance set by the CPUC as a planning standard, coupled with model results capable of demonstrating that the IOU's plans would minimize costs to meet the standard, as proposed in Section 1.3.1.

Other examples of separate funding approval processes for utilities to tackle unique and challenging efforts exist outside of the realm of wildfires. A special cost recovery mechanism was put in place to recover the initial construction costs of the Diablo Canyon Power Plant, where PG&E overran the projected budget during plant construction, and the CPUC approved PG&E to recover some overruns through a performance-based multiyear rate plan.[21,22] Another special cost recovery mechanism has been set for the Diablo Canyon Power Plant's eventual nuclear decommissioning costs, where PG&E collects monthly fees on customer electric bills to fund a Decommissioning Trust Fund, augmented by investment in stocks and bonds.[23] These cost recovery structures aimed at tackling unique cost challenges are examples of ways in which PG&E has historically been able to earmark funds for major efforts without direct competition with other funding needs.

[19] SB-1088 Safety, reliability, and resiliency planning: general rate case cycle. https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180SB1088

[20] SB-1088 Safety, reliability, and resiliency planning: general rate case cycle, Bill Analysis. https://leginfo.legislature.ca.gov/faces/billAnalysisClient.xhtml?bill_id=201720180SB1088#

[21] LA Times Plan to Recovery Diablo Canyon Plant Costs. https://www.latimes.com/archives/la-xpm-1988-12-20-mn-597-story.html

[22] "State Performance-Based Regulation Using Multiyear Rate Plans for US Electric Utilities." https://escholarship.org/content/qt4r13j347/qt4r13j347.pdf

[23] Diablo Canyon Decommissioning Funding. https://diablocanyonpanel.org/decom-topics/decom-funding/

3 Wildfire Risk Modeling Best Practices

This section summarizes learnings on wildfire risk modeling best-practices assembled based on interviewing the technical advisory committee (TAC). The TAC consists of experts across the domain of wildfire risk modeling. It includes representatives with a diverse range of expertise that may be relevant to PG&E, with the goal enhancing the best-practices in wildfire risk modeling. In addition to interviews with the TAC, this section also incorporates best-practices found in recent literature, as well as summarizing relevant takeaways from the recent OEIS Risk Modeling Working Group.

To respect the anonymity of TAC members, the summary of best practices is provided in aggregate, and commentary is not linked to individual interviewees. In reporting the learnings from interviews, this section primarily focuses on key takeaways that were shared across many interviewees. The interviewees included:

- Michael Goulden, Professor of Earth System Science, University of California, Irvine
- Chris Lautenberger, Ph.D., PE, President & CEO, CloudFire Inc.
- Greg Dillon, Director, Fire Modeling Institute, USDA Forest Service, Rocky Mountain Research Station
- Park Williams, Professor, Department of Geography, University of California, Los Angeles
- Janice Coen, Ph.D., Senior Research Scientist, Department of Environmental Science, University of San Francisco
- LeRoy Westerling, Professor, University of California, Merced
- Joe H. Scott, Principal Wildfire Analyst, Pyrologix LLC
- Ross Martin, VP, Risk Analytics, ZestyAI
- David Stoms, California Energy Commission
- Additional interviewees that preferred to remain anonymous.

Below, we summarized learnings from interviews with these advisory committee members and other external sources, including documentation from the California Department of Insurance, wildfire risk modeling literature, and publicly available information from private risk modeling companies. We present these as a series of topics for PG&E's consideration in further wildfire risk modeling efforts.

3.1 Summary of key findings

3.1.1 Validation and calibration's impacts on wildfire spread model

Industry-standard wildfire spread algorithm requires calibration to address shortcomings

Of the many wildfire risk models available from private and public bodies, many rely on the Rothermel equation as the primary driver of wildfire spread. This equation, dating back from 1972, comes from Missoula Fire Lab wind tunnel experiments of wildfire spread. Given the age and limited topographic variability of the research, the Rothermel equation contains shortcomings that new fire research better-understands. In particular, the Rothermel equation assumes radiant heat transfer from one particle to another, but new studies from the Missoula Fire Lab, run by the US Forest Service, suggest that convective air currents direct hot gases into fuels until those fuels combust, a phenomenon that the Rothermel equation does not fully capture. Technosylva's simulations rely on the Rothermel equation, with modifications, as is the industry standard for wildfire spread modeling.

Many wildfire risk modelers acknowledge and work around these shortcomings, either by incorporating new model components or calibrating the equation against empirical information and subject-matter expertise. This latter methodology requires extensive iteration on model versions; after running a wildfire spread model, subject matter experts convene to identify areas that deviate from expectation, and modelers then identify areas for modeling improvement. Additional research on convective fire may yield updates to the Rothermel equation or new algorithms.

Vegetation data quality and refresh cycle impacts risk model prioritization and validation

Amid discussions of data quality, TAC members repeatedly flagged that the accuracy, refresh cycle, and validation methods for vegetation and fuels datasets impact wildfire risk. Through conversation, we learned that many risk modelers use fuels data layers from LANDFIRE, an open-source, nationwide US Forest Service-generated model of vegetation, topography, and other geographic data. Industry-wide, LANDFIRE serves as a useful starting point for fuels in many wildfire risk models, in part because few other widespread, detailed datasets exist. However, we learned that LANDFIRE data may result in anomalies between one data vintage to another, and calibration or validation against empirical fuels measurements are often needed to produce results that are consistent with SME understandings. Alternatives to LANDIFRE include detailed fuel layers from Salo Sciences, a private company that provides a subset of PG&E's vegetation data. TAC members largely consider the Salo Sciences methodology, which relies on synthetic LiDAR, as a sound source of fuels layers, but caution that the company's new direction has reduced access to previously open-source information, making it harder for outside eyes to validate their methods.

Validating and refreshing fuel data impacts the quality of wildfire risk modeling, up to a point. Several interviewees noted that regular refresh and validation may help capture rapid vegetation growth in highly productive ecosystems, such as California's chapparal system, which grows more quickly than the state's coniferous forests. Frequently refreshing the fuels data also helps capture growth in burn scars from recent wildfires, where re-growth may not follow the same patterns of productivity or have the vegetation type as what was present in the area prior to the burning. Although many interviewees agreed that valid and up-to-date fuels data are important, another perspective that we heard is that the extensive model calibration process may obviate the need for detailed fuels and vegetation data, as the coarseness of calibration means that highly detailed fuels are not always captured by the final model. Finally, we learned that Technosylva refreshes their fuel cycle 3-4 times per year, with special focus on growth in burn scars and grass fuel areas, the latter of which dynamically changes based on annual moisture and fuel load.

3.1.2 Linkages between probability of wildfire ignition and wildfire consequence

Conversations with TAC members suggest that more closely linking probability of ignition and consequence may better-capture extreme wind's impact on wildfire ignition and spread. Extreme wind is a strong determinant of both the probability of ignition and consequences of wildfire spread. Extreme winds are likely to cause equipment failures or vegetation obstructions that lead to arcing between conductors and vegetation, resulting in fire ignition. After the ignition, extreme winds exacerbate the spread of fire at a faster rate through a larger area. Crucially, the wind speed impacts both the probability of ignition *and* the consequence. PG&E's current modeling considers drivers of ignition and consequence separately. Other California IOUs such as SCE and SDG&E similarly separate their risk and consequence modeling. To capture the effect of extreme wind on both wildfire ignition risk and consequences, some TAC members strongly recommend a new methodology that incorporates a temporal element to capture the linkage between probability of ignition and consequence during extreme wind periods.

As E3 understands it, v4 of the PG&E model calculates total circuit segment risk by directly multiplying average annual probability of ignition and average annual consequence for each pixel on a circuit segment and adding these pixels to get the total circuit segment risk. However, this annual averaging of probability of ignition and consequence doesn't adequately capture high wind periods. Several TAC members recommended parsing out the impact of high-wind events more specifically, for example by modeling ignitions during high wind times and multiplying that against consequence during those high wind times to adequately capture resulting risk. This methodology, applied to PG&E's existing spatial method of calculating risk per pixel, may reduce the undercounting of extreme wind's impacts on risk.

3.1.3 Additional consequence metrics for study and improvement

Changes to wildfire spread model duration

PG&E relies on Technosylva to model wildfire spread using a match-drop methodology, where the Technosylva model simulates thousands of ignitions across PG&E's service territory. In previous cycles, Technosylva modeled these fires for 8 hours, but in the most recent iteration of PG&E's risk assessment, they modeled fires for 24 hours to compare outcomes against those seen after 8 hours. Multiple risk modelers recommend a run time longer than 8 hours, as the largest fires may not be captured within the 8-hour span, though opinions vary on the appropriate model duration. One perspective that we heard is that different burn durations may capture different key wildfire consequences. For example, capturing smoke and health outcomes may require a longer burn duration given that they depend on the entire extent of a fire, whereas loss of life may be captured with a shorter burn duration as people evacuate from the immediate area. Among historical catastrophic California wildfires, some have burned for multiple days or weeks, while others reach their greatest size within the first 8 hours. Maintaining a longer run time ensures that larger fires are not artificially limited by the modeling spread achievable within the model run time.

Methods for assessing wildfire smoke and its health consequence

TAC conversations affirmed that health impacts associated with wildfire smoke are important consequences to explore and incorporate in modeling, yet it remains difficult to quantify these impacts. As discussed in the recommendations above, one of the most accurate ways to model atmospheric pollution from wildfire smoke requires studies of plume dispersion. In addition, incorporating data on fuels like duff, organic material in varied states of decomposition that is a key fuel stock in fires, could provide an accurate assessment of smoke from burning fuels. Such studies are computationally intensive, yet proxies for wildfire smoke's health effects exist for further exploration.

Incorporating ingress/suppression and egress/evacuation into wildfire consequence modeling

PG&E and other IOUs have recently begun incorporating the impacts of egress and suppression in their wildfire consequence modeling. TAC members caution that in some fire conditions, suppression through firefighter activity is not possible; in the most catastrophic historical wildfires, firefighter resources have been focused at the fire perimeter to stop further fire spread. Entering such catastrophic fires may not be possible, both because of limits to firefighting resources and because under certain fire weather conditions, suppression activities within the fire simply won't have impact. This perspective suggests that in some of the most consequential fires, suppression activities may not be able to reduce consequences.

New options for assessing burn severity and damage in consequence modeling

PG&E currently uses a binning methodology to capture consequences of wildfire spread. By speaking with risk modelers supplying property damage models for the insurance sector, we learned that more granular methods exist for capturing wildfire damages to structures and personal property at the community level or individual property level. New risk modeling innovations include aerial imaging to assess properties before and after wildfire. Machine learning models can be applied to these image datasets to assess contributions that property variables such as building material and surrounding vegetation have on wildfire consequence. This detailed approach to property damage modeling demonstrates that granular alternatives exist to supplement and inform PG&E's evolving consequence model framework.

Incorporating climate impacts into consequence modeling

Most risk interviewees agreed that we need to holistically incorporate climate impacts into wildfire risk assessment, especially when considering wildfire consequence modeling. Climate change increases uncertainty in a plurality of future risk and consequence factors, such as soil moisture, fuel growth, humidity, and more. The uncertainty that climate change introduces into fire modeling means that no set methodology exists to model climate impacts. Industry and academic experts continue to explore options to represent climate change's impacts on risk and consequence modeling.

For models trained on historical data, modelers have considered or begun training models on historical outlier weather years, reducing the window of past weather years to only include shorter, more recent years of data. Changing weather data also impacts fuels availability, but climate impacts on fuels are poorly understood. Warmer temperatures tend to dry out fuels more quickly, so studying fuels growth during historical wet year and dry years offers one proxy for fuels growth under global warming, as does studying fuel conditions in areas in Southern California, where temperatures are already hotter, drier, and closer to conditions that climate change may bring to PG&E's service territory.

Warmer, drier conditions will result in greater area burned, greater frequency of extreme fires, but with a wide range of uncertainty as to how much both factors will increase. Drier fuels will result in greater area burning, as decrease moisture content makes it easier for fuels to heat, ignite, and spread a fire faster. Extreme fires are also more likely under warmer, drier climate conditions.[24] Research suggests that increased area burned would nearly double the carbonaceous aerosol emissions in wildfire smoke,

[24] Littell et al. (2009). "Climate and wildfire area burned in western U.S. ecoprovinces, 1916-2003." *Ecological Applications*. https://doi.org/10.1890/07-1183.1

increasing the damaging health impacts associated with wildfire smoke.[25] Simulating wildfires under a range of potential climate impacts, such as changes in temperature, moisture, and related fuel growth, could provide insight into the most likely climate impacts. We spoke with researchers who continue to carry out such simulations, for the purpose of identifying common markers of climate impacts of bookends to capture the uncertainty that climate change introduces into risk and consequence.

3.1.4 Opportunities for collaboration and learning

The potential need for a statewide, open-source model

As IOUs like PG&E continue developing detailed models, interviewees raised the potential need for a statewide model, with varied rationale for why such a model may be useful. A recurring perspective raised that a statewide model could help ensure the entire risk modeling framework is transparent and potentially open source, providing insight into methods used to set mitigation strategy.

Another viewpoint is that the development of a best-in-class statewide model for California would set an example for other states to follow and could provide a re-usable framework with broad public benefit. While it would be difficult to reconcile the development of a statewide model with the ongoing extensive model development efforts amongst California's IOUs, exploring a statewide model or some synchronization between utility modeling could provide fruitful insights into best practices for use in California or in other states. One area where statewide synchronization appears achievable is under consequence modeling. As PG&E, SDG&E, and SCE all rely on Technosylva's wildfire spread simulations for an important component in their consequence modeling, these utilities have an opportunity to standardize how they use Technosylva's outputs to inform their final wildfire risk.

Incorporating key learnings from insurance companies

Though we did not speak with insurance companies directly, we had an opportunity to review key findings from the California Department of Insurance's recent survey of modeling methodologies involved in wildfire risk modeling. In addition, we surveyed ideas from the widely-used risk modeling performed by the company Verisk. From this survey, we offer a few areas for PG&E to explore in future iterations of their modeling and collaboration with State entities.

First, the California Department of Insurance (CDI) conducted a survey of prominent modeling methodology, which resulted in public available data and workshops held between CDI, catastrophe modelers, and stakeholders in insurance. After a series of insurance non-renewals left California homeowners without insurance options outside CAL FAIR, a public option expensive for both homeowners and the State, CDI increased their attention and investment in wildfire risk assessment. The findings from CDI's survey and workshops may contain information useful to PG&E modelers. CDI's review of catastrophe modeling could supplement PG&E's own consideration of new ways to model climate impacts on wildfire ignition and consequence. In addition, CDI's requested data from insurers may help PG&E better quantify wildfire consequences on a more granular level. CDI made some data from insurer review

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[25] Spracklen et al. (2009). "Impacts of climate change from 2000 to 2050 on wildfire activity and carbonaceous aerosol concentrations in the western Unites States." *Journal of Geophysical Research*. https://doi.org/10.1029/2008JD010966

publicly available. Much of this data features wildfire scoring from Verisk, a company whose models widely inform the insurance industry's analyses of wildfire risk.

Key learnings from other IOUs

Through TAC member conversations, we found that other investor-owned utilities face risk modeling challenges similar to those which PG&E experiences. These IOUs all model risk and consequence separately, with Technosylva providing wildfire spread analysis as part of consequence modeling. TAC members commented that the various IOUs have made progress in different areas, and that there may be learnings for PG&E in reviewing modeling progress across other IOUs. Below we present some recent highlights from modeling efforts by other IOUs:

- **San Diego Gas and Electric (SDG&E)**: Most consequence models do not consider the health effects of wildfire smoke, a far-reaching wildfire consequence that is difficult to capture. However, SDG&E incorporates a coarse mapping of fatalities-per-acre to estimate potential deaths from wildfire smoke. Finer analyses study the atmospheric dispersion of wildfire smoke plumes and quantify downstream epidemiological risk, yet operationalizing such studies in real-time or faster than real-time remains challenging. The California Air Resources Board has funded research on wildfire smoke's health effects, and future research efforts should study methods to operationalize models of wildfire plume dispersion and downstream epidemiological risk.
- **Southern California Edison (SCE):** During a wildfire event within or near a populated area, wildfire consequences largely depend on the resident population's ability to quickly evacuate the impacted area (egress) and on firefighter ability to quickly enter the impact area (ingress) to contain or suppress the wildfire. SCE's wildfire modeling incorporates a model of ingress and egress to investigate the ability of resident populations to quickly evacuate parts of their service territory. During catastrophic fires, challenges to egress are correlated with the probability of mass casualty events, as the Camp Fire indicates. During moderate fires, challenges to ingress are correlated to property loss, as suppression efforts rely on the ability to enter impacted population centers. PG&E has also begun to incorporate the impacts of ingress and egress in their modeling outputs. This is an area for potential collaboration between IOUs.
- **PacifiCorp:** Utilizing a different internal structure for their wildfire modeling, PacifiCorp breaks down some elements of their wildfire modeling into "attribute-specific" elements of the fire. For example, the likelihood of a wildfire could be influenced by a weighted sum of Fire Spread, Fire Behavior, and Fire Size Potential at a given location. This contrasts to modeling structures of other utilities where the fire impacts are holistically considered.

3.2 OEIS Risk Modeling Working Group

After reviewing the 2021 WMPs, OEIS identified a need for more consistency and transparency amongst utility wildfire risk modeling. They established the Risk Modeling Working Group (RMWG) in response. [26] The RMWG brought together utilities, experts, and other stakeholders to confer on the various utility wildfire risk models. Phase I took place from October 2021 through December 2022, with the goal of understanding current risk modeling processes amongst each utility and sharing information. Phase II will focus on identifying specific, actionable directions for improved risk modeling by utilities.

The technical advisory committee established for the purpose of the present review differs from the RMWG given that the present report is focused solely on PG&E's specific approaches, whereas the RMWG has a broader focus across many utilities. However, they both intend to gather best practices across the field to inform utility wildfire risk modeling. The RMWG identified many of the same shortcomings that are also highlighted in the present review, and made similar recommendations and comments including:

- a need for greater transparency in the consequence modeling;
- recommending further evaluation of avoided PSPS events;
- understanding the interplay between the probability of ignition and consequence models given that both ignition and consequence are heavily impacted by high winds;
- right-sizing the model development efforts and evaluating potential benefits before making significant changes; and
- increased data sharing across utilities

3.2.1 Summary of Risk Modeling Working Group Phase I

The Phase I summary report was released on June 15, 2023. This section provides the key takeaways for the Phase I topic areas relevant to this review. These takeaways appear as-written in the summary report.[27] We've shown points with particular relevance and overlap to the present review in **bold**.

Review of Consequence Models

- IOUs' existing approach to meteorology and climatology data sets differ in granularity, although many of the aspects are similar, such as evaluating wind, temperature, and humidity.
- All three IOUs rely on Technosylva at least in part to perform consequence risk modeling. This includes Technosylva's in-house fuel characterization and data collection, as well as data integration and modeling of socioeconomic/static vulnerability characteristics, egress, and terrain difficulty.

[26] Docket Log from Risk Model Working Group. https://efiling.energysafety.ca.gov/Lists/DocketLog.aspx?docketnumber=Risk-Model-Group

[27] Risk Modeling Working Group Summary Report, Phase I. https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=54072&shareable=true

- The RMWG needs more granular data on consequence risk models to fully evaluate them and understand what is being modeled; this data may require **greater transparency from data vendors** than what is presently offered.

Risk Drivers, Probability of Ignition Models, and Data/Inputs

- **IOUs and SMJUs should start evaluating how to integrate estimates for PSPS prevented consequences into modeling**, as suggested by MGRA. A good practice would be to consider the pros and cons and the accuracy. PG&E currently leads in this effort.
- IOUs and SMJUs should also evaluate how to translate outage and near-miss data into ignition risk data, if not already doing so, including overcoming outage location extrapolation through language processing and machine learning.
- Likelihood of ignition models need further evaluation to understand the impact from certain drivers such as balloon and vehicle contacts, and the sort of bias that may play on understanding risk in the planning and operational models.
- **IOUs and SMJUs should move toward equipment-specific failure models**, with most of the utilities already modeling conductors and are moving toward modeling additional equipment. This modeling is dependent on accurate equipment inventories and data.

Likelihood of Vegetation Risk Events and Ignitions

- Evaluation of tree species/genus is useful in determining vegetation risk, and databases should move toward accurate and granular species information as part of risk evaluations.
- **The RMWG should conduct further evaluation to determine which factors contribute to likelihood of events, including temporal factors such as climate and climate change.**
- The RMWG should conduct further evaluation to understand how to integrate LiDAR and NDVI data within modeling data sets, including the pros and cons of such, as well as correlations to identifying risk events.

PSPS Likelihood and PSPS Consequence, Reliability Analysis, and Impact

- IOUs have primarily built-out operational PSPS models based on historical back-casting from previous PSPS events as well as retroactive interpolation prior to PSPS.
- This area may benefit from data sharing given the large variances between number of events for IOUs and SMJUs.
- **The RMWG should conduct further evaluation on the balance between PSPS risk and wildfire risk for both the planning and operational models.**

Modeling Algorithms

- Understanding how IOUs are using the models is critical. Design basis is critical in an engineering system, but it is difficult due to the broad uncertainty in environmental impacts.
- **More evaluation and understanding on the interplay of co-factors across various portions of modeling is key, with wind being an important example given the effects on both ignition and consequence.**

- Model verification, validation, and sensitivity performance is key in understanding covariates and causalities relating to risk. **Part of this should involve data sharing across utilities regarding outages and ignitions to increase data set sizes and useability**
- The RMWG should conduct further evaluation to identify the difference between the probability of ignition and the probability that such ignition turns into a catastrophic wildfire.
- IOUs and SMJUs should be clear about the processes for validation, including the uncertainty percentages at each aspect of its model to understand compounding uncertainty. Validation should also include comparison to real-world data including weather station data.

Modeling Algorithms, Components, Linkages, and Interdependencies

- The RMWG should conduct further evaluation to understand the various types of machine learning models currently used, including validation and tactics to understand potential biases.
- Data use is key as inputs to machine learning models and could benefit from cross-utility sharing, particularly for SMJUs.
- There is variability across the Global Climate Model (GCM) followed by all IOUs in their current efforts to address climate change impact on their risk models, with some guidance from CPUC's Climate Change Adaptation Order Instituting Rulemaking (OIR) and CalAdapt.
- There is also much variability in how GCMs isolate climate change impact.
- Regarding climate change preparedness as of today, the IOUs are focusing on infrastructure hardening and system resilience as well as determining the necessary timing for hardening based on forecasted events.

Lessons Learned, Guideline Improvements, Topics for Next Session

- IOUs noted the commonalities present in their risk models, development methods, and data use will allow for greater collaboration going forward; they want the RMWG to move from organizing discussions to facilitating action.
- **Due to the complexity of the risk models used, any proposed changes should be evaluated for potential benefits to ensure the change and downstream effects are worth the cost.**
- IOUs noted that the RMWG should once again cover planning and operational models but at a greater depth than what occurred in Phase I. Additionally, going forward, a distinction should be made between the two types of models whenever a discussion on risk modeling occurs.
- SMJUs noted that it’s critical for Energy Safety to consider that smaller utilities do not have the customer base to justify the cost of implementing the mitigation research, planning, tools, and practices of large IOUs.

Comprehensive Accounting for Wildfire Smoke Consequences

The IOUs seem receptive to extending the way they calculate the consequence of fire to incorporate the impact of smoke and greenhouse gases, with the following caveats:

- IOUs would like the model and parameters to be provided to them, rather than developed by them.
- IOUs would like the model to be simple and compatible with the existing wildfire modeling parameters, so either of the following would be reasonable:

- An assumed cost per acre burned.
- An assumed cost per acre burned, adjusted based on geographic regions, like the HFTD map. The regional breakdown would presumably account for both typical vegetation, typical wind directions, and proximity to population centers. For example, the impact of wildfire smoke in some regions may be more detrimental than an equivalent number of acres burned in a different region.

4 PG&E Wildfire Risk Model Evaluation

In this section, we focus on areas where PG&E has improved the model substantially, and offer recommendations across several areas where PG&E can improve further. This section is structured as follows:

- **PG&E's incorporation of E3's v3 recommendations:** a summary of PG&E's progress towards the recommendations made in the prior review
- **Risk modeling framework:** a high-level description of PG&E's risk modeling framework
- **Overarching recommendations:** E3 recommendations that span across many elements of PG&E's modeling framework
- **WDRM:** summary of major changes and E3 recommendations on the distribution model
- **TCM:** overview of the transmission model and E3 recommendations
- **Wildfire consequence and risk:** overview of the consequence model, summary of major changes, and E3 recommendations

4.1 PG&E's incorporation of E3's v3 recommendations

Based on the prior review of the WDRM v3 model, E3 made several recommendations that fell into three categories: standardization and coordination, improvements to high-impact model input data and components, and expanding model applications to further use cases. PG&E has summarized their progress towards the key recommendations in their 2023 Wildfire Mitigation Program and interviews with E3. In this section, we summarize E3's v3 recommendations and describe PG&E's changes in response.

4.1.1 v3 recommendations on standardization and coordination

E3 recommended providing insight into PG&E's planned roadmap of model updates, including when and where these models will be integrated; along with a standardization of the SME relationship used to make such models.

Standardizing and documenting the relationship between SMEs and model clients

E3 v3 Recommendation: Understanding that the model supplements decisions that SMEs have made for years, E3 recommended leveraging SME expertise where necessary (e.g. where data was lacking) while being very clear as to the roles of the model versus SMEs in PG&E wildfire planning processes. Additionally, E3 suggested that internal PG&E clients that use the modeling outputs need to coordinate with the model developers to implement the model appropriately alongside their subject matter expertise.

E3 Progress Assessment: In the Wildfire Mitigation Plan, PG&E indicated that they developed and implemented a standardized client process as part of WDRM v4. This process consists of regular oversight meetings where SMEs provide iterative feedback on user goals, including Mitigation Program requirements. While PG&E has made significant progress towards improving transparency between the model team and the SMEs and client teams, E3 believes that PG&E would benefit from continued efforts towards this goal. For example, through an interview with an internal client team on the transmission side, E3 heard that additional socialization of the TCM validation would be helpful for the team to understand the model's status and readiness for use in their applications. We reiterate our belief that a continued focus on a standard process for interacting with SMEs and internal client teams stands to benefit all involved.

Establishing an expanded model roadmap for model direction

E3 v3 Recommendation: Given the model's size and complexity, E3 recommended creating a roadmap that enables update prioritization and communication with relevant model developers and downstream users.

E3 Progress Assessment: In the Wildfire Mitigation Plan, PG&E stated that they developed such a roadmap for the WDRM and TCM. In addition, PG&E plans to update this roadmap with items from the Energy Safety Risk Model Working Group and other SMEs. E3 still believes that there is more that PG&E can and should do with regards to a roadmap of planned changes. To this end, in the current review, E3 has recommended right-sizing planned development efforts based on critical needs and impact level. There is also an inherent tension between continually improving model results and incorporating these results into mitigation plans that may take several years to execute.

Coordinating PG&E's modeling with broader Statewide planning

E3 v3 Recommendation: E3 recommended the creation of a long-term Statewide master plan for wildfire risk modeling that would consider common risks impacting all California IOUs. E3 suggested that such a Statewide plan would guide the Wildfire Mitigation Plans, and that future versions of wildfire risk models from individual IOUs including PG&E could be used to comply with State-enshrined performance goals.

E3 Progress Assessment: While a vision for a long-term, coordinated wildfire risk modeling and mitigation process did not pass through the State Legislature, E3 observed a few promising developments in Statewide coordination, including: (1) 2022 CPUC Decision D.22-12-027 requesting that IOUs incorporate clear cost-benefit analyses of mitigation strategies, and (2) IOU collaboration with the OEIS Risk Model Working Group. E3 recommends that PG&E continue to initiate and engage with opportunities for Statewide collaboration and learning, to better streamline risk modeling and management.

4.1.2 v3 recommendations on high-impact data and model components

For a model as complex as PG&E's WDRM, making improvements to data inputs and model components requires careful prioritization to make effective use of modeling resources. E3 recommended that PG&E focus on making improvements to the consequence portion of the model, which has a large impact on the resulting risk prioritization yet requires many outstanding improvements. In addition, E3 recommended focusing data quality improvements through targeting high-impact data inputs that most impact model outcomes.

Re-assessing the consequence model approach

E3 v3 Recommendation: As stated in E3's reviews of v2 and v3 of the WDRM, the consequence model has an outsized impact on outcomes from the model, and E3 would like to see increased scrutiny from regulators on the consequence model's development and use. E3 also recommended that PG&E

continue improvements to the accuracy and biases of their consequence modeling, through vetting and making transparent the use of wildfire spread modeling from a private company, Technosylva.

E3 Progress Assessment: To improve the accuracy of the consequence model, E3 recognizes that PG&E collaborated with Technosylva to alter the duration of wildfire spread model simulations, from 8 hours in prior versions to 24 hours in v4 of the WDRM. This collaboration resulted from dialogue between PG&E, Technosylva, and other IOUs, a sign of increased transparency and collaboration. Additionally, PG&E incorporated Red Flag warnings, incorporated egress and suppression, now produces the full distribution of consequence as opposed to just point estimates, and significantly updated their datasets. This is all great progress, but E3 continues to see some opportunities for improvements to PG&E's consequence model components, as well as its overall transparency. It remains unusual that a private company with proprietary, non-transparent modeling so regularly informs utility and State wildfire policy implementation. While Technosylva is a respected member of the wildfire spread modeling industry and is used by all three IOUs in California, E3 once more recommends the State, in coordination with CalFire, establish a way to protect proprietary modeling information, but test and vet any private tool or model used by IOUs that significantly informs their wildfire plans.

Data refresh cycles and data sharing

E3 v3 Recommendation: E3 recognized that data gaps naturally occur in such a complex model, and data refresh cycles will be required for the model's function as data grows outdated. In light of such challenges, E3 recommended planning data refresh cycles as part of the overarching model roadmap, prioritizing filling gaps or refreshes for high-impact data, and collaborating to pool and transparently share Statewide data to supplement the aforementioned data updates.

E3 Progress Assessment: As part of WDRM v4's development, PG&E created asset data quality dashboards, where PG&E tracks data gaps and prioritizes which to fill as part of on-the-ground asset prioritization efforts. After viewing examples of data from these dashboards, E3 considers their formation a sign of meaningful PG&E progress toward prioritizing high-impact data collection. However, these dashboards lean toward reactive efforts responding to gaps or errors. E3 urges PG&E to continue proactively planning model refresh cycles as part of the model roadmap, as well as sharing and gathering data from State agencies or other IOUs to supplement data where possible.

4.1.3 v3 recommendation on expanding model use

As a comprehensive analytic tool, PG&E's WDRM model has an opportunity to inform mitigation planning across further use cases than seen in E3's review of WDRM v3. In our last review, we noted that the model provides value for PG&E's short-term (one-year) geographic targeting and mitigation, yet we recommended that PG&E expand the model's use to enable long-term, targeted mitigation planning in future iterations.

Consider using the model for longer-term planning of mitigation budgets

E3 v3 Recommendation: In E3's review of WDRM v3, the model was only used to support annual wildfire mitigation plans, but not long-term wildfire strategic planning to include overall portfolio balancing and budgeting. E3 recommended that PG&E build on the existing model, including adding a temporal element, to enable long term strategic planning. This method would internalize the tradeoffs of short-term solutions like PSPS against other long-term mitigations, such as system hardening.

***E3 Progress Assessment*:** In v4 of the model, the team mentioned the inclusion of *some* temporal elements to the model, but not to the degree originally envisioned in the v3 review which would enable a holistic and forward looking view of all wildfire mitigation plans and measures and provide insight into how the budget and portfolios should be determined and prioritized today. In this review of v4, we provide additional context for how this framework and balance could be achieved.

4.1.4 Summary of PG&E's stated progress

PG&E has provided details of their progress toward E3's recommendations for WDRM v3 improvements in their 2023 Wildfire Mitigation Plan. Details from the WMP are replicated in the Table 1, which also includes updated progress for v4 as of July 2023.[28]

Table 1 PG&E's stated progress towards E3 recommendations as of July 2023

Line No.	Recommendation	Progress	Next Steps	Update Jul 23
1	Standardizing and documenting the relationship between the model and SMEs	Developed and implemented standardized client process in development of WDRM v4 model.	Further document the SME to model relationship. Standardize processes for model use vs SME judgement. Continue supporting PG&E clients.	See presentation slide "*Improved Development Feedback Loop*" below this table (Figure 3)
2	Improving the transparency and validity of the consequence portion of the model	Updates to the model and data and better collaboration with other utilities to improve wildfire consequence model.	Further data improvements, process improvements for use of consequence outputs, and continued inclusion of temporal components.	WFC v4 release is based on 24-hr Technosylva simulations. Ongoing discussion with other utilities at RMWG meetings
3	Establishing a data quality control process	Developed asset data quality dashboards to prioritize asset data improvement projects.	Develop a predictable schedule for key data updates to assist PG&E clients and workplan developers.	Asset Quality Dashboard implemented in Foundry – see screen capture below this table. Expanded use of Foundry pipelines Closed gaps in dataset snapshotting
4	Establishing an expanded roadmap for model direction	Developed for WDRM and Wildfire Transmission Risk Model (WTRM).	Continue to provide a schedule of data and model updates for predictability and plan updates based on impact.	Roadmap provided in the WMP, but it needs improvement and updates. Updates will include planning for specific model output for integrated grid planning and Copperleaf budget tools.
5	Exploring potential further use cases of the model	Expanded individual sub-models to improve alignment with workplans in WDRM v4.	Expand the functionality of the model to provide a holistic and long-term strategic planning view.	See presentation slide "*Equipment Failures Alignment with Asset Strategy Work Planning*" below this table (Figure 4)
6	Coordinating PG&E's process with broader State-wide wildfire planning	Communicated recommendations to Energy Safety as part of the proposed work on coordinating utility and state wildfire plans.	Continue close collaboration with the state and other IOUs.	This item didn't make it through the state legislature.

[28] Note that the column entitled "Update July 23" did not originally appear in the WMP, but was a supplemental progress update provided to E3 by PG&E.

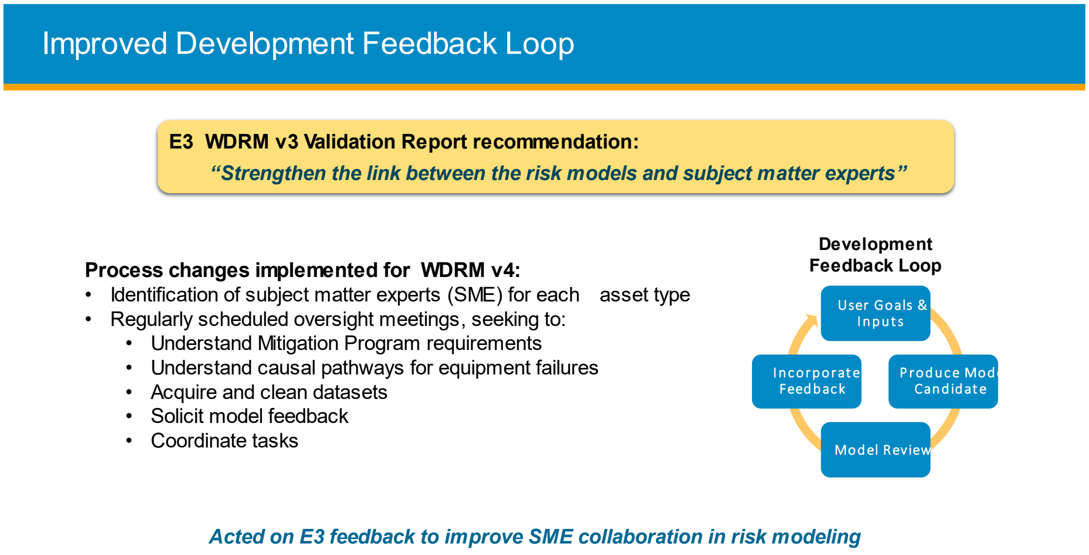


Figure 3 PG&E-provided documentation on SME feedback loop

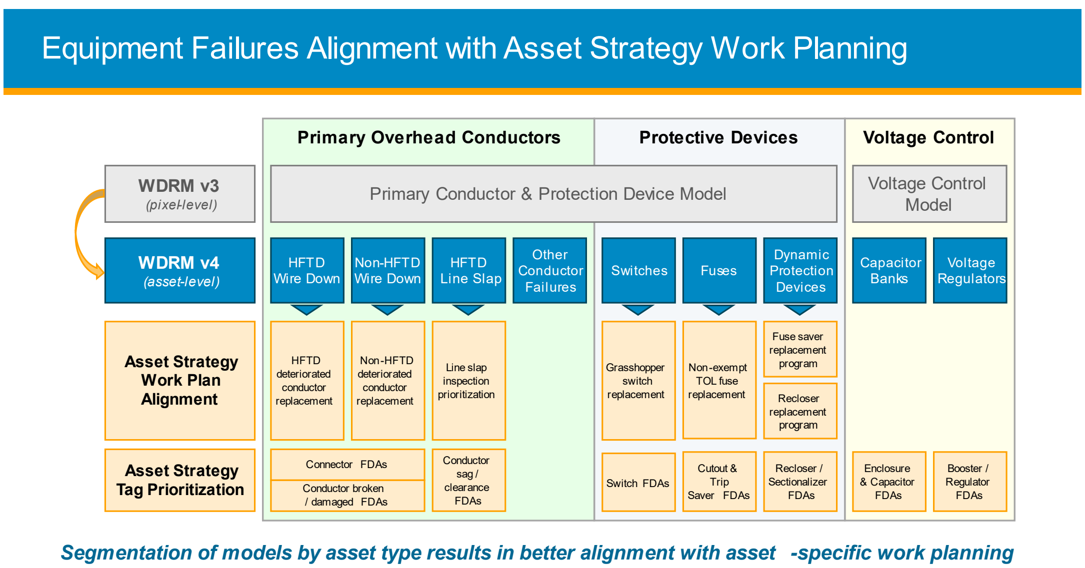
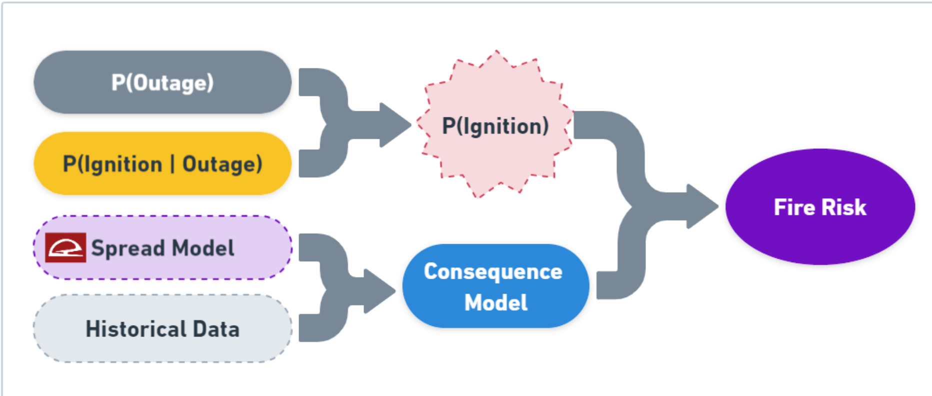


Figure 4 PG&E-provided documentation on aligning with asset strategy

4.2 Risk modeling framework

At a high level, PG&E's risk model is structured as follows. Based on PG&E's internal equipment data, probability of outage, P(O), is modeled across all available parts of the PG&E system. This probability of outage is then paired with a probability of ignition given outage, P(I|O), to produce a probability of ignition, P(I), for each part of the PG&E grid. Utilizing this insight into where fires could occur, the risk model then pulls in an external fire spread model generated by Technosylva and historical fire datasets to produce a fire consequence model. Finally, the P(I) and the consequence are multiplied to calculate the wildfire risk.



4.3 Overarching recommendations

4.3.1 Report risk + uncertainty in outputs and develop a process to understand how individual modeling updates impact results

One challenge that PG&E faces as they continue to update their model is the tension between stable outputs that allow for long-term mitigation planning and delivering the most accurate risk rankings possible to optimize their mitigation strategies. Large swings in relative circuit ranks between years make it more difficult for teams to plan and execute mitigation strategies that may take several years to carry out. These model refresh cycles occur on timelines that differ from the timelines for work-planning. Large swings in model outputs from one cycle to the next can create challenges for setting workplans, especially given that some workplans may take years to complete (e.g. large-scale undergrounding plans). While some of this tension may be eased by the updated cadence for model refresh (the WDRM is now expected to be refreshed on a 3-year cycle rather than annually, while the TCM will continue to be updated on an ongoing basis until it is more established), this may not alleviate the problem altogether. Incorporating uncertainty into the outputs can help PG&E understand whether the changing outputs are meaningful, or within the range of uncertainty. This could help to guide the planning teams in understanding whether existing plans are still in line with the most up-to-date results. Recent guidance from the CPUC ameliorates the issue of inconsistent ranking by asking the IOUs to bin results into tranches that determine mitigation priority (see Section 4.6.2). This coarser level of reporting provides more stable results between model versions. However, hiding model changes behind coarse rank-based reporting results in a loss of valuable information. Instead of hiding changes in circuit ranks between model versions, we should be asking two fundamental questions: Why did results change? And did results change *meaningfully*?

Answering the first of these questions requires development of a process to isolate impacts from individual modeling updates on final outputs as well as crucial intermediate outputs (e.g. probability of outage). Being able to link model updates to results changes would allow for more informed dialogue between the modeling team and risk mitigation planners around altering current mitigation plans and crafting more stable future mitigation plans. This approach also benefits the modeling team in right-sizing development efforts based on impact; a recommendation discussed in Section 4.3.2. Understanding the impact of individual changes will allow PG&E to focus on the models' sensitivities, and which changes are the most impactful. This can help PG&E in determining which updates may be most impactful in future iterations. Additionally, this approach would provide a major benefit towards quality assurance efforts, given that potential errors stemming from updates might be more easily discovered and rectified when anomalous modeling outputs appear. When all updates are lumped together, it is more difficult to trace the origin of shifts in the outputs, and erroneous changes might more easily slip through the cracks.

As an example, E3's v4 model review found that PG&E had implemented numerous changes compared to the v3 model, many of which were highly warranted. The suite of updates had a large impact on the risk-based ranking of circuit segments in the PG&E system. PG&E presented the final risk ranking changes for v4 relative to v3 but was not able to identify the impact of individual updates on these changes. By isolating the impacts of individual modeling updates, PG&E would be able to gain a more comprehensive understanding of which updates are driving major changes between versions.

To understand if results have changed *meaningfully* requires moving away from circuit ranking as the primary model output and moving to a risk + uncertainty framework. The inherent flaw with ranking is that it tells nothing of the space between consecutive ranks. Ranks 1 and 2 could reflect values that differ by almost nothing or that differ greatly. Thus, a circuit moving from one rank to another in successive model versions tells us nothing about how the risk at that circuit or others near it has changed. Rank-based tranches offer no solution to this: there is no guarantee that the difference in risk scores between two circuits in the same tranche will be less than the difference between circuits in adjacent tranches.

Reporting risk instead of rank provides more valuable and actionable information. Circuit risk scores are independent of other circuits, so impacts of model updates are more evident than when looking at rank, since a change in rank may indicate a risk increase, decrease, or no change at all. Furthermore, reporting risk is necessary if PG&E and the CPUC move to a planning framework that uses a risk planning standard. If we want to understand the cost of the risk associated with unmitigated circuits and the benefits associated with various mitigation measures, the actual risk must be reported instead of rank. It is also worth noting that risk scores may reveal clustering of results that would be masked by reporting only ranks. This clustering may be natural – revealing key drivers of risk – or it may be an artifact of modeling – revealing modeling assumptions that may be too coarse. In either case, this information provides value.

Undoubtably, risk scores will change between model versions. However, many of these changes will not be material changes, but rather improvements in result precision. PG&E's wildfire risk modeling ecosystem has rapidly evolved to meet the urgent need to identify and mitigate wildfire risk. However, this rapid evolution has resulted in reporting that implies single-valued or perfectly precise risk values, but in reality no modeling result is single-valued. Instead modeling results contain uncertainty and are best expressed not as single values but as ranges of values that depend on how well the model represents the real world and on the quality of the data. PG&E should admit this uncertainty in their model by providing risk + uncertainty as a standard output for each circuit.

This proposed risk + uncertainty reporting would highlight the challenging nature of wildfire risk modeling and mitigation planning in a way that improves the explainability of result changes. With model updates, we would expect to see risk score ranges both shrink and shift. Shrinking ranges would indicate improving model certainty. Shifting values whose ranges largely overlap between model versions would indicate no meaningful change to the risk, but shifting values whose ranges overlap little with prior results would indicate meaningful change. This loose framework allows for results to update in a way that keeps mitigation plans stable, but not at the cost of providing high value information.

Alongside improving the explainability of any modeling changes, being able to track confidence in any given result is also of paramount importance. With a measure of risk + uncertainty available, a planning team would be able to confidently prioritize the high risk / high confidence upgrades before the high risk / low confidence upgrades. In future model updates, the lower-confidence outputs would likely change, but this change would have been anticipated by the planning teams and would thus be of lower impact on mitigation plans. Model updates could also target improving result certainty where it is deemed too large for useful decision-making.

Illustrative example of risk + uncertainty benefits

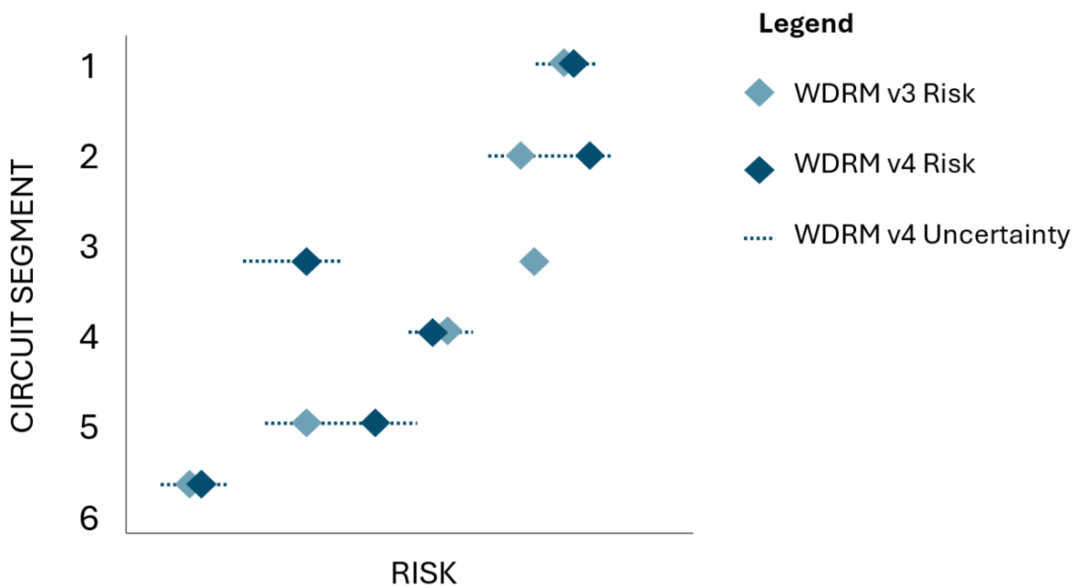


Figure 5 Illustrative example of how risk + uncertainty may inform a more complete understanding of changes between model versions

Figure 5 illustrates the impact of examining risk + uncertainty instead of risk rank alone. In this figure, the light blue and dark blue diamonds represent circuit segments in an illustrative 6-circuit segment system in v3 and v4. In this figure, the risk ranks have changed between v3 and v4. However, whether these rankings have changed *meaningfully* cannot be determined by looking at risk rankings alone without also taking the uncertainty into consideration. The dotted blue lines show the addition of illustrative uncertainty in v4 risk rankings, where uncertainty bands for each circuit segment's risk score allows for a meaningful assessment of changes.

First, we consider changes between segments 1 and 2. Considering rank alone would indicate that with the v4 update, segment 2 should be prioritized over segment 1 because it now has a higher risk ranking. However, upon further inspection of the uncertainty, these two segments have not changed meaningfully given the high level of uncertainty. In this case, it may not be beneficial for PG&E to update their mitigation plan prioritization to reflect this change given that changing the plan may not result in a meaningful increase in the risk buy-down in reality, especially given the high level of effort that it may take to re-prioritize the plans which may be better-spent on other crucial mitigation planning efforts.

As a second example, we look at circuit segments 5 and 3. For circuit segment 5, risk ranking has increased in v4, but within an uncertainty range that includes v3 risk ranking. This uncertainty band indicates that segment 5's risk ranking change is not necessarily a meaningful change when accounting for uncertainty. On the other hand, circuit segment 3 changes significantly in risk ranking between v3 and v4, where the v3 risk rank falls far outside the uncertainty band. In this case, PG&E may benefit from investigating sources of meaningful change in risk ranking and potentially reprioritizing mitigation planning accordingly.

Examining circuit segment 4 shows that the risk *rank* has increased in v4 relative to v3 due to the fact that circuit segment 3 has lower risk than segment 4 with the v4 update. However, despite the fact that circuit segment 4's risk rank has increased, the *magnitude* of the risk is actually lower than it was in v3. This important piece of information regarding the magnitude of the risk. Information about whether or not it risk is shrinking over time would be lost if only the rank were to be reported rather than the actual risk values. Examining the risk magnitudes rather than just the ranks may also aid PG&E in understanding risk clustering, which may be more informative with regards to how tranches should be defined and where there are meaningful thresholds in risk.

Finally, reporting the uncertainty with each model version would allow PG&E to understand whether or not they uncertainty bands are shrinking between one version and the next (although this is not directly illustrated in Figure 5).

We recognize that, in practice, uncertainties come from many sources and may be very large. Rather than trying to capture *all* sources of uncertainty, PG&E's modeling team and SMEs should engage in discussion to identify and quantify only the largest and therefore most impactful sources of uncertainty. It is likely that the inclusion of uncertainty leads to very large error bars. However, if it is indeed the case that the error bars are very large, that is also important information for both PG&E and the CPUC to be aware of as they continue to iterate on their plans and processes. For example, in the current tranche-based approach, PG&E only considers circuit segments in the first or second quintile for consequence to be in the top eight risk tranches (see Section 4.6.2 for more details on this new approach). The consequence model may be a large source of uncertainty given the high bias introduced by the binning approach. Consideration of the uncertainties would lend valuable information for PG&E and the CPUC to consider in understanding whether or not the current tranche system is well-suited to guide the mitigation priorities.

4.3.2 Right-size development efforts based on importance and impact

As PG&E continues to develop and improve their wildfire risk modeling ecosystem, E3 recommends that strong consideration be given to which of the planned modeling updates are imperative and will have meaningful impact before they are implemented. PG&E should seek to prioritize efforts that are deemed important for correctly assessing the wildfire risk across their system. The time and effort spent on various development efforts should be proportional to the estimated impact of the updates to be made. This right-sizing of development efforts should be considered across the overarching suite of models (i.e. WDRM, TCM, and consequence model), as well as for the efforts within each branch of models. For instance, the much higher wildfire risk on the distribution system relative to the transmission system may mean that the TCM does not require the same level of model detail as the WDRM. Similarly, the simplicity of the modeling process to translate wildfire simulation results into consequence values seems incongruent with the huge impact of consequence in the final risk scores.

4.3.3 Increase collaboration between modeling efforts

Through conversation with both the WDRM and TCM modeling teams, E3 noted that similarities exist between data requirements, threats and hazards, and output requirements in both models. Greater collaboration, learning, and synchronization between the two models would support efficient model development, calibration, and validation. To facilitate greater collaboration, E3 recommends that PG&E consider the following steps:

- Where appropriate, explore opportunities to fill data gaps and schedule data collection for sub-models or assets that share similarities.
- Share model improvements between the TCM and WDRM teams, particularly for sub-models that focus on a similar threat or hazard.
- Compare risk prioritization and mitigation between both models, to ensure that mitigation planning, budgeting, and actions align with areas of greatest risk.

As an example, the WDRM and TCM both require similar vegetation datasets to study vegetation's threat to outages on the distribution and transmission side respectively. Updates to the vintage or resolution of vegetation data can and should be scheduled or shared between modeling teams. Improvements in the vegetation sub-model on the distribution side may support improvements in their transmission counterpart, and vice versa.

4.4 WDRM

This section is focused on the review of the wildfire distribution risk model (WDRM). The section is structured as follows:

1. **Summary of major changes –** summary of the major changes to the WDRM model
2. **WDRM recommendations** – E3's recommendations for improvements

Note that this section is focused more specifically on the probability of outage and probability of ignition pieces of the WDRM. The consequence model and overarching risk modeling framework are discussed separately in their own respective sections.

4.4.1 Summary of major changes

Category	Equipment Failure	WDRM v3	WDRM v4
All Models	• Asset Strategy Alignment Enhanced		✔
	• Asset-level Predictions		✔
	• Incorporate Open Tags Data		✔
	• Causal Pathways Alignment		✔
	• Temporally Aware		✔
Support Structures		✔	✔
Transformers		✔	✔
Primary Conductors		✔	
Primary Conductor Breakout	• Wire Down Events		✔
	• Line Slap Events		✔
	• Incorporates Splice Data		✔
Voltage Control		✔*	
Voltage Control Breakout	• Capacitor Banks		✔
	• Voltage Regulators		✔
Protection Devices			
Protection Device Breakout	• Switches		✔
	• Fuses		✔
	• Dynamic protection devices		✔

Category	Contact From Object	WDRM v3	WDRM v4
Tree Population	• Tree Height	✔	✔
	• Strike Tree Count	✔	✔
	• Tree Canopy Density		✔
Animal	• Squirrel	✔*	✔
	• Bird	✔*	✔
	• Other	✔*	✔
Third Party	• Balloon	✔*	✔
	• Vehicle	✔*	✔
	• Other	✔*	✔
Tree Health	• Climatic Water Deficit		✔
	• SPEI		✔
	• Tree Mortality		✔
	• Tree Canopy Density		✔
Wind	• Wind Direction		✔

* Additional functionality added to v3 that was not part of a 2021 WMP Commitment

WDRM v4 features more granular modeling that improves work planning and causal pathway alignment

Figure 6 Excerpt from PG&E's documentation on changes to WDRM v4

PG&E has incorporated numerous changes into the v4 version of the WDRM relative to v3, many of which are illustrated in Figure 6. Major changes include the following:

Many predictions are now at the asset level. Previously, all probability of outage and probability of ignition predictions were made at the "pixel level", meaning that predictions were made for a particular geographic area. PG&E has updated their modeling to allow for asset-level predictions instead of pixel-level predictions, as shown in Figure 7. This allows for better alignment with the asset strategy teams for work planning.

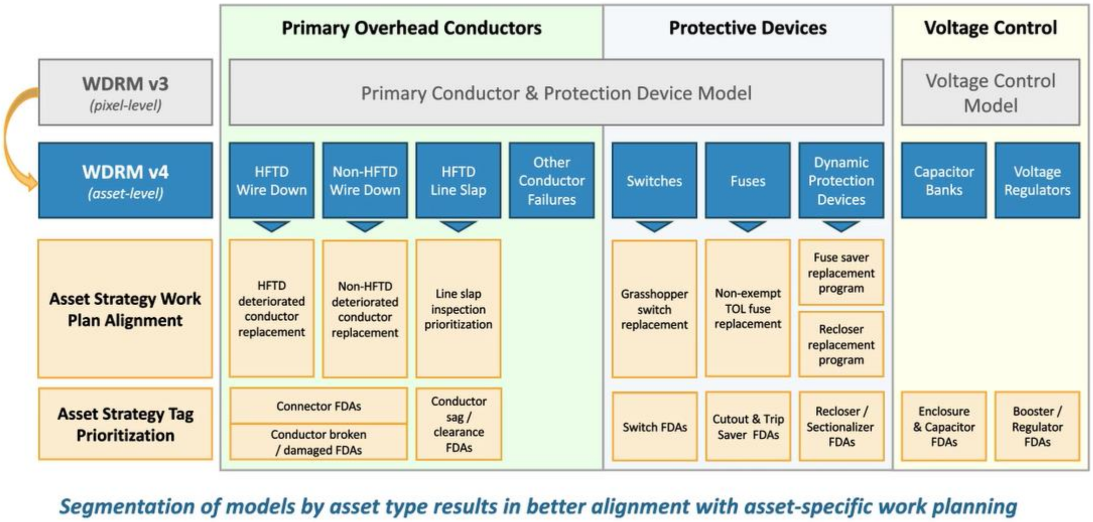


Figure 7 Excerpt from PG&E's documentation on v4 updates to align model with asset strategy team

PG&E is using line-weighted risk aggregation to account for bias in pixels with different lengths of conductor passing through them. Previously in the v3 model, pixel-level risk scores were independent of the length of conductor passing through the pixel. Therefore, in v3, two pixels would have similar risk scores if they had similar environmental characteristics and both had a conductor present with similar age and health, regardless of whether the length of conductor passing through the pixel was very short or very long. To avoid potential bias, PG&E introduced "line-weighted" risk scores in v4. The line-weighted risk score takes the raw risk score for a pixel and normalizes it based on the length of line passing through that pixel relative to the average line length passing through each pixel (see Figure 8).

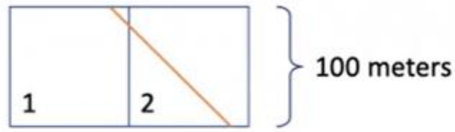


Figure 3: conductor lines crossing 100 meter by 100 meter pixels

In Figure 3, pixel 1 has approximately 20 meters of conductor (orange) passing through it, whereas pixel 2 has approximately 120 meters. If the two pixels have the same asset and environmental data, the raw risk values in each pixel will be identical. The formula to weight the risk values by the length of line passing through the pixel is:

$$r_{weighted} = r_{raw} \frac{l}{l_{average}} \quad (4)$$

where r_{raw} is the raw risk value, $r_{weighted}$ is the line-weighted risk value, l is the length of line passing through the pixel and $l_{average}$ is the average amount of line passing through each pixel. The weighted risk values tell us that pixel 2 is roughly six times riskier than pixel 1, not due to any environmental or asset characteristics, but simply because there is roughly six times more conductor passing through (120 meters / 20 meters = 6).

Figure 8 Excerpt from PG&E's documentation on line-weighted risk aggregation

PG&E is using ignition-weighted consequence scores to calculate total circuit segment risk. In the v3 model, the total circuit segment risk was calculated by summing the consequence scores for all relevant pixels, summing the probability of ignition, P(I), for all relevant pixels, and then multiplying those sums. However, that methodology did not account for the fact that P(I) and consequence may vary differently from one and other across the spatial extent of the circuit segment. As E3 understands it, PG&E has updated their v4 methodology such that P(I) and consequence are directly multiplied to calculate the risk for each pixel. The total circuit segment risk is then calculated by adding the risk over all relevant pixels (see Figure 9).

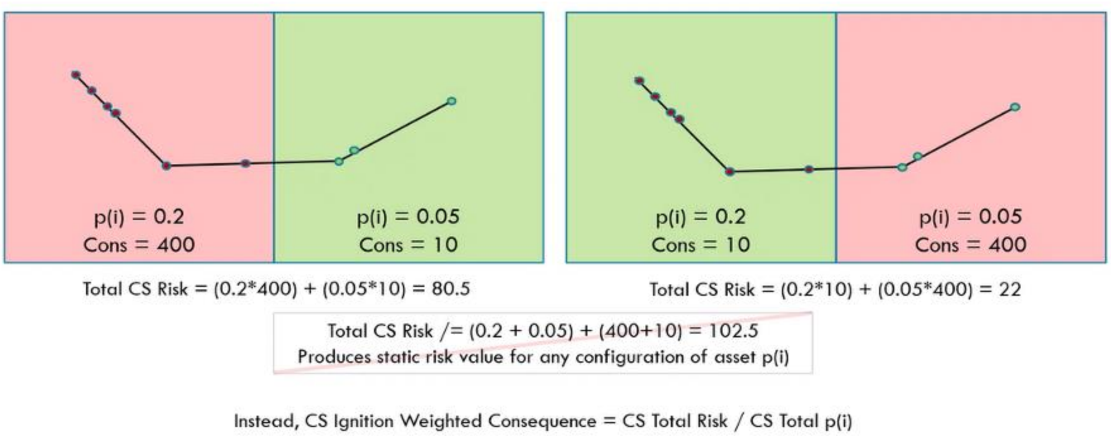


Figure 9 Excerpt from PG&E's documentation on total circuit segment (CS) risk

Equipment models are now segmented to align better with causal pathways. For example, in v3 there was a model for primary conductors that included switches, fuses, and DPDs. In v4, this model has been segmented so that switches, fuses, and DPDs each have their own models, and the primary conductor model has been further segmented into a wire down model and a line slap model (see Figure 10). This alignment with causal pathways may allow PG&E to incorporate features that are particularly pertinent for various failure modes, such as open repair tags.

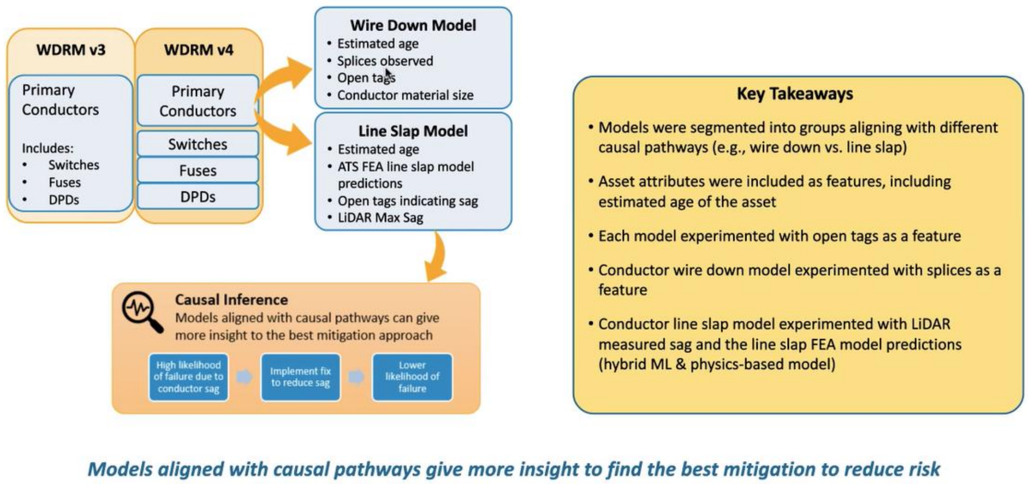


Figure 10 Excerpt from PG&E's documentation on v4 alignment with causal pathways

Equipment models now use a spatial-temporal approach. In v3, there was no time dimension to the probability of outage models, so the models were trained on weather data and equipment failures grouped together over all years (2015-2021). In v4, training data including asset attributes, weather data, and equipment failures were grouped by individual years (see Figure 11). The v4 asset models use an XGBoost architecture rather than the MaxEnt architecture previously used in v3 given the need for an architecture that could more readily support a spatial-temporal approach.

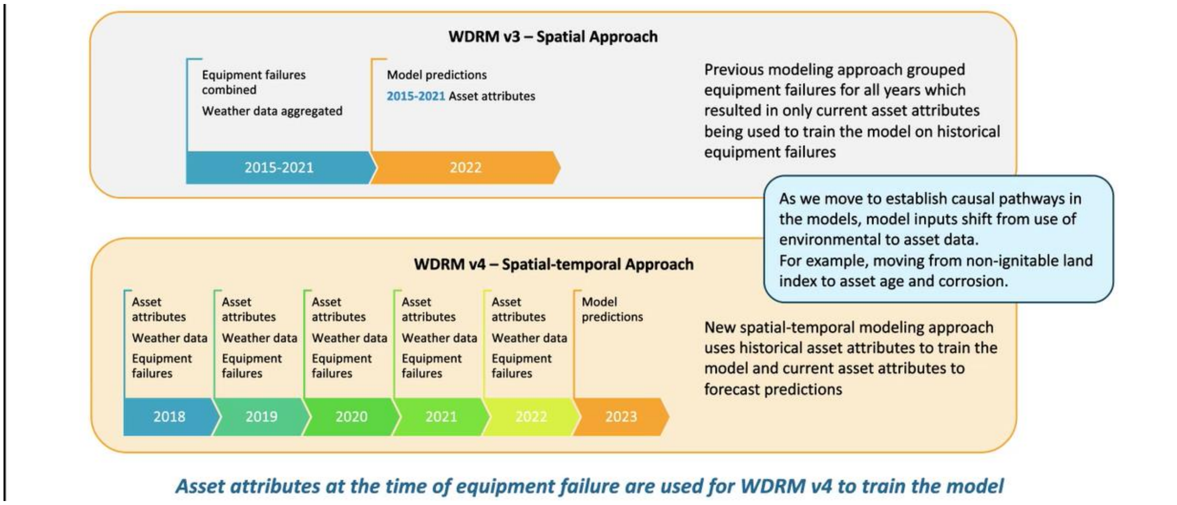
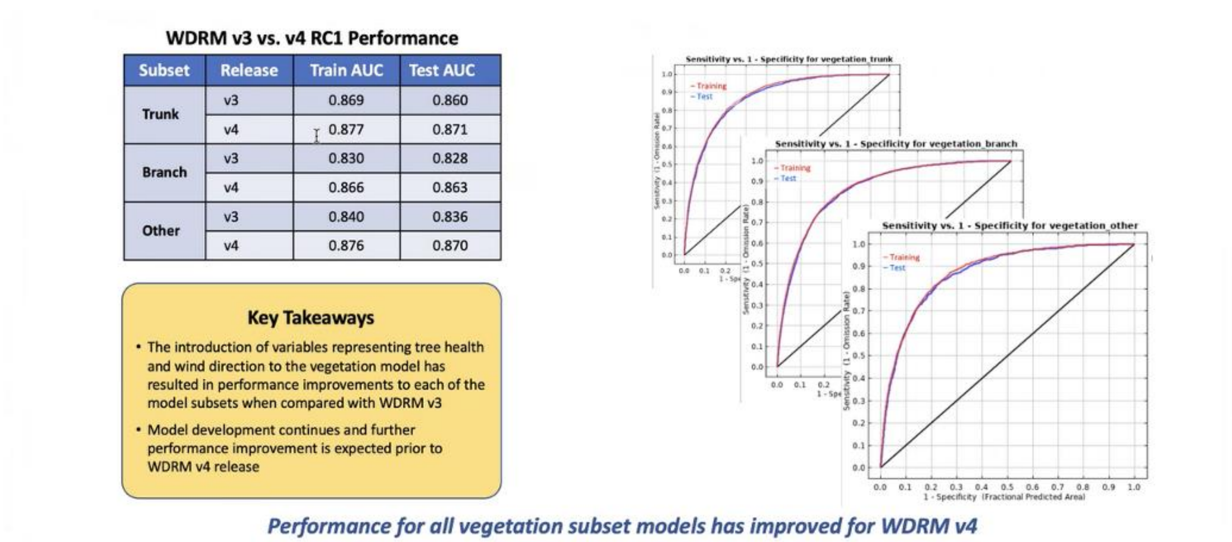


Figure 11 Excerpt from PG&E's documentation on v4 spatial-temporal approach

New features have been incorporated in the vegetation model. The new features were focused on capturing relevant factors such as tree health and wind direction, which were previously not accounted for. New features focused on tree mortality include a standardized precipitation evapotranspiration index (SPEI) indicative of drought, climate water deficits, and CAL FIRE high hazard zones for tree mortality. Historical wind direction has been incorporated with a new angular probability feature that uses a probability density estimate for a tree falling into a line based on the wind direction relative to line positions. The new features have resulted in slight improvements in the model's AUC (see Figure 12).


WDRM v3 vs. v4 RC1 Performance

Subset	Release	Train AUC	Test AUC
Trunk	v3	0.869	0.860
	v4	0.877	0.871
Branch	v3	0.830	0.828
	v4	0.866	0.863
Other	v3	0.840	0.836
	v4	0.876	0.870

Figure 12 Excerpt from PG&E's documentation on v3 vs v4 vegetation model performance

The "probability of ignition given outage", P(I|O), model was updated to incorporate causally similar outage subset groups that interact with environmental variables. The purpose of this update was to allow for a "subset aware" model that could handle the different environmental interactions between the various subsets. The WDRM groups outages into causally similar subsets of outages (e.g. animal_bird, primary_conductor_wire_down_cause, vegetation_branch, etc.). Each subset has its own model for probability of outage, P(O). However, there are not separate P(I|O) models for each subset, given the limited number of ignitions available for training data. Environmental factors that are important in determining the P(I|O) for one subset of outages might *not* be important for another. For example, the dry fuel moisture might be a very important covariate to consider when predicting the probability of an ignition caused by vegetation, but it may not be relevant for an ignition caused by equipment. PG&E sought to address this through grouping similar subsets and training separate probability of ignition given outage models for each subset to allow for the environmental interactions.

4.4.2 WDRM recommendations

Incorporate Temporal Dimensions in all Sub-Models

Including a temporal dimension into a machine learning model allows for the integration of time-dependent data, such as seasonal variations in weather and degradation of assets, which improves the accuracy and reliability of forecasts. The PG&E team has already made good progress in this area by updating the Equipment models to allow for a temporal dimension. E3 suggests that this improvement be expanded to the other models within the WDRM to further boost performance. For instance, this would allow the Vegetation model to be aware of the time that has passed since an area had last undergone maintenance.

Evaluate the overall effects of implementing P(I|O)

During discussions with the WDRM team over recent model results, it was shown that in some cases adding the step to calculate the probability of ignition given outage, P(I|O), reduced the predictive performance relative to the probability of outage, P(O), alone. For instance, this was the case for the "primary_conductor_wire_down_cause" subset. The loss of predictive performance for some subsets should be carefully examined, especially in cases where the subset may be a large contributor to ignitions (e.g. primary conductors). In line with E3's overarching recommendation of "right-sizing development efforts" E3 suggests that PG&E evaluate the effectiveness of this modeling direction, and reprioritize it as needed.

4.5 TCM

This section is focused on the review of the Transmission Composite Model (TCM). The section is structured as follows:

3. **Model structure –** summary of the structure of the TCM model, as well as planned changes
4. **TCM validations** – E3's summary of and comments on the validations that the TCM model contains
5. **TCM recommendations** – E3's recommendations for improvements

4.5.1 Model structure

Transmission Composite Model Structure

The TCM is structured to consider how an asset would withstand an environmental hazard given its current and future conditions. To achieve this, 3 main concepts are introduced:

- **Hazards:** A Hazard is any environmental condition which could push a component to fail. The two main hazards included in the TCM are Wind hazards, & Seismic hazards. Hazards come in various intensities, each with their own site-specific probability of occurrence. The **Hazard Curve** defines the relationship between Intensity & Probability
- **Fragility Function:** The fragility function describes how likely an asset is to fail at a given hazard intensity. As it is component specific, it varies based on the characteristics of the component. The function itself is a sigmoid, with adjustment parameters mean (μ) and uncertainty/spread (β).
- **Threats:** Threats are environmental conditions that modify an asset's strength. Threats may contribute to an asset's eventual failure, but will not directly cause failure by themselves. For example, if a wooden pole begins to decay over its lifetime, its strength is reduced. The pole will not break until there is a strong enough hazard to push the pole to break. Within the TCM, Threats are implemented as modifiers to the fragility function.

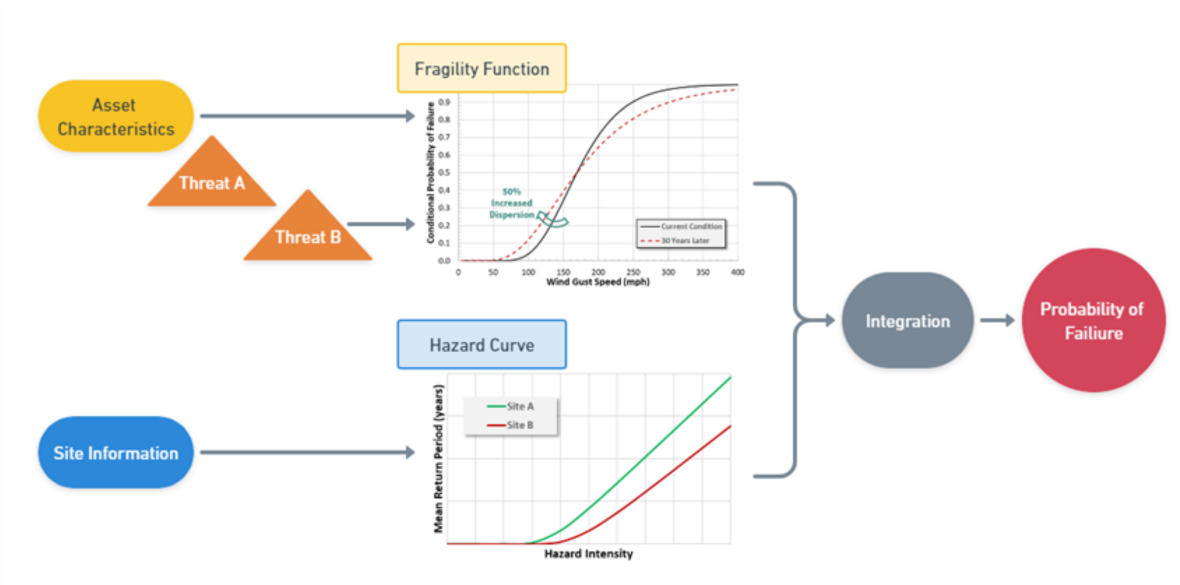


Figure 13 Schematic of PG&E's TCM model

Figure 13 shows a schematic of the TCM model. To illustrate how the TCM model works, we look to the example of the wood poles. A Component, in this case a wood pole, has site-specific characteristics (*latitude, longitude, historical weather*) alongside asset-specific characteristics (*wooden pole with diameter 1.25 ft*). Using historical weather data, the TCM generates a site-specific Hazard curve for wind data. Previous asset measurements indicate that the strength of this wood pole has degraded by 50% from its "New" state, modifying the asset's fragility function. The TCM then joins the updated fragility function with the site-specific wind hazard curve to produce an annual probability of failure.

Beyond the simple single-component single-hazard analysis outlined above, the TCM repeats a similar approach for all relevant combinations of hazards, components, and locations. Since the threats contributing to the weakening of a component are very component-specific, the TCM contains many sub-modules which focus on a specific threat-component grouping. For example, the "wood-pole decay" threat has a completely different model than the "cold-end wear" threat. Despite the unique internals of these bespoke models, they all share similar outputs. Many of the modules output a Design Life Reduction Factor (DLRF). These DLRF's are integrated into their respective fragility functions by increasing the uncertainty. The driving argument behind this adjustment is that, if the TCM expects that a component has lost strength due to a threat, the TCM becomes less certain about its ability to withstand a hazard.

Conservative Age Logic

The age of components is an important model input that tends to have a large impact on the probability of failure. PG&E has made a concerted effort to understand where there are gaps in their asset data through the use of a data quality dashboard. Their dashboard shows how complete the data is for each component type (e.g. above grade hardware, conductor, insulator, etc.), and what percentage of data is missing. Where PG&E is missing age data for a component, the age is estimated using "conservative age logic". The conservative age logic is designed to conservatively estimate the age based on other available records. In many cases where data is lacking, this logic leads to age estimates equal to the oldest verified installation date for similar components on the same circuit, or in some cases, to the oldest verified installation date for the same component type across the entire territory. As the name suggests, these age estimates tend to be highly conservative. There are several component types for which the conservative age logic is being used to fill in more than 40% of ages. This is one driver of conservatively-high risk outputs coming from the TCM model.

Bayesian Updating

PG&E uses Bayesian updating methodology to refine the TCM's outputs in response to extreme wind events. This Bayesian updating methodology is one step in the TCM's approach to modeling probability of transmission outage. It occurs in conjunction with the engineering fundamentals models described above. Historical outage and weather data is used to update the likelihood of transmission lines experiencing an outage during extreme wind events.

Under extreme wind events, transmission lines respond in a binary fashion, as in, the line experiences a structural failure that results in an outage, or it doesn't. These extreme wind events are represented as the maximum daily winds gust (3-second average) in the vicinity of a transmission asset. Daily, every transmission asset experiences some maximum windspeed and either survives or fails. Bayesian updating is the methodology for modifying the specified prior distributions for fragility median strength and dispersion based on historical outage and weather data. The result is a modified fragility curve.

The outage and historical weather data used for Bayesian updating comes from PG&E's outage database and weather modeling by PG&E Meteorology. PG&E used the past 30 years of historical data to create a distribution of maximum daily windspeeds associated with points on a grid of its service territory. Further, PG&E provided data from 2007-2020 on 16,000 outages on more than 900 transmission lines. These outages were narrowed down to ~5,000 wind-related outages based on SME input. This represents an expanded dataset relative to v1 of the TCM, which only used ~300 outages, as PG&E has continued to improve their methodology for classifying these wind related outages. Because not all historical outage data links specific transmission line component failures to a resulting outage, Bayesian updating modifies the risk of outage at the level of an individual transmission line. Because of this line-level updating, Bayesian updating occurs upstream of any component-level calibration using engineering first principles models. Bayesian updating occurs on an annual cycle, incorporating data from recent outages in each iteration.

This updated outage probability is modeled graphically as a fragility curve, where cumulative probability of failure is a function of wind velocity in miles per hour. This fragility curve consists of two unknown parameters: the lognormal mean and the lognormal standard deviation, or dispersion, of wind velocity. For all transmission assets, there is some wind velocity where the asset has a 50% chance of failure, known as the median fragility strength. Before Bayesian updating, PG&E assumes all assets have a median fragility strength of 170 mph, a dispersion of 0.25, and a standard deviation of 0.1. Bayesian updating uses Bayes' theorem of conditional probability to modify these *a priori* parameters using historical data.

In Bayesian updating, outages shift the median fragility strength lower, resulting in an overall left-shift in the fragility curve. The lower the windspeed during an outage event, the greater the left-shift. In complement, power lines that go without an outage are updated to a higher median fragility strength, resulting in an overall right-shift in the fragility curve. PG&E does not incorporate the effect of repairs into Bayesian updating, so penalties from historical outages remain associated with a given power line until it is completely replaced. For any given power line, the penalty from a historical outage decreases as the line survives additional days of extreme wind events without an outage.

To improve Bayesian updating methodology, PG&E may incorporate changes after completing ongoing data collection and quality assessments. To expand the outage dataset PG&E is currently studying equipment-related outages and uncategorized outages that SMEs did not categorize as wind-related. Through statistical modeling, these outages are being tested to see if they are correlated with high wind speeds, which may have contributed to outages indirectly. By doing say, PG&E may identify additional outages to incorporate into their Bayesian updating methodology.

PG&E also seeks to link data on wind-related outages to component failures that extreme wind events may have caused. PG&E is collecting data on which components caused wind-related outages. If sufficient additional information arises, they may change Bayesian updating to penalize the component group that caused the outage, rather than penalizing the whole line. Performing the updating methodology at the component level would enable incorporation of component-level repairs into Bayesian updating and remove the impact of historical outages on the repaired component.

4.5.2 TCM validations

PG&E uses two sets of empirical validation strategies for the TCM, one to validate the machine learning sub-models, and another to validate the engineering first principles sub-models. These strategies inform model calibration to external data and test the sub-model's readiness for integration into the TCM.

To validate machine learning sub-models in the TCM, PG&E sets aside a randomized subset of the model's training data. Downstream, this subset serves as validation data to test the accuracy of the trained sub-model. This strategy is standard practice across machine learning model development. Model validation depends on successful randomization and sufficiently large dataset size; a lack of randomization and insufficient results will negatively impact validation quality.

Unlike machine learning models, which are right-sized to historical outage data, the engineering first principles models make predictions unaligned with historical data, which need to be calibrated and validated. PG&E uses a combination of pilot studies, normalization and scaling, and empirical data collection to validate and calibrate the TCM engineering first principles sub-models.

Downscaling to reflect historical outages

To calibrate the wind and seismic engineering first principles sub-model at an asset level, the PG&E team scaled down each engineering first principle sub-model's outage predictions relative to the historical outages seen over time.

The engineering first principles models overpredict outages relative to historical outage data, which makes it necessary to scale TCM predicted outages down to true historical outages. Prior analysis informed this downscaling methodology. The original methodology recommended scaling all TCM outputs from all sub-models, but PG&E narrowed the scope to scale down only predictions from engineering first principles models. At the time of E3's interview with the TCM team, PG&E had not applied this calibration method to the TCM's current version, but it is E3's understanding that this calibration is part of planned changes.

This downscaling methodology applies at the asset level. However, PG&E has the ability to scale down predictions at the component level, which would enable comparison of risk between the TCM and the WDRM's component-level predictions. By comparing distribution and transmission components, PG&E could assess which system faces higher risk of outage and target their component-level mitigations appropriately.

Validating a new sub-model for incorporation into the TCM

Before incorporating an engineering first principles sub-model into the TCM architecture, PG&E uses existing empirical data, collected by the PG&E Applied Technology Services (ATS) team, to assess whether the model provides accurate prediction readouts. If sufficient data is present, PG&E performs qualitative or quantitative assessments of model suitability. Insufficient data or data gaps steer PG&E toward qualitative assessments, but a preference for quantitative validation methods remains.

As an example, PG&E validated a new polymer insulation degradation sub-model by searching the ATS database for repair tags associated with that model. From these repair tags, PG&E extracted the design-life reduction factors (DLRFs), values that represent the model's predicted degradation of transmission assets, at the latitude and longitude of each repair tag. Using these DLRFs, PG&E binned each repair tag by DLRF to assess whether the model predicts high degradation, and therefore high DLRFs, in areas with a high number of historical repair tags. This binning methodology provides a qualitative glimpse at whether the model's predictions align with historical data. Such binning requires human judgement to select a cutoff ratio of historical data density per model bin, which is a key limitation of this qualitative methodology. By binning, PG&E determined that the polymer insulator degradation sub-model was overpredicting degradation relative to historical repair tags, making the sub-model conservative. Because of this conservatism and the density binning methodology's qualitative limitations, PG&E did not incorporate the new sub-model into the TCM. Instead, PG&E approached their data quality team to target and collect necessary data for quantitative validation downstream.[29]

Validating and improving an existing sub-model in the TCM

PG&E validates specific sub-models in the TCM using a combination of existing data from ATS repair tags and data produced from validation pilot studies for this specific purpose. As an example, PG&E validated the atmospheric corrosion model using new data procured through ultrasound thickness testing (UTT). UTT is a quantitative, portable method to measure pole thickness, using a tube transducer that transmits a soundwave. Through a field study, PG&E obtained new measurements from asset structures with known structure ages. When PG&E compared these field measurements against model predictions of corrosion, the model's predictions of wall loss on poles were more conservative than tested pole thickness. This quantitative, tailored validation methodology indicated that the sub-model's conservatism required correction in the next model iteration. PG&E has since adjusted this model accordingly.

Collecting data for inputs, calibration, and validation

Apart from the pilot study data collection discussed in prior sections, PG&E designed a data quality tracker, a spreadsheet that documents and prioritizes gaps in PG&E input or validation data. Conversations between the data quality team and the modeling team inform data gap prioritization and correction. The data quality team solicits the modeling team's input on data gaps that need immediate fixing; of these gaps, the data quality team identifies which are easily filled and request empirical data to follow-up.

In addition, PG&E TCM model users collaborate with TCM model developers to track model calibration and troubleshooting through a custom TCM Feedback tracker. This tracker offers both developers and users that chance to identify areas for improvement, which developers and users prioritize based on projected developmental challenge of improvement. PG&E logs the status of each prioritized improvement, with assessments of overall completion, in this tracker. In the future, TCM users and developers hope to regularly refresh these prioritizations and track risk ranking impacts of implemented model changes.

[29] The polymer insulator degradation sub-model has since been updated and incorporated into the TCM after E3's initial discussion with the TCM team.

4.5.3 TCM recommendations

Address conservatism

Through discussion with PG&E and Exponent SMEs, E3 noted that the TCM currently overpredicts outages relative to historical outage data, rendering the model's outputs conservative. PG&E and Exponent studies indicate that certain sub-models may contribute to such conservative outputs. To build upon this ongoing study of model conservatism, E3 recommends that PG&E consider the following steps:

- Pilot the model with all PG&E asset teams, to identify the largest areas of conservatism at the asset level and plan model calibration accordingly.
- Identify key sub-models that drive overall TCM conservatism and plan model development to correct for conservative predictions.
- Continue to focus on improving data quality, especially the age data, which remains conservative and may contribute to overall model conservativism.

Improve Conservative Age Logic

In cases where asset age is missing or invalid, PG&E utilizes "Conservative Age Logic" to determine what value to utilize within downstream models. As its name suggests, this approach places a very conservative estimate on what age an asset is, often assuming that an asset is 50+ years old. These assumptions have significant implications for downstream calculations, as many of the PG&E's wildfire sub-models increase the riskiness of an asset as it ages. E3 recommends that PG&E re-evaluate this approach to handling missing data, as this could be a leading cause of some of the conservatism that the models are producing. Alongside this re-evaluation, E3 suggests that the downstream impacts of this conservative assumption be tested such that the entire PG&E team can be aware of the significance of its effects.

Develop robust validation procedures

PG&E has conducted pilot studies in an attempt to validate TCM sub-models, but they have yet to develop a standardized and clearly documented procedure for model validation. The limited number of transmission outages presents a data challenge in validating the models. Without clearly defined model validations, it is difficult for users to understand how much confidence can be placed in the various outputs. We recognize that PG&E has already taken creative steps to bolster the TCM model validation efforts given the lack of data, such as looking at repair tags in addition to just outages. However, we recommend that PG&E consider additional efforts to continue to improve their TCM validation process, including the following:

- Develop and document a transparent cadence for data validation and model calibration methods. Transparent communication of validation methodology and progress will better facilitate feedback cycles between model users and model developers.
- Determine a quality threshold for sub-model and overall model outputs to determine when a sub-model is sufficiently accurate and ready to use.
- Consider validation methodology that proactively collects dedicated validation data through field testing or proxy measurements in simulated laboratory conditions, as retroactive validation with repair tag-based validation is not always indicative of transmission system failures.

- Collaborate with other IOUs, in California or elsewhere, to pool data on transmission failures for transmission validation usage, as transmission geography is fairly similar across California IOUs.

We recommend these data validation procedures for the purpose of risk model improvement, but they also overlap with recommendations that the OEIS Wildfire Safety Advisory Board made to improve mitigation measures through asset inspection cycle cadence and repair tag prioritization.[30]

Scope out a model development plan

While PG&E has an existing model development plan in place, E3 has seen no indication that this plan has appropriate off-ramps to pause model development once the tool is adequately fit for purpose. Given the relatively small amount of risk attributed to PG&E's transmission system compared to the distribution system, the TCM model will likely require less detail than the WDRM. Another way to consider this is to think about aiming for an acceptable standard of risk instead of zero outages and ignitions on PG&E's system. As we noted in previous model reviews of the WDRM, such a standard would likely need to be set by the CPUC and IOUs together, but PG&E should carry out model updates with this concept in mind. If risk attributed to the transmission system is only a small fraction of some set standard, then the lower hanging fruit for modeling and mitigation will be elsewhere.

Quantified uncertainty would also inform the TCM development plan. If there are transmission assets falling into the high risk / high uncertainty category, model improvements to reduce this uncertainty may be worthwhile. However, if uncertainty bands are already small or risk is low but uncertainty is large, there would be little justification to improve modeling of those assets. Should levels of risk + uncertainty indicate that updates to the TCM would be unlikely to change near-term mitigation actions, PG&E should accept that model development has come to an acceptable temporary stopping point.

4.6 Wildfire consequence and risk

This section is focused on the review of the consequence model as well as changes to the ultimate risk ranking outputs. The section is structured as follows:

6. **Overview of consequence model–** summary of the structure of the consequence model
7. **Summary of major changes –** summary of the planned changes to the consequence model
8. **Wildfire consequence recommendations** – E3's recommendations for improvements

4.6.1 Overview of consequence model

The consequence model is used to determine how damaging a fire would be if one occurred at a specific time and place. At a high level, upstream model results are used to categorize a specific fire under 8 bins (previously 4 bins in v3). This binning is based on 4 data sources:

1. PG&E's FPI score

[30] Recent policy paper recommendations adopted by the Wildfire Safety Advisory Board. https://energysafety.ca.gov/news/2024/02/07/wsab-adopts-policy-paper-recommendations/

2. Technosylva's 24-hour fire simulations
3. High Fire Risk Area (HFRA) maps
4. Dry-wind conditions (new for v4 as described further in Section 4.6.2)

The FPI score and 2 datapoints from the Technosylva Fire simulations are joined together to determine a "Predicted Destructive Potential" (PDP) True/False value using the rules shown in Figure 14 for all geospatial locations and simulation days. PG&E's consequence modeling team noted that they believe the use of the FPI score is complementary to the Technosylva outputs. PG&E also highlighted that using the FPI score also offers the advantage of better alignment with operational considerations such as those used for PSPS and EPSS.

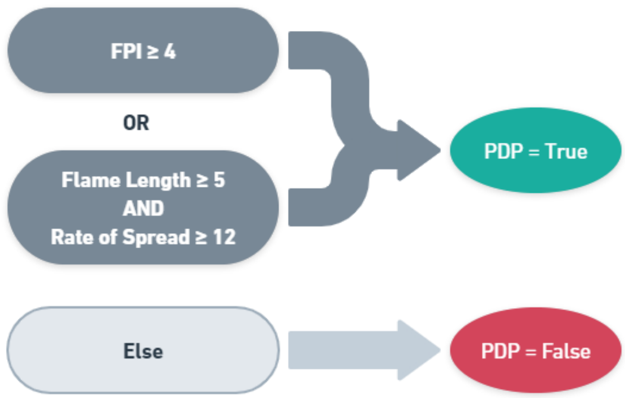


Figure 14 Diagram depicting PG&E's process for categorizing fires as predicted destructive potential (PDP)

The generated PDP values are then joined with the HFRA map and dry wind conditions to place fires into one of eight potential bins as listed in Table 2.

Table 2 Consequence bins for v4

Bin	Dry Wind Red Flag	HFRA	Predicted Destructive Potential
1	True	True	True
2	True	True	False
3	True	False	True
4	True	False	False
5	False	True	True
6	False	True	False
7	False	False	True
8	False	False	False

A consequence score is assigned to each bin based on the average historical consequence from fires in the bin using the CAL FIRE data. To determine the final wildfire consequence score for each location, each simulation at the given location is assigned a consequence score based on the bin that it classified in, and the consequence scores are averaged over all simulations at that location. This process is depicted in Figure 15 for v3 (note that v3 only had 4 bins since dry wind conditions were not used in binning. We note that this is a key part of the model in which uncertainty should be quantified: carrying through only the average instead of a range for each set of simulations likely results in a large amount of data loss.

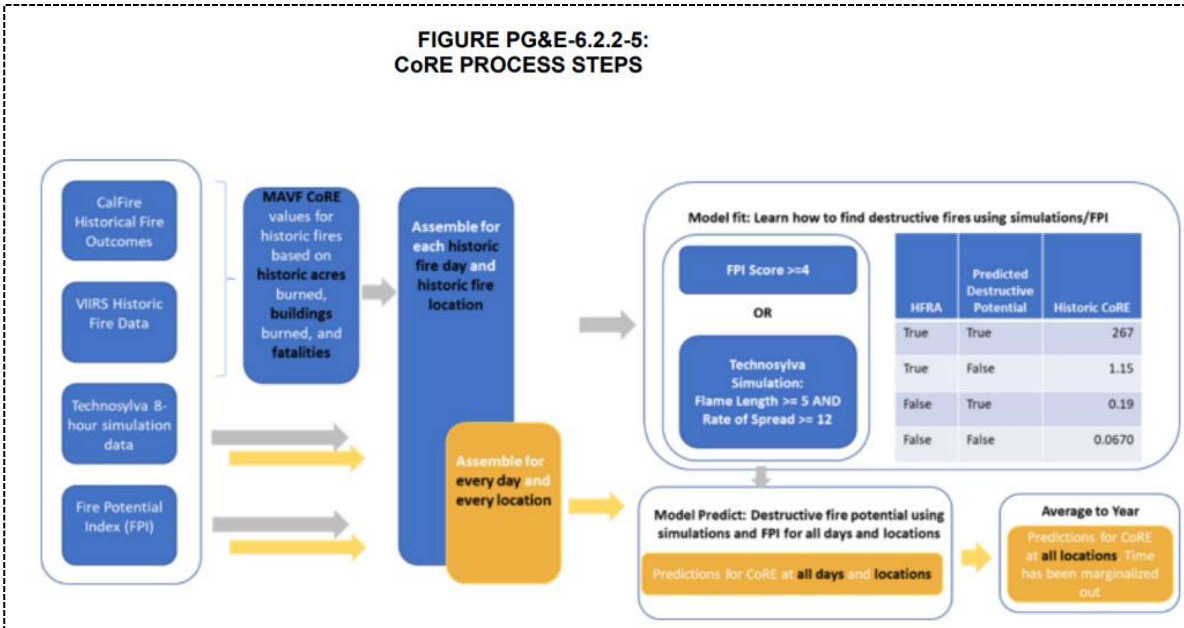


Figure 15 Wildfire consequence calculation steps as depicted in the 2023 Wildfire Mitigation Plan representing v3

PG&E developed this consequence binning methodology with an intention to anchor their consequence modeling against real-world outcomes. PG&E's consequence modeling team sought thresholds for the bins that would produce full recall of recent destructive fires based on historical data, capturing 'regimes' of conditions in which wildfires have occurred in the past. PG&E classified historical fires detected in the Visible Infared Imaging Radiometer Suite (VIIRS) dataset based on CAL FIRE data on outcomes for each fire. Classifier thresholds for the 8 bins were selected to best-capture regimes where destructive fires occurred based on these VIIRS and CAL FIRE datasets.

Through interviews with PG&E's consequence modeling team, E3 learned that this simplified regime-based binning methodology was PG&E's chosen solution to the bias-variance tradeoff presented by this problem. Historical wildfires span a large range of outcomes, but the most destructive fires are very rare events. Although classifying wildfires into relatively coarse bins introduces significant bias, more granular bins would lead to high variance due to the limited data on historical destructive wildfires. PG&E sought to avoid overfitting to the limited number of historical destructive fires, especially since this would likely make the model very sensitive to minor changes and updates in empirical fire data. PG&E modelers emphasize that they continue to assess other criteria to characterize and discriminate between high-consequence historical wildfires. Section 4.6.3 discusses E3's response to this methodology and recommendations for future study.

4.6.2 Summary of major changes

PG&E has made several changes to the consequence model as part of the v4 update. Many of the changes to the consequence model were aimed at satisfying new aspects of the risk-based decision-making framework required by the 2022 CPUC Decision D.22-12-027. Collectively, these changes tend toward synchronizing consequence modeling approaches across IOUs. Significant revisions that CPUC requested from IOUs in this decision included:

- replacing the previous MAVF framework with a cost-benefit approach where risk consequence is expressed in dollar values;
- using specified methodologies and sources in determining standard dollar values of each risk;
- requiring a cost-benefit ratio calculation for mitigations, where dollar values of mitigation benefits will be divided by dollar values of mitigation costs, resulting in comparable cost-benefit metrics for proposed mitigations; and
- ranking circuit segment risk using a tranche-based framework.

In response, PG&E implemented a subset of these changes, including calculating consequence scores that can be interpreted in dollars and implementing a tranche-based ranking system. They also incorporated additional changes outside of what was required by the decision. The major changes are summarized below:

Replacing the old MAVF framework with a cost-benefit approach and a new value of statistical life. The new scores can now be directly interpreted in dollars and should be more directly comparable to other IOU outputs once compliance is achieved across the board. PG&E noted that implementing the new framework did not drastically change the distribution of consequence, but rather the overall magnitude. While these changes would not necessarily impact the *prioritization* of mitigation efforts, they ultimately may impact the level of mitigation effort deemed necessary based on the dollar value of risk. Importantly, this update will allow for benefit cost assessment of potential mitigation measures. PG&E has begun developing a benefit cost analysis (BCA) tool in response to CPUC Decision D.22-12-027 that calculates the cost benefit ratio based on the new outputs. E3 has only limited insight into this BCA tool's workings, as it is in an early stage and actively under construction.

Implementing a tranche-based ranking of circuit segment risk, which combines quintiles of probability and consequence such that high priority tranches are quintiles making up the highest probability of ignition *and* consequence. The first five risk tranches are made up of circuit segments within the first quintile of highest consequence scores, and they are differentiated based on the P(I) quintile (e.g. Tranche 1 circuit segments have consequence scores in the top quintile and P(I) in the top quintile, Tranche 2 segments have consequence scores in the top quintile and P(I) in the second quintile, etc.). Tranches 6-8 continue with this pattern, beginning in the second quintile of highest consequence scores. See Table 3 below for a visualization of these tranches.

Table 3 PG&E tranche-based rankings of circuit segments

System Hardening/Undergrounding Tranche	Wildfire Consequence Quintile	Probability of Ignition Quintile
1	1	1
2	1	2
3	1	3
4	1	4
5	1	5
6	2	1
7	2	2
8	2	3

Notably, this methodology means that the top 8 tranches of risk only contain circuit segments that are within the first or second quintile of *consequence scores*. This means that in some cases, even if the probability of ignition is very high, if the consequence score is not within the first two quintiles, the circuit segment will not fall into a priority tranche. The tranche methodology therefore prioritizes high consequence circuit segments. PG&E noted that tranche-based ranking provides more stability between model years than the previous method of ranking each circuit segment separately. We offer thoughts on a risk + uncertainty reporting metric instead of (or alongside) tranches in Section 4.3.1.

Filtered lightning-started fires from the historical wildfire dataset. PG&E removed wildfires that occurred in lower-threat conditions yet substantially impacted consequence from their historical wildfire dataset, the VIIRS Historic Wildfire Data. This change generally removed large fires caused by lightning, including the 2020 lightning complex fires. PG&E considers it problematic to use lightning-caused fires as representative of utility-cased fire consequences, as these fires often start far from the electric grid in remote areas, where jurisdictional issues may delay timely suppression efforts, resulting in larger burned areas and outsized impacts on consequence weighting.

Incorporated the impact of dry wind conditions on consequence modeling. In the past, red flag warning conditions have been predictive of high consequence fires. To consider their impacts, PG&E incorporated a threshold for dry, high-wind conditions as part of calculating consequence scores. This change results in three conditions determining a fire's ultimate scoring, the first two of which PG&E used in prior model versions—whether the fire occurs in an HFRA, whether it is predicted destructive, and whether wind conditions surpass the dry-wind condition threshold. Notably, this change leads to 8 potential consequence bins rather than just the 4 bins present in v3.

Incorporated updates to better-reflect egress and suppression. In v4, PG&E added a two-step approach to correct raw wildfire consequence outputs for the effects of egress and suppression (see Figure 16). Since suppression (i.e. the ability of firefighting activities to suppress a fire) is correlated with the number of structures destroyed, the base wildfire consequence outputs indicating structures destroyed are adjusted to correct for suppression. This is step 1 of the two-step process. Then, since egress (i.e. the ability for people to evacuate an area) is correlated with fatalities per structure, the fatalities per structure are adjusted for egress. This is step 2 of the two-step process. To model suppression, PG&E is using Technosylva's Terrain Difficulty Index (TDI) to predict the fraction of a building that is lost from a fire.

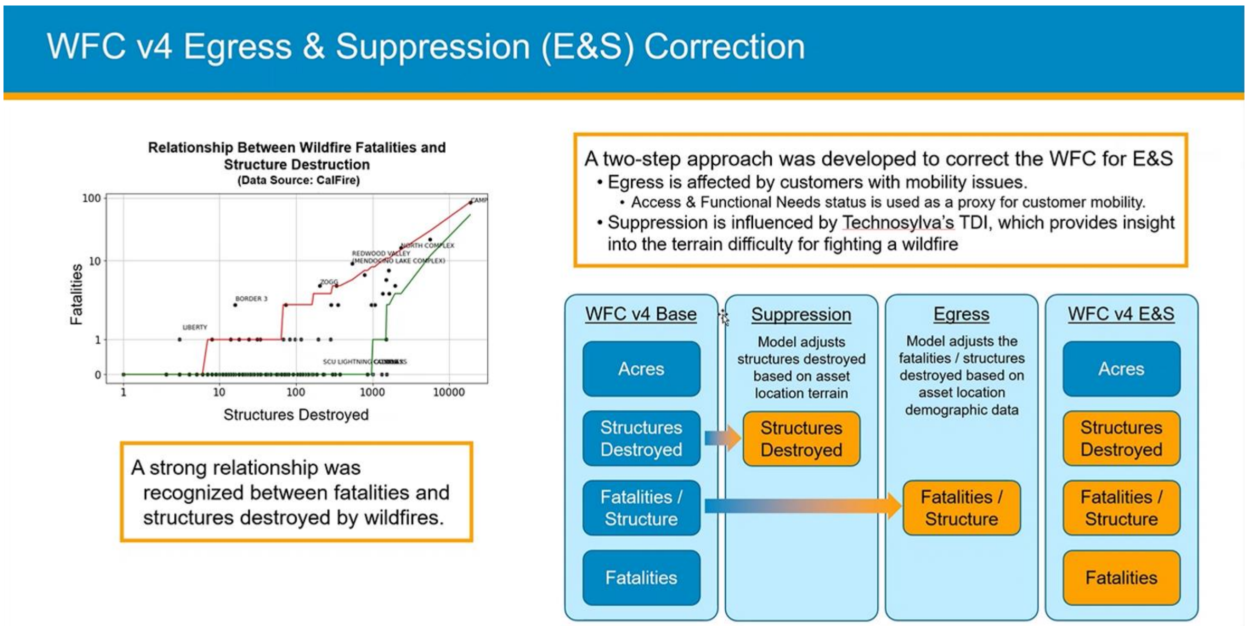


Figure 16 Excerpt from PG&E's documentation on v4 update to egress and suppression

4.6.3 Wildfire consequence recommendations

Consider improvements to coarse binning approach

Although there has been a large focus on Technosylva's wildfire spread model that feeds into the consequence score, it's important to recognize the Technosylva outputs themselves do not constitute the final consequence scores. Rather, a subset of the Technosylva outputs is used along with other metrics (i.e. PG&E's FPI score) to classify modeled fires into bins as summarized above. Ultimately, each modeled fire can only receive one of the eight consequence values that are assigned to these bins based on historical VIIRS and CAL FIRE data.

This regime-based binning approach inherently reduces the level of resolution available within the modeling results, blurring the significant amount of upstream detail available. Alongside this binning, E3 has learned that in practice, the main driver for the Predicted Destructive Potential metric is the FPI score rather than simulations coming from the Technosylva analysis. Through this binning approach, the current implementation of PG&E's risk model simplifies down a diverse and detailed set of simulation results. A natural question that arose during E3's review is whether the simplifications made during the binning approach undercut the usefulness of the initial detail of the Technosylva simulation outputs.

Through interviews with PG&E's consequence teams, E3 came to understand that PG&E has intentionally taken a simplistic modeling approach to better capture historical wildfire consequence data associated with past destructive fires, and to avoid false precision from relying solely on fine-grained simulations, as discussed in Section 4.6.1. PG&E's consequence team noted that while simulations are well-suited to model *some* of the important contributors to wildfire consequence (e.g. fuels and terrain), they are lacking in other important areas (e.g. ember transport and convective wind). In developing this binning approach, PG&E sought to better-represent "regimes" of conditions where destructive fires have arisen in the past, and the thresholds for the consequence bins were chosen with the aim of producing full recall of historical destructive fires.

E3 acknowledges that PG&E had sound rationale behind their consequence binning approach given their aims to avoid false precision and to fully capture regimes of historical destructive fires. However, this binning approach inherently leads to a large range of possible outcomes that are ultimately condensed to single point estimates of wildfire consequence. The consequence score is ultimately a large driver of the final risk tranches, and therefore, E3 believes that it is highly important to acknowledge and understand the limitations of the current approach and the large amount of uncertainty in the outcomes. E3 suggests that PG&E work towards capturing and communicating the uncertainty in these consequence estimates, especially given the large range of possible outcomes that are being distilled into single point estimates. Although it may be more challenging for key decision-makers (e.g. planners and regulators) to digest uncertainty bands compared to point estimates alone, it is critical for them to be aware of uncertainties in the outputs that they are presented with to make informed decisions based on the available data.

In addition to addressing the uncertainty in the current consequence outcomes, E3 also recommends that the consequence team continue to seek improvements to the fidelity of the model given its importance to the final risk tranches. For example, during discussions with TAC members, E3 came across alternative approaches to quantifying damages from wildfires (see Section 3.1.3). While PG&E is replacing the prior MAVF framework with a dollar-value approach consistent with the new requirements outlined in Decision D.22-12-027, E3 suggests that an updated burn-severity/damage model should be explored to evaluate the potential improvements that may be gained from utilizing new innovations in the risk-modeling field. For example, instead of using mean historical values from CAL FIRE, an alternative option is to calculate the consequence score based on actual structures that fall within these footprints of simulated wildfires.

Improve transparency and assessment of proprietary wildfire spread modeling and the wildfire consequence model at large

As stated in prior reviews, E3 recommends that the State, in collaboration with CAL FIRE and Technosylva, conduct a review of Technosylva's data inputs, methodology, and model outcomes. Though Technosylva serves a trusted source of wildfire spread modeling with their findings published widely in academic and professional journals, it remains unusual for the State and utilities to rely on outputs from a proprietary model with limited transparency into its inner workings. In this review cycle, Technosylva has provided E3 with a general overview of the model framework. Technosylva's spread modeling relies on the Rothermel equation with modifications, a practice widely used across the wildfire spread modeling field. Further insight into the model's workings, whether through public documentation or internal review with State agencies and Technosylva's client IOUs, would provide deeper understanding of the model's workings to contextualize the model's outcomes.

In addition, E3 recommends that PG&E work towards increased transparency with regards to the key consequence modeling choices they have made. As described above, PG&E's consequence model relies on a binning approach that groups fires into 8 different regimes. PG&E's consequence team chose this approach for several reasons, including the desire to anchor consequence results to previously observed real-world outcomes, and to avoid false precision given the "black swan event" nature of destructive wildfires. However, the rationale behind their choices could be described in more detail to allow stakeholders to understand why they have taken this approach rather than relying on the wildfire simulation outputs. While PG&E provided a brief description of this methodology in the 2023 Wildfire Mitigation Plan, E3 understood the rationale behind this method only after dialogue with PG&E consequence modelers. Additional publicly available information on the binning approach would allow readers to better understand the complex nature of this problem and the solutions that are currently being used. For example, more information could be given on the historical fires in the regimes that are modeled, and why these regimes are meaningful. Additionally, more information on the use of the FPI score would help to clarify how this metric may be complimentary to the Technosylva simulation outputs, and why this metric is being used to supplement the simulations in developing consequence scores.

Incorporate additional consequence impacts, including air quality and health impacts

Wildfire smoke has the potential to spread far beyond the initial burn area, carrying with it myriad pollutants that impact air quality and downstream human health. Such pollutants include particulate matter, a mixture of solid and liquid droplets suspended in the air that include or adhere to different compounds, like acids, ammonium sulfate, ammonium nitrate, organic carcinogens such as polycyclic aromatic hydrocarbons, heavy metals, and more. Fine particles such as PM 2.5 have the potential to irritate the human nose, throat, lungs, and of the smallest, circulation.

Health effects from wildfire smoke include exacerbating existing health conditions and contributing to the development of new ones. Short term exposure over a few days can cause increase irritation of the respiratory track, bronchitis, reduced lung function, asthma exacerbation and other lung disease, heart failure, heart attacks, strokes, and increased risk of emergency room visits and hospital admissions. Individuals with respiratory and cardiovascular disease, children, the elderly, environmental justice communities, and occupationally-exposed workers are more likely to experience negative health effects from wildfire smoke.

PG&E's modeling does not currently consider the consequences of wildfire smoke within their risk and consequence modeling. Future iterations of PG&E's modeling should consider utility-caused wildfire smoke's consequences as well as factors that contribute to concentrated smoke conditions. E3 recommends that PG&E, in collaboration with the State and other IOUs, consider a simple, standardized statewide approach to model the consequences of smoke from utility-caused wildfires. Because smoke is a complex, computationally expensive consequence to model, standardizing a simple statewide modeling approach would prove beneficial to all utilities and State agencies considering the health consequences of wildfire smoke.

In the absence of utility-caused wildfires, other causes may ignite wildfires and create substantial smoke with downstream health impacts. As a result, a comparable counterfactual to smoke from a utility-caused wildfire may not be the simple absence of wildfire smoke, as fires, smoke, and downstream health consequences may still occur. Future modeling should explore options for a suitable counterfactual to the consequences of smoke from utility-caused wildfires. These counterfactual sources may include smoke from controlled burns set as part of wildfire mitigation, smoke from other human-caused wildfires, or smoke from wildfires ignited by natural causes. Accordingly, smoke-related consequence may be valuable to consider in mitigation planning at the state level; some mitigations may impact the potential of utility-caused smoke impacts while others may impact the potential of smoke impacts from a wider variety of causes. We recommend that smoke-related consequences from utility-caused wildfires and mitigations options be evaluated with reference to an appropriate counterfactual.

If smoke were to be incorporated in the consequence score, careful consideration would need to be given to how this might impact the geospatial distribution of consequence. For example, the consequences related to smoke would likely be more concentrated in highly populated areas. The consequence score is main driver of the risk tranche assignment for circuit segments (e.g. only circuit segments in the top two quintiles of consequence are considered to be in the top eight risk tranches). If higher consequence scores were assigned to densely populated areas because of the smoke, an unintended result may be that circuit segments with higher probabilities of ignition that are located in more rural areas may be de-prioritized. This is not a desired outcome. Although the details of *how* to incorporate smoke impacts would need careful thought in this regard, we still suggest that impacts from smoke lead to substantial consequences that should be accounted for when comparing the costs and benefits of wildfire mitigations.

Consider the differences in mitigation lifetimes

One challenge in comparing various mitigation strategies is that different mitigation options may have varying implementation timelines and useful lifetimes. For instance, tree trimming may be quick to plan and execute on but has a limited risk reduction lifetime given that the trees will eventually grow back, whereas undergrounding may take years to plan and execute, but may lead to more permanent risk reductions. A single comparison value (e.g. cost benefit ratio) may not be sufficient to incorporate the important considerations around the risk reduction qualities of the various measures. E3 recommends that PG&E consider looking at operational mitigation strategies separately from longer-term mitigation strategies in their modeling efforts.

5 Conclusions

E3 conducted a review of PG&E’s v4 Wildfire Distribution Risk Model (WDRM) and Transmission Composite Model (TCM). This review built on E3’s prior reviews of the v2 and v3 versions of the WDRM model, performed in 2021 and 2022 respectively. In addition to reviewing PG&E’s updates to their modeling framework, E3 also conducted interviews with experts from across the wildfire risk modeling domain to gather best practices that may be relevant to PG&E’s efforts.

Our findings from this review are based on documentation provided by PG&E on their v4 model, interviews with PG&E's risk modeling team, and interviews with experts comprising the external technical advisory committee assembled by E3. The following bullets re-state the most pertinent recommendations stemming from our present review:

+ **PG&E should focus on using its model to develop transparent and justifiable company-wide mitigation budgets.** PG&E should focus more strongly on using the models to drive planning decisions around budget-setting and allocation to mitigations based on quantitative findings, and to improve transparency in justifying their proposed mitigation plans. E3 outlined a comprehensive least-cost planning framework that could be used to achieve this (see Section 1.3.1). However, balancing wildfire mitigation costs against other critical system needs will remain impossible absent guidance on acceptable levels of wildfire risk from the regulator that will drive clarity on the budget envelope. PG&E's nascent Integrated Grid Planning (IGP) team may play a critical role in filling this gap in utilizing wildfire risk modeling outputs to systematically justify and balance wildfire mitigation plans along with other system needs.

+ **Given the unique nature of wildfire risk and mitigations, consideration should be given to cost recovery mechanisms outside of the traditional general rate case.** Transparent and quantitative analysis can go a long way towards showing the true economic benefits to wildfire mitigations and building confidence in their justification. However, the current cost recovery mechanisms present the challenge of balancing wildfire mitigation costs with other critical needs across PG&E's electricity system. It is worth considering whether a separate cost recovery mechanism for wildfire risk mitigation would alleviate this challenge, especially with regards to more permanent wildfire risk mitigations that would occur over long time horizons and many other distinguishing facets of wildfire risk. This would require action on the part of the regulators and possibly legislators as well.

+ **Development efforts should be right-sized based on impact.** As PG&E continues to develop and improve their wildfire risk modeling ecosystem, E3 recommends that strong consideration be given to which of the planned modeling updates are imperative and will have meaningful impact before they are implemented. PG&E should seek to prioritize efforts that are deemed important for correctly assessing the wildfire risk across their system. The time and effort spent on various development efforts should be proportional to the estimated impact of the updates to be made.

+ **PG&E should seek to improve and justify simplifications made in the consequence model.** The consequence model coarsely bins its inputs, placing simulated fires into High and Low impact buckets. This binning approach inherently reduces the level of resolution available within the modeling results, blurring the significant amount of upstream detail available. This simplified approach was an intentional choice by PG&E's modeling team to anchor the outcomes to historical data and avoid false precision due to limited data and a lack of real-world validation of the detailed simulations. However, this approach also leads to point estimates of consequence that represent a large range of possible outcomes. E3 recommends that PG&E take steps to quantify and communicate the uncertainty around the consequence scores given the high-bias nature of this modeling approach. Additional public documentation on PG&E's rationale behind these modeling choices were made may also be beneficial. Finally, we recommend that PG&E continue to seek improvements to this approach, especially given that the consequence score is the key driver of the final risk tranches. Notably, although Technosylva simulations are being used across the IOUs in California, there is no standardization of how these simulations should be used to generate final consequence scores. This may be an area ripe for discussion and collaboration within the State.

+ **Uncertainty should be incorporated into modeling outputs to stabilize results.** E3 recommends that PG&E and the CPUC shift the focus of model outputs to quantify absolute risk with uncertainty for each circuit instead of circuit ranks or tranches based on rank. This reporting would avoid loss of risk score information that occurs when outputs focus on ranks. Alongside the change in output reporting, PG&E should develop a standardized process to determine the granular impacts of future modeling updates. The results of this standardized process should not only reveal how the results have changed, but also why they have changed at a particular modeling step. Incorporation of this improved reporting and version tracking will help ease the tensions between a long-term planning need for stability and the overall need for accuracy in risk quantification.

+ **PG&E should consider incorporating air quality and health impacts.** Wildfire smoke has the potential to spread far beyond the initial burn area, carrying with it myriad pollutants that impact air quality and downstream human health. PG&E does not currently consider the consequences of wildfire smoke within their risk and consequence modeling. E3 recommends that future iterations of PG&E's modeling consider utility-caused wildfire smoke's consequences, particularly those incremental to smoke and consequences from wildfires that result from other causes, as well as factors that contribute to concentrated smoke conditions. E3 recommends that PG&E, in collaboration with the State and other IOUs, develop a simple, standardized model to assess utility-caused wildfire smoke dispersal and downstream health impacts. Despite the potential uncertainties associated with modeling wildfire smoke impacts, E3 still believes it to be an important part of a holistic view on wildfire risk. This uncertainty should be captured, potentially as an additional sensitivity, in line with the recommendations above.

As with in our previous reviews, overall we have seen considerable improvement between versions of the PG&E wildfire risk modeling effort. This review provides some specific technical aspects that E3 strongly recommends PG&E should implement into their process to continuously improve. While many of our recommendations can be implemented by PG&E directly, several could benefit from more concrete regulatory support and guidance. Specifically, our top recommendation to consider implementing an overall wildfire risk management planning framework that minimizes costs for customers. Without clear targets from the regulator, it becomes increasingly difficult to develop a roadmap for improvement of the models and the overall mitigation process. E3 understands how challenging it would be to establish such a framework that requires reaching broad consensus on risk thresholds, balancing of competing interests, and development of complex forecasts, but we also believe that the current framework embeds core targets and assumptions implicitly. For example, PG&E believes that the long-term benefits of undergrounding outweigh the short-term cost increases for its customers. Based on its most recent statements, the CPUC is uncertain. Given our long history in working closely with the CPUC, other state agencies and the public and private load serving entities in California to develop an industry leading integrated resource planning process for the electric power system we believe California is up to the challenge and will continue iterating and refining, as they have done with so many other industry-leading planning processes. While California is among the vanguard of jurisdictions deploying effective short-term risk mitigation measures, it lacks the longer-term planning framework/proceedings that would allow it to develop a safe and resilient grid at least costs to consumers.