Wildfire Risk Mitigation for Electric Power Systems

Alyssa Kody
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Electrical and Computer Engineering Department
North Carolina State University

FREEDM Research Symposium
April 2, 2024

On the Grid

California Wildfires

Caused by Power Lines

Acres Burned

- = 0 - 4,500 acres
- = 4,500 - 20,000 acres
- = 20,000 - 97,000 acres
- = 153,336 acres
- = 963,309 acres
- = California Transmission System

Total Fires: 429

PCS: NAD 1983 California (Teale) Albers (Meters)
GCS: NAD 1983
DATA SOURCE
Department of Forestry and Fire Protection(CAL FIRE)
Note: Data spans 1959 - 2021
SCALE: 1:5,796,789
Designed by Helen Asimina Tosteson

Top 20 Most Destructive California Wildfires

	FIRE NAME *(CAUSE)*	DATE	COUNTY	ACRES	*STRUCTURES*	DEATHS
1	**CAMP** *(Powerlines)*	November 2018	Butte	153,336	**18,804**	85
2	**TUBBS** *(Electrical)*	October 2017	Napa & Sonoma	36,807	**5,636**	22
3	**TUNNEL - Oakland Hills** *(Rekindle)*	October 1991	Alameda	1,600	**2,900**	25
4	**CEDAR** *(Human Related)*	October 2003	San Diego	273,246	**2,820**	15
5	**NORTH COMPLEX** *(Lightning)*	August, 2020	Butte, Plumas, & Yuba	318,935	**2,352**	15
6	**VALLEY** *(Electrical)*	September 2015	Lake, Napa & Sonoma	76,067	**1,958**	4
7	**WITCH** *(Powerlines)*	October 2007	San Diego	197,990	**1,650**	2
8	**WOOLSEY** *(Electrical)*	November 2018	Ventura	96,949	**1,643**	3
9	**CARR** *(Human Related)*	July 2018	Shasta County, Trinity	229,651	**1,614**	8
10	**GLASS** *(Undetermined)*	September 2020	Napa & Sonoma	67,484	**1,520**	0
11	**LNU LIGHTNING COMPLEX** *(Lightning/Arson)*	August 2020	Napa, Solano, Sonoma, Yolo, Lake, & Colusa	363,220	**1,491**	6
12	**CZU LIGHTNING COMPLEX** *(Lightning)*	August 2020	Santa Cruz, San Mateo	86,509	**1,490**	1
13	**NUNS** *(Powerline)*	October 2017	Sonoma	44,573	**1,355**	3
14	**DIXIE** *(Under Investigation)**	July 2021	Butte, Plumas, Lassen, & Tehama	963,309	**1,311**	1
15	**THOMAS** *(Powerline)*	December 2017	Ventura & Santa Barbara	281,893	**1,063**	2
16	**CALDOR** *(Human Related)*	September 2021	Alpine, Amador, & El Dorado	221,835	**1,005**	1
17	**OLD** *(Human Related)*	October 2003	San Bernardino	91,281	**1,003**	6
18	**BUTTE** *(Powerlines)*	September 2015	Amador & Calaveras	70,868	**965**	2
19	**JONES** *(Undetermined)*	October 1999	Shasta	26,200	**954**	1
20	**AUGUST COMPLEX** *(Lightning)*	August 2020	Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, & Colusa	1,032,648	**935**	1

California Department of Forestry and Fire Protection (CAL FIRE).

August 2023
Maui, Hawaii Fires

8/13/23 Lahaina, Hawaii, AP

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- 101 fatalities, $5.5 billion in damages

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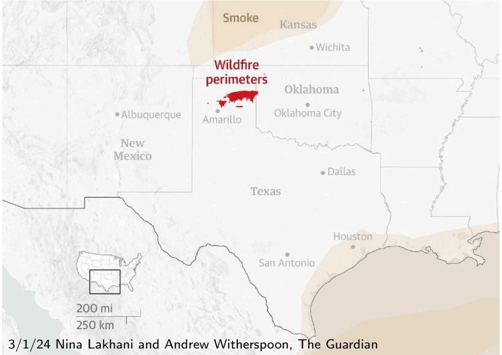
February 2024
Smokehouse Creek Fire



3/1/24 Nina Lakhani and Andrew Witherspoon, The Guardian

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- Largest wildfire in Texas history (1.2 mil. acres)

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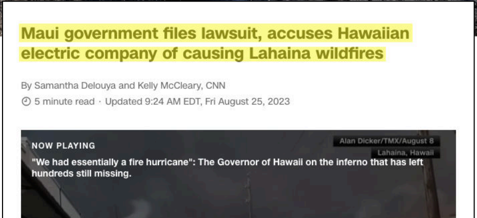

Maui government files lawsuit, accuses Hawaiian electric company of causing Lahaina wildfires

By Samantha Delouya and Kelly McCleary, CNN

5 minute read · Updated 9:24 AM EDT, Fri August 25, 2023

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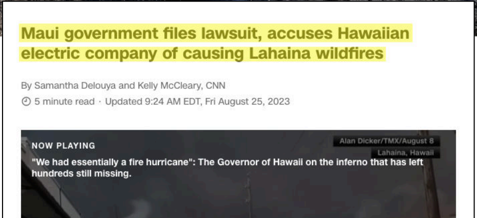

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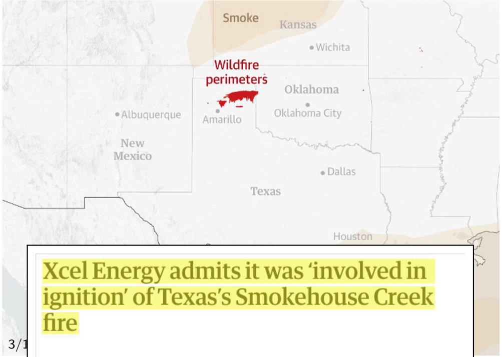

Xcel Energy admits it was 'involved in ignition' of Texas's Smokehouse Creek fire

Electric utility company acknowledges it appeared to play role in the largest wildfire in modern US history

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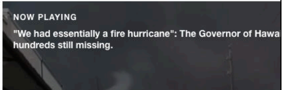

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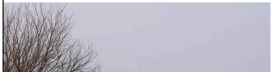

Utility-Caused Wildfires Are Becoming a National Problem

Climate change is raising the risk of blazes that are started by power lines and other utility equipment in many parts of the U.S. besides California.

Share full article

Workers replaced power lines that the Smokehouse Creek Fire damaged last month in

High Wildfire Risk Conditions

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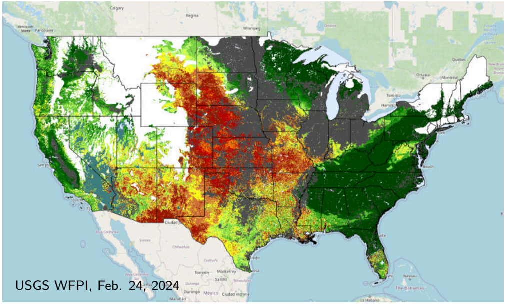
- High winds, high temperatures, dry vegetation, low humidity



USGS WFPI, Feb. 24, 2024

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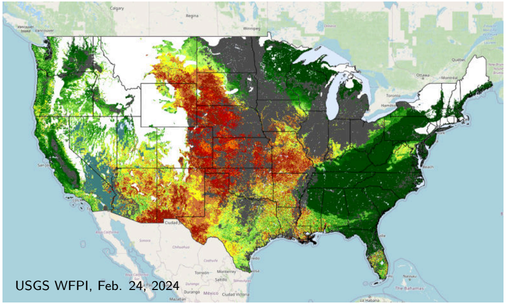

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Spark from Power Infrastructure

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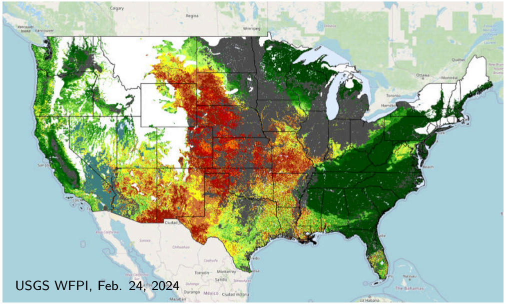

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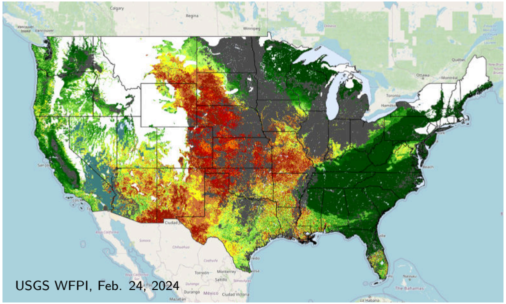

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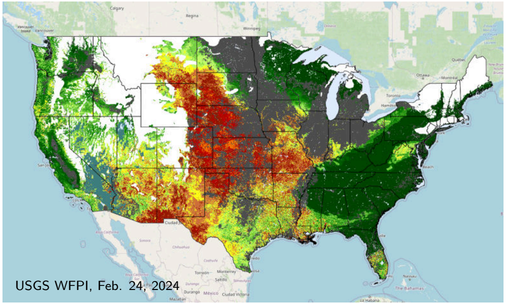

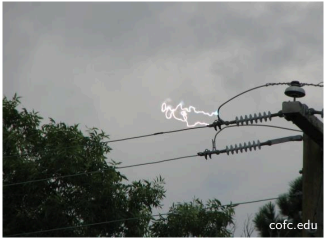

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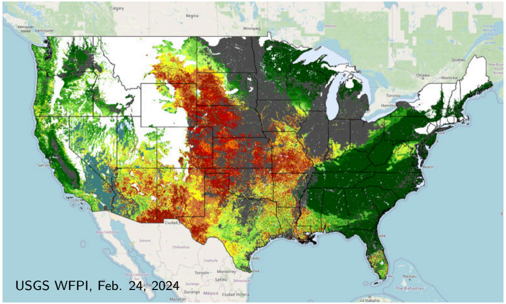

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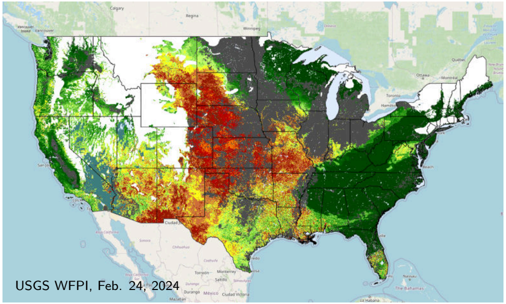

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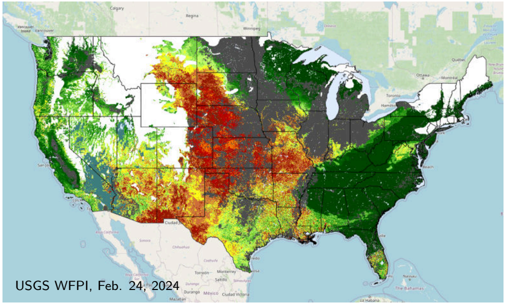

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Wildfire Ignition Prevention Schemes

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Category 1:

Immediate preventative action

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Short-term modifications

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- Increased vegetation maintenance
- Increased monitoring (e.g., sensors, cameras)
- Fast-trip settings

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Long-term hardening and planning

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Category 2:

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- Fast-trip settings

Category 3:

Long-term hardening and planning

- Fire-resistant poles
- Undergrounding
- Covered conductors
- Distributed energy resources

Public Safety Power Shutoff (PSPS)

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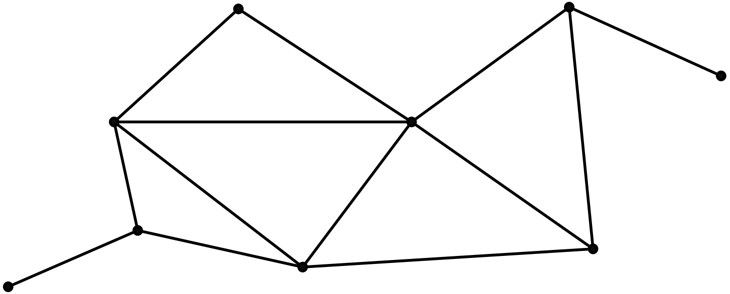

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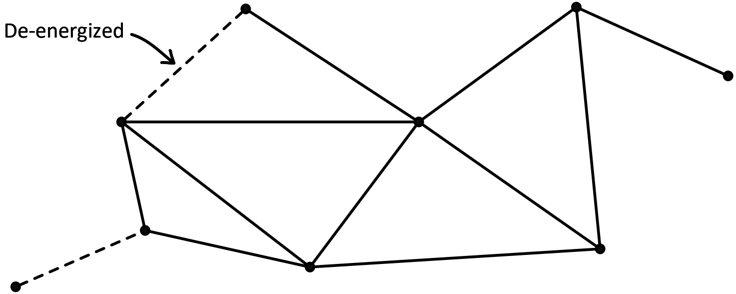

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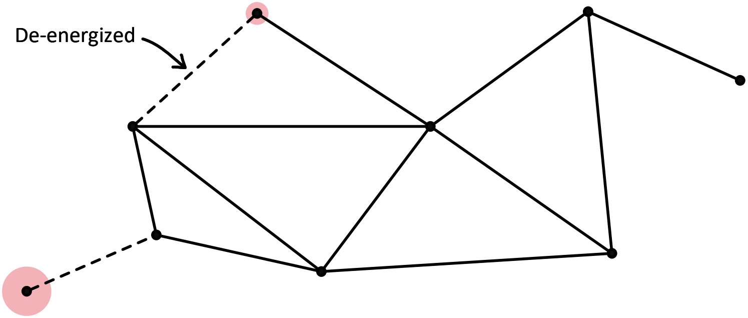

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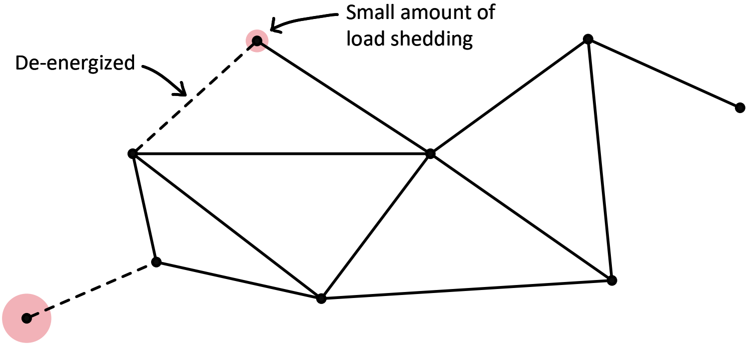

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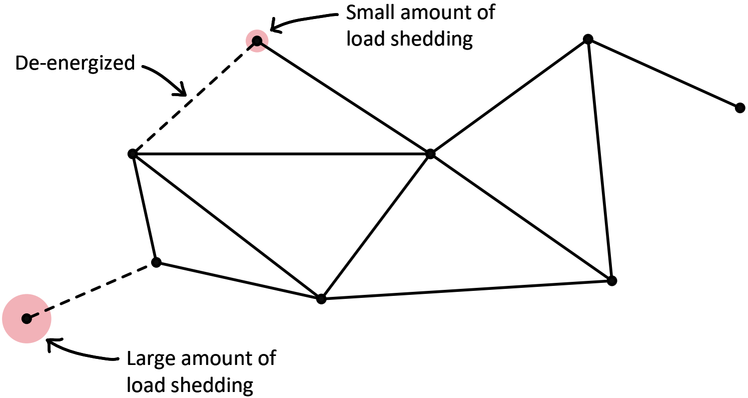

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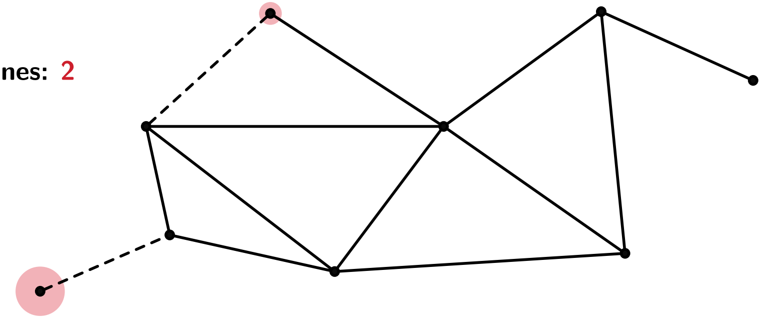
De-energized Lines: 2



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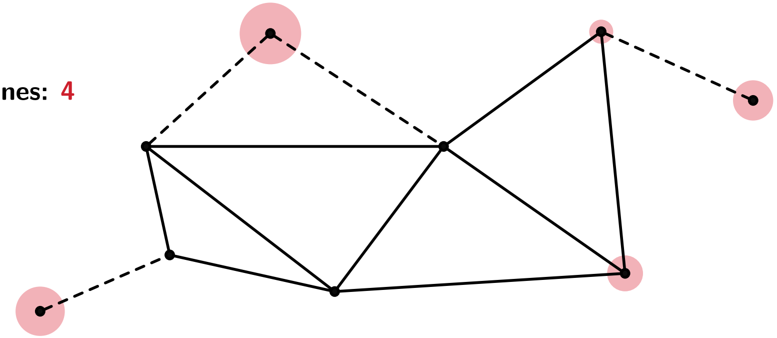
De-energized Lines: 4



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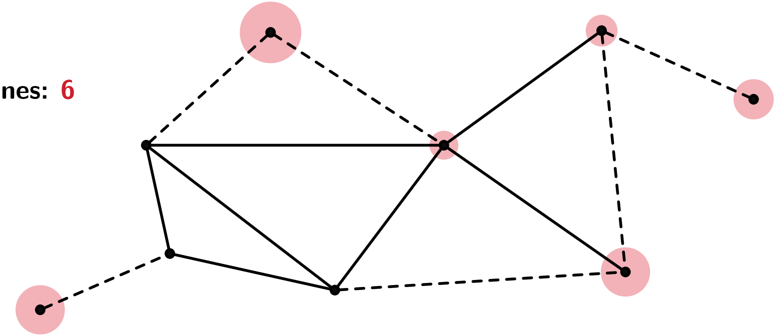
De-energized Lines: 6



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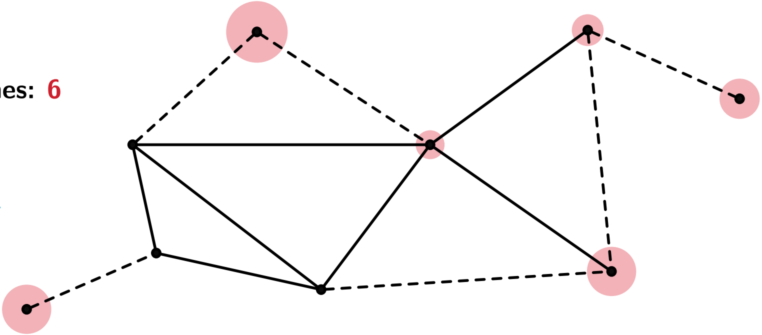
Wildfire Risk ↓
Load Shedding ↑



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A mother and daughter push a crate of food across the El Verano Elementary School yard during a food distribution for families affected by October's planned power ou
Wernikoff for CalMatters

Pacific Gas & Electric turned off power to Ana Patricia Rios' neighborhood in Sonoma County for eight days in October, three at the beginning of the month and five near the end. The mother of three young boys watched twice as nearly all of the food in her refrigerator spoiled. She threw out at least $500 worth of meat, fruit, vegetables, salsas and other food that would have supplied her family with months of meals.

“It's a big impact because we need the food that we lost,” Rios said in Spanish, two days after the lights finally came back on.

Similar losses occurred throughout Rios' wooded, hilly neighborhood, which is mostly home to Hispanic families. Many are vineyard and hospitality workers, and sometimes several families share a house.

Making matters worse, last weekend, Rios received a PG&E alert that her family might be plunged into the dark once again this week. She decided to cook the one package of meat in her freezer, which is now mostly empty to avoid another colossal loss.

“Even if the electricity doesn't arrive,” she said, “the bills do.”

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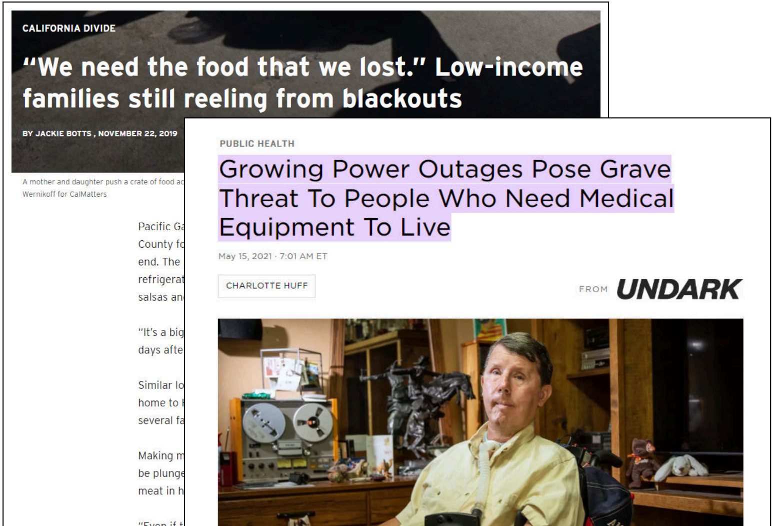

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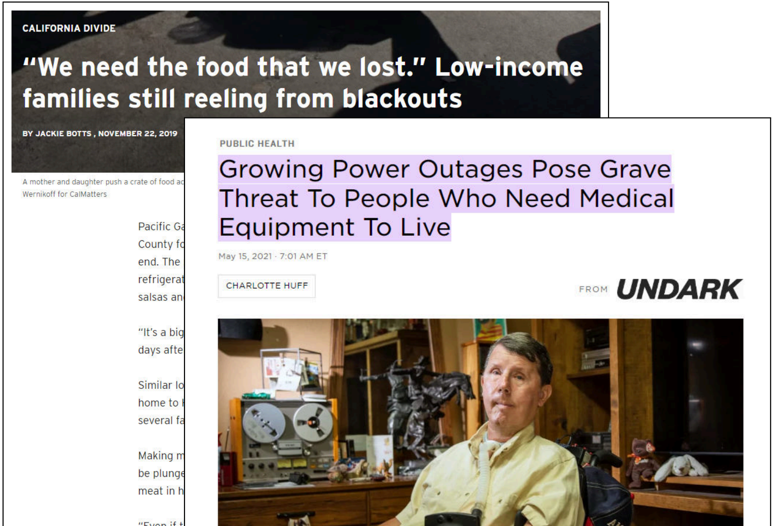
> "**160,000** instances of power shutoffs to customers with **medical needs** from 2017 to 2021."
>
> -Associated Press


CALIFORNIA DIVIDE

“We need the food that we lost.” Low-income families still reeling from blackouts

BY JACKIE BOTTS , NOVEMBER 22, 2019

A mother and daughter push a crate of food ac… Wernikoff for CalMatters

PUBLIC HEALTH

Growing Power Outages Pose Grave Threat To People Who Need Medical Equipment To Live

May 15, 2021 · 7:01 AM ET

CHARLOTTE HUFF

FROM UNDARK

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Utility	Outage Start	Outage Duration	Circuit Name	Customers Impacted
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PG&E	9/25/2019 3:06	0 days, 13 hrs, 14 min	BIG BEND 1101	185
PG&E	10/9/2019 0:45	2 days, 16 hrs, 56 min	BIG BEND 1101	190
PG&E	10/23/2019 14:31	1 days, 1 hrs, 44 min	BIG BEND 1101	190
PG&E	10/26/2019 17:00	4 days, 0 hrs, 56 min	BIG BEND 1101	189
PG&E	9/7/2020 15:34	3 days, 2 hrs, 27 min	BIG BEND 1101	234
PG&E	9/27/2020 4:05	1 days, 12 hrs, 57 min	BIG BEND 1101	237
PG&E	10/14/2020 18:20	1 days, 21 hrs, 58 min	BIG BEND 1101	237
PG&E	10/22/2020 5:08	1 days, 8 hrs, 24 min	BIG BEND 1101	239
PG&E	10/25/2020 14:58	1 days, 22 hrs, 57 min	BIG BEND 1101	239

California Public Utilities Commission (CPUC)*

*PSPS Big Bend 1101 analysis initially completed by Mark Specht. https://blog.ucsusa.org/mark-specht

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PG&E	10/25/2020 14:58	1 days, 22 hrs, 57 min	BIG BEND 1101	239

California Public Utilities Commission (CPUC)*

*PSPS Big Bend 1101 analysis initially completed by Mark Specht. https://blog.ucsusa.org/mark-specht

Hawaii utility faces scrutiny for not cutting power to reduce fire risks

Before the Maui wildfires, Hawaiian Electric did not have a plan — adopted widely in California and other states — to shut off power in certain lines in advance of dangerous winds

By Brianna Sacks

August 12, 2023 at 10:27 a.m. EDT

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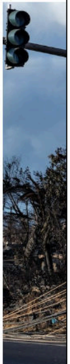
Before th
California

August 12, 20



WILDFIRES

It's official: Power shutoffs underway across Oregon amid fire danger

Additional power shutoffs are possible through the day

by: Hailey Dunn
Posted: Sep 9, 2022 / 06:24 AM PDT
Updated: Sep 9, 2022 / 09:37 PM PDT

SHARE

PORTLAND, Ore. (KOIN) — With a **red flag warning** in effect across Oregon Friday, mass power shutoffs are happening across the state because of high winds and extreme fire conditions.

Fire danger is expected to rise by Friday afternoon. Gusty winds are forecasted to ramp up with speeds up to 30-40 mph in Portland and the Willamette Valley. KOIN 6's meteorologist Natasha Stenbock says high winds paired with Oregon's dry, warm weather bolsters fire danger.

| **Fire danger, red flag warning in effect across Oregon and Washington ›**

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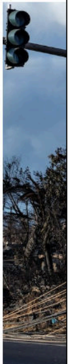

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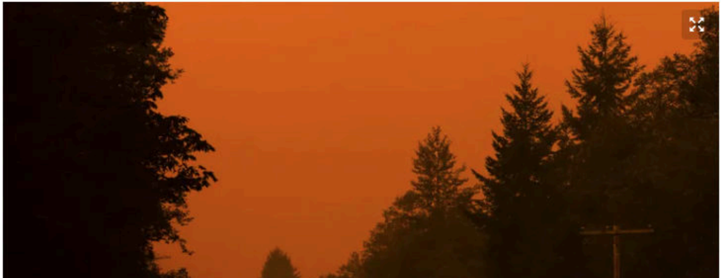
| **Fire danger,**

WA utilities proactively turn off power as wildfires come west

Sep. 11, 2022 at 8:13 pm | *Updated Sep. 12, 2022 at 8:35 am*



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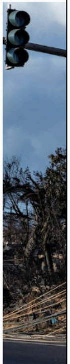

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Xcel Energy prepares for high winds, possible proactive power shutoffs, extended outages

by: Dailyn Wells
Posted: Mar 23, 2024 / 09:28 PM CDT
Updated: Mar 24, 2024 / 02:57 PM CDT

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Wildfire Ignition Prevention Schemes

Category 1:

Immediate preventative action

- Public Safety Power Shutoffs (PSPS) events

Category 2:

Short-term modifications

- Increased vegetation maintenance
- Increased monitoring (e.g., sensors, cameras)
- Fast-trip settings

Category 3:

Long-term hardening and planning

- Fire-resistant poles
- Undergrounding
- Covered conductors
- Distributed energy resources

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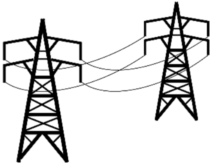

- Undergrounding
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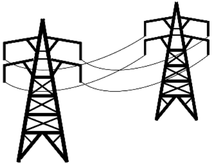

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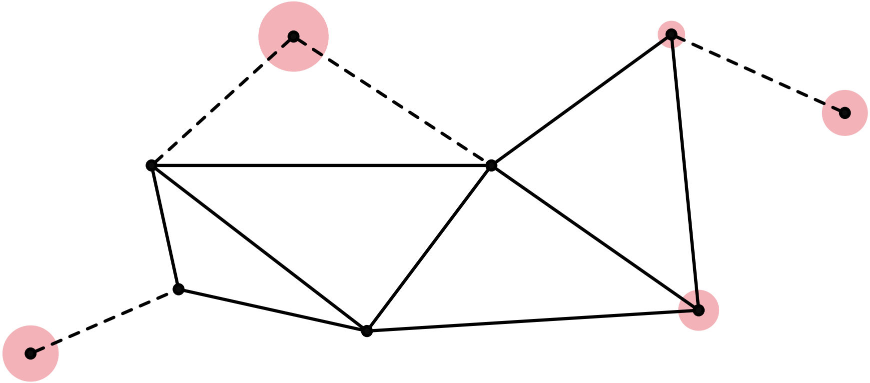

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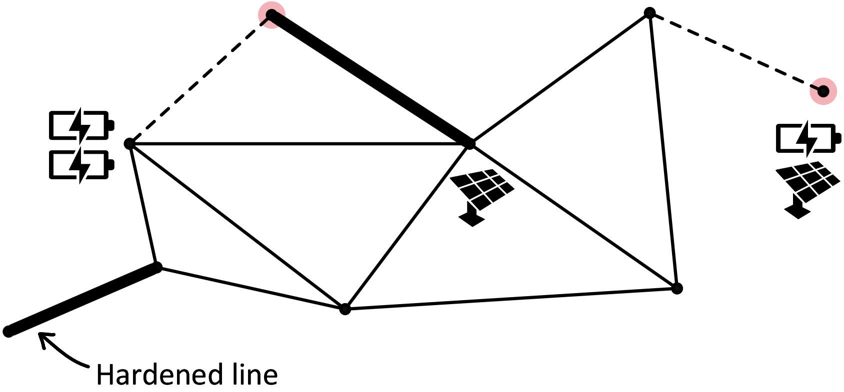

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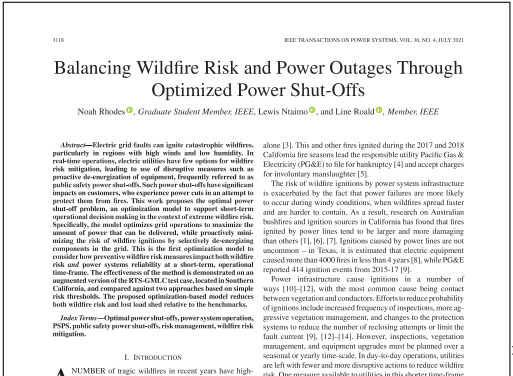

3118 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 36, NO. 4, JULY 2021

Balancing Wildfire Risk and Power Outages Through Optimized Power Shut-Offs

Noah Rhodes, *Graduate Student Member, IEEE*, Lewis Ntaimo, and Line Roald, *Member, IEEE*

***Abstract*—Electric grid faults can ignite catastrophic wildfires, particularly in regions with high winds and low humidity. In real-time operations, electric utilities have few options for wildfire risk mitigation, leading to use of disruptive measures such as proactive de-energization of equipment, frequently referred to as public safety power shut-offs. Such power shut-offs have significant impacts on customers, who experience power cuts in an attempt to protect them from fires. This work proposes the optimal power shut-off problem, an optimization model to support short-term operational decision making in the context of extreme wildfire risk. Specifically, the model optimizes grid operations to maximize the amount of power that can be delivered, while proactively minimizing the risk of wildfire ignitions by selectively de-energizing components in the grid. This is the first optimization model to consider how preventive wildfire risk measures impact both wildfire risk *and* power systems reliability at a short-term, operational time-frame. The effectiveness of the method is demonstrated on an augmented version of the RTS-GMLC test case, located in Southern California, and compared against two approaches based on simple risk thresholds. The proposed optimization-based model reduces both wildfire risk and lost load shed relative to the benchmarks.**

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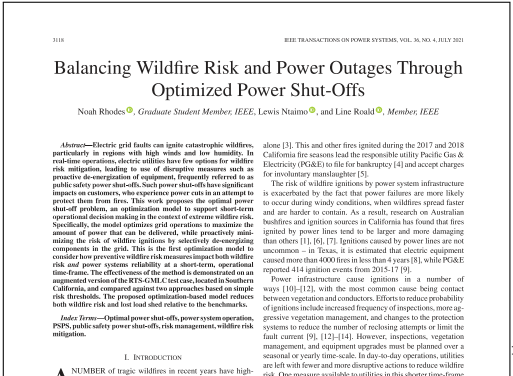
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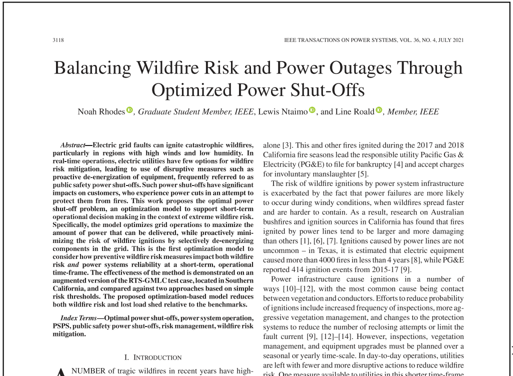

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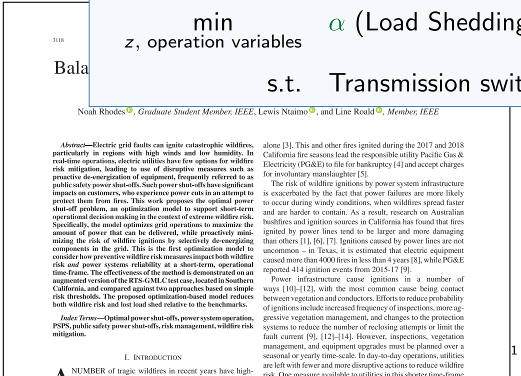
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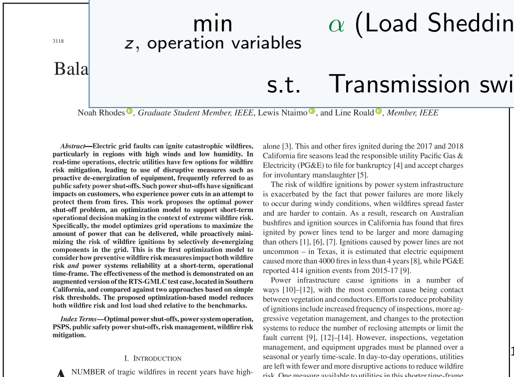
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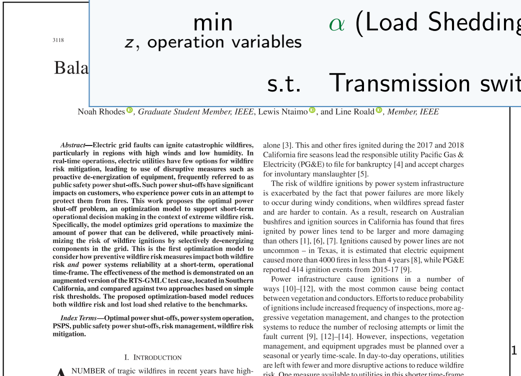
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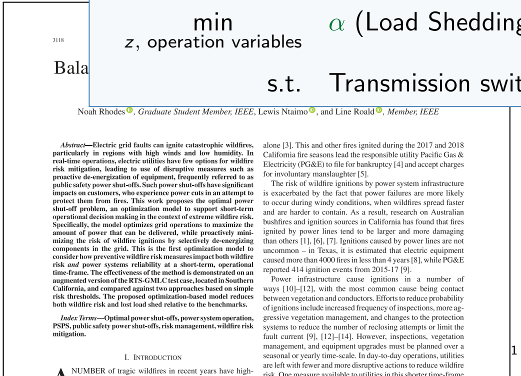

3118

Bala

Noah Rhodes, *Graduate Student Member, IEEE*, Lewis Ntaimo, and Line Roald, *Member, IEEE*

***Abstract*—Electric grid faults can ignite catastrophic wildfires, particularly in regions with high winds and low humidity. In real-time operations, electric utilities have few options for wildfire risk mitigation, leading to use of disruptive measures such as proactive de-energization of equipment, frequently referred to as public safety power shut-offs. Such power shut-offs have significant impacts on customers, who experience power cuts in an attempt to protect them from fires. This work proposes the optimal power shut-off problem, an optimization model to support short-term operational decision making in the context of extreme wildfire risk. Specifically, the model optimizes grid operations to maximize the amount of power that can be delivered, while proactively minimizing the risk of wildfire ignitions by selectively de-energizing components in the grid. This is the first optimization model to consider how preventive wildfire risk measures impact both wildfire risk *and* power systems reliability at a short-term, operational time-frame. The effectiveness of the method is demonstrated on an augmented version of the RTS-GMLC test case, located in Southern California, and compared against two approaches based on simple risk thresholds. The proposed optimization-based model reduces both wildfire risk and lost load shed relative to the benchmarks.**

***Index Terms*—Optimal power shut-offs, power system operation, PSPS, public safety power shut-offs, risk management, wildfire risk mitigation.**

I. Introduction

A NUMBER of tragic wildfires in recent years have high-

alone [3]. This and other fires ignited during the 2017 and 2018 California fire seasons lead the responsible utility Pacific Gas & Electricity (PG&E) to file for bankruptcy [4] and accept charges for involuntary manslaughter [5].

The risk of wildfire ignitions by power system infrastructure is exacerbated by the fact that power failures are more likely to occur during windy conditions, when wildfires spread faster and are harder to contain. As a result, research on Australian bushfires and ignition sources in California has found that fires ignited by power lines tend to be larger and more damaging than others [1], [6], [7]. Ignitions caused by power lines are not uncommon – in Texas, it is estimated that electric equipment caused more than 4000 fires in less than 4 years [8], while PG&E reported 414 ignition events from 2015-17 [9].

Power infrastructure cause ignitions in a number of ways [10]–[12], with the most common cause being contact between vegetation and conductors. Efforts to reduce probability of ignitions include increased frequency of inspections, more aggressive vegetation management, and changes to the protection systems to reduce the number of reclosing attempts or limit the fault current [9], [12]–[14]. However, inspections, vegetation management, and equipment upgrades must be planned over a seasonal or yearly time-scale. In day-to-day operations, utilities are left with fewer and more disruptive actions to reduce wildfire risk. One measure available to utilities in this shorter time-frame

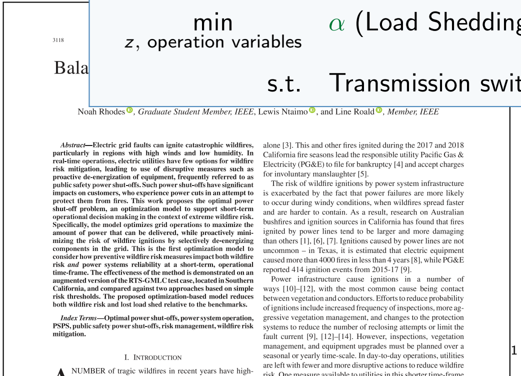
- Tradeoff parameter: $\alpha \in [0, 1]$
  - $\alpha = 0$, Only wildfire risk reduction
  - $\alpha = 1$, Only load shedding reduction

- Utilities often select lines to de-energize using **risk thresholding methods**
  - Wildfire risk parameter: $r^\ell \implies$ De-energize line ℓ if $r^\ell > \textit{risk threshold}$

- **Network-wide optimization** outperforms thresholding methods
  - De-energization variable: $z^\ell \in \{0, 1\} \implies z^\ell = 1$ (Energized), $z^\ell = 0$ (De-energized)

$$\min_{z,\ \text{operation variables}} \quad \alpha\ (\text{Load Shedding}) + (1-\alpha)\ (\text{Wildfire Risk})$$

$$\text{s.t.} \quad \text{Transmission switching constraints (DC power flow)}$$



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1

- Tradeoff parameter: $\alpha \in [0, 1]$
  - $\alpha = 0$, Only wildfire risk reduction
  - $\alpha = 1$, Only load shedding reduction
- Wildfire Risk $= \sum_{\ell \in \text{Lines}} (r^\ell z^\ell)$

- Extend to **multi-time period**

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- Incorporate infrastructure investment decisions

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- Place infrastructure based on **worst-case representative 24-hour period**

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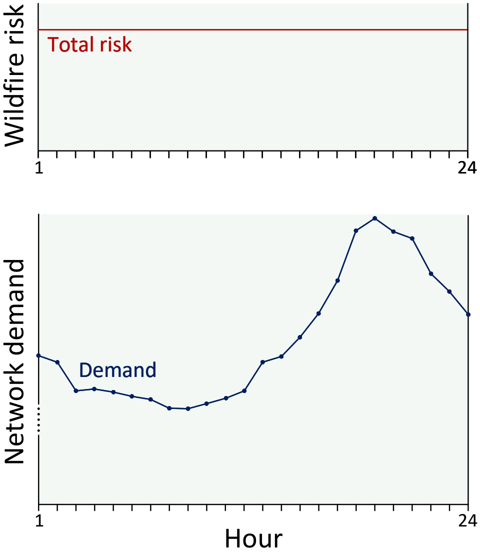

- Extend to **multi-time period**

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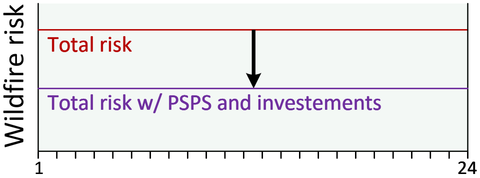
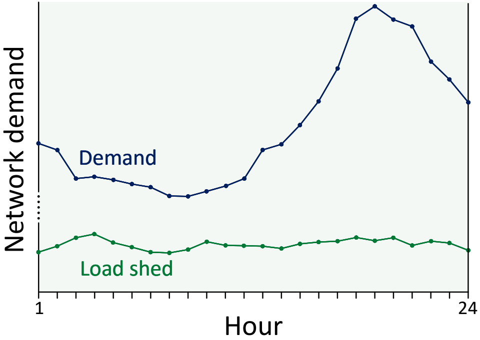
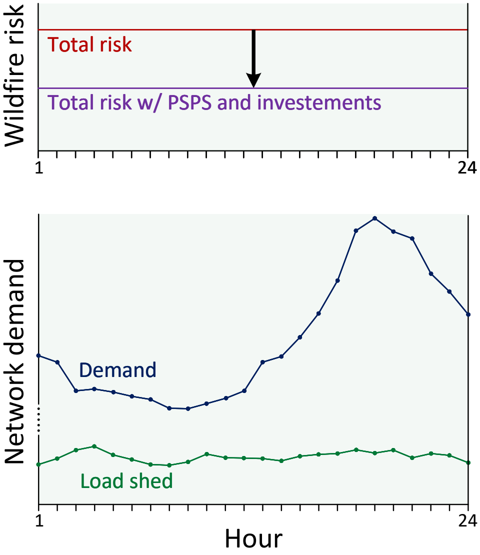




- Extend to **multi-time period**
- Incorporate infrastructure investment decisions
- Place infrastructure based on **worst-case representative 24-hour period**
  - Consider day with peak demand
  - Assign risks to be average of top 10% of historical highest risks
- Test infrastructure decisions on **sequential simulation** of the 2021 wildfire season



Problem Formulation

$$\min_{\substack{z,\ \text{operation variables} \\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

Problem Formulation

$$\min_{\substack{z,\ \text{operation variables} \\ \text{infrastructure variables}}} \quad \alpha\ (\text{Load Shedding}) + (1-\alpha)\ (\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

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Budget constraint

$$\text{Objective function} = \alpha \underbrace{\left(\frac{\sum_{hour} \sum_{bus} \text{load shed}}{\text{total demand}} \right)}_{\text{Load Shedding}} + (1-\alpha) \underbrace{\left(\frac{\sum_{line} r^{\ell}(z^{\ell} - \beta y^{\ell})}{\text{total risk}} \right)}_{\text{Wildfire Risk}}$$

Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

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Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t.
- Transmission switching constraints (DC power flow)
- Line hardening/management constraints
- Battery constraints
- PV solar constraints
- Budget constraint

- Line hardening variable: $y^{\ell} \in \{0, 1\}$

Problem Formulation

$$\begin{aligned} \min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad & \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk}) \\ \text{s.t.} \quad & \text{Transmission switching constraints (DC power flow)} \\ & \text{Line hardening/management constraints} \\ & \text{Battery constraints} \\ & \text{PV solar constraints} \\ & \text{Budget constraint} \end{aligned}$$

- Line hardening variable: $y^{\ell} \in \{0, 1\}$
- Hardening risk reduction $\beta \in [0, 1]$

Problem Formulation

$$\min_{\substack{z,\ \text{operation variables} \\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)
Line hardening/management constraints
Battery constraints
PV solar constraints
Budget constraint

- Line hardening variable: $y^{\ell} \in \{0, 1\}$
- Hardening risk reduction $\beta \in [0, 1]$

Method	β	Reference
undergrounding	1.0	*CPUC*
covered conductors	0.5	*CPUC, WECC*
vegetation management	0.25	*PG&E, Palaiologou 2018*

Palaiologou, et al. "Using transboundary wildfire exposure assessments to improve fire management programs: a case study in Greece." International Journal of Wildland Fire (2018).

Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

- Line hardening variable: $y^\ell \in \{0,1\}$
- Hardening risk reduction $\beta \in [0,1]$
- Harden/manage entire line

Method	β	Reference
undergrounding	1.0	*CPUC*
covered conductors	0.5	*CPUC, WECC*
vegetation management	0.25	*PG&E, Palaiologou 2018*

Taylor, Sofia, and Line A. Roald. "A framework for risk assessment and optimal line upgrade selection to mitigate wildfire risk." Electric Power Systems Research (2022).

Problem Formulation

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Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\ (\text{Load Shedding}) + (1-\alpha)\ (\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

- Standard mixed-integer linear battery model

Problem Formulation

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s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

- Standard mixed-integer linear battery model
  - Variables for battery placement, state, charge and discharge

Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)
Line hardening/management constraints
Battery constraints
PV solar constraints
Budget constraint

- Standard mixed-integer linear battery model
  - Variables for battery placement, state, charge and discharge
- Solar output per location, hour and day using NREL's PVWatts calculator

Problem Formulation

$$\min_{\substack{z,\ \text{operation variables}\\ \text{infrastructure variables}}} \quad \alpha\ (\text{Load Shedding}) + (1-\alpha)\ (\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)

Line hardening/management constraints

Battery constraints

PV solar constraints

Budget constraint

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Line hardening/management constraints

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Budget constraint

- Consider range of budgets: \$100M to \$1B

Problem Formulation

$$\min_{\substack{z,\text{ operation variables}\\ \text{infrastructure variables}}} \quad \alpha\,(\text{Load Shedding}) + (1-\alpha)\,(\text{Wildfire Risk})$$

s.t. Transmission switching constraints (DC power flow)
Line hardening/management constraints
Battery constraints
PV solar constraints
Budget constraint

- Consider range of budgets: \$100M to \$1B

Infrastructure	Cost	Reference
battery[1]	\$20 million per battery	*NREL*
solar PV[2]	\$940 per 1-kW-DC array	*NREL*
undergrounding	\$3 million per mile	*CPUC*, PSC of WI
covered conductors	\$0.5 million per mile	*CPUC*, *MISO*
vegetation management[3]	\$0.01 million per mile	*LREC*

[1] 100 MWh lithium-ion grid-scale battery.

[2] Fixed-tilt, utility-scale PV system.

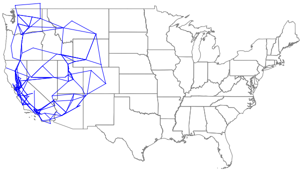
[3] Over a 20 year period.

Test Cases

RTS-GMLC API

73 buses, 120 lines, 99 generators

WECC-240



240 buses, 448 lines, 143 generators

Test Cases

RTS-GMLC API

73 buses, 120 lines, 99 generators

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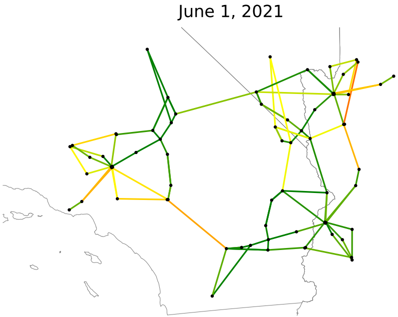
73 buses, 120 lines, 99 generators

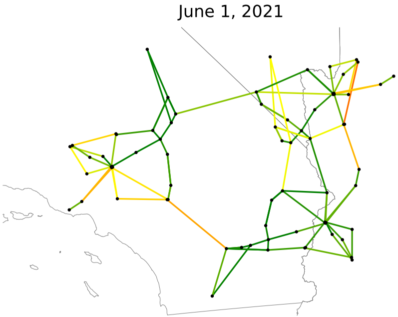


- Risks r^ℓ assigned using USGS Wind-enhanced Fire Potential Index

Test Cases

RTS-GMLC API

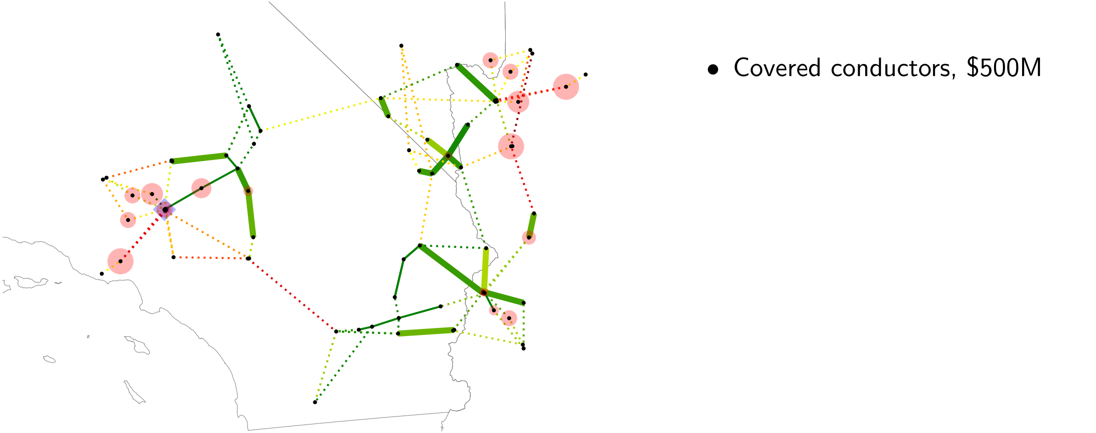
73 buses, 120 lines, 99 generators



- Risks r^ℓ assigned using USGS Wind-enhanced Fire Potential Index
- Evaluate 3 cases:
  1. solar + batteries + **enhanced vegetation management**
  2. solar + batteries + **covered conductors**
  3. solar + batteries + **undergrounding**

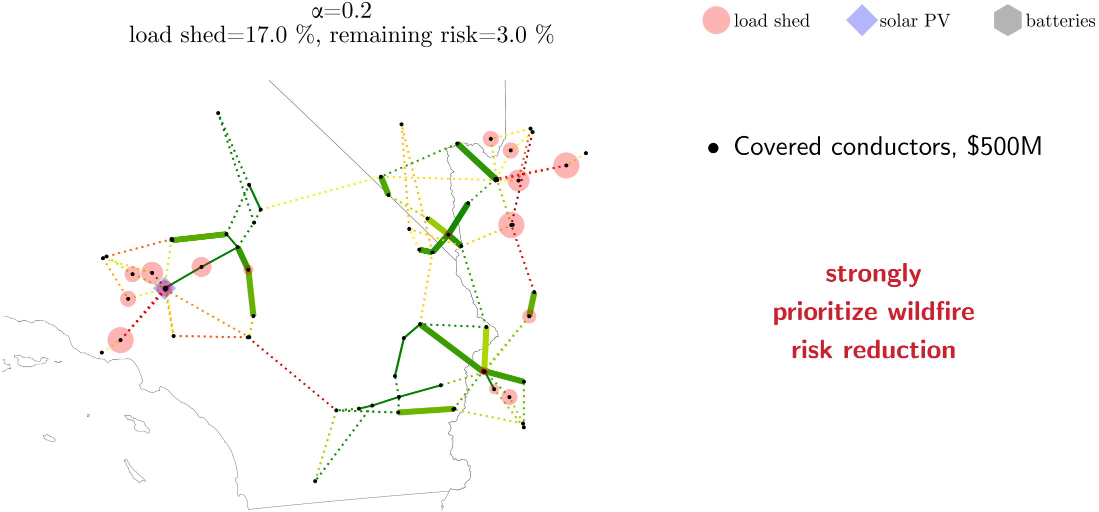
Infrastructure Placements

α=0.2
load shed=17.0 %, remaining risk=3.0 %



- Covered conductors, $500M

Infrastructure Placements

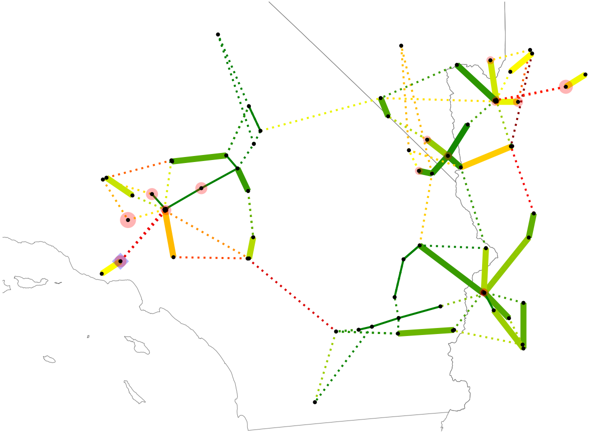


- Covered conductors, $500M

strongly prioritize wildfire risk reduction

Infrastructure Placements

α=0.5
load shed=4.0 %, remaining risk=10.0 %



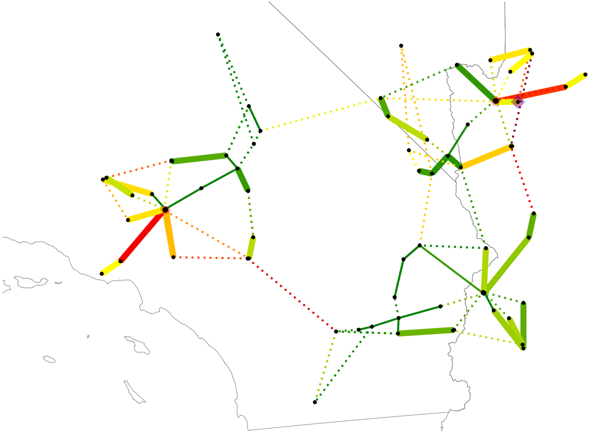
load shed   solar PV   batteries

- Covered conductors, $500M

evenly weight
wildfire risk
and
load shedding

Infrastructure Placements

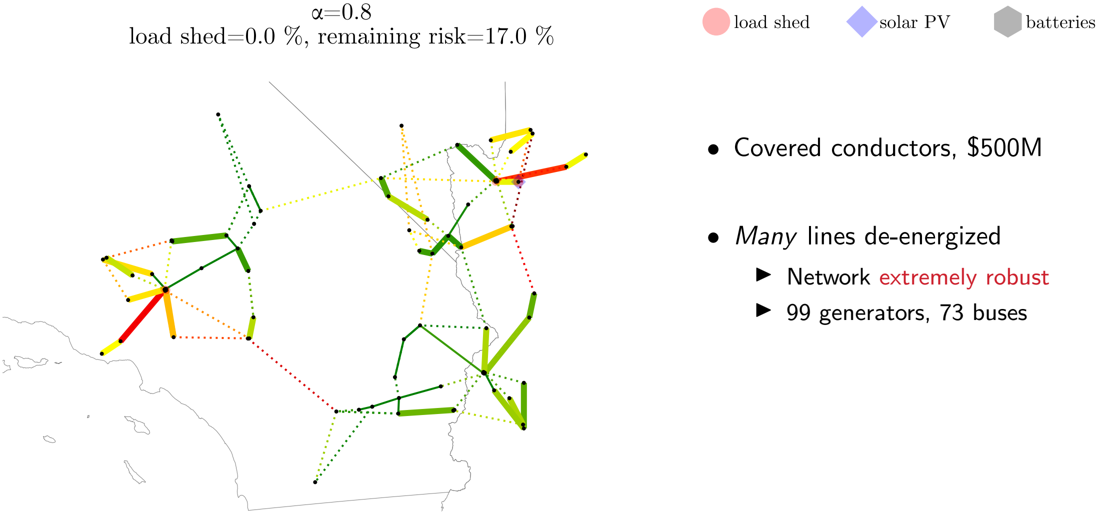
α=0.8
load shed=0.0 %, remaining risk=17.0 %



- Covered conductors, $500M

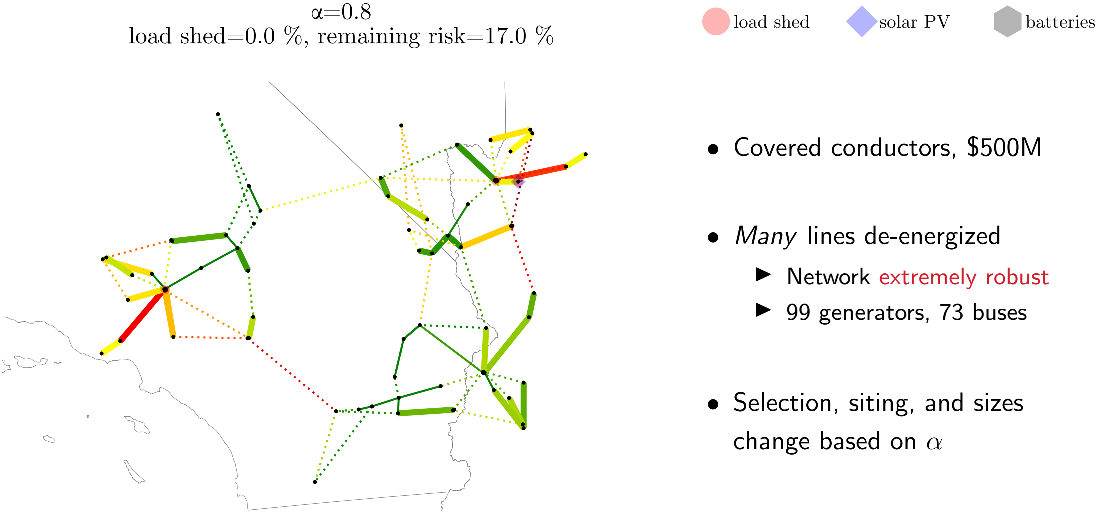
strongly prioritize load shedding reduction

Infrastructure Placements



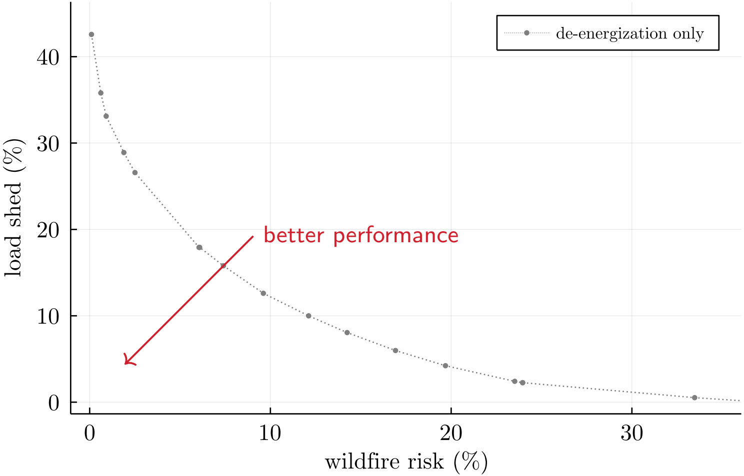
- Covered conductors, \$500M
- *Many* lines de-energized
  - Network extremely robust
  - 99 generators, 73 buses

Infrastructure Placements



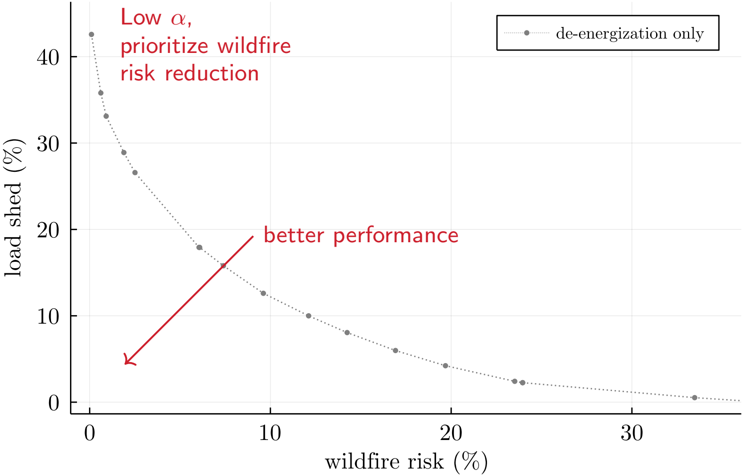
- Covered conductors, $500M
- *Many* lines de-energized
  - Network extremely robust
  - 99 generators, 73 buses
- Selection, siting, and sizes change based on α

Infrastructure Trade-off Curves



- Budget = $500M

Infrastructure Trade-off Curves



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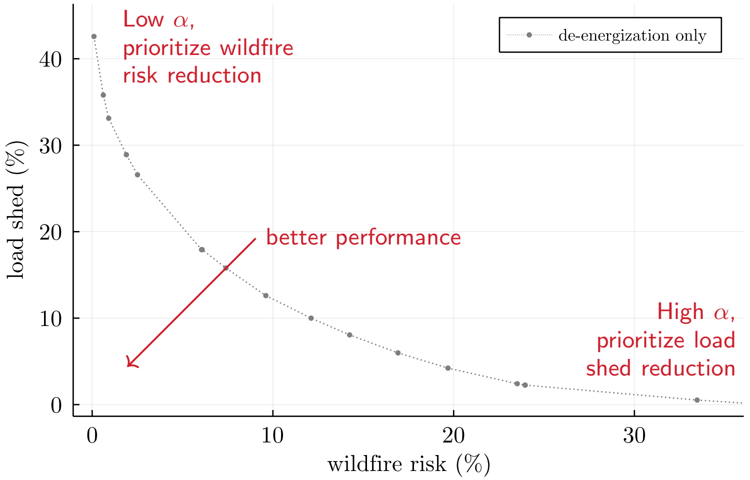

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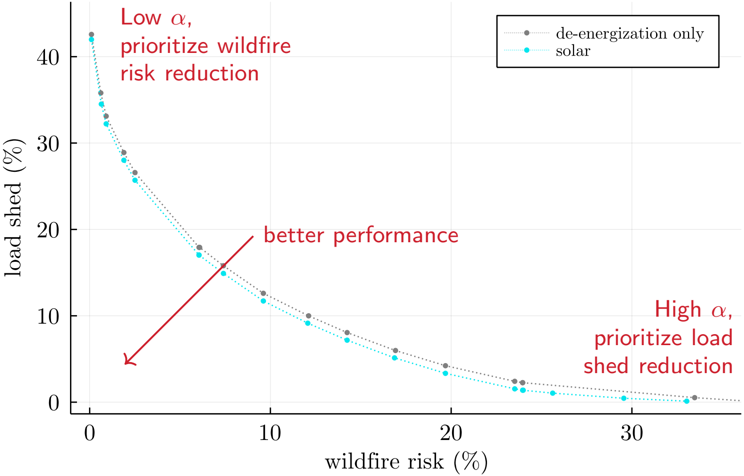

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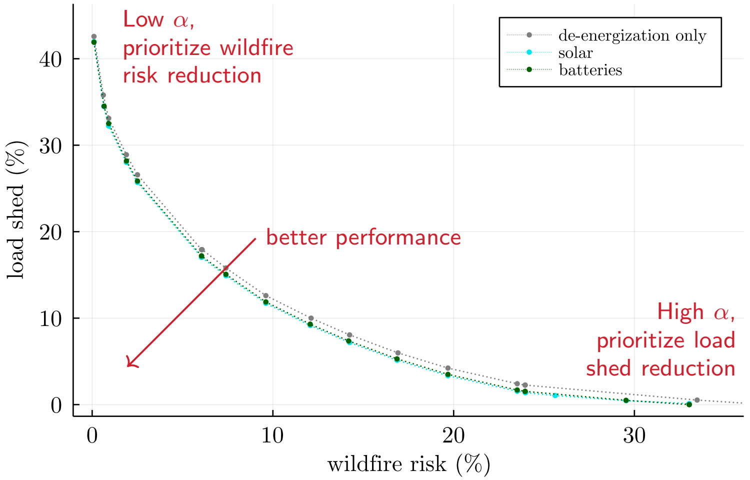

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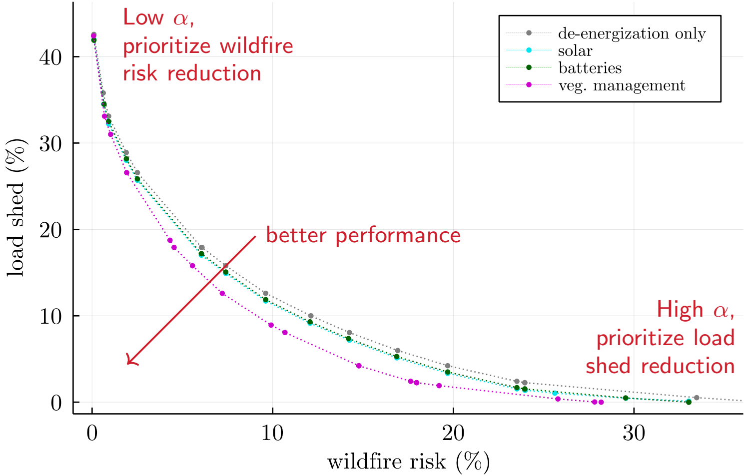

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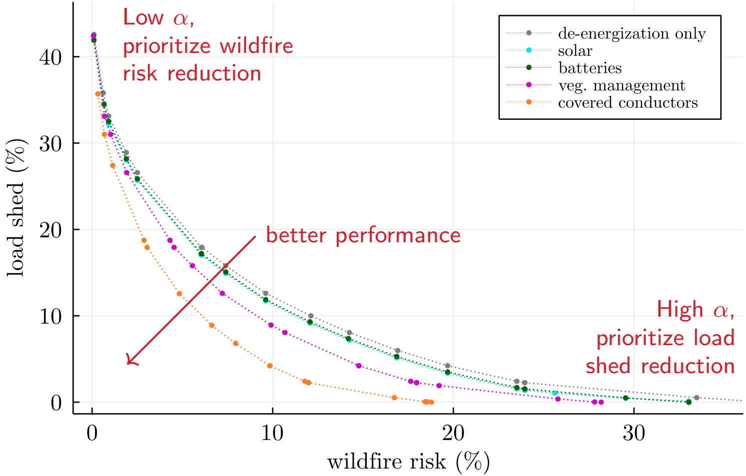
Infrastructure Trade-off Curves



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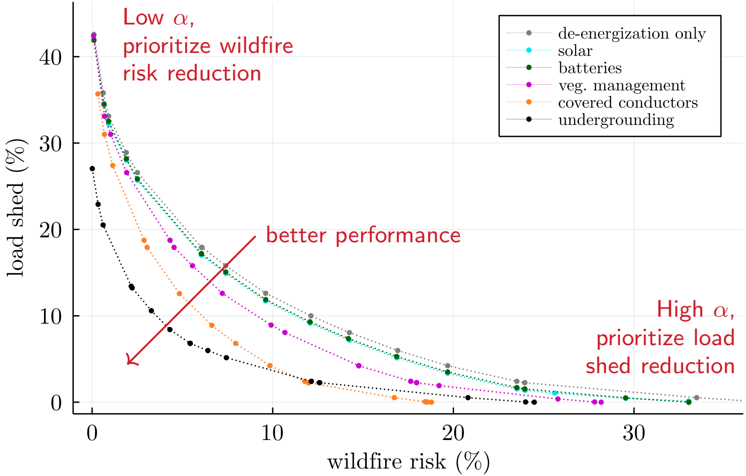
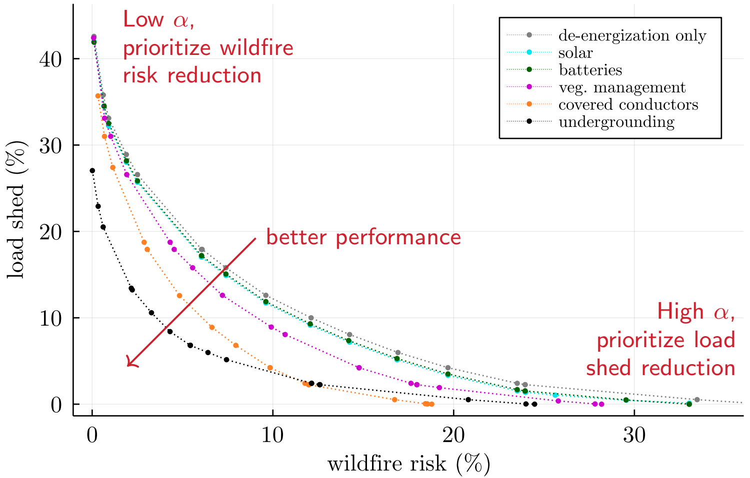
Infrastructure Trade-off Curves



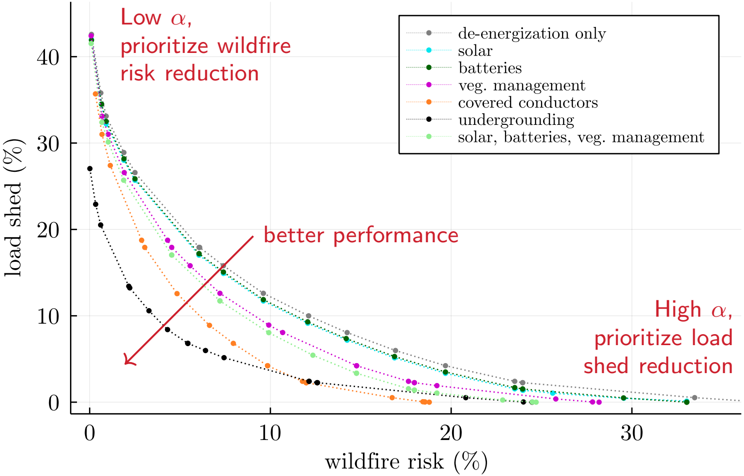
- Budget = $500M

Infrastructure Trade-off Curves



- Budget = \$500M
- Most improvement via line hardening or management measures

Infrastructure Trade-off Curves



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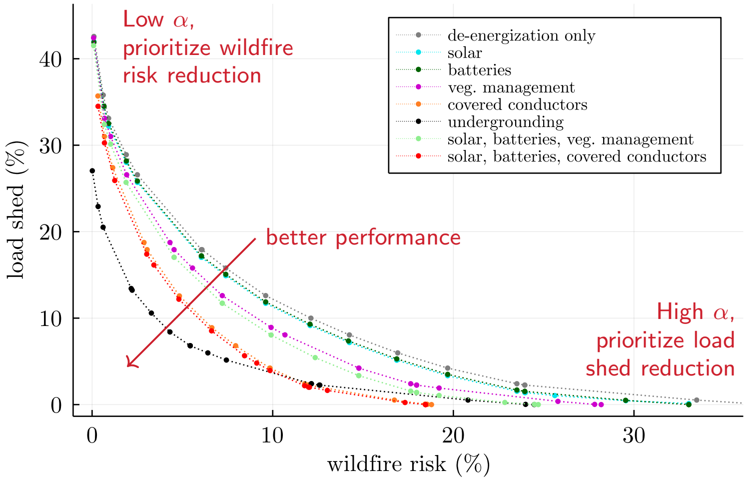
Infrastructure Trade-off Curves



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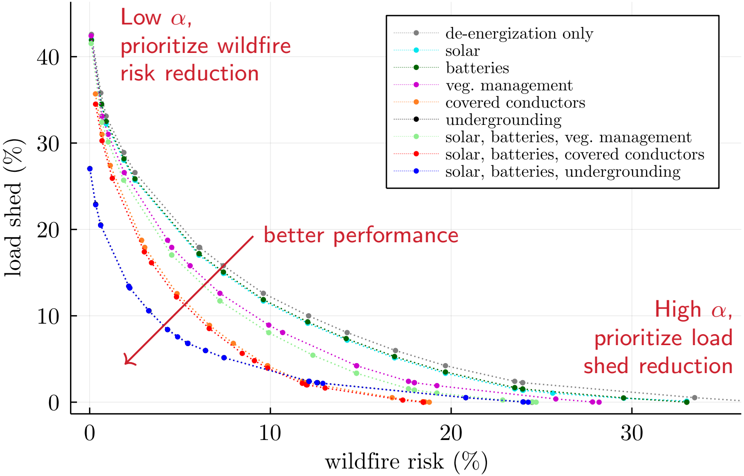
Infrastructure Trade-off Curves



- Budget = \$500M
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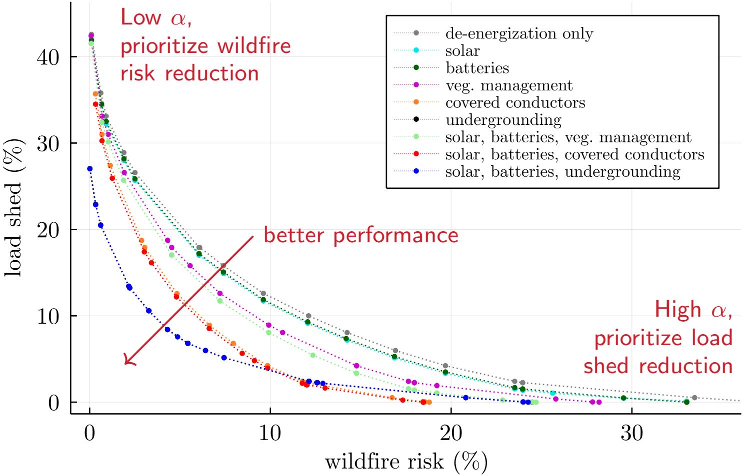
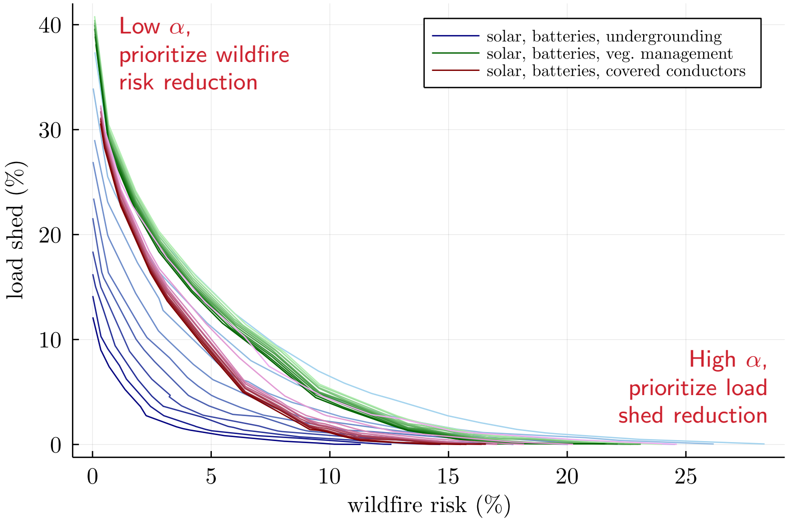
Infrastructure Trade-off Curves

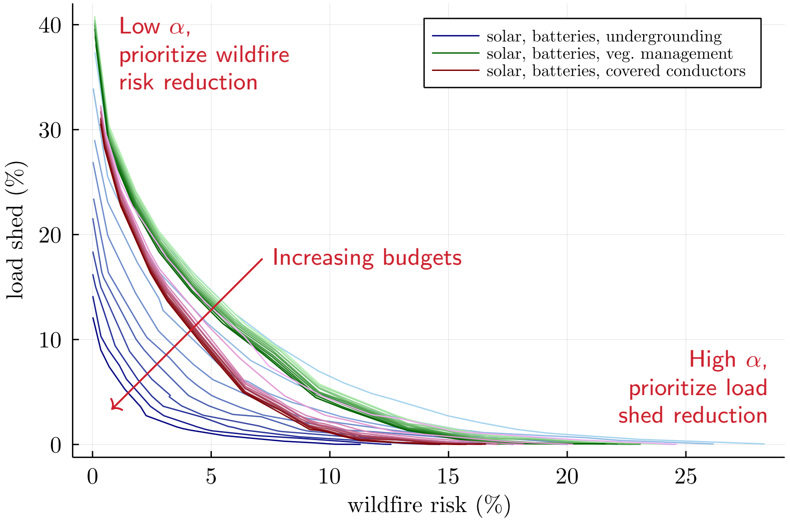


- Budget = \$500M
- Most improvement via line hardening or management measures
- Combinations of investments driven mostly by line hardening or management

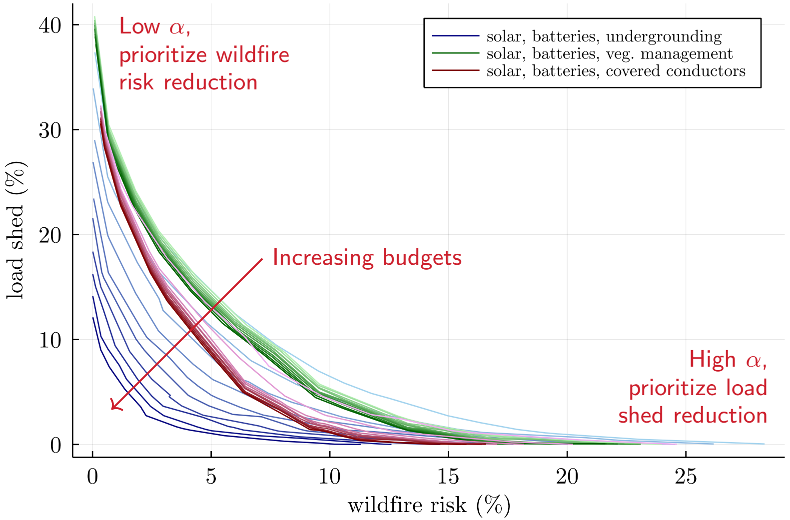
Budget Trade-off Curves



Budget Trade-off Curves

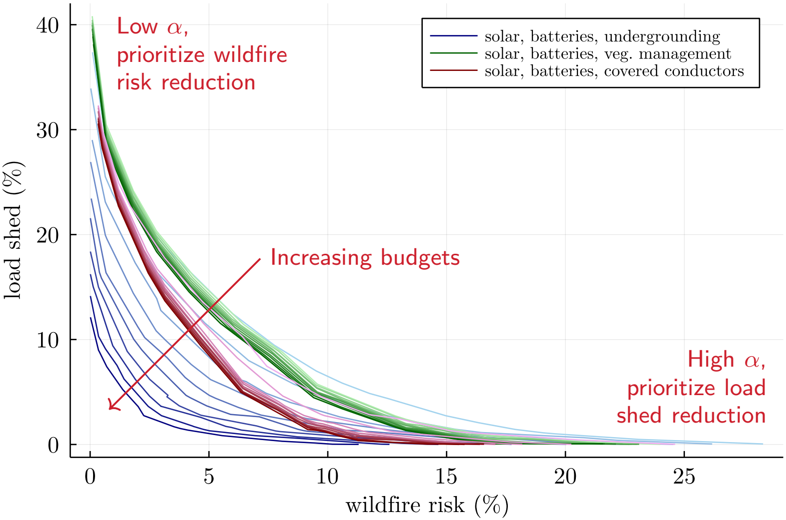


Budget Trade-off Curves



- Curves based on season-long simulation

Budget Trade-off Curves



- Curves based on season-long simulation
- Most "*bang for your buck*" if undergrounding power lines

Long-Duration Battery Investment Using Distributed Optimization

[Piansky, R., Stinchfield, G., Kody, A., Molzahn, D.K. and Watson. J.P. (2024). "Long Duration Battery Sizing, Siting, and Operation Under Wildfire Risk Using Progressive Hedging"]

Long-Duration Battery Investment Using Distributed Optimization

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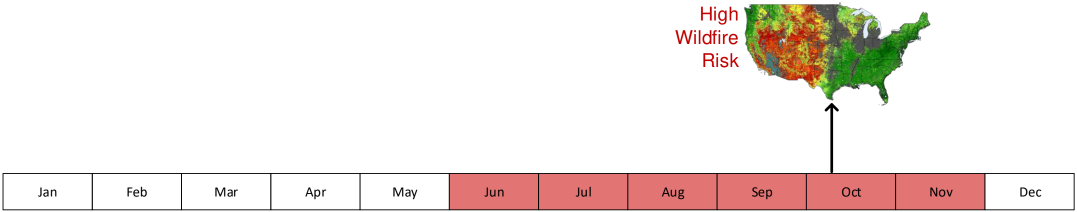

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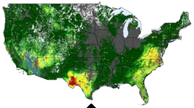
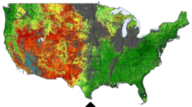
Long-Duration Battery Investment Using Distributed Optimization

Low Wildfire Risk



High Wildfire Risk



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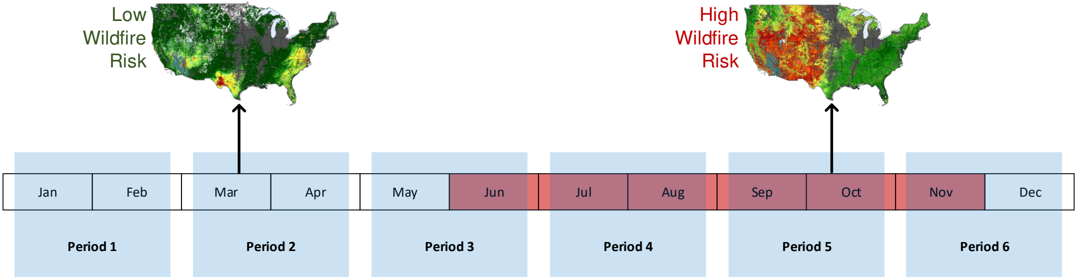

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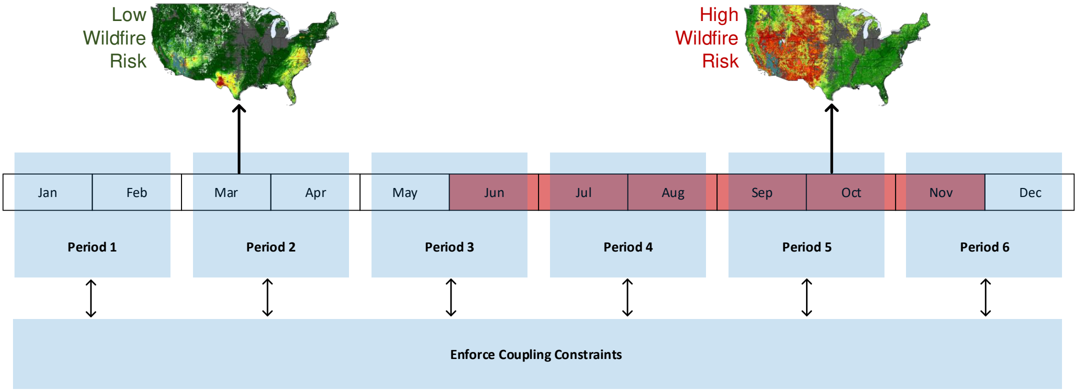

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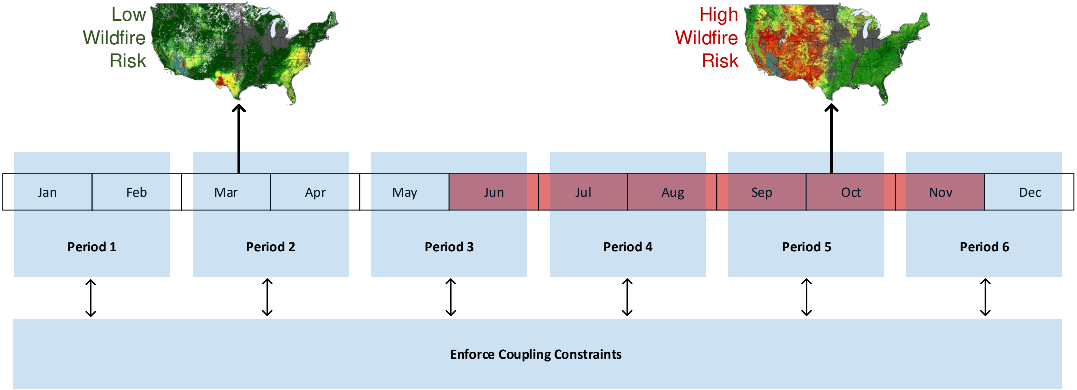

Georgia Institute of Technology

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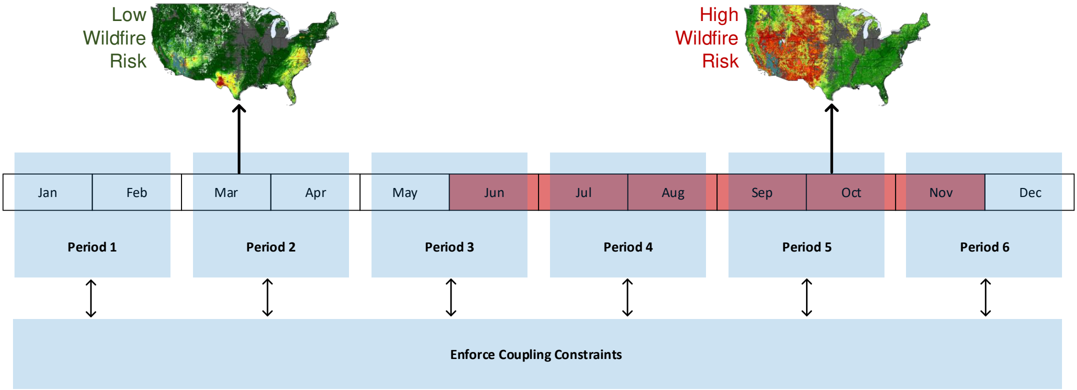

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Lawrence Livermore National Laboratory

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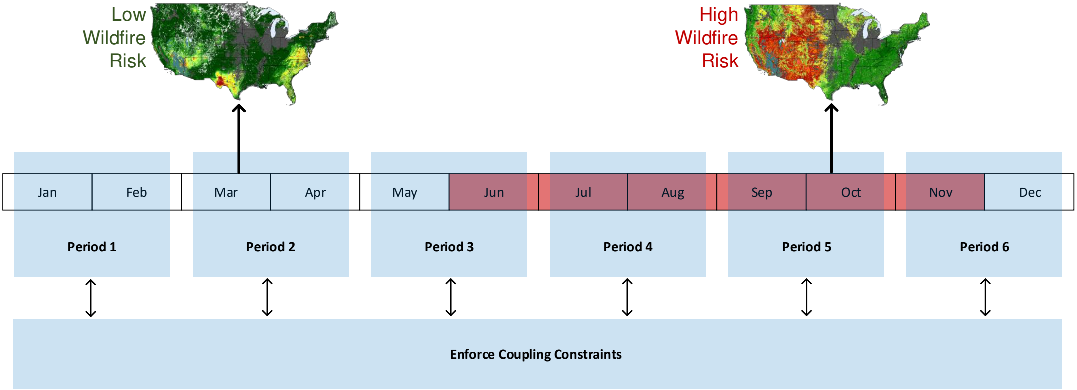

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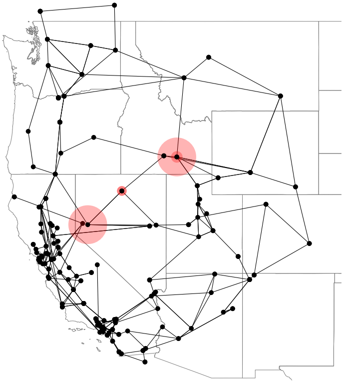
Battery Placements on WECC Network

April 2021
(no wildfire risk)



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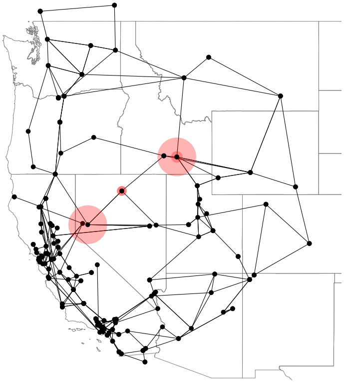
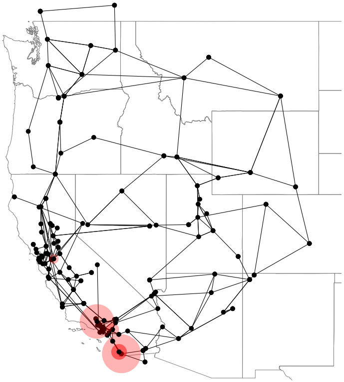


June 2021
(wildfire risk)



Battery Placements on WECC Network

April 2021
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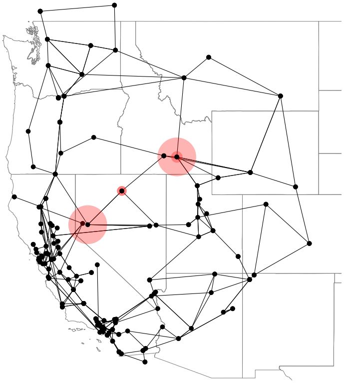

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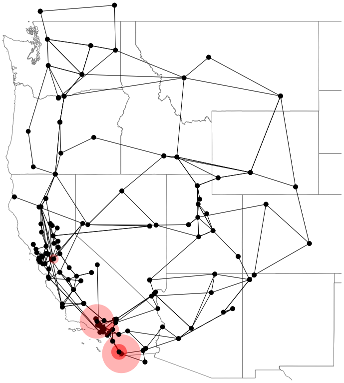
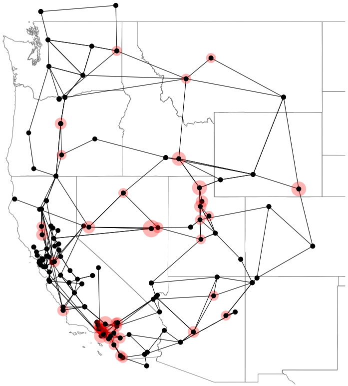


Full 2021 Year
(multi-use)



Undergrounding Selections in Accordance with the Justice40 Initiative

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"...directs 40% of the overall benefits of certain Federal investments... to flow to disadvantaged communities"
-DOE

Justice40 Image: LeSar Development Consultants

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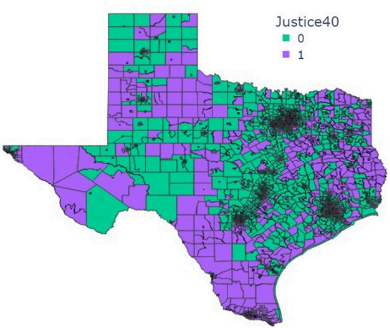
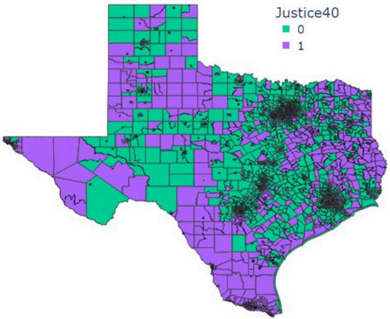
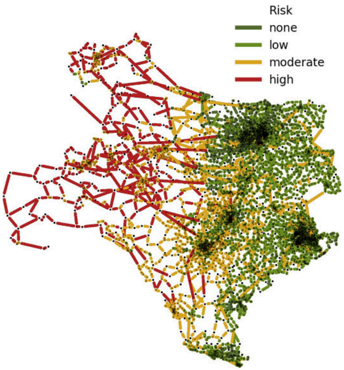


Undergrounding Selections in Accordance with the Justice40 Initiative

JUSTICE 40
PEOPLE
POWER
PROSPERITY

“...directs 40% of the overall benefits of certain Federal investments... to flow to disadvantaged communities” -DOE





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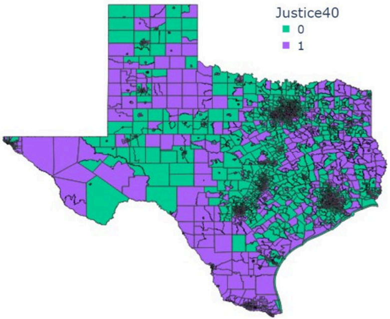
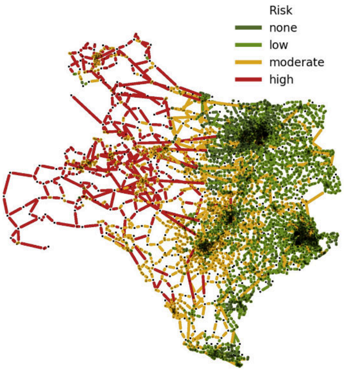
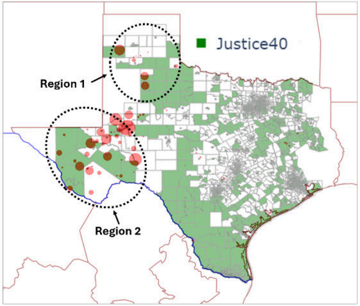




Massachusetts Institute of Technology

Georgia Institute of Technology

Load Shedding and Disadvantaged Communities



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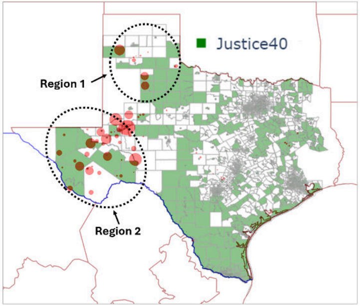

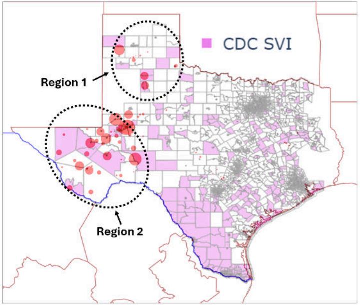

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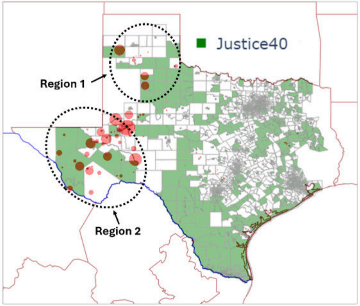

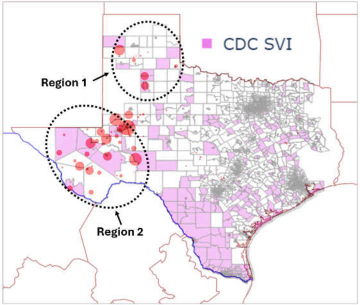

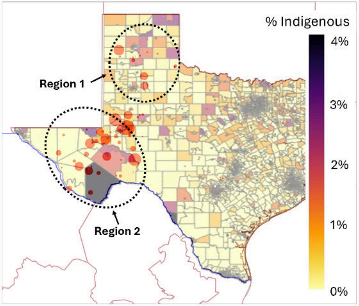

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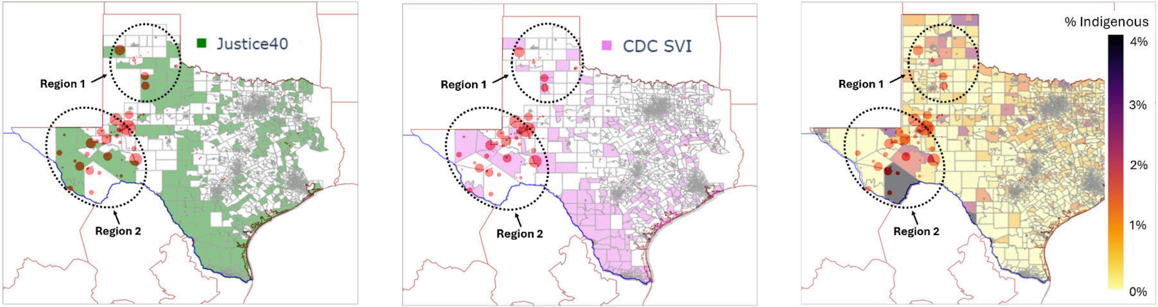
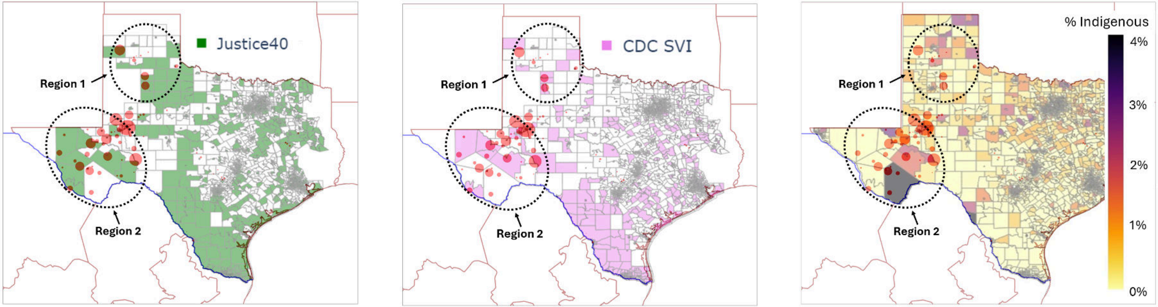


- Majority of load shedding due to PSPS events occur in circled regions

Load Shedding and Disadvantaged Communities



- Majority of load shedding due to PSPS events occur in circled regions
- Exploring how to capture the vulnerability of these areas, and how to select undergrounded power lines

Thank You

aakody@ncsu.edu

Pok Rie/pexels.com

Investment in Wildfire Risk Mitigation

- **Utility:** PG&E undergrounding plan
  - 10,000 miles of power lines

PG&E Aims to Curb Wildfire Risk by Burying Many Power Lines

The California utility said the work would involve about 10,000 miles of its network, a project potentially costing tens of billions of dollars.

Give this article

Investment in Wildfire Risk Mitigation

- **Utility:** PG&E undergrounding plan
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- **State:** California Wildfire Investment
  - $536 million for wildfire resilience

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Office of Governor
GAVIN NEWSOM

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Governor Newsom Signs Landmark $536 Million Wildfire Package Accelerating Projects to Protect High-Risk Communities

Published: Apr 13, 2021

Governor and legislative leaders tour fuels management project that helped protect a Butte County community from last year's North Complex Fire

Early action funding invests in wildfire resilience projects including forest management, fuel breaks and hardening infrastructure in high-risk communities

Early budget action builds on the Governor's announcement last week of an expanded state task force to deliver on key commitments of the Wildfire and Forest Resilience Action Plan

OROVILLE EAST– Ahead of peak fire season, Governor Gavin Newsom today signed a $536 million wildfire package enabling the state to take urgent action on projects that support wildfire suppression, improve forest health and build resilience in communities to help protect residents and property from catastrophic wildfires in diverse landscapes across the state. The Governor signed SB 85 alongside legislative leaders at a fuels management project in the Lake Oroville State Recreation Area that helped protect a Butte County community from last year's North Complex Fire.

The legislative package builds on Governor Newsom's early action funding for wildfire resilience proposed in his 2021-2022 state budget. It funds projects to restore the ecological health of forests and watersheds, fuel breaks around vulnerable communities, statewide fire prevention grants targeting projects to advance community hardening, and improvements to defensible space to mitigate wildfire damage. This early action plan is part of the Governor's overall proposed $1 billion

Investment in Wildfire Risk Mitigation

- **Utility:** PG&E undergrounding plan
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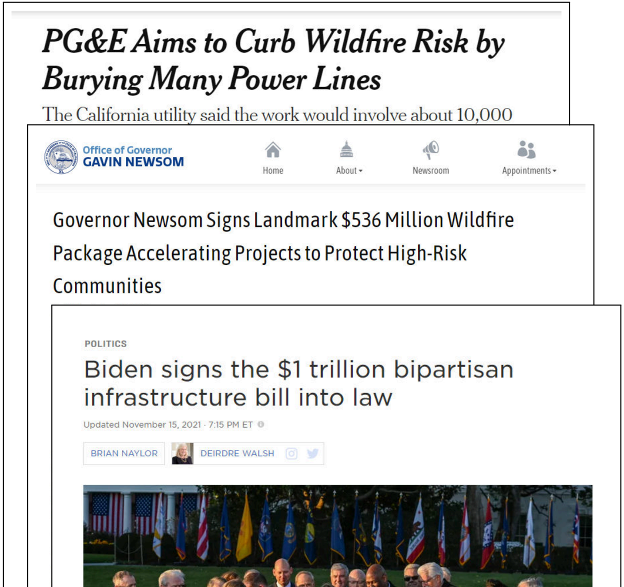
- **State:** California Wildfire Investment
  - $536 million for wildfire resilience
- **Federal:** Infrastructure Bill
  - $5 billion harden against extreme weather events



PG&E Aims to Curb Wildfire Risk by Burying Many Power Lines

The California utility said the work would involve about 10,000

Governor Newsom Signs Landmark $536 Million Wildfire Package Accelerating Projects to Protect High-Risk Communities

POLITICS

Biden signs the $1 trillion bipartisan infrastructure bill into law

Updated November 15, 2021 · 7:15 PM ET

BRIAN NAYLOR
DEIRDRE WALSH

Investment in Wildfire Risk Mitigation

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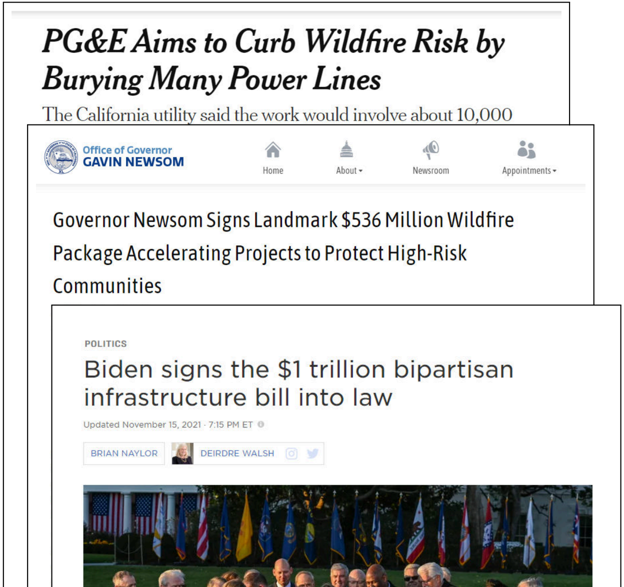
How should we invest in infrastructure to reduce wildfire ignition risk and load shedding?



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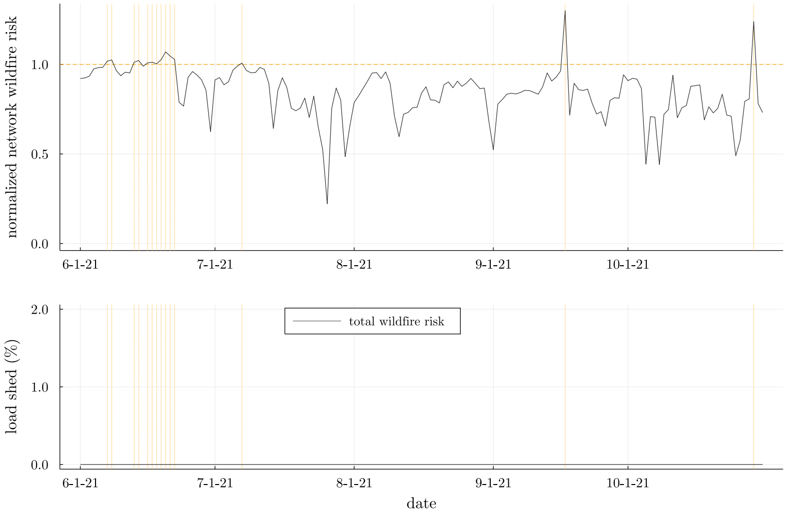
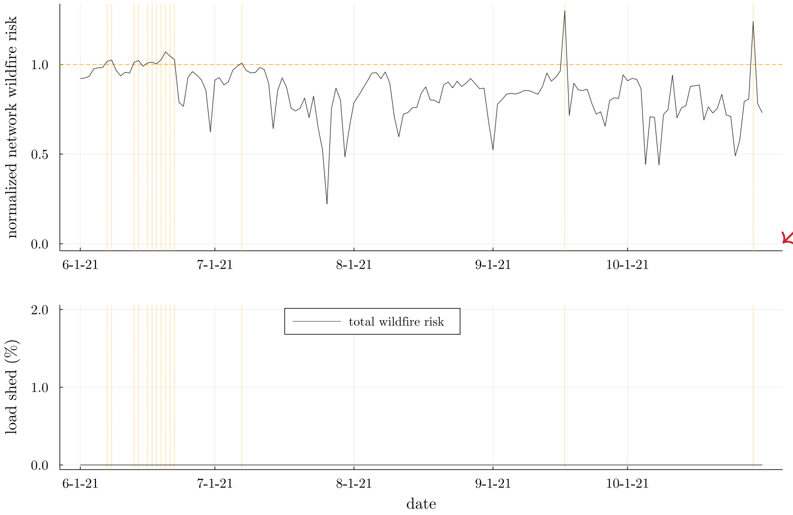
2021 Wildfire Season Simulation



- \$500M Budget, $\alpha = 0.8$

2021 Wildfire Season Simulation



Date in 2021 season

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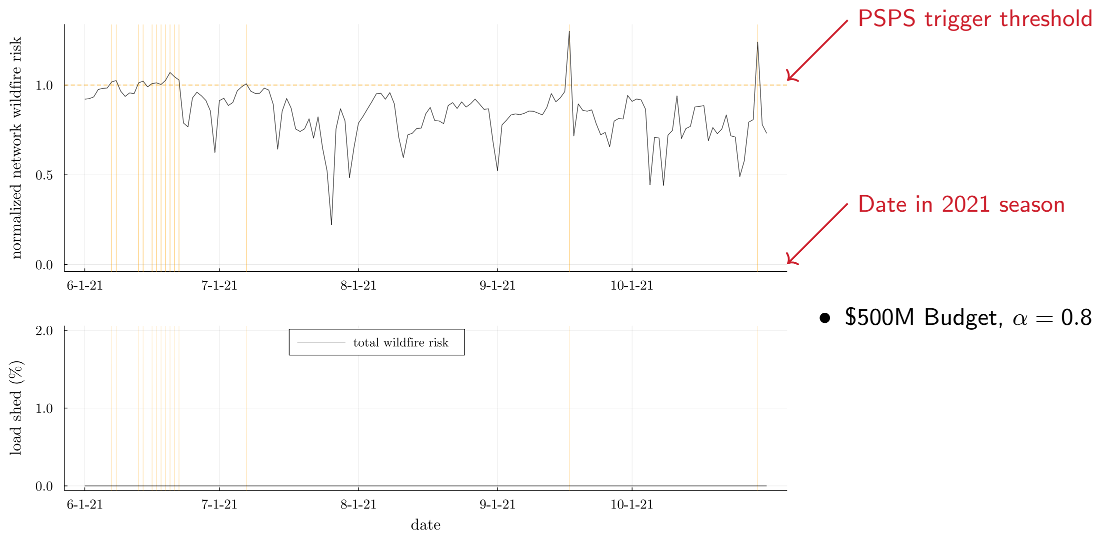

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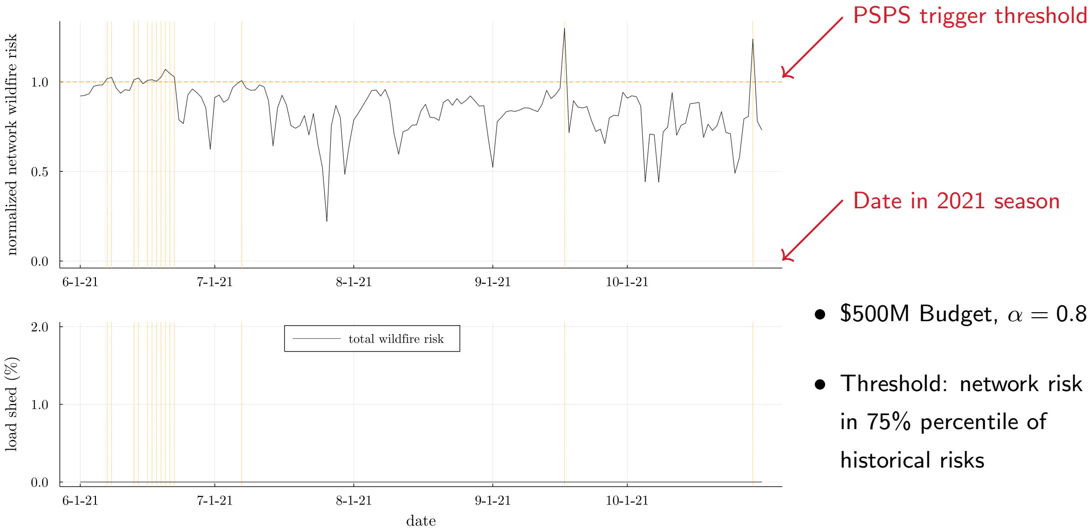
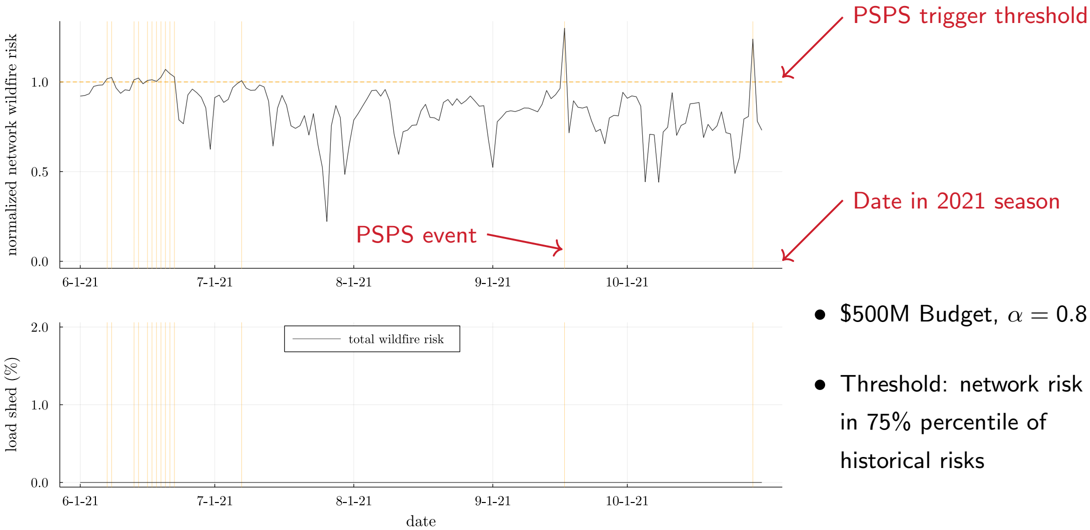


- \$500M Budget, $\alpha = 0.8$
- Threshold: network risk in 75% percentile of historical risks

2021 Wildfire Season Simulation



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2021 Wildfire Season Simulation

PSPS trigger threshold

Date in 2021 season

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2021 Wildfire Season Simulation

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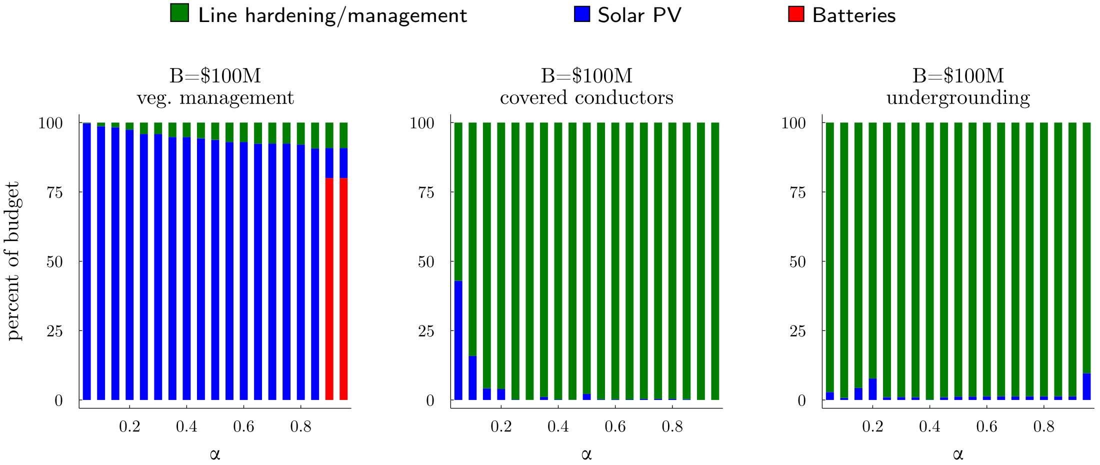
Budget Breakdown



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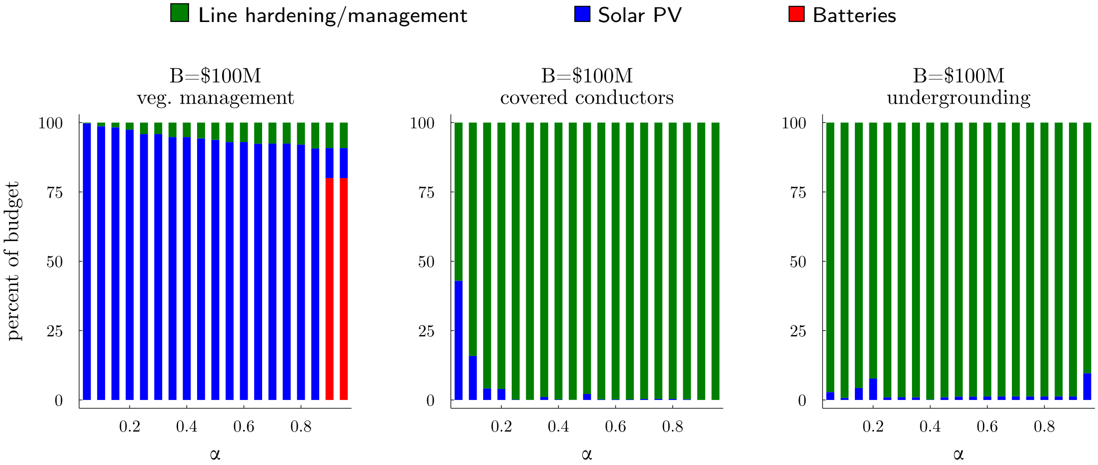
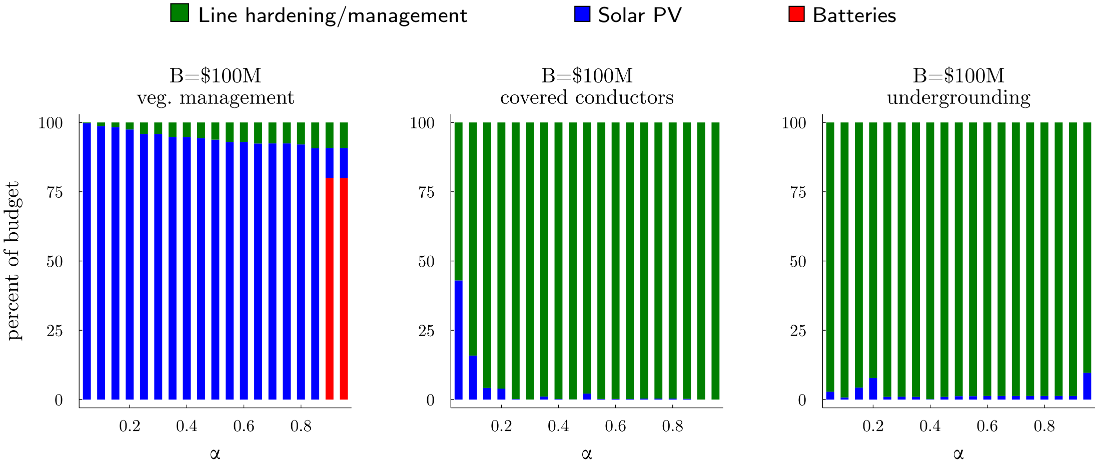


Low α,
prioritize wildfire
risk reduction

Budget Breakdown



Low α,
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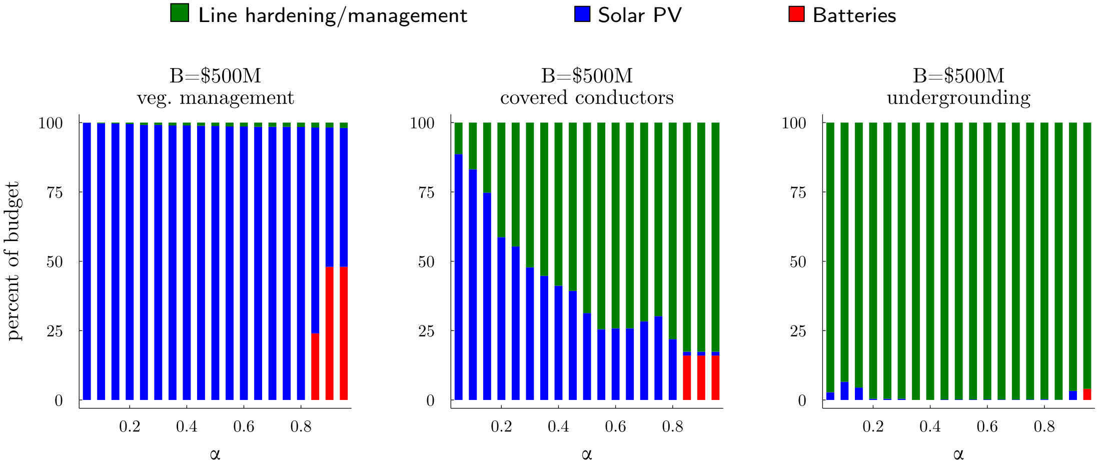
risk reduction

High α,
prioritize load
shed reduction

Budget Breakdown



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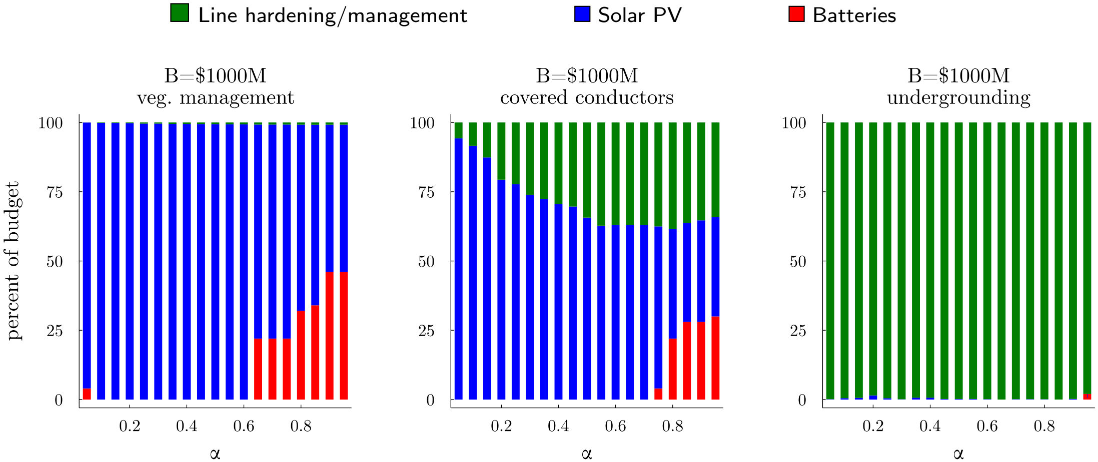

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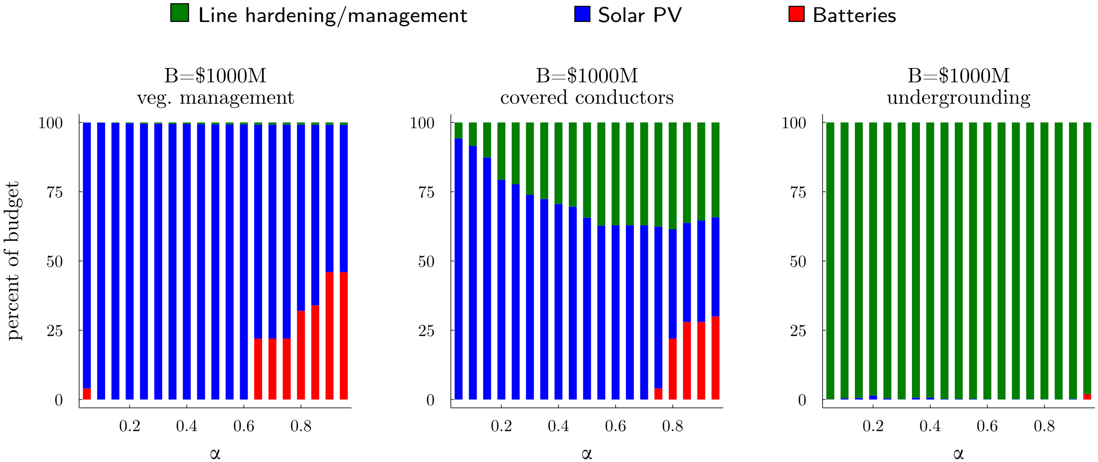

Low α,
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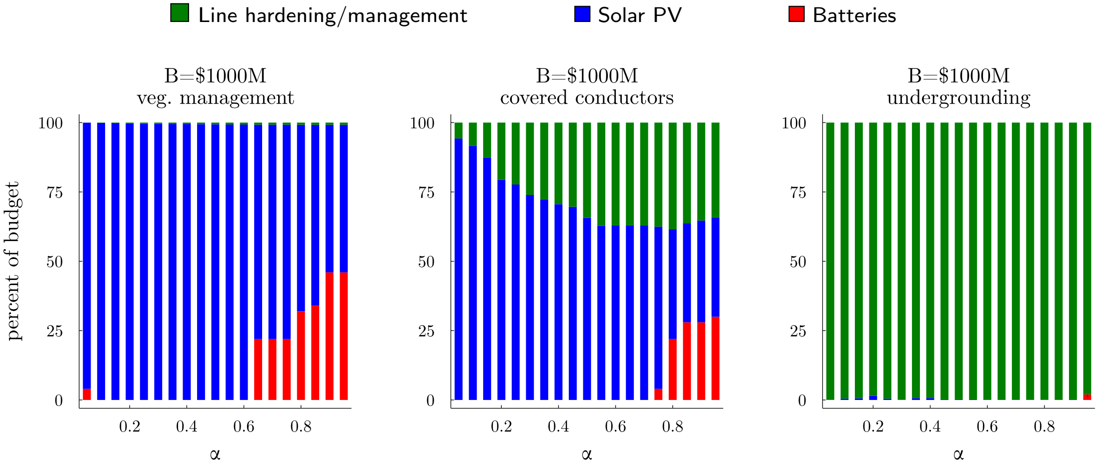
1. Almost entire budget on undergrounding

Budget Breakdown

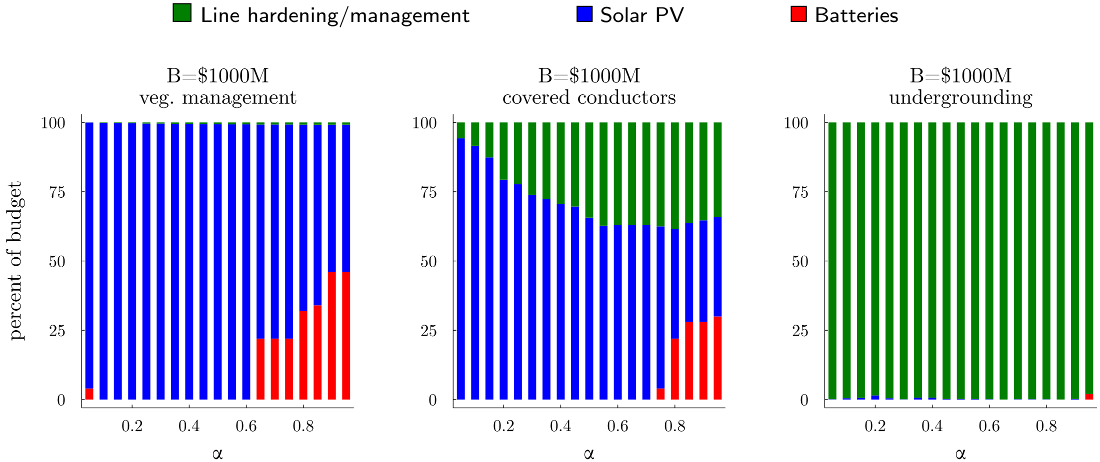


Low α, prioritize wildfire risk reduction

High α, prioritize load shed reduction

2. Low $\alpha \Rightarrow$ de-energizing reduces risk more

Budget Breakdown



Low α, prioritize wildfire risk reduction

High α, prioritize load shed reduction

3. High $\alpha \Rightarrow$ connectivity makes batteries more useful