NREL
Transforming ENERGY

Impact of Wildfires on Solar Generation, Reserves and Energy Prices

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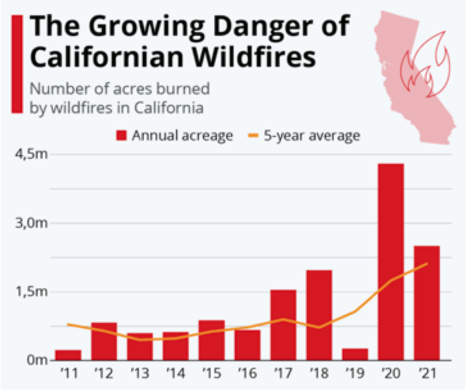
Photo by Dennis Schroeder, NREL 55200

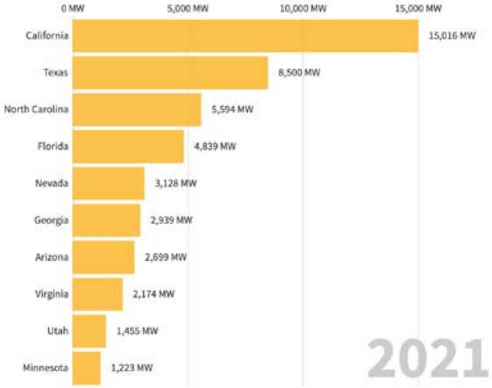
Agenda

Background

- The threat of ***wildfires*** is on the rise in both frequency and intensity across the US, particularly in western states.
- With the bulk grid shifting towards a greater reliance on ***solar generation***, wildfires can introduce significant variability and uncertainty to the energy availability.
- To facilitate decision makings in reserve procurement, system planning and reliability investment, it is critical to understand how wildfires impact the electricity market both historically and in the future.



Source: Cal Fire



Source: American Clean Power Association's annual market report of 2021

*Just in the recent five years from 2017 to 2021, **288,819 wildfires** have occurred across the U.S., burning over **40 million acres** and causing **billions of economic loss**.*

Source: National centers for environmental information, annual wildfire report

Project Overview

Objective: To provide a screening-level analysis to quantify the impact of wildfires in CAISO from the perspectives of solar generation, operating reserve and electricity prices:

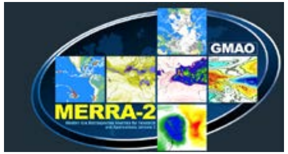
- Wildfire-caused changes in ***solar irradiance***.
- Damages to the transmission lines, substations and power plants are out of the scope.

- **Wildfire data:**

National Interagency Fire Center

USGS science for a changing world — U.S. Geological survey

- **Aerosol optical depth (AOD):**



- **Solar Radiance:**

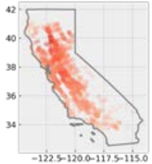
NREL NSRDB Data Viewer

Data collection and integration

Solar irradiance profiles at ***three different wildfire levels***:

No Wildfire

2020 Wildfire



Enhanced Wildfire

Wildfire scenarios development

Historical wildfire-market impact analysis using real-world data

California ISO | OASIS

Projected wildfire-market impact analysis based on simulated data

PLEXOS BY ENERGY EXEMPLAR

WECC/CAISO model

Wildfire-market impact analysis

Datasets

Historical wildfire agency data (direct measures)

Data type	Data source	Locational precision	Temporal precision	Magnitude measure/unit
Wildfire records	Fire agencies: CDF, DOD, LRA, USF, NPS, BLM, CCO	Latitude and longitude of the fire perimeter centroid	Start date and end date	Burn area (Acres)

Historical meteorological data (indirect measures)

Data type	Data source	Locational precision	Temporal precision	Magnitude measure/unit
Clear-sky GHI	NSRDB	2 km x 2 km grid	15-min	(W/m2)

Historical market data

Data type	Data source	Locational precision	Temporal precision	Magnitude measure/unit
Real-time PV generation	CAISO OASIS	System-level	5-min	MW
Real-time operating reserve		System-level	5-min	MW
Day-ahead reserve requirement		Zone-level	1-hour	MW
Energy locational marginal price (LMP)		Node-level	1-hour (DA) 5-min (RT)	$/MW

✓ **Wildfire-PV generation impact:**
- System-level
- Monthly resolution

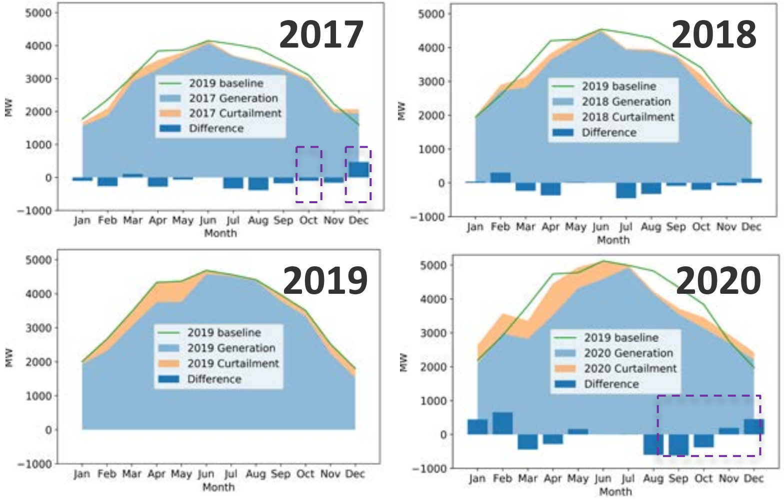
✓ **Wildfire-reserve impact:**
- System-level
- Monthly resolution

✓ **Wildfire-price impact:**
- Both system-level and zone-level
- Both monthly resolution and daily resolution

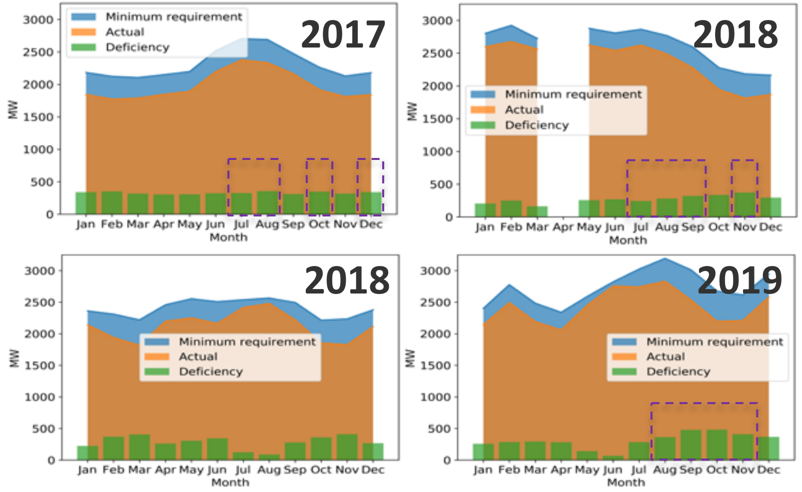
Historical Wildfire-PV Generation and Wildfire-Reserve Impacts

- ❑ Months with greater wildfires impacts are with relatively **higher solar generation reductions** (compared to a 2019 baseline).
- ❑ Months with greater wildfire impacts are with relatively **higher reserve requirement** and **higher reserve deficiency**.

- *2019 is selected as the baseline given its lowest wildfire record.*
- *Purple dashed lines frame the months with burning areas greater than 0.2 million acres in each year.*

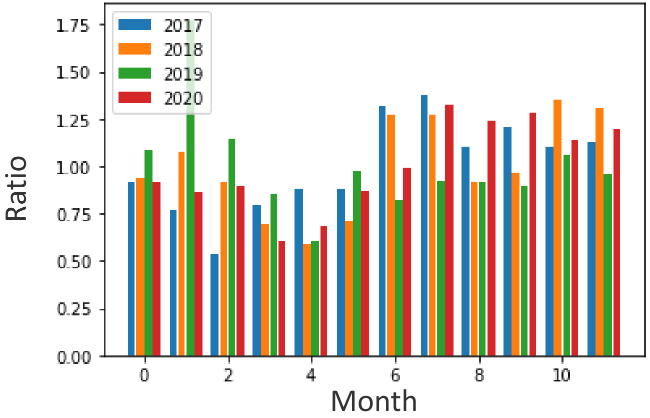


Monthly solar generation profiles



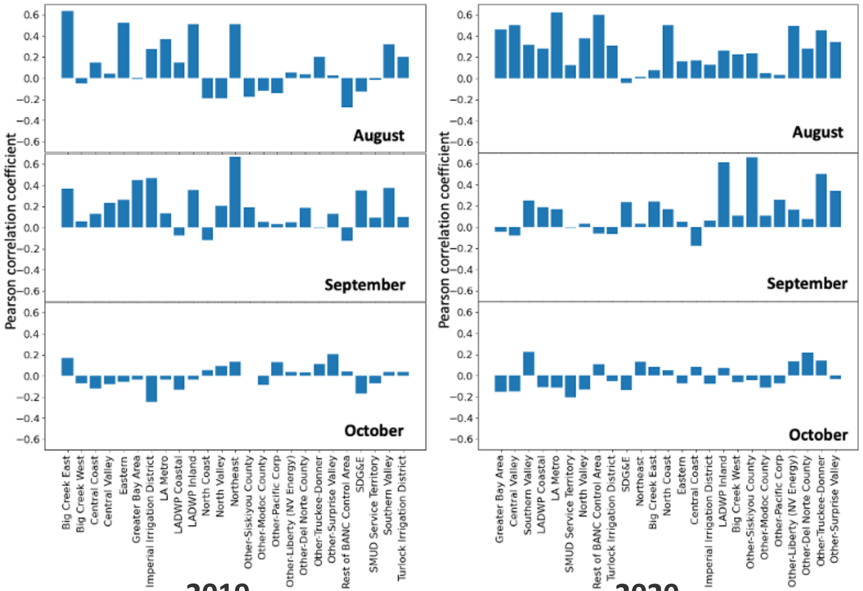
Monthly operating reserve profiles

Historical Wildfire-Price Impact



Ratios between monthly averaged market prices and yearly averaged market prices

- ❑ 11 out of 12 months with burning area above 0.2 million acres contribute to **greater-than-average market prices**.
- ❑ **More significant positive correlations** between $clearsky\_GHI_{zone}^{difference}$ and market prices are observed in 2020.

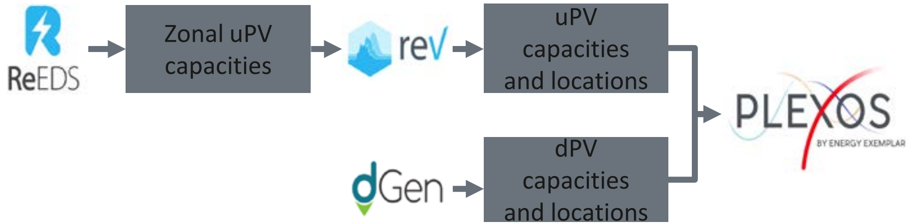


2019 **2020**

Zone-level Pearson correlations between $clearsky_{GHI_{zone}^{difference}}$ and energy prices

$$(clearsky_{GHI_{zone}^{difference}} = clearsky\_GHI_{zone}^{nowildfire} - clearsky\_GHI_{zone}^{2020wildfire})$$

PLEXOS Model development



Tools used to generate the PV metadata

Two infrastructure years

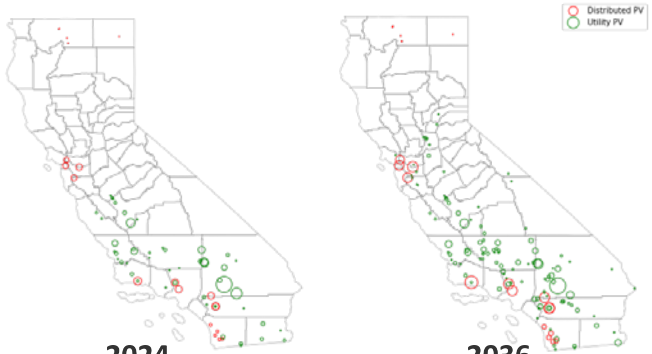
Infrastructure year	Generator cost and performance assumption	Renewable energy resource supply curves	Distributed generation assumptions	Solar penetration levels
2024	2019 ATB Mid-Case[1]	2019 Standard Scenarios Mid-Case[2]	dGen Mid-Cost RE adoption[3]	32%
2036	2019 ATB Low for PV and Wind[1]		dGen Low- Cost RE adoption[3]	36%

[1] Cole, Wesley J., et al. *2019 standard scenarios report: a US electric sector outlook*. No. NREL/PR-6A20-75798. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2020.

[2] Vimmerstedt, Laura J., et al. *2019 annual technology baseline*. No. NREL/PR-6A20-74273. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2019.

[3] Sigrin, Benjamin, et al. *Distributed generation market demand model (dGen): Documentation*. No. NREL/TP-6A20-65231. National Renewable Energy Lab.(NREL), Golden, CO (United States), 2016.

- WECC PLEXOS models for two infrastructure years: 2024 and 2036, are developed using NREL developed tools (**ReEDS**, **reV** and **dGen**).
- PV generation profiles under three wildfire scenarios are created using NREL's renewable generation simulator, **System Advisor Model (SAM)**.
- Load profiles are based on 2020 WECC Anchor Dataset (ADS) and load growth factors provided in EIA Annual Energy Outlook 2020.



2024 **2036**

PV capacity distributions

Reserve Requirement

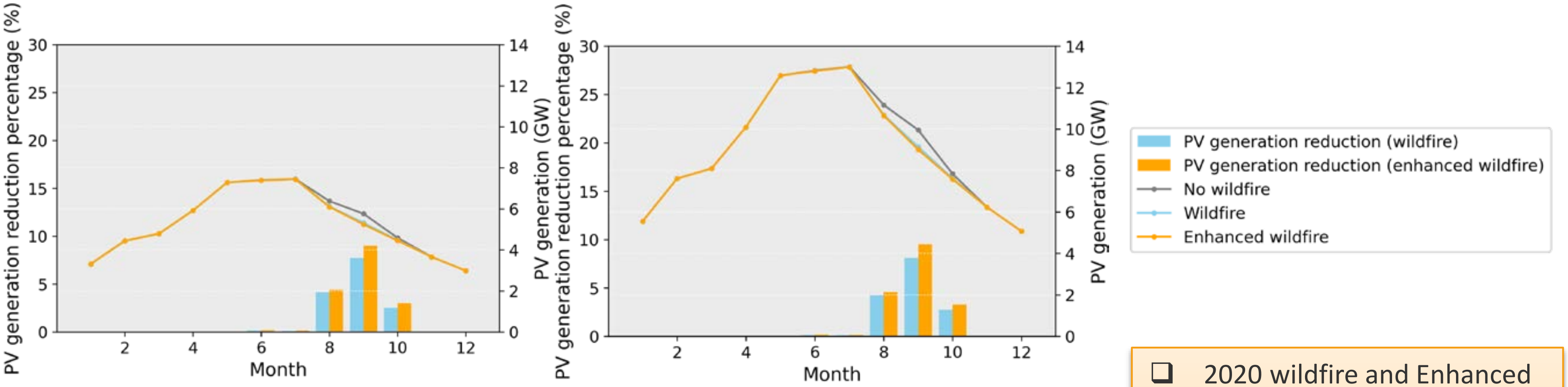
- Regional-level reserve requirements are defined to cover the uncertainties in wind and solar generations[1] based on their sub-hourly variabilities.
- The uncertainties are estimated based on 30-minute ahead forecasts and confidence intervals that covered 95% of the forecast errors.
- Persistence forecast and SPI (Solar Power Index)-based persistence forecast are applied for winds and PVs, respectively.

$$RR_{total} = \sqrt{(1\% \cdot Load)^2 + (RR_{wind})^2 + (RR_{PV})^2}$$

RR_{total}: Regional-level system reserve requirement
$Load$: Regional-level loads
RR_{wind}: Regional-level wind reserve requirement
RR_{PV}: Regional –level solar reserve requirement

[1] Ibanez, E.; Brinkman, G.; Hummon, M.; Lew, D. (2013). “Solar Reserve Methodology for Renewable Energy Integration Studies Based on Sub-hourly Variability Analysis: Preprint.” Prepared for the 2nd Annual International Workshop on Integration of Solar Power into Power Systems on November 12–13 in Lisbon, Portugal. NREL/CP-5500-56169. Golden, CO: National Renewable Energy Laboratory, 8 pp.

Projected Wildfire-PV generation impact



2024 **2036**

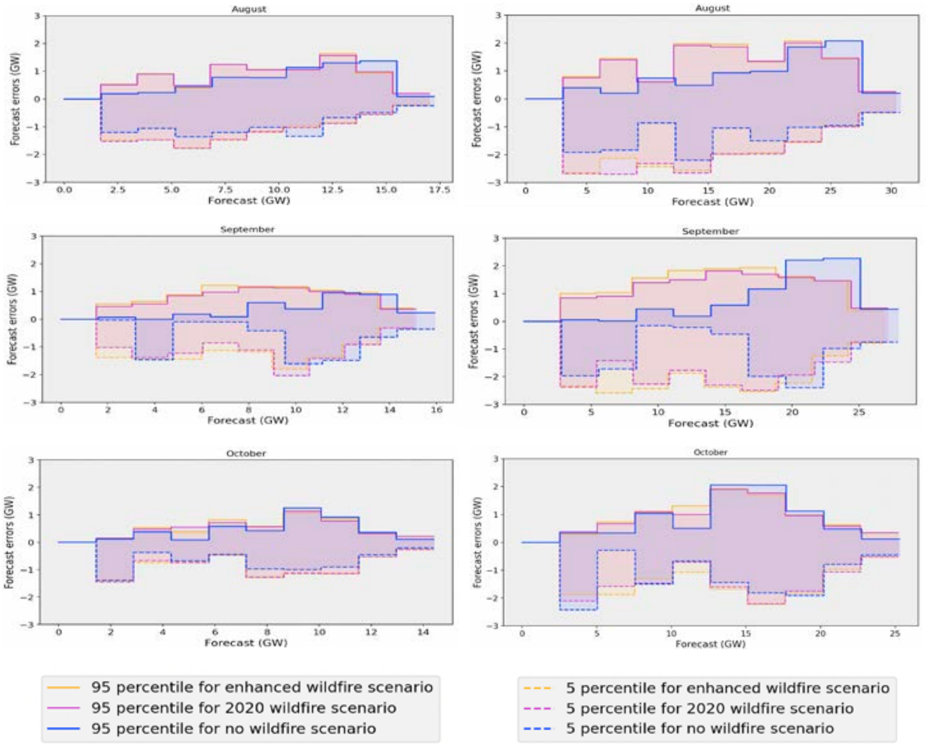
Monthly PV generations and reductions

2024	Jun	Jul	Aug	Sep	Oct
Wildfire	10.8 MW	7.8 MW	263.2 MW	443.9 MW	115.1 MW
Enhanced Wildfire	12.2 MW	10.3 MW	280.1 MW	519.9 MW	136.8 MW

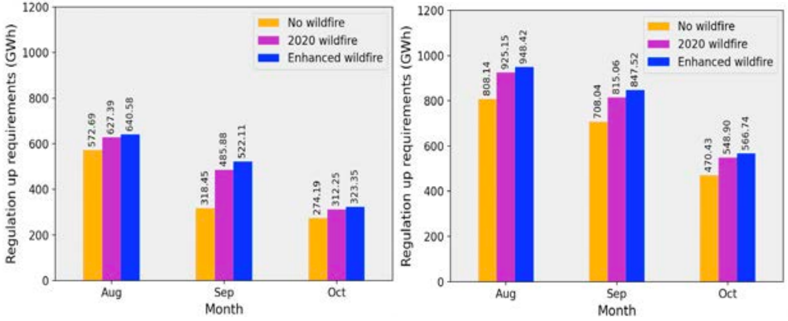
2036	Jun	Jul	Aug	Sep	Oct
Wildfire	18.6 MW	12.6 MW	477.9 MW	809.1 MW	216.9 MW
Enhanced Wildfire	21.4 MW	17.0 MW	510.7 MW	947.7 MW	257.5 MW

- ❑ 2020 wildfire and Enhanced wildfire could result in up to 8% and 10% reduction of monthly solar generation, respectively.
- ❑ Similar reductions of monthly solar generations are observed in 2024 and 2036.

Projected Wildfire-Reserve Impact



2024 **2036**



2024 **2036**

Monthly system reserve requirements

- Higher PV forecast uncertainties, especially for periods with higher PV forecast values.
- 2020 wildfire and enhanced wildfire increase the monthly reserve requirements by up to 53% and 64%.

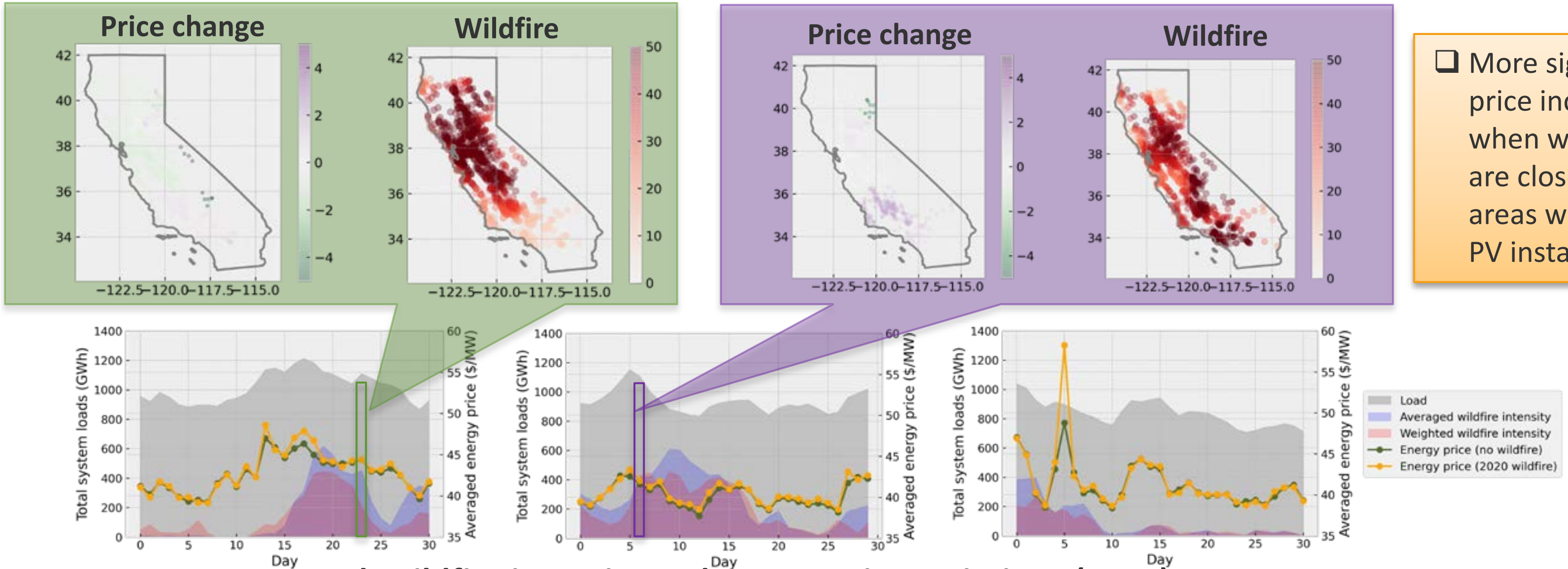
Projected Wildfire-Price Impact

2024	No Wildfire	2020 Wildfire	Enhanced Wildfire
Mean	39.27 $/MW	39.57 $/MW	39.62 $/MW
Standard deviation	17.20 $/MW	20.57 $/MW	22.15 $/MW
P[price > $100/MW]	0.16%	0.19%	0.20%

2036	No Wildfire	2020 Wildfire	Enhanced Wildfire
Mean	72.83 $/MW	75.80 $/MW	76.17 $/MW
Standard deviation	256.07 $/MW	263.50 $/MW	264.94 $/MW
P[price > $100/MW]	5.59%	5.82%	5.82%

- Wildfires could result in:
  - Higher averaged prices
  - Higher price volatility
  - More price spikes
- More significant impact on prices when PV penetration increases.

Impact of Wildfire Locations



- ❑ More significant price increase when wildfires are closer to areas with dense PV installations.

Load, wildfire intensity and energy price variations (2024)

❖ Two clear-sky-GHI-based indexes are introduced to quantify the wildfire intensity

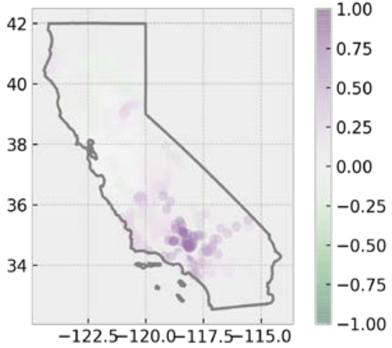
- $Averaged\ GHI\ differences = \frac{\sum_{n \in N}(clearsky\_GHI_n^{nowildfire} - clearsky\_GHI_n^{2020wildfire})}{|N|}$
- $Weighted\ GHI\ differences = \frac{\sum_{n \in N}(clearsky\_GHI_n^{nowildfire} - clearsky\_GHI_n^{2020wildfire}) \cdot C_n}{\sum_{n \in N} C_n}$

Wildfire-Price Correlations

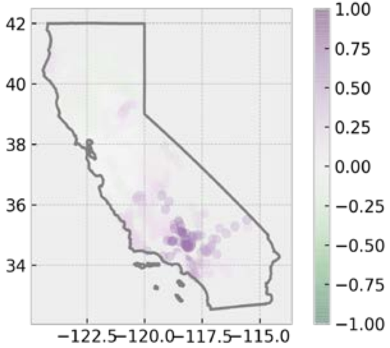
R^2	Weighted wildfire intensity	Averaged wildfire intensity
2024 (2020 Wildfire)	0.20	0.16
2024 (Enhanced Wildfire)	0.18	0.15
2036 (2020 Wildfire)	0.40	0.35
2036 (Enhanced Wildfire)	0.46	0.39

System-level correlation

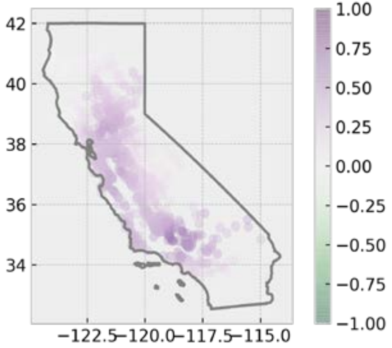
- ❑ Stronger correlations between the wildfire and price observed in the year (2036) with higher PV penetration and when weighted wildfire intensity index is applied.
- ❑ More widespread influence of wildfires on prices when PV penetration increases.



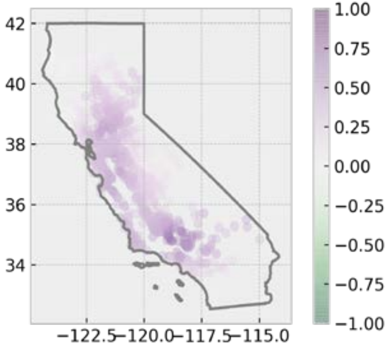
2024
(2020 wildfire)



2024
(Enhanced wildfire)



2036
(2020 wildfire)



2036
(Enhanced wildfire)

Node-level correlation

Conclusions and future work

Conclusions:

- ❑ Compared with $Averaged\ GHI\ differences$, $Weighted\ GHI\ differences$ could serve as a better indicator for measuring the system-level wildfire impact on market prices.
- ❑ Nodes with greater wildfire-price impact are nodes with greater PV installation capacity in general, instead of nodes closer to the wildfire centroid.
- ❑ With the growing PV installation trend, it is expected the wildfire impacts on market prices to be more severe and widespread.

Future work:

- ❑ Extend the production cost model to enable day-ahead (DA) - real-time (RT) simulation
- ❑ Study how different designs of operating reserve requirements could help reduce the RT risks (e.g., price spikes, reserve shortage) introduced by wildfires.
- ❑ Incorporate more realistic wind, thermal outage, and hydro profiles governed by the same underlying weather condition.

Thank you

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