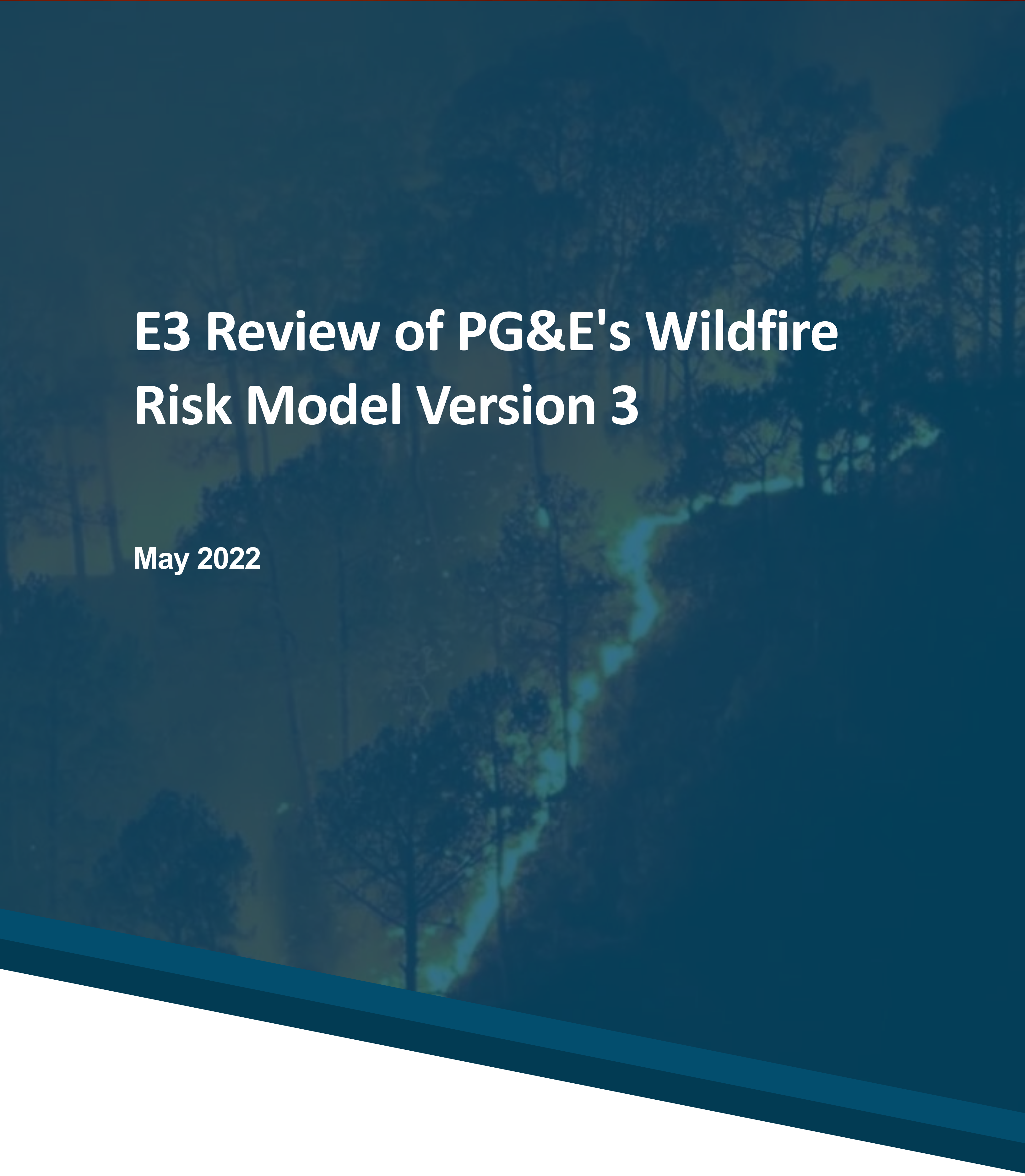

E3 Review of PG&E's Wildfire Risk Model Version 3

May 2022

Energy+Environmental Economics

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1) Executive Summary

a) Introduction

Energy and Environmental Economics (E3) was hired by PG&E to provide an independent peer review of Version 3 of its Wildfire Risk Model (v3). E3 produced a similar review and report for Version 2 (v2) of the same model and it was filed as part of PG&E's Wildfire Mitigation Plan (WMP) submission to the California Public Utilities Commission (CPUC) Wildfire Safety Division in 2021[1]. The scope of our initial engagement was limited to an assessment of whether the v2 model was fit for its intended purpose.[2] We concluded that the model did provide more accurate information than its predecessor and was suitable for prioritizing mitigation work on distribution circuits within high fire risk areas.

PG&E's most recent wildfire risk model (v3) represents a substantial expansion of the capabilities of its v2 model to include additional asset classes, modeling methodology, and data sources to predict ignitions and equipment failures across its entire service territory to allow for prioritization of both the type and location of mitigation work performed. Moreover, there are now several sub-models that can be used to develop composite probabilities and risks including separate models for support structures and transformers. The v3 model also has incorporated 2020 and 2021 data on outages, ignitions and PSPS damages as well as a host of new covariate data that includes:

(1) Important new data on tree species;
(2) LiDAR-based tree locations and heights in the high fire threat districts and satellite-derived tree height and location in all other areas;
(3) A range of information defining poles, structures and transformer assets; and,
(4) Meteorological data including wind-speed, vapor pressure deficit, and the R-score values used to define dangerous conditions in the operational models that determine when and where to call PSPS events.

With this more expansive model and its broader list of applications, PG&E has asked E3 to expand its scope beyond the quality and suitability of the v3 model for its current applications, to include:

(1) Review the suitability and applications of consequence data in the modelling framework;
(2) Review the specific use of the Risk Model Information in each of its operations areas; and,
(3) Describe potential future uses of v3 and longer-term multi-year wildfire planning models.

To effectively provide guidance on this broader scope, E3 has added Dr. Michael Wara to its review team. He is the director of the Climate and Energy Policy Program and a senior research scholar at the Stanford

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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] file:///Users/ren/Downloads/TN10374-2_20211013T135128_E3_Review_of_PGE's_2021_Wildfire_Distribution_Risk_Model%20(2).pdf

Woods Institute for the Environment and was a commissioner on California's Catastrophic Wildfire Cost and Recovery Commission. Dr Wara is also an expert in California law and policy concerning wildfires and the utility industry. He recently authored A *New Strategy for Addressing the Wildfire Epidemic in California*, a white paper identifying needed interventions – such as natural fire regime restoration, prescribed burning incentives and institutional reform – and how to achieve them. Dr. Wara contributed to situating the PG&E model within the broader State wildfire response effort and the use of models of this type in future regulatory oversight of wildfire planning.

The structure of this report is a review of v3 WDRM in escalating detail and meant for various audiences. The Executive Summary, including the Summary of Findings and Recommendations, is a high-level review of the model and E3's recommendations. The Wildfire Risk Model Evaluation goes into more detail, provides more background, and covers more of the model aspects as well as the pros and cons. The Technical Review Appendix (Appendix 1) directly cites PG&E documentation provided during the review. This Technical Review Appendix is written for a technical audience including the PG&E modeling team and technical staff at the regulatory agencies. We have also included Appendix 2: Agency and State Context Examples and Recommendations which goes into more detail on the potential for wholesale coordination amongst all wildfire planning stakeholders.

b) Summary of Findings

PG&E has made substantial progress in transforming its model from one that was primarily used to <u>validate</u> mitigation measures chosen by its subject matter experts (SME) within high fire zone areas to a model that can be used to <u>supplement and prioritize</u> the targeting of mitigation measures across its entire service territory.

PG&E intends to finalize v3 in the first quarter of 2022 for more expansive use in evaluation and prioritization of mitigation measures implemented in 2023. This construct of v3 appears to be consistent with their commitment in their WMP to refocus mitigation work to achieve a target where 80 percent of their work is focused on mitigating the risk of the highest 20 percent of identified line segments.

While PG&E should be commended for its rapid development of a model that shows substantial promise to increase the effectiveness of their mitigation work, our recommendations focus on a few existing gaps:

+ Standardizing and documenting the relationship between the model and subject matter experts
+ The transparency and validity of the consequence portion of the model
+ Establishing a data quality control process
+ Establishing a roadmap for model direction
+ Exploring potential further use cases of the model
+ Coordination of PG&E's process with broader State-wide wildfire planning

These focus areas and specific recommendations aim to build a transparent and effective wildfire mitigation planning process that continually improves as shown in Figure 1 below. While many of the recommendations are directly within the jurisdiction of PG&E, there is also a substantial role for the State and regulatory agencies to play in continuing to provide leadership. We hope these findings provide PG&E

steps to ensure their wildfire planning is as effective as possible. We also recognize that some barriers would be best addressed by the State and should be standardized across IOUs.

Figure 1 Crawl, Walk, Run, Fly Cycle for PG&E Wildfire Risk Planning

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.

c) Recommendations

Standardization of SME & Model Relationship

PG&E remains committed to developing and using best-in-class models to supplement the decisions that its subject matter experts (SMEs) have been managing for many years. We agree with PG&E that better decisions will come from a process that uses a combination of rapidly expanding and changing data, models that learn from this data and experts who have sufficient experience to effectively use the information to make prudent and efficient mitigation decisions.

PG&E's modelling team describes an evolving relationship where the SMEs are beginning to trust the models more as each version becomes increasingly useful and produces more valid and consistent results. We believe it would be helpful if this feedback loop between SMEs and model were formalized as the models and decision process matures.

Each of the following recommendations aims to clarify the roles of the model versus the SMEs on an ongoing basis and foster continuous and sustained improvement of the model.

- The model development team should be consulted on a regular basis to assist in model use and interpretation.
- Documentation and training materials are an important part of the feedback loop for each new model version.
- Documentation of SME input/feedback should be rigorous, documented, and standardized.
- A "model exception process" should be established for cases in which SMEs contradict model outputs.

The model is not the only source of information relied upon to draft prioritization and mitigation plans. SMEs rely on several other datasets and their own expertise as well. Often, these additional datasets are consulted to fill in gaps not currently covered by the model. While the team developing PG&E's WDRM model communicates regularly with the SMEs using the model, we are recommending that the SMEs be required to consult the model development team during their plan formalization phase and certainly before finalization of their mitigation or prioritization plan. This validation step between SMEs and the model development team will ensure that the model results are being interpreted and used correctly, and that any additional data brought to bear by SMEs does not contradict or double count any model inputs.

As the model becomes more and more complex, it will become increasingly difficult for SMEs to understand how to interpret results. This lack of understanding could lead SMEs to rely on overlapping or contradictory data, leading to incorrect double counting or dilution of model outputs. To accomplish this collaboration, PG&E should consider training SMEs on model updates and inputs on a regular basis, but especially when large development milestones are reached. SMEs should ideally be adequately trained to review and vet supplementary data and models being leveraged. This process could also help identify supplementary data that is being used that should be included in the modeling framework in future updates.

As stated, SME input is critical to this process and necessary in several instances to fill in gaps where data or the model is lacking. However, the process by which SMEs provide input should be standardized and documented as much as possible. For inputs which are primarily SME-driven, for example mitigation effectiveness scores, SMEs should be required to fill out a standard survey of questions documenting their score. To the extent SME input is softer, for example weighting outputs to optimize for worker efficiency or other aspects not captured in the model, annotations should be documented in an *inputs, assumptions, additions and exceptions* document filed alongside prioritization and mitigation plans. All supplemental datasets used to draft the prioritization and mitigation plans should be cited in the *inputs, assumptions, additions and exceptions* documentation as well. This documentation will create institutional knowledge which can be built on, allow for identification of key gaps and trends across cycles, create transparency and allow for external validation, and allow for validation of SME inputs and calibration of the model.

The development of this model supports an important goal to have an accurate and unbiased process through which to prioritize mitigations and effectively reduce the threat from wildfires. Once again, while SMEs are critical to this process, they introduce the potential for bias into prioritization and mitigation plans. The model has already reached a level of maturity in several use cases that necessitates less SME input and influence. As the model matures, reliance on model outputs versus SMEs will naturally increase. This will coincide with the model increasing in complexity and nuance. As this transition occurs, documentation of when and why SMEs are choosing to contradict the model outputs will become increasingly important. We recommend that SMEs be required to file an *exceptions report* explaining their decision to contradict the model that is first approved internally by other PG&E SMEs and the model development team, and then published externally by the CPUC or OEIS. To the extent these exceptions are approved, they should be flagged as areas for improvement in future model development. The strength and effectiveness of the feedback loop between the modelling team and the SME's can be measured by the number and importance of the exception reports. PG&E's goal should be to strengthen the communication and reduce the number of exception reports over time. That said, wholesale reliance directly on model outputs should not and cannot be the goal. SMEs provide a vital sense check on the model results and must be empowered to review and override model outcomes based on their best judgement. This SME input will remain critical even as the model matures.

Consequence Model

As identified in E3's review of v2 of the WDRM, the consequence model has an outsized impact on the final risk score. Given the magnitude of this component of the model, E3 would like to see increased scrutiny from regulators into the development and use of the consequence model and data. While PG&E has made improvements to the consequence model and data used in the overall risk model, there are still a number of remaining concerns.

- Proprietary and unique nature of consequence data from Technosylva
- The consequence cost estimates use of mean historical fire data
- The accuracy and potential bias of the consequence data

Technosylva is a respected leader in wildfire science and consequence modeling, and they consistently publish the science underpinning their model in peer-reviewed journals for public consumption. However, E3 has concerns about the level of reliance on this proprietary product and the fact that each investor-owned utility (IOU) is leveraging a unique product from the company for use in their Wildfire Mitigation Plans. E3 recommends that given this heavy reliance on Technosylva for such a critical part of the State's wildfire mitigation, the Office of Energy Infrastructure Safety (OEIS), in coordination with CalFire should conduct a review of the model to vet the inputs, assumptions, and outputs. To our knowledge this process has been at least partially impeded by the proprietary nature of the model, but OEIS and CalFire could take sole receipt of proprietary information from Technosylva while protecting Technosylva's intellectual property and ensuring that sensitive information remain confidential. OEIS and CalFire should also engage with the public documentation Technosylva has produced. This would also give OEIS the opportunity to understand the virtues as well as the flaws, biases, and omissions in the Technosylva model and potentially support data creation or research to further this science for the benefit of the State.

It is unusual for the State to rely extensively on proprietary, non-transparent data and models for either utility or State policy implementation. E3 would also recommend that the data products being leveraged by IOUs be examined. It is our understanding that each IOU is leveraging slightly different outputs and products from Technosylva. E3 recommends that OEIS acquaint themselves with these products and standardize and document the approach, transparency and public availability of the data used in calculating wildfire consequence across IOUs.

Another improvement that we recommend is to, in the near-term, share consequence range data with SMEs for destructive fires for use in decision-making, and in the long-term, to supplement the use of historical fire consequences. Currently, mean consequence is used to calculate total risk potential. This simplified approach has the potential of improperly prioritizing work and mitigations by obviating this information from SMEs and decision-makers. In the near-term, E3 recommends continuing the use of the mean for prioritization purposes but supplying the probability and cost range of destructive fires to SMEs for use in mitigation planning. In the long-term, E3 recommends supplementing historical consequence data with location specific data to reflect a more accurate representation of actual consequence potential. This method should be developed alongside the regulator and be sure to include consideration of equity.

Data Quality and Data Sparsity

PG&E has made substantial progress in both updating and adding to datasets between v2 and v3 of the WDRM. The v3 model uses an impressive breadth and combination of available data and estimation methodologies leveraging both more recent ignition data, post public safety power shutoff (PSPS) inspection data, and key drivers of those ignitions and an extensive time series of equipment failure and weather-related data.

However, E3 still recognizes a data quality and data sparsity issue that will persist in any model with similarly expansive scope. There are some model components, for example the risk reduction model, which rely on SME judgement regarding measure effectiveness. This isn't inherently a bad practice today, but PG&E should establish a roadmap to incorporate more empirical data over time and/or establish a process to vet SME data on an ongoing basis.

There are several input files crucial to the structure and outputs of the model that do not currently have a required refresh cycle. For example, for v3, PG&E ingested updated LiDAR data and merged that data with satellite-derived tree data to gain an in-depth and better understanding of the state of vegetation in their entire service territory. The adoption of this new satellite tree data allows for a refresh on a much more regular cadence and improves the lag time between acquisition and use compared to just LiDAR. This data update impacted the model outputs, especially for vegetation management. While it should be celebrated that PG&E is now using updated data for this task, PG&E should also consult with its vegetation management experts to institute a required refresh schedule for this data in the model to ensure accuracy with changing conditions. In a broader sense, for each critical dataset, conversations with the SMEs to institute reasonable refresh cycles and data quality parameters should be had and implemented as standard practice.

Several of the datasets crucial to PG&E's modeling infrastructure (e.g. outages and ignitions) will naturally degrade over time if PG&E is successful. This expected degradation should be built into the modelling roadmap, but it should also be recognized as a clear risk to modeling outcomes and approach longevity. Strict and clear thresholds should be placed on data to mitigate this issue and back-up approaches, or supplementary datasets should be explored.

One area that E3 recognizes as an opportunity for regulator intervention is in helping establish these data refresh cycles, pooling data across the state and IOUs, and/or establishing channels of communication between stakeholders. The wildfire challenge is one that should be met with a united front in the state and data-sharing is an easy first step in alignment. PG&E has invested substantial resources to gain a better understanding of conditions impacting wildfires, as have other IOUs and the state. All of this data should be accessible and used by any relevant party to contribute to the solution.

Model Roadmap

The urgency and value to produce a continuous stream of useful and responsive models, as evident in the rapid progression from v2 to v3, cannot be over emphasized. However, the lack of a roadmap hinders both the model development team's ability to prioritize updates and the model users in their ability to understand where and when there will be changes to the model that could impact their workplans. The latter point is especially important given workplans are often several years long, difficult to get approved, and should build upon past workplans. A roadmap, even if its high level and uncertain, creates an opportunity to plan for incremental model improvements and to make explicit linkages with new sources, company experts, and other workstreams.

We view a long-term multi-year roadmap as a fundamental component of model design based on its ability to align visions and create accountability. A roadmap also helps guide the model development on an organized process. Ideally, a process which includes identification of new or improved data that is required will support the following activities:

+ Increased engagement with SMEs to work out characterization of various interventions in the model
+ Proposals for small scale testing of novel mitigation or modelling technologies to better understand their capabilities
+ Increased engagement with Technosylva and improve feedback between PG&E and Technosylva with the goal of continuous improvement of the consequence model
+ Reinforce the avenues for feedback from measure performance data and SME effectiveness estimates to assess actual and expected measure performance

Given the significance of the consequences model to overall model performance, more robust engagement with Technosylva on the performance, strengths and weaknesses of that model component is well justified. We note that understanding of the performance of the consequences model and areas for improvement need not be limited to examination of utility caused wildfire events. PG&E should work with Technosylva to examine consequence model accuracy and precision for all wildfires in a given year – the out of sample wildfires - to better understand the strengths and weaknesses of the current model architecture.

We note that the feedback in the last step may be difficult to quantify, due to the rare nature of wildfire events, but we encourage PG&E to perform some form of assessment. Establishing these goals for data collection and testing early on will pay dividends in the future by allowing for longitudinal assessments and rich datasets. Having this process spelled out benefits PG&E by allowing them to set reasonable expectations for outcomes and timing, and it benefits the regulators and other parties by providing accountability of tasks, schedule for delivery and reporting requirements. As the State's own planning process matures, creation of this roadmap would also help align PG&E's plans with the State's goals and objectives in the long-term.

Future Model Applications

V3 of PG&E's model is appropriately focused on prioritizing the geographic targeting and design of mitigation measures as reflected in its stated 80-20 goal. In this short-term context PG&E's model reflects a combination of state-of-the art modelling approaches combined with historical equipment outage data and ignition data to produce an industry leading approach. Although there is no formal test for the value of PG&E's v3 model, we have seen evidence that it produces positive value today and believe that it has the potential in future versions to be used for multi-year planning by both PG&E and even used by the State and its oversight agencies or other IOUs as an example to base their models off.

As PG&E's risk mitigation efforts increase over time to respond to the rapid growth of wildfire risk, the next set of modeling applications should pivot towards addressing planning questions. These questions encompass the size and effectiveness of the portfolio of mitigation measures being requested, authorized, and implemented as well as the interaction and timeliness of the measures as they are deployed in a rapidly changing environment. V3 of PG&E's model already produces estimates of the residual unmitigated wildfire risk within a single year. Extension to cover a multi-year period would increase the number of useful model applications.

In today's planning paradigm, reducing and/or avoiding IOU-caused outages, ignitions and wildfire damage are the predominant objectives of the IOUs in California. While this is what the IOU's have been directed to mitigate, this narrow perspective has the potential to create an over-reliance on Public Safety Power Shutoffs (PSPS) as a mitigation strategy, which can cause significant damage to ratepayers. The model currently includes PSPS related hazards and damages and weights the probability given ignition prediction to the days that experience the greatest number of outages which effectively and appropriately prioritizes PSPS prone regions for mitigations. However, the application of the model is only being used to budget for the top 20% of risk and PSPS naturally becomes the status quo mitigation for the other 80% should any fires materialize in those areas or line segments. In future applications of the model, these trade-offs should be optimized to avoid long-term reliance on PSPS events, including exploring the need to increase near-term budgets for system hardening and other mitigations. These trade-offs need to be fully internalized in the model.

The use of the model to help determine mitigation budgets and in other planning applications requires the addition of a time dimension to incorporate the duration and effectiveness of mitigation measures and use this information to determine which projects are funded, as opposed to predetermining the budget and risk cutoffs. We understand there are limitations to how much work can be done in any given year given workforce and supply constraints, but those constraints should not be obscured by the model application for workplan development. In fact, those constraints should be made explicit and addressed to the extent possible.

State-level Long-term Wildfire Mitigation Planning

The 2020 and 2021 wildfire seasons have demonstrated both the growing risk of wildfire in California as well as the fact that the causes of high consequence wildfires are diverse. At present, IOUs constitute a large portion of the budget and responsibility for effective and efficient management of wildfire risk, but there are large complimentary wildfire mitigation efforts at the federal, State, and local levels that should be considered holistically with utility efforts. In this broader context, future versions of wildfire risk models similar to the v3 WDRM could be used by both utilities and State agencies to comply with State-enshrined performance goals that include all mitigation measures and are consistent with overall defined transparent set of costs and risks defined at both the measure and Statewide portfolio levels.

A longer-term vision for more effective management of the Statewide risk would incorporate each of the individual utilities Wildfire Mitigation Plans with plans being created by all actors with control over wildfire risk mitigation. Overall, each of these WMPs and roadmaps could be guided and coordinated by a State-developed California Wildfire Mitigation Plan, possibly through OEIS wildfire planning oversight. Although this coordinated modelling approach does not exist today, it could be constructed by combining the best practices from the CPUC Integrated Resources Plan and the CARB Scoping Plan regulatory processes where one master plan is created and affected regulated bodies and support agencies create sub-plans compliant with the master plan for their respective jurisdictions. This holistic, Statewide approach to wildfire mitigation planning will confer a host of benefits, not the least of which is ratepayer and/or taxpayer financial and safety protections. These protections will materialize through implementation of the most efficient and effective wildfire mitigation plan to achieve the State's goals. See the discussion in Section 4 of this review for a more complete discussion of creating a Statewide master plan.

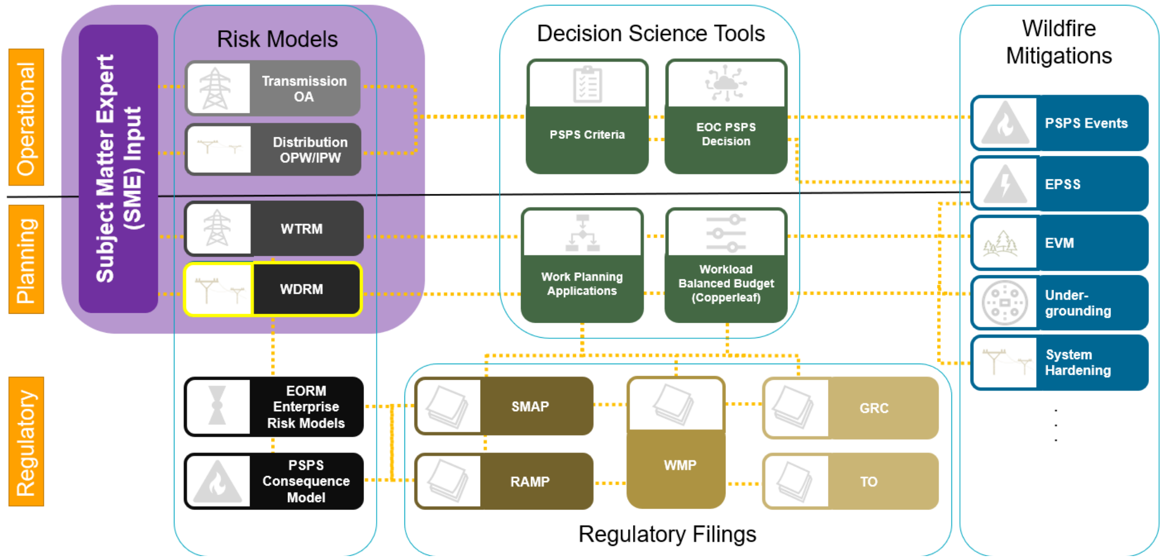
2) Wildfire Risk Model Evaluation

PG&E has made a substantial effort to incorporate feedback from the CPUC, stakeholders, E3 and its internal users to update the WDRM between versions 2 and 3. The updates made represent real improvements in several critical areas. From E3's review, the modeling team includes a group of highly skilled professionals from inside and outside of PG&E. The model is leveraging the best available data and methods to prioritize risk levels by geographic area and ignition type allowing for evidence-based decision-making. This model represents an improvement from v2.

Most of modeling limitations are driven by limitations in data and resources which are difficult for the modeling team to directly solve. For most of these areas, E3 recommends that PG&E develop a process to introduce more transparency and a culture of continuous improvement. There are other areas where PG&E should consider augmenting their modeling or reporting of results that are directly identified. We have also included a review of how well PG&E has been able to enact the E3 recommendations shared for v2 of the model.

This review is narrowly defined to review the v3 WDRM, but this model sits within a whole suite of PG&E models used to support PG&E's risk planning and regulatory filings. See the figure below for an overview of each of the models and tools used to support this entire process. E3's review is focused primarily on the WDRM (box highlighted in yellow), but we do make some suggestions for increased synergies and transparency amongst the modeling suite as well as suggestions for how to ensure these models are aligned in their objectives.

Figure 2 PG&E's Model Ecosystem[3]



a) PG&E Incorporation of E3's v2 Recommendations

E3's recommendations on the v2 framework broadly fell into three categories: Context and coordination, model methods and data, and fire simulation and consequence. PG&E has addressed many of these recommendations in the current v3 modeling. There are some remaining suggestions that PG&E plans to address or incorporate into modeling in the next round (v4). In this section, we summarize E3's previous recommendations along with descriptions of PG&E's corresponding v3 actions:

1. Context and coordination: E3's recommendations in this category focused on providing a clearer picture of models' connections to PG&E's long-term roadmap and strategy. We recommended that:

    a. E3 v2 Recommendation: PG&E provide a long-term roadmap for WDRM development and indicate how the various modeling pieces and their interactions fit into it.

        i. E3 Progress Assessment: PG&E has partially addressed this by providing better context and descriptions of model interactions. However, as described above, we continue to believe that a long-term WDRM roadmap is missing and that it would be a valuable piece of information to connect the yearly changes being implemented to long-term modeling and strategic goals.

    b. E3 v2 Recommendation: PG&E develop closer integration between the WDRM model and the PSPS model.

[3] P37, PG&E Wildfire Risk Governance Committee presentation December 15, 2021

i. E3 Progress Assessment: The WDRM model and PSPS model now share data from the same Technosylva model and the parallels between both models (both predicting Probability of Ignition given outages) is recognized. This too is a step in the right direction, and we believe that PSPS is a very short-term targeted form of relatively expensive mitigation and should be consistently evaluated alongside other mitigation measures. As PG&E develops documentation for v3 we recommend that they develop a section comparing the sources of data used in both models and any progress made to increase consistency.

c. E3 v2 Recommendation: PG&E's modelling team develop a closer integration with the mitigation plans being designed exclusively by SMEs.
    i. E3 Progress Assessment: PG&E has successfully implemented SME inputs on mitigation measures in the v3 model. SME input is also given in the form of effectiveness factors for various mitigation measures. E3 believes this is good first step and that more refinement is needed in the next round to make SME contribution and its mechanism more consistent and transparent.

2. <u>Model data and methods:</u> This category of recommendations is focused on PG&E's choice of model algorithms, reported metrics, and data used. In the first round of review, we recommended that:

    a. E3 v2 Recommendation: PG&E compare MaxEnt to other modeling approaches to be certain that it is the most appropriate choice.
        i. E3 Progress Assessment: In the v3 model, a different algorithm, Random Forests, was used for the asset models. Formal testing of modeling approaches was conducted Q1 2022, for the Probability of Ignition given Outage model, variations of Random Forests, XGBoosted trees, and Logistic Regression.

    b. E3 v2 Recommendation: PG&E to directly tie the models to mitigation measures by modeling outages and then ignitions.
        i. E3 Progress Assessment: PG&E implemented this fully. The modeling framework now consists of a Probability of Outage model followed by a Probability of Ignition given Outage (See section 0).

    c. E3 v2 Recommendation: PG&E strengthen the ties between model covariates and mitigation measures.
        i. E3 Progress Assessment: This was addressed in v3 by retaining variables with overlapping predictive value or similar permutation importance.

    d. E3 v2 Recommendation: PG&E devise a method to include climate impacts both in weather data and in geographical scope of the WDRM.
        i. E3 Progress Assessment: PG&E addressed this by expanding the model to the entire PG&E system. This is a substantial improvement – expanding beyond HFTDs ensures that areas outside the HFTDs that are on the verge of becoming

high-risk can now be identified. PG&E argues that their use of the worst fire days for consequence simulations is a proxy for future climate impacts. They also note that Technosylva uses projections of 2030 fuels levels to provide another useful projection of future risk.

3. Fire simulation and consequence: These recommendations pointed to improvements in fire simulation metrics, uncertainty consideration, and better ways of communicating important fire simulation variables. For this area, E3 recommended that:

    a. E3 v2 Recommendation: PG&E make improvements in fire simulation transparent to stakeholders. We suggested that even though PG&E did not have internal wildfire experts on their team, they could both document differences in the way that the utilities were incorporating consequence data in their risk scoring and incorporate wildfire simulation modelling advances.
        i. E3 Progress Assessment: PG&E provided a list of improvements on the wildfire simulation front that materially affected the results. We continue to recommend more transparency in this area.

    b. E3 v2 Recommendation: PG&E improve the communication around the intuition behind key variables that are used in fire simulation tools. This could be a valuable piece of the puzzle connecting drivers of wildfire spread and mitigation options.
        i. E3 Progress Assessment: One particular area where this has been incorporated is in the new use of LiDAR and satellite data to produce more accurate and SME consistent modelling results via fall-in tree counts/heights.

    c. E3 v2 Recommendation: PG&E reduce the sensitivity of results to the chosen cutoff between fire size categories.
        i. E3 Progress Assessment: PG&E believes that the number of simulations at a location is large enough that the consequence distribution looks continuous. In other words, the simulation results will not be anchored or particularly sensitive to fire size categorization. A determination of "destructive potential" as a fire size category is still made, but the real-world consequences of fires placed into those categories can be used to generate expectation values for such classifications and effectively calibrate the consequences.

    d. E3 v2 Recommendation: PG&E consider using a range of consequence for each location instead of the mean of the simulations values as used in v2.
        i. E3 Progress Assessment: Although PG&E continues to use the mean value in v3, the consequence calculation is now calibrated to historical data such that now the range of consequence is smaller. In this review, we repeat our recommendation that consequence scoring be based on a range of consequence values at each location instead of a single-valued mean, which we believe may more accurately capture uncertainties in consequence models.

b) Wildfire Risk Model v3 Purpose

The model is currently being used to support the overall PG&E Wildfire Mitigation Plan by what PG&E calls its priority business units. These business units leverage the model to develop their risk scores which are used to develop workplans. The model supports determination of the location for prioritization and mitigation types to include in the workplans. The model does not support near-term workplans or daily operations. The model is not currently being used to set budgets within or amongst business units or mitigation strategies. There are also several other steps to workplan development and authorization that fall outside of the purview of the model.

PG&E made many changes and improvements between v2 and v3 of the model:

- Including an automated composite risk scoring methodology tailored to business units and ignition types.
- Extending the probability of ignition model and wildfire consequence model beyond HFTDs or HFRAs to cover the entire distribution system
- Adding models for support structures and transformers which necessitated using outage data to supplement ignition data in the modeling framework
- Developing and evaluating a wider range of model algorithms including extending beyond the MaxEnt framework exclusively used in v2 and including using Random Forest Classifier for the Support Structure Outage Model(s) and Transformer Outage Model(s)
- Updating training data sets with 2020-2021 outages, ignitions and PSPS damages. LiDAR tree and species data was also included along with several data updates for assets and meteorology
- Improved coordination in use of common data between the PSPS model and WDRM model
- Developing risk reduction metrics for mitigation options at a more granular level

The four priority business units or mitigation programs being targeted for immediate use of this updated model are:

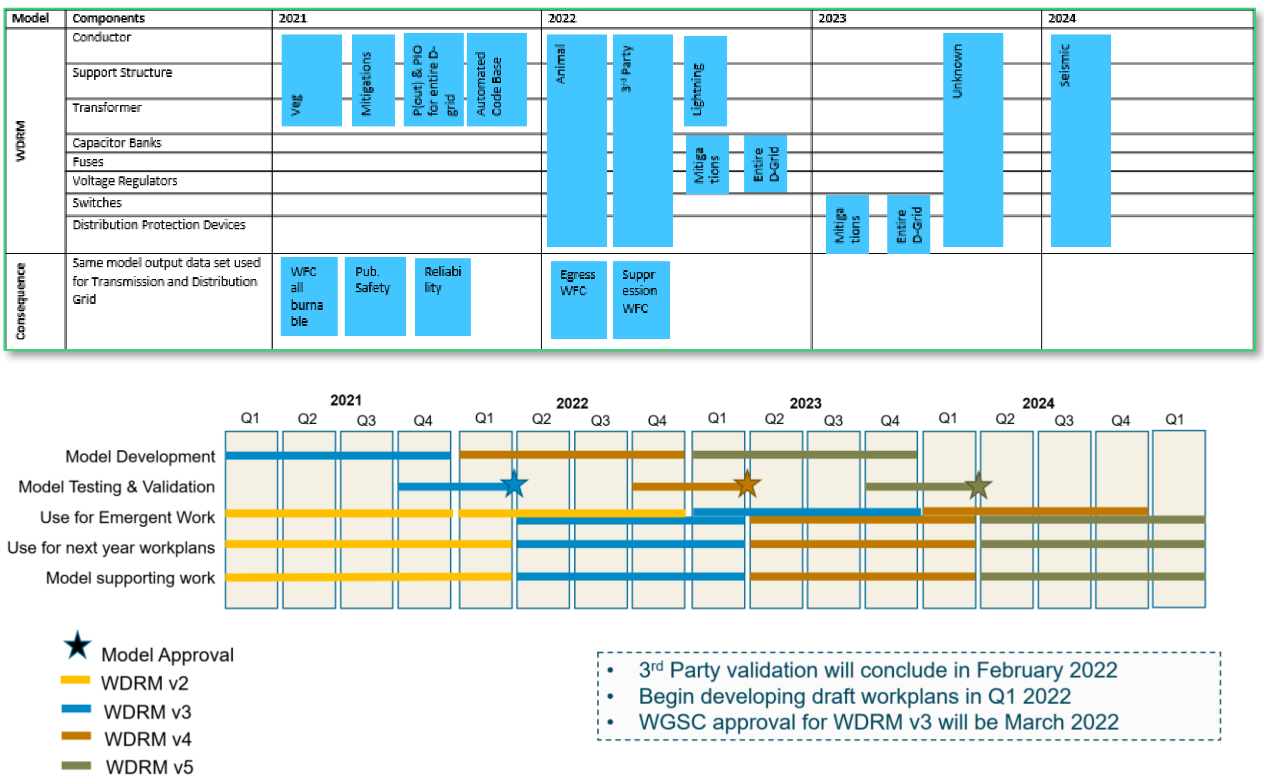
- System Hardening
- Enhanced Vegetation Management
- Poles and Support Structure Replacement
- Transformer Replacement

The assets/components currently included in the model include:

- Conductor
- Support Structure
- Transformer
- Capacitor Banks
- Fuses
- Voltage Regulators
- Switches
- Distribution Protection Services

Cumulatively these improvements leverage higher quality data, add new components to the model to expand its use, and tailor the modeling framework to more closely align with what the business units need to build their work and mitigation plans. While v3 of the model did not support any of the mitigation planning in the PG&E 2022 Wildfire Mitigation Plan, PG&E has made an internal commitment that the model will be used in Q2 of 2022 to start developing workplans for the priority business units. Workplans with shorter implementation cycles will be adjusted first in 2022, followed by emergent work during 2022, and then for longer term work for 2023 and beyond. This current plan for expanded use of the model over the next two years is shown in Figure 3.

Figure 3 PG&E Model Schedule



c) Review

In this section, we focus on areas where PG&E has improved the model substantially and several key factors that PG&E can improve. The technical details of our review of each of these same model characteristics can be found in the Technical Appendix to this review. The first two sections focus explicitly on v3 of the model, detailing the pros and cons of aspects of that model. The third section discusses updates that we recommend be considered as PG&E begins planning and developing v4 of the model.

There are systemic changes somewhat outside of PG&E's control that could also contribute to a more effective model and, in turn, mitigation plan. These changes include more standardization amongst IOUs and better coordination of datasets. E3 urges PG&E to continue their coordination with federal and State agencies and other IOUs to ensure the best data and methods are being brought to bear on this problem. Additionally, there may be a role for the State or the regulator to play in standardizing IOU approaches, ensuring federal and State level data is being made available to all, and generally coordinating amongst the parties. We expand upon this potential State role in the Agency and State Context section.

Pros (v3)

PG&E made substantial advancements between v2 and v3. Highlighted below is a summary of the standout advancements made. The conciseness of this section should not be taken as indicative of the balance of pros and cons in v3 of PG&E's model. Rather, the focus of this review is to provide critical feedback to ensure PG&E's model is as robust as possible. Our critiques are small in comparison to the magnitude of improvements made and the speed at which they have been implemented.

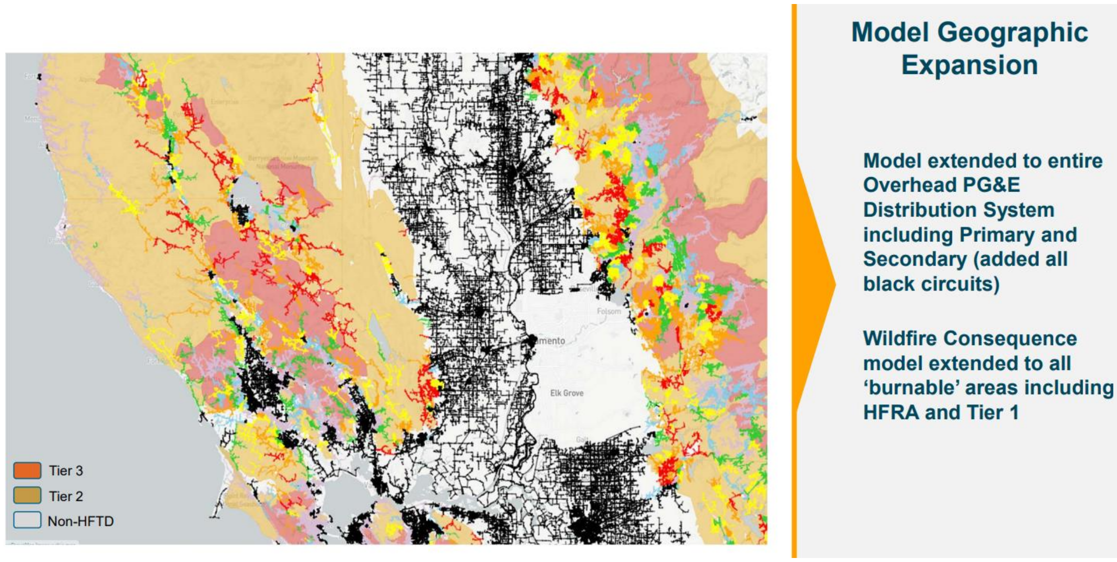
Composite Model

In order to facilitate more tailored model outputs for business units that are specific to their risk areas and mitigations, PG&E developed and automated what it calls a *Composite Model* methodology. Where v2 of the model allowed for comparison amongst geographic areas, the composite model allows for comparison across ignition and mitigation types at a granular level. The composite model allows PG&E business units to focus on mitigation of ignitions within their direct purview, improving the model's relevance for their particular mitigation plans and workplans. To achieve this ignition specific composite model, the data input is limited to only relevant ignitions which ensures there is no double counting of ignitions. The model is currently capable of modeling composites of ignition types for which PG&E has enough data that represents statistically significant event probabilities. In the future, with increased data collection or availability, this functionality could also potentially be leveraged to calculate the risk mitigation potential for mitigations being considered. PG&E also automated this process, per the CPUC recommendation.

Geographic Expansion

V3 of the model also substantially expands its scope to include wildfire risk beyond High Fire Risk Areas (HFRAs) by calculating probability of ignitions in all of the PG&E territory. This is an important inclusion that can incorporate high-risk areas outside of the HFRA designation, and can be used to potentially redefine HFRA boundaries year over year as our understanding of rapidly changing climate and risks change into the future.

Figure 4 PG&E Geographic Expansion[4]



Data and Risk Model Updates

PG&E also changed the structure of their model substantially and to favor a more robust dataset through incorporation of outage data to supplement ignition data. Version 2 of the model was trained only on ignition data which is a relatively small data set.

Given an expanded data set that included both ignitions and outages, PG&E instituted a change to their definition of risk translating from

$$Risk_{v2} = Ignition\ Probability \times Wildfire\ Consequence$$

to

$$Risk_{v3} = Outage\ Probability \times Ignition\ Probability\ Given\ Outage \times Wildfire\ Consequence$$

In this model update, PG&E also incorporated several new or updated datasets that increased the accuracy of the model. For example, PG&E developed much more detailed tree data including satellite, LiDAR and species data, in part due to the emphasis internal SMEs place on such data when describing and explaining the vegetation caused outages. These data sets provided a better understanding of vegetation related risks related to things like tree height and proximity to overhead lines. There were also several refreshes to PG&E asset data, now current to 2022-01-01, and inclusion of updated internally sourced meteorology datasets.

PG&E also increased the alignment of v3 and the PSPS model by incorporating data from their internal meteorology team directly into the consequence scoring and as explanatory variables when modeling probability of outages and the probability of an ignition given an outage. Specifically, PG&E leveraged the Fire Potential Index (FPI) from 2004 to 2020 to supplement the consequence outputs from Technosylva.

[4] PG&E'S WILDFIRE DISTRIBUTION RISK MODEL (WDRM) OFFICE OF ENERGY INFRASTRUCTURE SAFETY WORKSHOP OCTOBER 5, 2021

The FPI is produced by the meteorology team for use in the PSPS model and assigns a fire danger rating based on the probability that small fires will grow to be large or catastrophic.

Table 1 PG&E Fire Potential Index Table

P(Large or Catastrophic) Percentile	FPI Rating Description	FPI Rating	FPI Rating Detail
<50th	Low	R1	Very little or no fire danger.
50th	Moderate	R2	Moderate fire danger.
75th	High	R3	equipment to certain hours of the day.
94th	Very High	R4	limited to specific areas and times.
99.5th	Extreme	R5	open flames is not allowed in certain areas.
CFPd percentile: 99.7th	PSPS	R5+	catastrophic wildfires are possible. This is typically when fire danger is R5, "plus" there are high-risk weather triggers

In v2, PG&E relied on Technosylva's rate of spread and flame length metrics, combined into a 1 to 5 FBI (fire behavior index) score to determine whether a fire was destructive, but this approach classified many non-destructive fires as destructive in hindcasting sensitivities. In v3, PG&E supplements the Technosylva rate of spread and flame length data, with FPI values (fire potential index) for the same locations to classify locations/times capable of hosting destructive fires at greater than R4. This updated approach establishes expected consequences for ignitions at any given grid location.

Risk Reduction Metrics for Mitigations

In v3 of the model, PG&E has defined attributes like applicability, efficacy, and fraction of work complete that characterize mitigation outcomes, and has begun scorekeeping of risk reduction potential metrics for several categories of mitigations. These metrics can inform the risk buy down, or risk mitigation potential, of specific mitigations as they relate to subsets and composites. This allows for mitigation prioritization based on effectiveness and the ability to tailor fit certain mitigations to specific outage or ignition types. This provides each mitigation program an estimate of the amount of risk they will be reducing if they perform their mitigation at a location or on a set of assets, etc.

Data to characterize mitigation applicability and efficacy can come for first principles, simulation, empirical outcomes of past efforts, or subject matter experts. In practice, SMEs – via a series of discussions on definitions and best practices with the modeling team - are the primary source of the mitigation metrics used as inputs to the risk reduction portion of the v3 model. For example, the System Hardening team has deemed the following four outage characteristics relevant when quantifying the effectiveness of System Hardening: outage cause, supplemental cause, equipment involved, and equipment condition. Then for each mitigation, SMEs determine effectiveness factors of those mitigations as they relate to specific outage or ignition characteristics. So, for example, system hardening is assumed to be 90% effective if the outage cause is vegetation, specifically a felled tree branch, that is impacting overhead conductor. However, system hardening is assumed to be only 20% effective against animal caused outages (e.g. birds) impacting capacitors. For some mitigations, there is enough empirical data to provide at least a partial picture of observed mitigation effectiveness (e.g. pole replacement). SME's typically define more characteristics of outages than are covered in the model or historical dataset, so the modeling team has decided to take a weighted average of the effectiveness factors mapped onto each training event (outage, ignition, PSPS damage, etc.) according to its cause, sub-cause, equipment type, etc. This allows PG&E to create one effectiveness factor for each mitigation category for each subset.

PG&E has also developed a method to further classify the effectiveness of mitigations based on their location, or their spatial effectiveness, which allows them to understand the effectiveness of a mitigation for specific outage characteristics at each pixel. To apply this further degree of specificity the effectiveness factor for the pixel is the weighted average of the effectiveness factors for the subset weighted by the probability of ignition from each subset. Having this additional specificity allows for more targeted mitigation planning to prudently allocate budgets.

Cons (v3)

While v3 of the model represents a real improvement over v2 of the model, the increased complexity of the model has led to additional challenges which need to be addressed in this version or future versions. The cons identified in this section revolve primarily around a lack of thresholds for use, documentation, or standardization of process.

Composite Model

The composite model is intended to give a more granular look at risk related to causes of ignition defined by the users and to compare and prioritize mitigations for these ignitions specifically. While the composite model represents a move towards a more tailored approach to SME and business unit needs, the current formulation relies upon a relatively small training dataset. While the modeling team does some validation to ensure there is usable data to move forward with specific subsets and composites, there is no data quality threshold or standardized check for predictive power. Predictive power is assessed for sub-models and has been found to be satisfactory, but documentation of the process and definitions for “satisfactory” are lacking. Figure 5 below illustrates area under the curve (AUC) and concentration factors for individual sub-models ranked highest to lowest. While the Transformer sub-model is not as effective at predicting ignitions, it was deemed by PG&E to have a satisfactory failure prediction. Individual composites for specific workplans are assembled from these sub-models.

Figure 5 Sub-model Predictive Performance Measures

subset_name	mean annual wildfire season ignitions	p(i) pred i AUC	p(i) pred i avg. precision	p(i) top 20% Concentration Factor
animal_squirrel	5.7	0.889	0.0011	4.00
support_structure_equipment_electrical	83	0.868	0.0047	3.90
vegetation_trunk	47	0.851	0.0016	3.69
voltage_control_equipment_type	14	0.857	0.0012	3.69
third_party_balloon	15	0.813	0.0009	3.39
vegetation_branch	58	0.775	0.0009	2.77
vegetation_other	26	0.755	0.0006	2.62
animal_other	15	0.742	0.0009	2.53
third_party_vehicle	38	0.725	0.0009	2.41
animal_bird	31	0.703	0.0003	2.36
primary_conductor	139	0.702	0.0023	2.33
other_equipment_type	45	0.670	0.0005	2.32
support_structure_equipment_cause	28	0.664	0.0000	2.13
secondary_conductor	31	0.663	0.0014	2.05
third_party_other	15	0.636	0.0010	1.87
transformer_equipment_cause	9	0.541	0.0000	1.13
transformer_equipment_leaking	0	nan	nan	nan

While the current validation approach is effective for the time and the current model applications, developing a threshold could help establish a pathway for new composites that require more data gathering and to ensure existing composites are meeting minimum performance thresholds. PG&E has acknowledged that one challenge stemming from the composite model structure is that the approach has the potential of slicing data too thin in separating the limited outage and ignition data into distinct subsets.[5] Additionally, if PG&E is successful in mitigating growing risk, the already limited dataset of ignitions will continuously become sparser, even if this may be a longer-term problem. Given the number of subsets possible and being requested, and the relative lack of data to support those subsets, E3 recommends setting a standard predictive performance metric to move forward with subset and composite creation. Another approach to improving composite model quality that PG&E is exploring is to introduce interaction terms for specific sub models where only distinct outage types are likely to lead to ignitions. E3 supports this work to better formulate these composite models but recognizes that this approach may not be scalable.

Consequence Model

PG&E made some improvements to the consequence modeling in this version, but there are several areas for improvement. Overall, given the importance of this data in determining where and how to mitigate risk we think it would be prudent for the regulator to have more working knowledge of and oversight into

[5] Source: PG&E Composite model: Internal architecture discussion composite_model_concepts v2(1).pptx, Slide 13

the Technosylva model and other consequence modeling approaches, and potentially standardize the products being used by IOUs if deemed appropriate. This would be a great way to better align the IOU models in a critical area where the utilities have no particular internal expertise.

There is uniform reliance on Technosylva, a proprietary and non-transparent product, by IOUs but each seems to be leveraging a unique product from the company for use in their Wildfire Mitigation Plans. E3 recommends that given this heavy reliance on Technosylva for such a critical part of the State's wildfire mitigation, OEIS and CalFire should conduct an audit of the model to vet the input, assumptions, and outputs. This would also give OEIS the opportunity to understand the flaws, biases, and omissions in the Technosylva model and potentially support data creation or research to further this science for the benefit of the State. For example, currently the Technosylva modeling as used by PG&E over-indexes on grassland fires and calculates consequences for 8-hour long burn times. We know that canopy fires have been the most extreme historically and that fires can take longer than 8 hours to grow into destructive fires. Additionally, the Technosylva model does not currently include climate impacts or mitigation efforts such as suppression or egress potential in their modeling structure.

In v3 of the model, PG&E has moved from exclusively using consequence outputs from Technosylva and CalFire to using Technosylva, PG&E's FPI R-score (which is used to call PSPS events), and public satellite data from the Visible Infrared Imaging Radiometer Suite (VIIRS). This updated approach leverages real and observed fire behavior and consequence outcomes, which is an improvement over v2. However, while these outcomes are actually ranges, PG&E is using the mean consequence from each range in their risk modeling. The current structure of the consequence model uses VIIRS observed fires and Technosylva simulations to classify fires or simulations as either *destructive*,[6] or *potential conditions*,[7] or *not destructive potential conditions by ignition point*. The probability of a destructive or non-destructive fire for each ignition point is then determined to be the number of days within the sample window, 2014-2020, where conditions matched those defined for a destructive or non-destructive fire, over the total number of days in the timeframe. PG&E then manually calculated the cost of each historical VIIRS fire by assessing the number of acres and facilities burned, assigning $1M/structure and $1,175/acre.[8] The cost of a destructive fire was defined as the mean value for each category, destructive or non-destructive. The actual consequence value at each ignition point is then calculated to be:

$$\begin{aligned} &Consequence\ of\ Risk\ Event\ (CoRE) \\ &\quad = (Probability\ of\ destructive\ fire\ \times\ Mean\ cost\ of\ historical\ destructive\ fires) \\ &\quad + (Probability\ of\ nondestructive\ fire\ \times Mean\ cost\ of\ historical\ nondestructive\ fires) \end{aligned}$$

The use of the mean for prioritization may poorly characterize risks in areas with large ranges of consequence. The use of the mean cost to calculate total risk could overlook areas with potentially very high risk or prioritize them lower. Using the mean to calculate risk-spend-efficiency could also improperly overlook areas with high mitigation efficiency and promote smaller scale mitigations in areas that actually require more fundamental changes. The reverse is true if the mean is obviating a very low range. We

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[6] Destructive Fire: PG&E Fire Potential Index (FPI) Fire Danger Rating R>=4 <u>or</u> Technosylva Criteria: Flame Length >= 5 ft, Rate-of-Spread (ROS) >= 12 chains/hour

[7] Destructive Fire: PG&E Fire Potential Index (FPI) Fire Danger Rating R>=4 <u>or</u> Technosylva Criteria: Flame Length >= 5 ft, Rate-of-Spread (ROS) >= 12 chains per hour

[8] Where data on acres and facilities was not available, the cost was assumed to be zero

recognize the clarity a point estimate brings to the prioritization process but recommend exploring other more robust measures than the average expected value to replace the single point estimate which might improve the quality of information communicated to decision-makers and SMEs. These new metrics, which could be supplementary, could capture more of the long-tail effects that may impact decision-making. Specifically, if SMEs are made aware of the probability of destructive fires for a given location and the range of cost consequences, that may serve as an additional point in their decision-making process. In that case, they could identify mitigations that may better serve that location.

Additionally, while the use of consequence data on historical fires is a decent place to start and this valuable information should not be discarded, E3 recommends PG&E attempt to supplement this data with more specific cost estimates. These estimates should be developed alongside the regulator, but could be based on characteristics of the geography such as number of people in a given area, density of buildings, value of land (e.g. cropland). It is also important to consider equity in these calculations as well to ensure that the consequence model does not inappropriately overweight affluent neighborhoods only.

Finally, particularly over the timeframes that mitigation can be implemented, a look-back approach to consequence, using fire weather data from the 2014-2020 period, may create inaccuracies and bias in consequence estimates because climate, weather, and drought conditions are non-stationary. Best available science indicates an acceleration in fire weather conditions. We recommend that PG&E at least evaluate the possibility of using estimates of intensification of key fire weather variables that may increase consequences for the longer-term use cases of the model. We note that as PG&E attempts risk prioritization over longer planning time horizons, reliance on current and past conditions as inputs to the consequence model becomes less justifiable.

Risk Reduction for Mitigation Options

The current risk reduction calculation framework relies primarily on SMEs in dialog with the risk modeling team. SMEs decide which characteristics of an outage are useful to consider, determine a list of mitigation options, and determine how effective each of those mitigations is corresponding to the identified outage characteristics and location. This is not inherently a weakness. In this case the SME input is a basic requirement given that lack of data (e.g., limited deployment history with novel mitigation strategies and divergence between theoretical and achievable potential for mitigation measures in the real world) would otherwise make this modeling effort impossible. However, there is no standardization or documentation surrounding the SME process which is a shortcoming of the structure. To the extent possible, where SME feedback is being heavily relied upon for support in the model, there should be a standardized process and documentation to justify the SME’s stance, and which can be built upon as the model matures. This documentation would also help build an understanding of where there is a lack of data or SME understanding and, therefore, where the risk reduction framework should not be relied upon exclusively for decision making. Additionally, where there is a lack of understanding of root causes or poor model performance, those areas can be flagged as priorities to gather more data either through field testing or consultation with other experts. Currently, most of the priority mitigation programs or business units slated to be first users of v3 are only relying on subset effectiveness factors and not spatial effectiveness factors in their mitigation planning. A standardized process for data collection and SME input would flag this as an area for improvement.

Another area for increased documentation and institution of a data quality improvement strategy is in the outage characteristics used to establish effectiveness scores. SMEs are currently tasked with compiling the relevant outage characteristics most important to determining mitigation effectiveness. These characteristics, and justification for why they were chosen and why others were not prioritized, should be documented. The model currently takes a very long list of outage characteristics identified as important by SMEs and collapses the list into categories that match subset areas. These subset areas were defined based on existing data and currently PG&E simply doesn't have the data to build models to give predictions for the likelihood of each type of outage characteristic. Given this, PG&E should institute a process for tracking the characteristics identified by SMEs that are not currently collected after outages occur, especially to the extent those characteristics are 1) associated with high effectiveness scores, 2) recurring across mitigations, and 3) easy to collect.

Outside of SME input, some of the aspects of the model structure should also be examined and potentially renovated. Currently the model uses historical data to weight effectiveness of mitigations. This method assumes that future outages will resemble historical outages and in doing so biases effectiveness scores and mitigations towards the conditions of the past. PG&E should consider whether there are trends of outage types increasing or whether some outage types are expected to increase due to climate impacts. The effectiveness scores should then be weighted using those expected future states. The same principal also applies for spatial effectiveness scores. To the extent that spatial characteristics are expected to change in the future, spatial effectiveness scores should consider that change. The forecast of these expected changes would need to be consistent with the lifetime of the mitigation being considered, however, the model currently does not employ any temporal consideration.

Currently the model measures the risks and mitigation reductions relative to a typical wildfire season, assumes maximum potential impact for the mitigations, and users are expected to impose their own knowledge of limitations on implementation that would prevent addressing all assets and time decay of resulting benefits. The process through which SMEs impose their knowledge of mitigation effectiveness should be documented in general, but in particular to ensure that the default maximum potential is not overstating the effectiveness of mitigations. Regarding the lack of an embedded consideration of decay of resulting benefits, this structure seems to make sense in today's climate where we are reacting to overwhelming near-term risk, however, this is not a scalable approach.

E3 understands that there is substantial added complexity in incorporating a temporal component to the risk and consequence portions of the model, but recommends immediate consideration of time as a characteristic of mitigation measures. The exclusion of a temporal component makes it impossible to compare mitigations with differences in lifetimes and their relative effectiveness in different locations. System hardening, for example has a lasting mitigation effect spanning decades where tree trimming lasts only as long as it takes branches to grow back. It does not seem that mitigations are being compared or prioritized amongst mitigation programs (e.g. comparison of system hardening versus vegetation management) given the vast differences in magnitude and duration of mitigations, but instead mitigations are prioritized within a fixed budget for each program area. This step of adding time as dimension will help enable this comparison.

Another key weakness is the model's inability to consider ranges where necessary. SMEs are asked to put a fine point on effectiveness with limited historical experience and sometimes for novel mitigations. The ability to apply ranges to effectiveness and carry that through to the decision-making stage so it is clear to what degree there is uncertainty in the mitigation is important.

PG&E should also consider applying weighting or confidence factors to SME effectiveness scores. To the extent that ranges can be produced for overall effectiveness, that can be leveraged, but there are circumstances present in the model structure today that may be more well suited to confidence weightings. For example, SMEs provide mitigation effectiveness factors relative to outages, not all of which have the same potential to cause ignitions. The model multiplies effectiveness scores by an “ignition given outage” factor, which ensures some targeting towards ignitions based on the coarse bucketing of subset characteristics but does not prevent biasing towards mitigations to avoid outages and not necessarily ignitions. This could be solved by working with SMEs to focus on ignition-relevant mitigations or by creating an additional weighting or screening to deprioritize mitigations focused exclusively on outages. To do this, there would have to be an analysis of the suite of outage characteristics identified by SMEs, not just those captured by the subset classifications. SME-identified outage characteristics could be analyzed for their applicability to ignitions. Adding this step to explore a mitigation’s applicability to avoidance of ignitions will also support exploration of mitigations which fall outside of the current modeling framework. Mitigations such as undergrounding assets are difficult to model given the WDRM has not started to model underground assets and therefore has no subset data to support risk, consequence, or risk mitigation modeling.[9]

In the longer term, as the utilities implement more mitigation measures, it would be ideal to build up a structure that allows for more reliance on empirical data for measure effectiveness. We recommend that PG&E consider instituting a process to record the effectiveness of specific mitigations deployed and the regulators should consider enabling a process for SME input so IOUs can cross-collaborate and vet both model inputs and mitigation choices.

E3 also recommends that PG&E begin exploring ways to use the model, or new models focused on causal inference, to explicitly measure mitigation effectiveness. Our understanding is that currently there are covariates which correspond directly with mitigations. For example, system hardening replaces equipment which effectively reduces the covariate in the risk model of age to zero. However, the covariates in the model are not as independent (e.g., age is highly correlated with manufacturer which is not a covariate) and therefore using the covariates and the risk model in this way would not currently be analytically sound. E3 understands these current limitations and supports PG&E’s current focus on developing models that are predictive rather than causal but would urge PG&E to consider a more quantitatively robust approach to estimating the effectiveness of its mitigation measures and its overall plan. This could happen in the current predictive modeling framework through incorporation of better independence in covariates and alignment with mitigations, or by developing separate causal inference models to support mitigation planning.

[9] Note that undergrounding is being considered in a separate modeling process outside of the core WDRM model. The Asset Strategy team has created a metric called High Fire-Wildfire Feasibility Efficiency to prioritize and rank circuit segments for undergrounding. This strategy does not rank undergrounding as a mitigation strategy against other mitigations within the WDRM structure.

Structural Recommendations

Highlighted above were specific pros and cons about existing aspects of the v3 WDRM. We turn now to structural recommendations which apply to the entire risk modeling and mitigation planning process. PG&E is developing a modeling suite (see Figure 3) to meet a diversity of operational, financial, and planning questions. PG&E has proposed a pilot Probabilistic Risk Assessment or “PRA” model which would integrate all models into a single electric system view of wildfire risk.[10] E3 believes that it is very important to align the models into one system. This will, importantly, allow for comparison of risks and mitigations amongst the mitigation areas, which we do not believe is currently being accomplished.

This integrated modelling approach will also allow PG&E to start to explore important metrics such as the aggregate baseline risk and total risk mitigated. Establishing an aggregate baseline risk would give all stakeholders a better understanding of the magnitude of the problem, the degree to which we are making progress, and engender a productive conversation with the State and Federal Government and regulators about our communal risk appetite and long-term risk mitigation targets. Understanding these key concepts around wildfire risk would also allow for a more streamlined optimization in the model focused on meeting key mitigation targets developed in concert with OEIS, the State and other stakeholders. E3 believes this effort can be started today for each individual model in PG&E’s suite, calculating aggregate baseline risk and total risk for each modeling area or establishing a roadmap to do so, which would allow PG&E the ability to roll up their risk metrics across the entire company. If the regulator and the State gain a better understanding of total risk by jurisdiction (e.g. IOU and federal) and geography, the State can better target prudent investments into specific mitigations or regions. Currently PG&E is using the v3 model to prioritize mitigations within fixed budgets for each business unit or mitigation program area. The integrated approach should enable a cross comparison of mitigations to drive overall budget allocation and to target mitigations most effectively across the mitigation program areas (e.g. vegetation management vs system hardening).

Another key area for structural improvement to the model is temporal granularity. This was touched on in some specific sections above, but in the longer-term PG&E should develop a roadmap to include a temporal dimension into all key areas of their modeling. Mitigation measures all have defined lifetimes. Consequences are defined over periods of time as well. Strong scientific evidence suggests that wildfire consequence risk metrics driven by weather are unlikely to remain static over periods as long as a decade. Even the probability of ignition or ignition given an outage has a time dimension. If each of these variables had additional temporal granularity future versions of the model or PG&E’s more integrated approach should be able to provide reasonable estimates of expected wildfire damages under different portfolios of mitigation measures implemented over different time periods.

Finally, as PG&E grows its modelling capabilities it will become increasingly important to continue to develop and update its modelling Roadmap. Currently the v3 model is using a range of datasets representing different years of available data. The roadmap should have the expected cadence of data

[10] PG&E documentation states “PG&E is working to develop a reference model of the PRA in 2021 and potentially, depending on the effectiveness of the reference model, to use the PRA for planning in 2022”

updates to ensure the model is reflecting current conditions.[11] V3 has made progress in aligning data vintages and ensuring data is up to date; however, this process of data refresh is not standardized or documented. Additionally, PG&E should establish a data cleaning process that attempts to amend and forecast current conditions to better match average longer-term conditions. This is currently being done with burn scars within the model but could be applied to other areas as well. Where fires have occurred, they are less likely to occur in the immediate future over areas with burn scars that coincide with loss of fodder. This process of data cleaning should be considered for other key areas depending on the date of the data and the characteristics of each dataset. To the extent data cleaning is occurring, documentation of the process is vital.

3) Appendix 1: Technical Review

This technical review gives in depth overview of key v3 modelling components and provides recommendations for improvement. It is broken down into model structure, which covers structural aspects of the model, and suitability of data, which focuses on datasets used the model.

a) Model Structure

Composite & Aggregation Framework

This section will provide an overview of the composite modeling framework that PG&E has applied in the v3 WDRM model, followed by highlighting areas of improvement.

Overview

PG&E's v3 WDRM model uses a composite modeling framework that allows for the calculation of risk scores at a granular level for mitigations that pertain to specific business units. The v3 model is primarily trained on outages, given that there is more data available for outages compared to ignitions. The target set of outage events have been divided into categorical "subsets" that each have distinct causal pathways leading to failure.

In this composite model framework, a separate sub-model for probability of outage, P(O), has been trained for each subset. The output of a sub-model is P(O) for the given subset for a particular asset or "pixel" of geographical area in PG&E's service territory. P(O) is then fed into a single logistic regression model that calculates the probability of ignition given outage, P(I|O). The P(I|O) model is trained on the entire set of ignitions for all the subsets, with the subset category included as a categorical covariate.

[11] As a compliment to v3, PG&E's business units are using the Palantir Foundry data system which does support some automatic and regularly scheduled data packages and exports for things like asset data. Datasets for outage, ignition, and PSPS hazards and damages are currently in Foundry but not regularly exported.

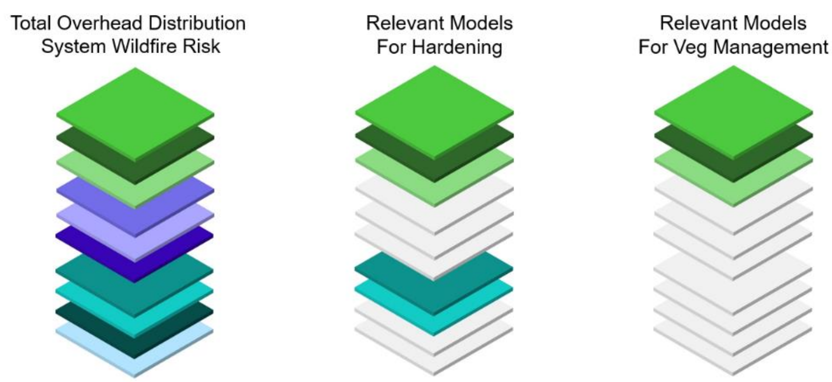
A “composite model” sums the probability of ignition across all relevant subsets pertaining to a particular business unit. The probability of ignition is multiplied by the consequence score to calculate a risk score. Risk scores can then be aggregated across assets and geographies for various work planning purposes (e.g. aggregated over a circuit segment to compare the risk across different segments).

Composite risk scores for a given business unit are meant to guide the prioritization of assets and geographies with high-risk reduction potential in work planning. Today, PG&E is focusing on four business units as the target users for the model:

- System Hardening
- Enhanced Vegetation Management
- Poles and Support Structure Replacement and Test & Treat
- Transformer Replacement

1. Although PG&E is initially targeting these four business units, they plan to expand to other business units in the future. They also plan to expand the list of subsets to include additional outage categories. Figure 6 illustrates the composite framework and how various groups of outage subsets can be composited together to calculate the risk scores pertaining to distinct business (e.g. System Hardening and Enhanced Vegetation Management).

Figure 6 Schematic of composite model framework including examples of different subset groupings relevant to specific business units and mitigation efforts.[12]



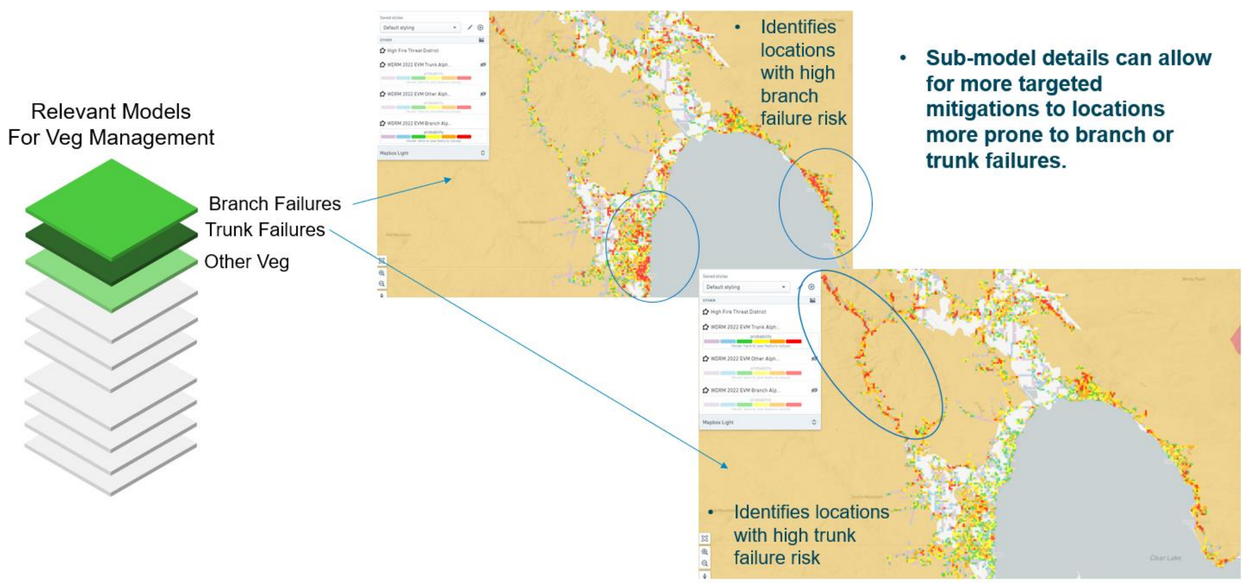
The composite framework also allows for comparison of risks from distinct causal pathways that may warrant different mitigation measures. For instance, the Enhanced Vegetation Management composite model has sub-models including outages from branch failures, outages from trunk failures, and other vegetation related outages. The causal pathways leading to a branch related outage compared to a trunk related outage are qualitatively different. For example, the wind and weather conditions that would lead to a branch breaking are different than the conditions that would lead to an entire trunk breaking. Different mitigation measures may also be better suited to reduce risk from these distinct outage subsets (indeed “branch work” and “tree removal” are already different vegetation management programs). Tree trimming may suffice to mitigate branch failures, where more extensive vegetation management might

[12] Source: Slide 8, WDRM v3 Features.pptx

be required to mitigate trunk failures. The composite framework allows for risks from these distinct outage categories to be broken out separately so that the most appropriate mitigations can be determined for each geographical region, as shown in Figure 7.

In an effort to tie mitigation measures directly to their relative risk reductions, PG&E has assigned effectiveness factors to each combination of mitigation measure and subset. The determination of effectiveness factors is largely a SME driven process rather than being directly tied to model inputs. To determine the risk reduction for a given mitigation effort, the effectiveness factors for various mitigation options are applied to the risk scores from each subset. Risk scores for an asset or geography can be compared before and after mitigations are applied to determine the risk reduction potential for each potential mitigation. Different types of mitigations can then be compared based on how much risk they can reduce.

Figure 7 Example of risk scores calculated from different vegetation-related outage subsets[13].



Areas for Improvement

The composite model structure offers flexibility in that each composite model is built up of sub-models pertaining to the subsets of outages that are relevant for a specific business unit. This flexibility broadens the potential for the model to be widely used in mitigation workplans across PG&E. However, the continually evolving nature of the model also leads to several challenges that PG&E will need to address, especially as PG&E expands the list of target business units and outage subsets.

1. The model is intended to be used to compare and prioritize mitigations. The composite structure provides a straightforward method to compare mitigation measures as they apply to a

[13] Source: PG&E Wildfire Risk Governance Committee presentation December, 15 2021 12.15.21 Wildfire Risk Governance Forum_v4.pptx, Slide 27

single business unit. However, given the differences in magnitudes of various mitigation measures (e.g. wholescale infrastructure replacement in system hardening vs individual transformer replacements), it is difficult to assess whether comparison of mitigation measures would be valid *across* composites. For example, it is difficult to compare the outcomes from trimming trees in EVM to completely replacing assets in system hardening mitigations. These different mitigation efforts have distinctly different timelines for mitigation enactment (workplan cycles) and lifetimes for remaining effective.

2. Careful consideration should be given to the validity of results from each sub-model based on the available data and validation metrics for the corresponding subset. PG&E has acknowledged that one challenge stemming from the composite model structure is slicing data too thin in separating the limited outage and ignition data into distinct subsets[14]. Since some types of outages are more common than others, the amount of data available is highly variable amongst subsets. E3 suggests that PG&E document a standard process for deciding whether a sub-model is valid for use in a composite, especially as new subsets are added. There should be clear thresholds for data availability and sub-model performance to ensure that a new sub-model is not overfit to a small sample of data.

3. In its current form, the P(I|O) model does not always improve the predictive power compared to using the P(O) model alone to predict ignitions. The P(I|O) model is trained globally across all subsets. However, the data on ignitions is even more limited than the outage data, and not all subsets are equally likely to lead to an ignition. For some subsets with very few ignitions, this results in the P(I|O) model overweighting local/environmental conditions in predicting ignitions. If there is no spark from the outage, then conditions like wind and fuel will not be as important in predicting whether there will be an ignition. However, the P(I|O) model may not capture this subset-specific quality given the sparsity of data. The validation metrics show that in these cases, the P(O) model is a better predictor of ignitions than the P(I|O) model[15]. E3 recommends that PG&E continue their efforts in evaluating how subset-specific interaction terms can improve the P(I|O) model performance on distinct subsets.

4. Clear and succinct documentation would improve the usefulness of PG&E's model. The documentation should allow the various model users to understand the model capabilities and limitations and should be updated to clearly describe which of the model components are mature for various use cases. It is important for potential model users to know whether the documents they are viewing are consistent with the model version they plan to use. Keeping up to date documentation that is synchronized with the model as it continues to evolve is a challenge that PG&E will need to address.

[14] Source: composite_model_concepts v2(1).pptx, Slide 13

[15] Source: https://ethreesf.sharepoint.com/:u:/s/PGERiskAssessment/EfZL2gZG5g9Fkf98VER1xs4BvlVgBqu-pEMfH3w8hWwiPA?e=jgsb5J (see "prediction performance" section of the notebook)

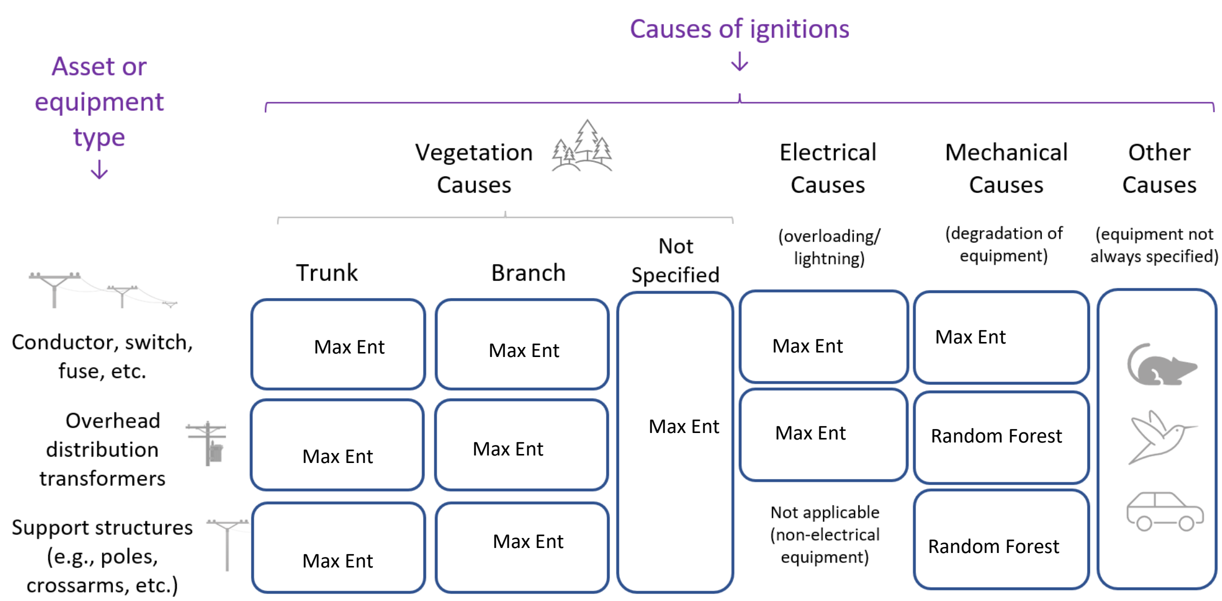
Algorithm Selection for Models

While PG&E's new compositing paradigm has the potential to be extremely useful, it introduces both the possibility and problem of selecting appropriate algorithms for each data subset. PG&E's WDRM framework trains the outage prediction in each subset data "silo" independently, while it trains the P(I|O) model globally with subset aware inputs. Because of these two different treatments, WDRM can choose heterogeneous algorithms in the outage prediction stage, while it can only select one algorithm for the P(I|O) model. This section explores the impact of the separate modeling choices made in outage prediction and P(I|O), while the gains and losses from this dichotomy are discussed in the previous section.

Outage models: Random Forest vs Maxent

For the outage prediction models, PG&E currently chooses a heterogenous structure and employs two distinct algorithms: random forest for support structure or transformer caused outage, and Max Ent for everything else, including vegetation caused outage on any equipment or conductor outage from any causes.

Figure 8 An example diagram showing one of the possible ways of dividing into subsets of outage event. Note that two subsets are using random forest, while the rest are Max Ent.[16]



PG&E has given a qualitative explanation for this assignment, explaining that as Max Ent hails from ecological modeling of annual events and is more suitable for modeling spatially sprawling and naturally occurring processes such as branches falling from trees. Random Forest, on the other hand, is described

[16] Source: Slide 16, PG&E V3 WILDFIRE DISTRIBUTION RISK MODEL (WDRM) October 5, 2021

by PG&E to be more suitable for handling spatially discrete processes such as equipment failure that are explained more from characteristics such as age or manufacturer type and less so for geography.

E3 acknowledge Max Ent's parsimonious nature allows it to comfortably handle spatially continuous yet sparse events such as an outage. The algorithm also includes implicit treatment for an imbalanced dataset.[17] However, there is no intrinsic barrier for the random forest approach or any other machine learning method to be applied to spatially continuous or imbalanced problems. For a spatially continuous problem, an entire group of models named *Convolutional Neural Networks* are dedicated to recognizing multi-dimensional patterns.[18] For data imbalance, it is true that models will suffer from attention issues that cause the patterns of non-outage events to obscure the more important outage events. Proper regularization can be applied successfully to prevent such skewed attention and curb overfitting in many cases. [19]

When it comes to choosing between different statistical methods in their ability to produce accurate predictions the most frequently used approach is through trial and error, thus letting the performance metric dictate the best source of data and modelling approach. PG&E indicated that the formal testing of model approaches other than Max Ent for spatial/pixel models will be done in Q1 2022. E3 welcomes this positive step in evidence-based algorithm selection and believes it has the potential to inform future model development.

In summary, E3 agrees that the current algorithm choices are directionally suitable for each subset but unfortunately lacks concrete evidence that they would outperform other algorithm choices. E3 encourages PG&E to develop the quantitative metrics based on trial and error of a variety of algorithms. E3 also proposes the PG&E consider the use and testing of a *convolutional neural network* approach described above as it is especially suited for continuous multi-dimensional pattern recognition.

Outage models: Direct Ignition Prediction vs P(I|O)

In v2 the approach PG&E used was to directly predict ignition probability with the covariates. In this cycle the approach is revised to predict outage probability first, and then predict the ignition probability given outages. The pros and cons of these two methods are thoroughly discussed in the body of this report. In essence: v2 relied on direct prediction of ignitions with a much more recent and small data set within high fire zone areas. In v3, PG&E incorporates a system wide much larger data set of all outages and ignitions and therefore must rely on an Indirect prediction approach.

Ultimately, as with many machine learning models, predictive performance determines the best approach. The data comparing the performance of training the models on ignitions or ignitions given outages shows that the models have similar performance across all the subsets.

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[17] For more evidence and explanation on this, please refer to PG&E's previous report filed with OEIS here: https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=51800&shareable=true

[18] Yamashita, Rikiya, et al. "Convolutional neural networks: an overview and application in radiology." Insights into imaging 9.4 (2018): 611-629.

[19] Sun, Yanmin, Andrew KC Wong, and Mohamed S. Kamel. "Classification of imbalanced data: A review." International journal of pattern recognition and artificial intelligence 23.04 (2009): 687-719.

With this conclusion in mind, it is E3's opinion that the approaches are equally predictive. The v3 model however has a much broader set of applications in both ranking mitigation measures and comparing their implementation across much broader geographic areas.

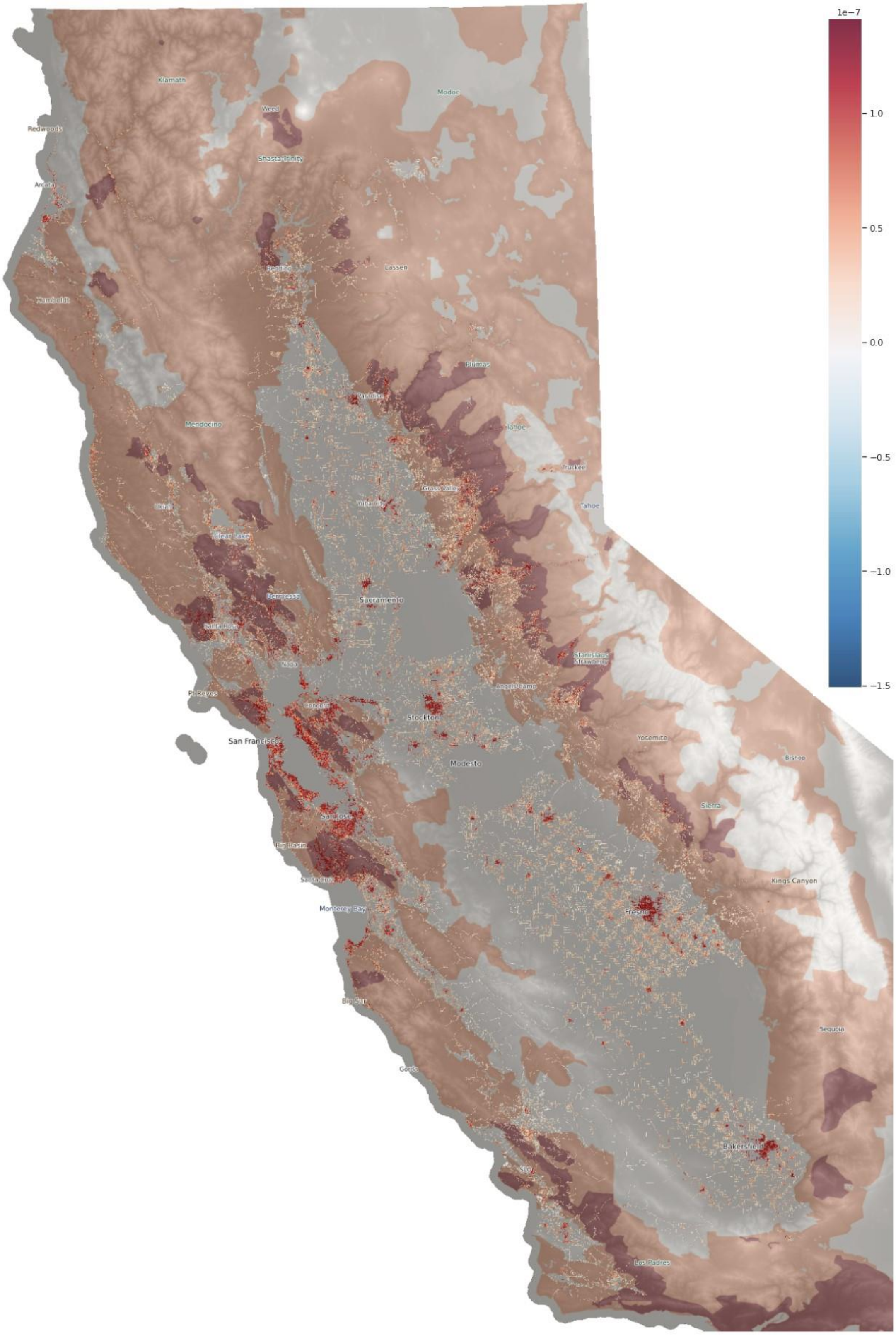
P(I|O): Logit Regression for all models

As a reminder, PG&E trained P(I|O) model globally rather than in each subset as the outage models, therefore only one single choice of algorithm for the P(I|O) model is needed. PG&E stated that they have consistently been fitting variations of Random Forests, XGBoosted trees, and Logistic regression. They found the tree-based methods tend to over fit the data as showcased in the gap between training and testing set metrics. PG&E believes that this is consistent with the literature on their performance when using data with less training data. E3 also agrees with PG&E that that the logistic regression approach is often more parsimonious in parameters and less prone to overfitting.

Modeling Burnable Areas (HFRAs)

As part of the v3 modeling effort, PG&E expanded the wildfire risk model to areas beyond HFTD Tiers 2 and 3 (which were the areas modeled in v2). First, the entire model was expanded to include all 'burnable' areas – including all HFRAs and Tier 1 areas. In 'non-burnable' areas, the probability of outages and ignitions are available, but the consequence of ignitions within these areas is not. Overall, E3 believes this is a step in the right direction. The intensity and frequency of wildfires are predicted to increase with climate change, and it is prudent to include areas currently classified as non-HFTD areas in the modeling framework. This way, there is a higher chance that areas that are currently classified as non-HFTD, but are prone to becoming high-risk for wildfires, are identified ahead of time. Once these areas are identified, a deeper dive can be conducted into these areas to understand the covariates contributing to the high probability of ignition information can be passed on to the mitigation team to identify appropriate preventive actions. Wildfire incidence/spread in areas might change because the underlying environmental conditions or the factors causing wildfires to have changed.

Figure 9 PG&E Risk of Ignition Overlayed with HFTD areas



All available data is used to train the models; so this includes within and outside HFRAs. However, PG&E mentioned that, anecdotally, model fits seem better within the HFRA than outside. This issue is expected to be addressed and researched in 2022 and another reason why we have recommended that PG&E also consider developing either accuracy thresholds and ranges for predicted risk.

Risk Reduction for Mitigation Options

The end goal of the WDRM modeling effort is to equip PG&E with the quantitative foundation to make informed decisions about investing in and prioritizing among mitigation options. Geographic areas (pixels) have varying levels of wildfire risks and within each pixel, there are multiple contributing factors to this risk. The composite and aggregation framework that PG&E has adopted in v3 allows it to a.) identify pixels with the highest wildfire risk, and b.) within those pixels, identify the biggest drivers of risk. For example, a high-risk wildfire location A might have transformers as the biggest driver of risk, while vegetation might be the primary driver in another high-risk location B.

To effectively prioritize and allocate budget across its business units, PG&E must first recognize that there are two categories of mitigation options depending on how long the benefits they deliver last (short-term and long-term). As the name suggests, short-term options are those that mitigate wildfire risk, but only in the short-term. An example of this would be vegetation management or PSPS events. Trimming trees and branches might reduce risk today, but these actions need to be performed again in say 3 years, when trees grow back and increase wildfire risk again. On the other hand, a corresponding long-term option is undergrounding circuit sections which, while being relatively more expensive upfront avoids the need for recurring future actions and costs.

To accurately decide if a short-term or a long-term option is the best use of PG&E budget, PG&E needs to be able to compare short-term benefit of an option to the long-term benefit of another. To calculate long-term benefit though, there needs to be a way to calculate the benefits for each future year, which in turn requires a way to calculate the need for each year (the need here is the wildfire risk that requires to be mitigated). Unfortunately, within the current scope of the v3 modeling framework, there is no way to do this. As of yet, there is no “time-dimension” to either calculate the predicted need each year or to estimate the multi-year risk mitigation effectiveness of options.

The lack of time-dimension in the modeling framework also means that PG&E has no way to prioritize risk-mitigation efforts by considering implementation time. Some areas might have a high risk of ignition, but may take longer to implement because for example, the vegetation is denser (for EVM) or the terrain is challenging (for System Hardening).[20] The time dimension is also important for exploring the impact on overall program cost-effectiveness of interim short-term measures that must be employed while longer-term measures are deployed.

[20] PG&E does recognize this implementation-time disconnect between their EVM efforts and modeling in their WMP. One of the important changes PG&E made to address this is that they have changed their internal target achievement metrics to require *“80 percent of the work completed over the next three years be performed on circuit segments that are among the top 20 percent highest risk”.* While E3 believes that this is a step in the right direction, prioritization still is done in an ad-hoc manner. Moreover, there is no indication that efforts to bridge this gap have been taken for non-EVM options.

Finally, many of the improvements taken in the v3 modelling framework reflect the reality that the wildfire consequence risk is not static over multi-year time scales. This changing consequence risk – the impacts of sustained drought and climate change - also needs to be incorporated into a longer-term modelling effort targeting cost-effective mitigation. Taken together, the inability to consider implementation time, the inability to compare mitigation options across years, and the inability to consider secular variation in wildfire consequence due to climate change means the now-and-expensive may be prioritized over those that deliver long-term benefits.

b) Suitability of Data

Model data

PG&E has expanded the dataset used in training the WDRM v3 model compared to the v2 model[21]. The updated dataset draws from LiDAR data for HFTDs and satellite data for non-HFTDs to determine key vegetation-related covariates such as tree height, distance from lines, and (via separate data sets) species. PG&E has stated that using the LiDAR data for tree height – one of the covariates that is most closely correlated with P(I) – has led to significant improvements in predictive performance[22]. The v3 dataset was also updated to include events from 2020-2021. E3 commends these additions to the dataset which have led to clear improvements in model performance and capture a more complete and up-to-date picture of recent outage and ignition events.

PSPS damages have also been included in the outage data. After the post-PSPS inspections, damages that would likely have led to outages were recorded and included in the outage dataset used to train the WDRM v3 model. These were considered as outages in the training data—E3 supports this decision to include this information in the dataset. PSPS events are generally called during days with some of the worst weather conditions for wildfire risk. By including the outages that would likely have occurred in the absence of the PSPS shutdowns, the new WDRM dataset is both conservative and more complete in capturing important outage events with regard to wildfire risk. This is particularly important given that ultimately one desired outcome of undertaking wildfire mitigation efforts is to have fewer PSPS shutdowns. The addition of the PSPS data is also a step in the right direction of aligning the PSPS and WDRM efforts. The probability of ignition given outage modeling is also marginalized using weather conditions for each historical day, weighted by the count of outages for each day to produce planning horizon appropriate aggregate values. This has the effect of emphasizing the conditions that are present when the most outages occur – another reinforcement of the observation that events are concentrated in time/conditions.

[21] Source: PG&E Wildfire Risk Modeling Workshop Report OEIS workshop supplemental response PG&E.docx

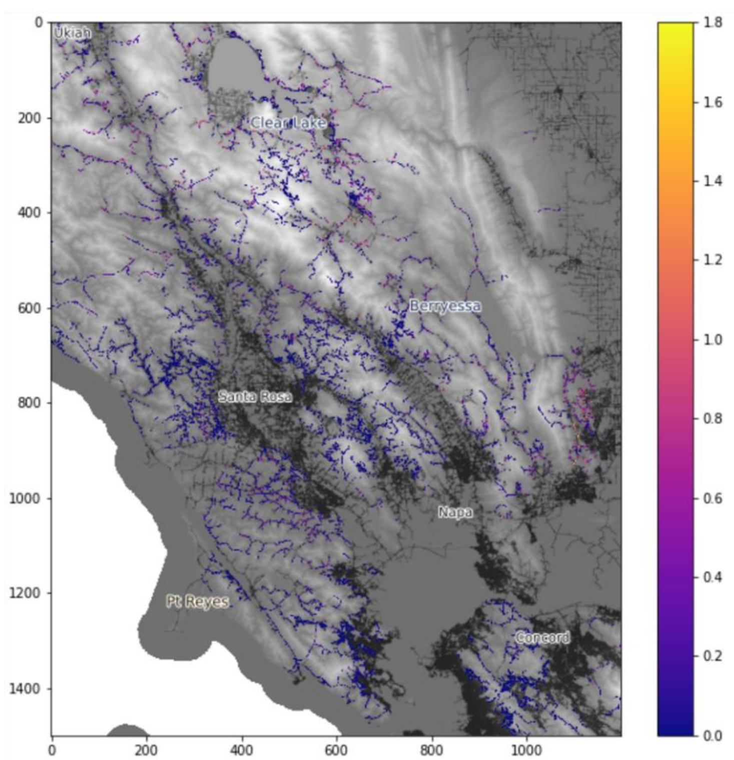
[22] Source: PG&E Wildfire Governance Steering Committee Meeting presentation Appendix December 15, 2021. 12.15.21 Wildfire Risk Governance Forum_v4_APX.pptx Slide 22

Risk Reduction for Mitigation Options

To measure the effectiveness of a mitigation measure in reducing wildfire risk, PG&E used numerical values called Effectiveness Factors. These factors depend not only on the type of mitigation measure, but also the type of outage. An outage here can be as granular as being characterized by parameters such as *'cause', 'supplemental cause', 'equipment involved', 'equipment condition'*. For example, one type of outage can be characterized by *'Animal', 'Bird found', 'Capacitor', 'Blown'* being values of the aforementioned parameters respectively. PG&E System Hardening SMEs provided the modeling team with over 5000 types of such combinations, while vegetation management provided only a handful of expected efficacy values, and pole replacements provided efficacy values conditional on pole types and other site conditions. Additionally, depending on the type of the outage in consideration, effectiveness of mitigation factors might vary. For example, '*Vegetation Management'* can have say a 90% effectiveness factor if the Cause type was '*Vegetation*' (and supplemental cause was '*Branch fell on line*'), but only a 20% effectiveness if the Cause is '*Animal'/'Bird'* flying into the capacitor (these are hypothetical numbers).

In v3 modeling, to better align and simplify the mitigation effectiveness scores calculation, PG&E aggregated them to the subset level using a weighted average of historical record of outages. The mitigation type's potential risk reduction was calculated by first multiplying probabilities of ignition at the subset level with the effectiveness factor of the subset and then by multiplying this with the consequence value for that subset. This method can be extended to calculate risk reduction for each mitigation measure in each pixel. An example of this potential risk reduction by System Hardening in the North Bay region is shown in Figure 10.

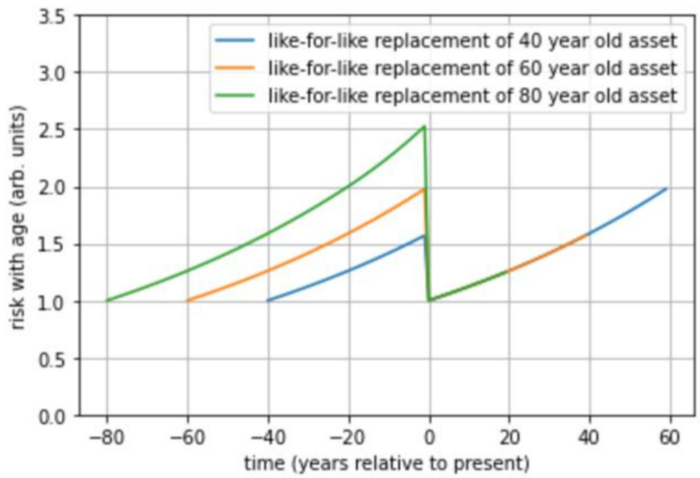
Figure 10 Example of Potential Risk Reduction by System Hardening in the North Bay region



Except for transformers, Effectiveness Factors were SME inputs. PG&E mentioned that data is incomplete or insufficient to confidently calculate effectiveness factors for all mitigation measures. PG&E also mentioned that for some mitigations (e.g., pole replacement) the modeling team is working on empirical modeling methods to support/inform SME provided/endorsed numbers.

Transformer mitigation effectiveness: For transformers, a like-for-like replacement reduces risk that equals the risk of the current transfer minus the risk of a new transformer. Unlike other mitigation options that use an effectiveness factor, for transformers, a replacement's reduction of risk depends on the initial risk of the transformer being replaced. See Figure 11.

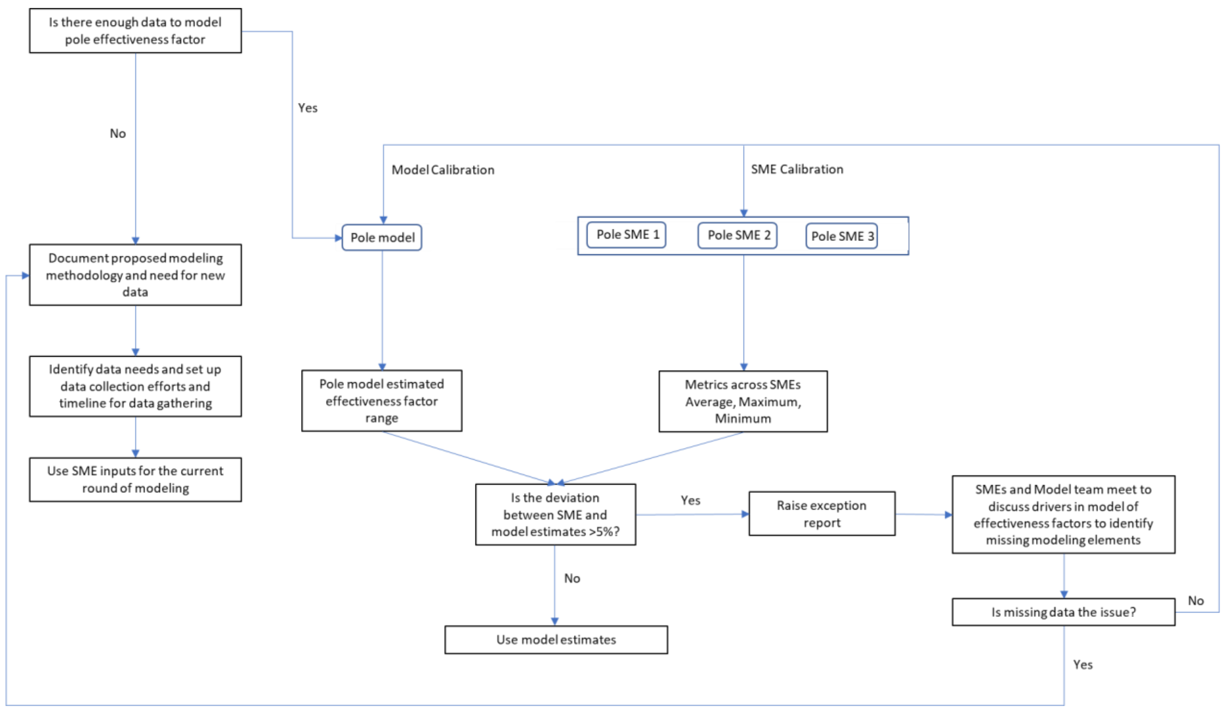
Figure 11 Example of Model Use for Mitigation Effectiveness Calculations: Transformer Replacement



Validating SME input:

It is clear from the risk reduction framework that Effectiveness Factors are a crucial link between probability of ignition modeling and mitigation actions. These values will decide to a large extent the relative benefits from various mitigation measures for the same type of outage. Given their outsized importance, E3 recommends PG&E institute processes that bring transparency to the methodology. Specifically, PG&E should document and make available the method through which SME input was sought (the questions asked, and the answers sought), the number of SMEs giving input per effectiveness factor, and any efforts to benchmark the SME inputs to inferred effectiveness from the modeling or from ex-post observations. E3 understands that such an effort is already underway for pole replacement and recommends instituting such processes for all mitigation measures. [See WMP statement about 80/20].

Figure 12 Pole Replacement Mitigation Effectiveness Process



Inclusion of non-HFTD Data

While the previous v2 model only covered geographical areas categorized as HFTD Tiers 2 & 3, the v3 model covers all burnable areas within PG&E territory. This extension allows the probability of outage and ignition to be calculated in "non-burnable" locations. However, the consequence scores from the Technosylva fire simulations were only calculated for "burnable" areas (HFTDs and HFRAs). E3 recognizes the merit in extending the model beyond the limited HFTD alone, especially given that effects of climate change may expand the geographical regions that see high risks from wildfires. However, E3 recommends that PG&E investigate whether the inclusion of data from non-burnable areas is diluting the calculated probability of ignition, as P(I|O) will not be the same given an outage in a burnable area compared to a non-burnable area. PG&E has shown that the categorization of burnable or non-burnable areas is the most important covariate included in the P(I|O) model for conductors[23]. In fact, PG&E has anecdotally mentioned that model fits are better within HFRA zones than outside. Hence, separate models for burnable and non-burnable areas may be more appropriate because of the qualitative differences in these regions. While the inclusion of the new data may not change the risk or mitigation rankings if applied across all modeling uniformly, they may impact the magnitude of risk and therefore impact downstream metrics such as risk spend efficiency.

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[23] Source: PG&E Wildfire Governance Steering Committee Meeting presentation Appendix December 15, 2021 [12.15.21 Wildfire Risk Governance Forum_v4_APX.pptx](), Slide 32

4) Appendix 2: Agency and State Context Examples & Recommendations

a) Summary

The reality of the wildfire challenge in California is that it is an existential threat to the health and welfare of the state's residents that is not limited to investor-owned utility ignitions. Risk from wildfires is only expected to increase given impacts from climate change and the costs to mitigate this risk are vast and growing. And the State has a concern to ensure that funds invested in the wildfire risk reduction maximize reduction of consequences from all causes of wildfire, not just utility caused wildfire. The tradeoffs between increasing risk and financial harm need to be balanced by many entities beyond just the IOUs. While PG&E and other IOUs have begun a process of continuous improvement of their wildfire risk modelling, there is an absence of such effort on the part of entities that control other material sources of wildfire risk. We do not know what the level of acceptable wildfire risk is for the State of California, how utility mitigation actions contribute toward achieving that level of risk, and the degree to which other known, cost-effective strategies might reduce overall and utility risk, reduce ratepayer cost and reduce ratepayer plus taxpayer cost. Given the magnitude of expenditures on the part of many parties, there is a need for California State government leadership and guidance to effectively coordinate and optimize all wildfire mitigation activities in the State for the most prudent plan going forward.

PG&Es approach to risk modelling has allowed it to construct estimates of baseline risk; estimate how operational changes, system maintenance and near-term capital investments can be targeted to reduce risk; and create a structure in which to target these investments to maximize return for ratepayers. However, as the company looks to extend the model and its useful applications, we see the need for a new, longer-term planning focused model that is better integrated with other strategies being taken by federal, State and local governments as well as by private citizens in order to effectively evaluate prudent longer term (4 to 10-year) planning and investment cycles.

Figure 13 below shows some of the key links needed within an efficient State-wide fire mitigation process. It begins with coordinated federal, State and utility planning to determine the longer-term budgets needed for mitigation measures necessary to maintain acceptable levels of risk. These budgets and indicative plans could then be used to develop more specific investment in risk mitigation measures using models similar to what PG&E has developed as v3. Ultimately the remaining unmitigated risk could be managed through shorter term operations like PSPS or prepositioning of CalFire assets. Finally, the process repeats itself over time to be recalibrated and respond to the rapidly changing dynamics of this quickly evolving challenge.

Figure 13 Need for New Long Term Planning Model to Determine Overall Need for and Appropriate Mix and Timing of Wildfire Risk Mitigation Measures

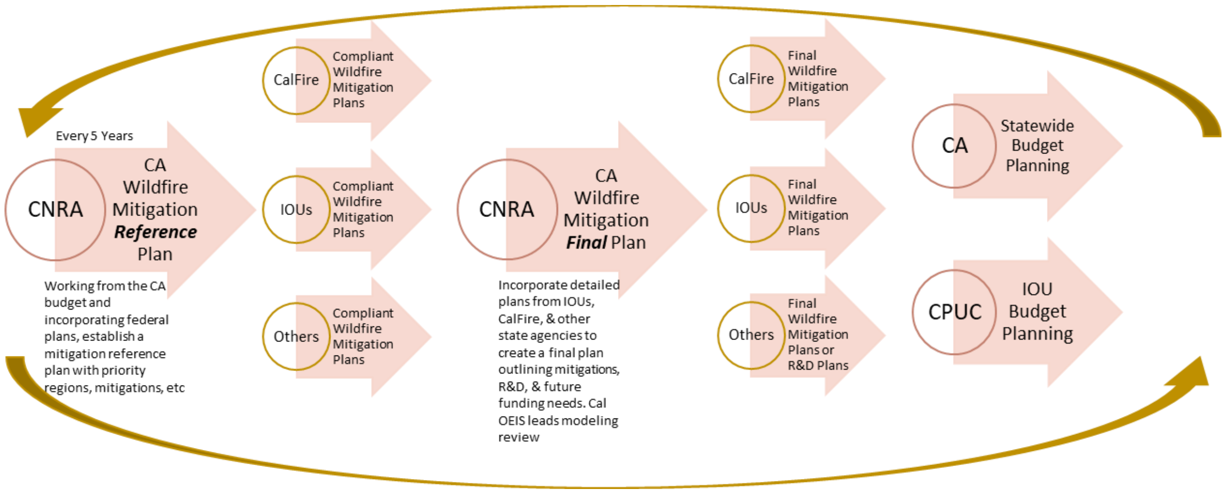
As a first step to instituting a Statewide wildfire mitigation plan which regulated entities can look to for guidance, the State should consider establishing goals and objectives via a statewide, all hands, all lands California Wildfire Mitigation Plan process. These goals would need to define quantitative risk tolerance levels and risk mitigation goals and would necessitate establishing a baseline level of risk. Similar to California's greenhouse gas (GHG) emissions standards, where we have instituted a standard for performance, "40% emissions reductions by 2030…", measured off a baseline risk level, "…off of 1990 emissions levels." Given the complexity of wildfire risk in the State, determining this baseline will require research into wildfire risk we have experienced and expect to experience as well as determination of reasonable mitigation targets into the future by key actors such as CalFire, federal land managers, private landowners, and electric utilities. This analysis could incorporate recent work the CEC and other agencies have funded to understand the impacts from climate change on wildfire risk. It could also incorporate existing collaborations between CalFire and Technosylva.

Compiling a portfolio of wildfire mitigation plans, all supporting and aligning with the State's plan, will ensure the State is prudent in taxpayer and ratepayer investments to achieve maximum mitigation. This approach will allow mitigations to be compared across jurisdictions and/or allow mitigations to synergistically build on one another. Costly State or federal forest-wide debris removal may be forestalled by targeted vegetation management by the IOUs. Or, alternatively, costly grid hardening may be avoided through State-led controlled burns. This ability to optimize across all of the solutions will drive the most effective mitigation plans for all wildfires but could also support overall budget allocation.

The model is currently being leveraged for granular IOU work prioritization and mitigation planning, but E3 believes that future or derivative versions of this model could be repurposed and developed to inform long-term budgets for all wildfire mitigation activity in the State (inclusive of federal, taxpayer, and ratepayer funded mitigations) and for each mitigation area, and to develop estimates of total risk and test risk mitigation portfolios.

One example of a broader modelling process analogous to the one E3 recommends for wildfire risk is the CPUC IRP process. During the IRP process the State agency determines a Reference System Plan using E3's capacity expansion model RESOLVE, then each load serving entity (LSE) leverages that Statewide model and reruns it with granular inputs to determine their relative contribution and align with their respective portion of the State goals. The LSE plans are then aggregated up and compliance with the CPUC Reference System Plan is validated before LSE plans are confirmed and LSEs are cleared to make investments. The structure of the Wildfire Mitigation Planning process could mimic this approach where the State conducts an overall model run to determine baseline risk, mitigation planning, and rough budgets (Figure 14 CA Wildfire Mitigation ***Reference*** Plan) then IOUs and other actors such as CalFire could run similar models incorporating the specifics of their roles, jurisdictions and plans. Following this, the State or OEIS, would reconcile the plans and allocate budgets accordingly (see CA Wildfire Mitigation ***Final*** Plan). This structure would instill certainty and transparency in the process and clearly delineate jurisdictions and responsibilities amongst all actors to tackle this existential threat. It would also help to ensure coordination between different types of risk mitigation investment and so increase cost-effectiveness of the entirety of California wildfire mitigation.

Figure 14 Example of State-lead Holistic Wildfire Mitigation Planning



This structure will also allow for State-level design on critical aspects of the model that are driving large investments in the State. Deciding on one model structure to drive the State level planning and all sub-models will allow for alignment of objective functions within the model. As stated in the WDRM Model Evaluation section of this report, E3 believes that PG&E should reassess their own model objectives to better maximize ratepayer well-being. Ultimately, it would be best if the State determined how the model was designed to optimize for competing goals such as safety, affordability, equity, and reliability.

b) Background and Justification for Statewide Process

At present, within its service territory, PG&E and its ratepayers are by far the largest investors in wildfire mitigation. While Statewide non-IOU totals cannot be disaggregated into IOU service territories, 2021 IOU spending in WMPs was $8.4B while Statewide wildfire risk mitigation funded through tax and Greenhouse Gas Reduction Fund (GGRF) contributions totaled $1.5B. In addition, the federal government invested tens of millions of dollars in reducing hazardous fuel conditions within the State on federal lands and private actors contributed as well. These non-IOU investments are currently not at a scale where, in a single year, they will materially alter PG&E's assessment of risk and risk spend efficiency or alter its targeting to maximize both. However, over the timescale of a decade, if maintained at their present scale, they do have the potential to materially alter the effectiveness and targeting of PG&E investments. This may be consequential for PG&Es own analysis because of the growing role of longer-term mitigation actions in its approach to risk mitigation.

We identify as a major gap in PG&E planning, the lack of a comprehensive, Statewide, all-mitigation risk process. While PG&E cannot be the actor to undertake such a planning process, many of the tools and models it is utilizing and developing could be leveraged by such a process to more optimally allocate effort across all potential risk reduction measures. The efficacy and value of PG&E long term planning using the WDRM is significantly limited by the lack of such a Statewide all-wildfire risk all-wildfire mitigation process.

The activities undertaken by non-utility actors within California target different aspects of the wildfire risk reduction problem than those undertaken by PG&E. PG&E's WMP implementation aims to reduce the consequences of utility caused wildfire by avoiding high consequence utility ignitions. By contrast, private, local, State and federal investment in wildfire risk mitigation primarily targets fuels reduction and maintenance of fire breaks as a means of reducing consequence of all wildfires by modifying fire behavior once ignitions occur. These are conceptually distinct approaches to reducing hazard and risk that certainly compliment and may substitute for each other.

There is no reason to assume, and good reason to doubt, that levels of acceptable residual risk that drive spending on fire risk reduction in the utility space are the same, or even close to the same, as those that determine spending levels in taxpayer and GGRF funded wildfire mitigation. This is because we currently have no process comparable to the utility Risk Assessment Mitigation Phase (RAMP) and WMP processes for evaluating wildfire related risks at the State level, even as experience from recent fire seasons indicates that even excluding incremental risk from electric utilities, these risks are very large. In short, we do not know quantitatively what the level of acceptable wildfire risk is for the State of California, how utility mitigation actions contribute toward achieving that level of risk, and the degree to which other known, cost-effective strategies might reduce overall and utility risk, reduce ratepayer cost and reduce ratepayer plus taxpayer cost.

The State has an active process to develop, update and implement a comprehensive plan to reduce overall risks from wildfire. Governor Newsom created the Wildfire and Forest Resilience Task Force (Task Force), an interagency effort to develop a comprehensive strategy to address the problem of catastrophic wildfire in California. The Natural Resources Agency negotiated an MOU with federal land managers in 2020 in which each side agreed to achieve 500,000 acres per year of fuel reduction treatments by the mid-2020s. In January 2021, the Task Force issued its conclusions in the California Wildfire and Forest Resilience Action Plan (Action Plan). In late 2022, the Task Force issued California's Strategic Plan for Expanding the Use of Beneficial Fire (Beneficial Fire Plan). The Task Force maintains an active dashboard where progress on initiatives identified in the Action Plan can be reviewed. While these planning efforts are critical for making progress on removing barriers to action, they do not include any attempt to quantify risk similar to RAMP and WMP planning processes in the utility sphere.

Simultaneously, the federal land management agencies have been working to address risks to California from wildfire on federal lands and recently released a nationwide strategy, Confronting the Wildfire Crisis: a strategy for protecting communities and improving resilience in America's forests, that has major implications for fuels management on California forests over the next decade. In particular, it is the first risk-based identification by the USFS of areas that, because of their characteristics and locations relative to communities, will be prioritized for fuels treatments. The USFS has also identified the first "firesheds" where it intends to comprehensively address hazardous fuels management backlogs via a campaign of thinning and prescribed fire.

Unfortunately, these efforts are not currently coordinated using risk metrics with the extensive planning and investment occurring within IOUs targeting utility-line ignition prevention. Given the regressive nature of electricity rates relative to taxation, the pressure on electricity rates, and rising concerns regarding lack of affordability of utility bills for many customers, in the long-run, much stronger coordination with other State and federal efforts is essential to minimize cost while maximizing wildfire risk reduction.

E3 believes that in order for IOUs to effectively plan on timescales beyond the current General Rate Case, the California Natural Resources Agency (CNRA), in collaboration with and leveraging the risk modelling already being conducted by the IOUs, needs to conduct a quantitative, scenario-based modelling process on a regular cycle that is integrated and coordinated with the WMP process. Given that WMPs are now submitted to and evaluated by the OEIS, an office within CNRA, and given the increasing comprehensiveness of Task Force activities and planning and given long-term capital planning being undertaken by PG&E with respect to undergrounding high-risk system components, the time to initiate such a process is now.

Such a Statewide Wildfire Mitigation Planning process would need to achieve the following outcomes:

- Establish a baseline and forecast of key metrics for wildfire risk for the State as a whole and by geographic location;
- Agree on reasonable levels of unmitigated planned risk for the State to assume and manage via fire suppression;
- Develop risk spend efficiency estimates for a variety of wildfire risk mitigation actions with geographic specificity;
- Agree on a reasonable budget for utility and non-utility actions to keep State within planned risk boundaries given the cost and risk-spend efficiency of mitigation alternatives.
- Accurately track and integrate into planning, the longer-term costs of a changing climate and its impact on key drivers of risk;
- Develop a model capable of linking together different combinations of mitigation measures and their joint impact over time;
- Ensure that the regulatory and oversight process is as transparent and inclusive of all key stakeholders as possible.

Such a process would be a significant expansion of CNRA and or Task Force responsibilities but would also create clear metrics for the State against which to evaluate progress on wildfire. The Action Plan, Beneficial Fire Plan, and the FY21-22 budget and FY22-23 proposed budget represent an unprecedented investment of effort and resources towards wildfire risk reduction in California. These funds will also be supplemented by additional federal resources from the Bipartisan Infrastructure Framework. But the State lacks a metric for success – a measure beyond activities conducted and money spent. These efforts are measured largely by inputs – dollars spent and acres treated, rather than outputs – reduced risk to the state of wildfire. Given the large and growing impacts as well as spending on wildfire mitigation, ultimately, voters deserve to know how our efforts stack up against our best attempts to measure risk.

A California Wildfire Mitigation Plan process would also serve to create a clear Statewide budgeting process for wildfire risk mitigation efforts. It would capture all costs from the perspective of State taxpayers and utility ratepayers. These costs include the costs of damages including service interruptions, economic disruption, structure loss, death, and smoke related morbidity and mortality. They also include the costs of mitigation measures including utility ignition prevention, hazardous fuels treatments, community-level fuel breaks, and home hardening. Federal costs, including the costs of fuels mitigation as well as disaster related financial transfers should also be included in this overall financial estimate. In the long run, local, state, and federal wildfire suppression costs should also be included.

By combining rigorous, scientific estimates of baseline risk, residual risk, and the benefits of mitigation measures with comprehensive budgeting, a California Wildfire Mitigation Planning Process would allow for comparison of alternative expenditures in a geographically targeted way. It would allow for transparent comparisons between different types of spending, and of revenue sources, for wildfire mitigation. And all relevant stakeholders would have an opportunity to provide feedback on both the modelling approach, the inputs and the outputs.

A California Wildfire Mitigation Plan process could function on a longer timescale than the utility specific Wildfire Mitigation Plans. Given the scope and timescale of many mitigation activities, CNRA could implement a new planning cycle once every 3 to 5 years. This process would begin by preparation by CNRA of a Wildfire Reference Scenario. This scenario would describe, in quantitative and geographically specific terms, what CNRA believes is possible given current State budget resources. After publication of this reference scenario, actors such as CalFire, IOUs, federal agencies, and private actors seeking grant funds, could propose actions consistent with the reference scenario over the planning horizon. The CNRA would then incorporate these proposed actions via modelling, into a final California Wildfire Mitigation Plan. Key actors would then develop subsidiary Wildfire Mitigation Plans reflecting their contributions to accomplishment of the C-WMP. These nested plans would then provide key inputs for budget needs over the planning cycle, both in General Rate Cases for IOUs and from State and federal resources for other actors.

We emphasize that this is just one hypothetical approach to a Statewide planning effort. But we have attempted to identify key characteristics and outcomes that such a process would possess and produce. Without a process like this, it is difficult, if not impossible, to evaluate IOU plans beyond 1 to 2 years, where assumptions of “no change” outside of the electricity system in both baseline risk and mitigation measures appear reasonable. It is our judgment that assuming no change in either baseline risk or mitigation investment is not credible beyond this timeframe, which leaves utilities unable to plan over the timeframes that are necessary to make key strategic decisions (for example comparing undergrounding versus covered conductor in different geographies).

If the need for a coordinated Long Term Planning process and model seems abstract and difficult to achieve, the Statewide Integrated Resource Planning (IRP) process that is run by the CPUC provides a recent and fairly relevant example. Prior to the CPUC developing this Statewide process to determine the need for new resources, each utility was left to develop its own compliant plans and the lack of coordination led to very slow implementation of both policy and reliability goals. The CPUC now is tasked with developing Statewide plans that comply with all operating and reliability standards and legislation. Load serving entities procure or build resources to meet the specific needs identified in the IRP.

The IRP process, along with matching analogous steps for a Wildfire Risk Mitigation process are shown in Table 2below. The first step in the IRP process assures that the energy system is sufficient to meet all operating and reliability standards. The standards themselves are determined from cost and risk tradeoffs under a variety of difference scenarios. This would be equivalent to setting an acceptable Wildfire risk level for the State through analysis of different scenarios that would test drivers and feedback loops reflective of our best climate models and different levels and combinations of mitigation measures. The standard could be defined as any number or combination of Wildfire performance metrics including expected damages, number of ignitions or number of expected large fires and could also differ by geographic region.

In our hypothetical California Wildfire Mitigation Plan process, the long-term planning models are then used to test the effectiveness of various mitigation measures followed by combinations of measures to develop and approve the best portfolio for the State. These results are then used by all actors within the state to plan longer-term mitigation actions consistent with the overall C-WMP. These actions might be incorporated into separate WMPs for key actions that would need to show consistency with the overall state plan. Utility mitigation measures should then be shared and coordinated with other State and federal entities to assure that the collective plan is consistent with acceptable mitigation cost and residual risk including expected power interruptions. The package of combined federal, State and utility plans could then be brought back to the agency overseeing the process for approval authorization.

Table 2 IRP Analog for Coordinated Wildfire Planning

Step	Electric Integrated Resource Planning	Wildfire Planning
1. Set risk standard	Reliability standard (e.g. 1 day in 10 years loss of load) determined (informed by value of lost load)	Set acceptable level of risk
2. Run probabilistic risk models	Use loss of load probability models to understand nature of risk and benefits of various investment options (resource ELCCs)	Run risk models to understand relative benefits of various mitigation activities
3. Optimize the system	Least-cost capacity expansion optimization	Optimize risk mitigation benefits against costs (incl. investment + wildfire damages + shutoff damages)
4. Guide sub-system planning	Filing requirements for load serving entities (LSE) plans based on system optimal plan	Share optimal state plan with federal gov't, state gov't, CPUC/utilities
5. Optimize sub-system	LSE plan development	Federal/state/utility planners optimize investments within budget constraints, informed by system view
6. Aggregate sub-systems back to system	LSE plan aggregation, check system against reliability standard, cost optimal view	Combine federal/state/utility plans and check they meet the risk standard at near-optimal cost
7. Confirm new investments	Regulator decision approving LSE plans and related investments	Finalize federal/state/utility investments and operating strategies w/ relevant regulatory approval (CPUC)
8. Make investments + operate the system	LSEs procure new reliability resources + CAISO operates the grid	Agencies make investments and implement approved operational strategies

The 2020 and 2021 wildfire seasons in California have made abundantly clear that catastrophic wildfire cannot be addressed simply by utility wildfire risk mitigation. The State is responding in comprehensive fashion via Task Force activities such as the Action Plan, the Beneficial Fire Plan and their implementation. But addressing a crisis of this scale can benefit from leveraging the process developed to manage utility risk mitigation. This is especially true with respect to the sophisticated modelling and risk management approaches that OEIS has pushed the utilities to develop and that CalFire now uses for operational planning. Moreover, for the IOUs to avoid inefficient use of ratepayer funds, a transparent, rigorous, and comprehensive process for the entire State to reduce wildfire risks is needed. By developing a California Wildfire Risk Mitigation Plan on a periodic basis, the State can make sure that all wildfire mitigation funds are spent in a coordinated and maximally effective manner. That will keep Californians safer and preserve precious State and ratepayer resources for investment towards other objectives.