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Building Community Resilience Across California

A Statewide Analysis of Climate Vulnerability and Resilience Hub Potential

2024

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About PSE Healthy Energy

PSE Healthy Energy is a nonprofit research institute dedicated to supplying evidence-based scientific and technical information on the public health, environmental, and climate dimensions of energy production and use. We are the only interdisciplinary collaboration focused specifically on health and sustainability at the intersection of energy science and policy. **Visit us at psehealthyenergy.org and follow us on X @PhySciEng**.

About Asian Pacific Environmental Network

Asian Pacific Environmental Network (APEN) is an environmental justice organization with deep roots in California's Asian immigrant and refugee communities. Since 1993, we've built a membership base of Laotian refugees in Richmond, Chinese immigrants in Oakland, and Asian immigrants and refugees in the South Bay region of Los Angeles. Through building an organized movement, we strive to bring fundamental changes to economic and social institutions that will prioritize public good over profits and promote the right of every person to a clean and healthy environment in which their communities can live, work, learn, play, and thrive.

About Communities for a Better Environment

Communities for a Better Environment (CBE) is a statewide Environmental Justice organization building people power in low-income and communities of color in Richmond, East Oakland, Wilmington, and the South East Los Angeles Cities. Using our triad model of Organizing-Research-Legal, we have led successful campaigns and projects that empower CBE youth and adult members to reshape their communities and environment. Visit us at cbecal.org and follow us on Instagram at @cbecal.

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Introduction

Climate change is increasing the frequency and intensity of extreme weather in California. Many communities now face a range of overlapping climate-related hazards, including dangerously high heat, power outages, and wildfire smoke. However, in certain communities, climate hazards compound with underlying factors, such as socioeconomic challenges and environmental pollution, to create particularly high levels of climate vulnerability. Protecting these vulnerable communities requires resilience solutions that address both the short-term risks posed by extreme weather and everyday resilience challenges experienced by communities.

One emerging solution is the concept of **resilience hubs**, defined herein as "physical institutions that offer space for community members to gather, organize, and access resilience-building social services on a daily basis, and provide response and recovery services in disaster situations."[1] Outfitting resilience hub facilities with solar arrays and batteries (referred to hereafter as **solar+storage resilience hubs**) can deliver distinct advantages for community resilience by keeping essential services online during power outages. Because resilience hubs are permanent, they have the advantage of providing services on an on-going basis that can help address the underlying drivers of vulnerability within at-risk populations. This permanence sets resilience hubs apart from other forms of emergency response, such as emergency shelters, and is essential to strengthening a community's resilience before disaster strikes.

Yet on the ground across California, resilience hub development has proven both complex and difficult to fund. In communities such as Richmond in the Bay Area and Wilmington in Los Angeles, community members have dedicated significant time to ensuring resilience hub design and operation meet local needs and have faced challenges securing funding from a patchwork of existing state incentives and private funders. As statewide support for resilience hubs emerges, policymakers must also navigate challenges inherent in resilience hub policy design. For instance, how do we identify and prioritize the communities which might benefit most from a hub? And how can incentives and policies be designed to help communities overcome financing barriers?

This report provides analysis and recommendations to support state and local leaders navigating common challenges in resilience hub design and deployment. Our findings and recommendations are based on a statewide analysis and local case studies conducted by PSE Healthy Energy in collaboration with Communities for a Better Environment and Asian Pacific Environmental Network.

In **Section 1** of this report we analyze climate vulnerability across California and identify communities that may be most severely affected by climate impacts and chronic pollution threats. In **Section 2** we use an inventory of nearly 20,000 schools, community centers, libraries, and places of worship across California to analyze regional potential for solar+storage resilience hubs. Using this inventory, we assess how resilient energy can address community needs and identify potential barriers to funding and deployment. In **Section 3**, we discuss how to align state perspectives with community knowledge and priorities, and provide recommendations on how to support hub deployment for those who need it most.

WHAT IS A RESILIENCE HUB?

Resilience hubs are facilities that provide year-round services and support their communities before, during, and after emergencies.[1,2] They should:

- **Be community-driven.** Distinct from emergency shelters, hubs provide consistent programming and services that reflect local needs and priorities. This ongoing relationship between hub and community not only helps to establish trust, but ensures that services address the root causes of vulnerability and empower local residents to become more resilient long term.[3]
- **Provide resilience-building services.** Hubs help communities prepare for, withstand, and recover from emergencies. This could mean offering first aid training throughout the year, providing clean and cool air during a heat wave, or helping people access federal funds after a disaster.
- **Feature resilient, sustainable, and accessible design.** Hubs support the community with coordinated communication, resources for everyday needs and disaster mitigation, while also reducing carbon pollution. Renewable energy-based backup systems (such as paired solar+storage), are a key component of both carbon reduction and emergency management, providing resilient power to continue critical services even during power outages, while also lowering greenhouse gas emissions. Accessible designs, including ADA and transportation considerations, also make them accessible to everyone.

For more details, see USDN's 2019 report on Resilience Hubs.[2]

The technical methods and data supporting this analysis can be found on [PSE Healthy Energy's website](#).

1.0 Climate Vulnerability and Risk Across California

The Technical Advisory Council in California's Integrated Climate Adaptation and Resiliency Program defines climate vulnerability as the "degree to which natural, built, and human systems are at risk of exposure to climate change impacts."[4] In this section, we examine three critical components of climate vulnerability and their geographical intersection to identify areas in California that most need resilience investments and could benefit from easy access to resilience hubs. These components are **(Figure 1.1)**:

- **Population Sensitivity** refers to a population's inherent sensitivity to being harmed by exposure to climate hazards. It is influenced by various factors, including the population's health and demographic makeup, working conditions, and environmental pollution (e.g., air pollution, drinking water contamination, etc.).[5]
- **Adaptive Capacity** considers how quickly households and communities can prepare for and bounce back from disaster. This can be influenced by a range of factors, including historical disinvestment, lack of access to resources, and compounding social and economic stressors.[5]
- **Climate Exposure Risk** is the extent to which a population is exposed to climate hazards.[5]

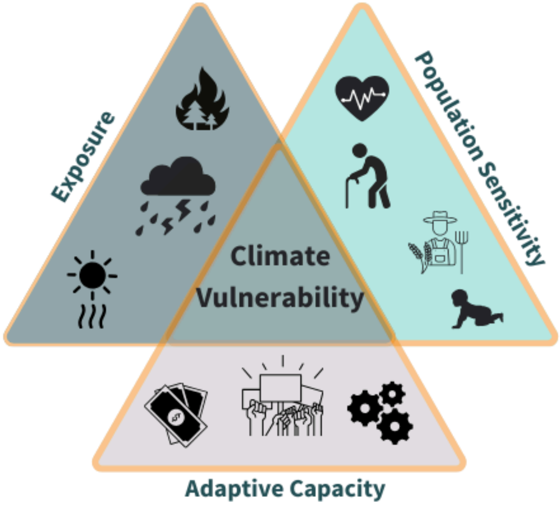


Figure 1.1: Components of Climate Vulnerability. Three overarching factors contribute to climate vulnerability: 1) the sensitivity of communities to climate impacts; 2) their adaptive capacity, which encompasses the ability to withstand and bounce back from climate impacts; and 3) a community's likelihood to face climate hazards.

1.1 Populations with Elevated Climate Vulnerability

California currently uses CalEnviroScreen, among other tools, to formally designate communities as disadvantaged. In the context of climate change, however, CalEnviroScreen lacks a climate framework and omits essential indicators needed to identify climate-vulnerable communities throughout the state. We created a **Climate Vulnerability Index (CVI)** to address this gap.

The CVI builds on CalEnviroScreen by adding climate vulnerability indicators that communities indicated are important. The CVI indicators are organized into two main domains that align with the definition of Climate Vulnerability: 1) Population Sensitivity and 2) Adaptive Capacity **(Figure 1.1)**. We then integrate the Population Sensitivity and Adaptive Capacity domains into the CVI score to identify populations with the highest climate vulnerability **(Figure 1.2)**.

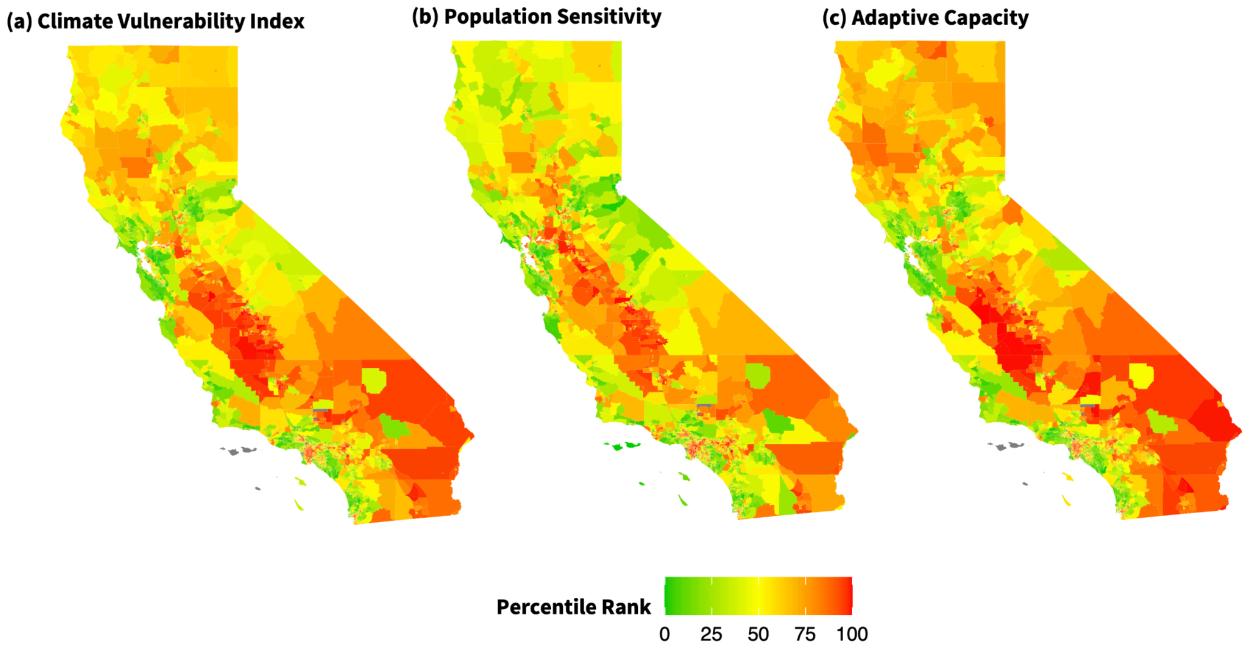


Figure 1.2: Climate Vulnerability Index. Maps show census tracts colored by their (a) climate vulnerability, (b) population sensitivity, and (c) adaptive capacity rankings relative to other tracts. Higher percentile rankings and reddish colors denote higher climate vulnerability, population sensitivity, and limitation in adaptive capacity.

The CVI is at the census tract level but we use California's thirteen economic regions and county divisions to discuss our results. Doing so allows easier discussion of climate vulnerability trends throughout the state. We divided the Population Sensitivity, Adaptive Capacity, and CVI scores into quartiles, assigning the vulnerability labels very high (75-100th percentile), high (50-75th percentile), medium (25-50th percentile), and low (1-25th percentile). In contrast to a dichotomous classification of vulnerable and non-vulnerable, this gradient approach to vulnerability classification avoids designating census tracts right below a cutoff as non-vulnerable and is likely more reflective of actual vulnerability patterns.

CLIMATE VULNERABILITY INDEX VS. CALENVIROSCREEN

Many very vulnerable communities from the CVI also overlap with the most vulnerable quartile using CalEnviroScreen. However, the CVI also highlights the need in some places not reflected in the State's tool—for example, the adaptive capacity challenges in the Redwood Coast and North State regions. The differences between CalEnviroScreen and CVI highlight the importance of using more than one climate vulnerability framework to ensure communities in need are captured, as all vulnerability indices have limitations.

Populations with High Sensitivity

Every community has a degree of population sensitivity, but some regions in California have noticeably higher levels. The three San Joaquin Valley regions (Northern, Central, and Kern) have the highest population sensitivity based on the indicators we analyzed. More than 75 percent of the census tracts in each of these regions have very high or high population sensitivity **(Figure 2b)**. Although air quality is a concern in all of California, long-term high levels of air pollution contribute significantly to population sensitivity in this area. In fact, most of the San Joaquin Valley is considered in serious or extreme non-compliance with the National Ambient Air Quality Standards for ozone or fine particulate matter. Communities in these regions also struggle with high rates of cardiovascular diseases and asthma and have a large population of outdoor workers, increasing their vulnerability to poor air quality. Within these regions, counties such as Kings, Madera, and Merced have some of the highest hospitalization rates for cardiovascular disease in California; and in Madera and Tulare, as much as 20 percent of the workforce works outdoors. The Los Angeles and Inland Empire regions follow the San Joaquin Valley in population sensitivity, with more than half of census tracts in these regions having very high population sensitivity. Like in the San Joaquin Valley, poor air quality and health disparities contribute to population sensitivity in Los Angeles and the Inland Empire.

Populations with Low Adaptive Capacity

Adaptive capacity is another component that influences how severely climate hazards impact communities. Based on the socioeconomic, social, and infrastructure capacity indicators we evaluated, the three regions of the San Joaquin Valley (North, Central, and Kern) also have the lowest adaptive capacity in California **(Figure 2c)**. More than 50 percent of the census tracts in the Central San Joaquin Valley and Kern are classified as having very high limitations in adaptive capacity. Poverty, health professional shortages, lack of green spaces, and low voting turnout (an indicator of social power and cohesion), among other factors, contribute to the regions' low adaptive capacity estimates. After the San Joaquin Valley, the Redwood Coast is another region with notably limited adaptive capacity. The rural nature of the Redwood Coast affects access to resources, such as the internet and hospitals. The Redwood Coast also has high poverty and low air conditioning prevalence, the latter of which may increase vulnerability given the projected increases in extreme heat days in that area.

RACIAL AND ETHNIC MAKEUP OF CLIMATE-VULNERABLE CENSUS TRACTS

On average, census tracts with very high climate vulnerability have higher Black and Hispanic population percentages relative to the state's average. On average, vulnerable census tracts are eight percent Black and 64 percent Hispanic, relative to the state averages of six and 38 percent, respectively. The average White Non-Hispanic population is 15 percent, and the Asian population is seven percent, which is lower than the state averages of 39 percent and 14 percent, respectively.

Overlapping areas of high population sensitivity and low adaptive capacity can lead to severe climate vulnerability. These communities likely have the greatest need for climate resilience investments. The CVI shows that, on average, Imperial, Kings, Tulare, and Merced counties have the highest climate vulnerability in California: in these counties, nearly all census tracts have high or very high climate vulnerability **(Figure 1.3)**. However, communities with very high vulnerability exist in nearly every county. For example, Fresno, San Joaquin, and Los Angeles are home to both census tracts with very high and low climate vulnerability. Developing strategies to target climate resilience investments to the most in-need populations is crucial to mitigate the inequities of climate impacts.

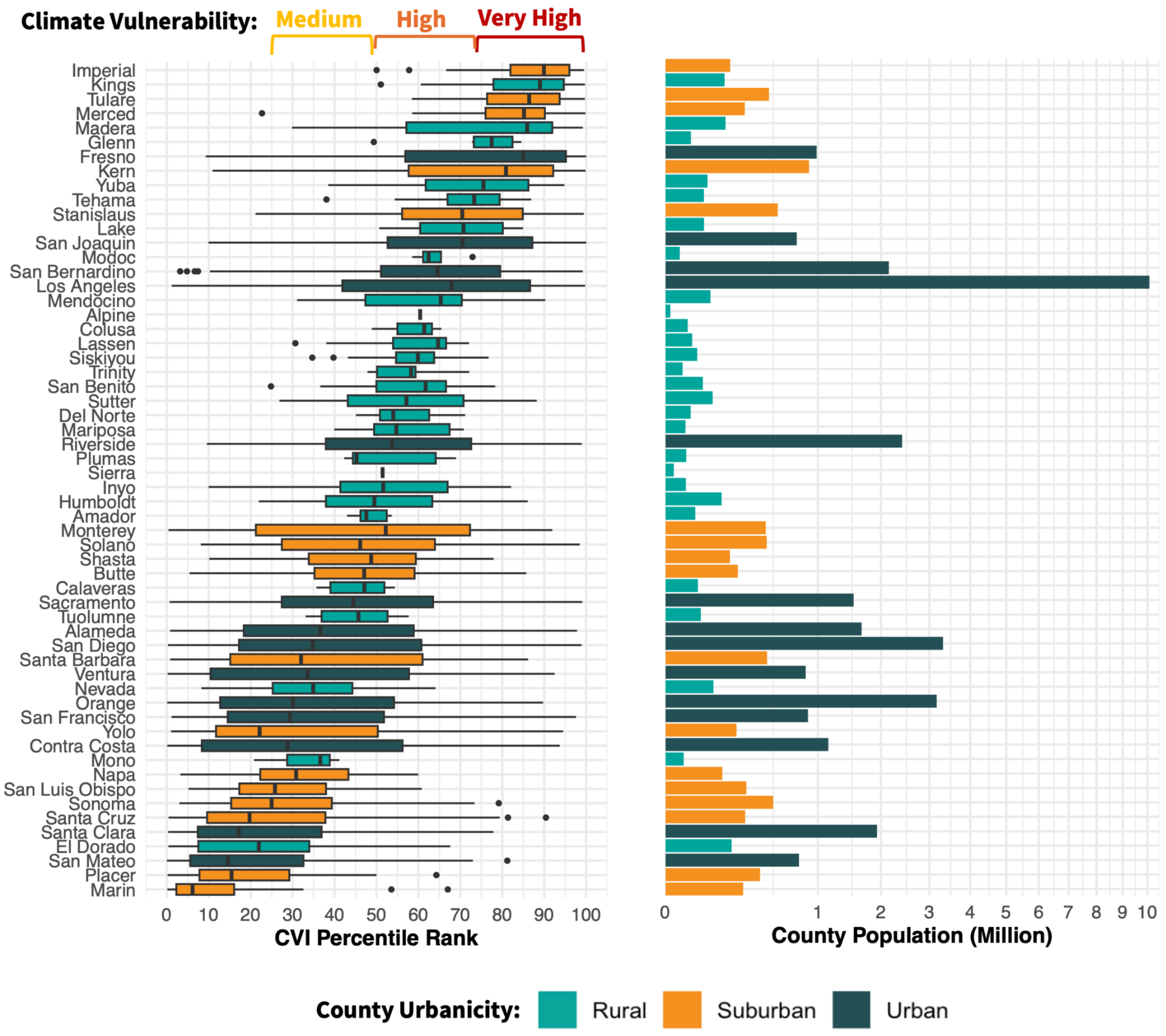


Figure 1.3: Climate vulnerability by county. Counties are ordered based on their climate vulnerability, with the ones with the highest average climate vulnerability appearing at the top. The boxplots for each county show the range of census tract CVI values within each county, and the bar chart on the right side shows population size. The X-axis in the population bar chart was scaled to improve the visibility of high population values.

As with any vulnerability index, the CVI cannot fully capture communities' experiences. Data limitations restrict the scope of analysis and constrain the climate vulnerabilities we can capture or characterize. For example, we found that data on tribal and native communities is particularly limited. Our analysis provides insight into statewide trends and should be supplemented with on-the-ground assessments of vulnerability and need.

1.2 Regions with Elevated Climate Risk

In addition to communities' adaptive capacity and sensitivity, their likelihood of facing climate hazards is a critical driver of climate vulnerability. Not all Californian's are equally at risk of exposure to threats such as extreme heat, wildfire smoke, and public safety power shutoffs **(Figure 1.4)**. And in areas where multiple climate hazards overlap or compound with underlying risk factors, the public health and safety risks of local populations are higher.

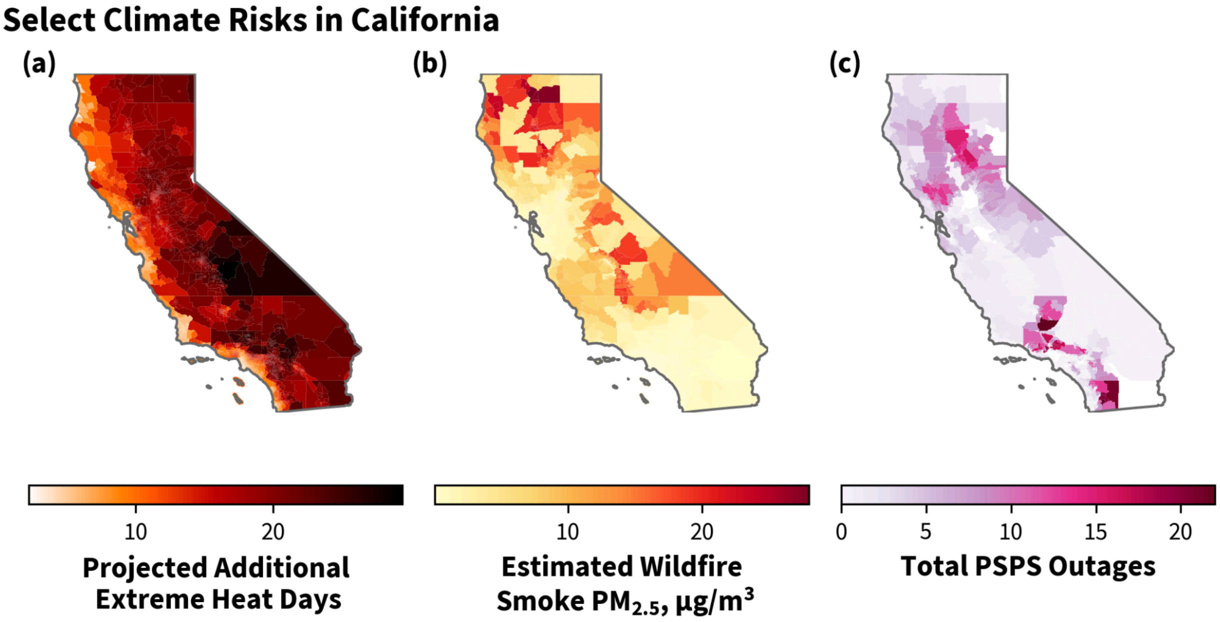


Figure 1.4: Climate risks mapped to census tracts. (a) Projected annual number of additional extreme heat days, 2030-2050.[6,7] (b) Estimated average historic additional PM2.5 over the years 2006-2020 due to wildfire smoke ($\mu g/m^3$).[8] (c) Average annual number of reported outages from 2013-2022 due to Public Safety Power Shutoffs.[9,10]

For example, some communities in Northern California are impacted by all three of the aforementioned hazards. When these occur simultaneously, households may be forced into potentially dangerous tradeoffs between opening windows to cool off or keeping them shut to keep out polluted air. Further south, communities in the Central Valley that already deal with high levels of chronic pollution face increasing extreme heat. Rising temperatures can lead to more ozone formation and trap more air pollution, increasing Valley residents' exposure risk.

Siting resilience hubs in areas that are more likely to experience dangerous climate impacts can ensure at-risk communities have access to the cooling, air filtration, backup power, and other protective services they provide. Understanding exposure trends can also be used to prioritize funding across the state.

1.3 Regions Facing High Vulnerability and High Risk

Vulnerable populations living in areas with significant climate risk have greater need for resilience hubs. **Figure 1.5** maps populations with high and very high climate vulnerability that also face higher threats of extreme heat, wildfire smoke exposure, and Public Safety Power Shutoffs. Regions facing overlapping risks are prominent in the Central Valley, as well as portions of the Inland Empire, the Sierras, and rural northern California. These areas should be prioritized for resilience hubs, which can help minimize risks from heat, poor outdoor air quality, and power outages.

OTHER DISASTER RISKS

This report focuses on extreme heat, wildfire smoke, and Public Safety Power Shutoff risk, yet many other risks exist. For instance, communities throughout California face risks from flooding, wildfires, and earthquakes. These risks should also be assessed and considered in resilience hub siting and design—including potentially avoiding certain sites, such as buildings built on or below slopes with high landslide risk—and may pose additional financial or design challenges not considered within this analysis.

Wilmington community members participating in community visioning and mapping in 2016. Photographer: Ernesto Arevalo.

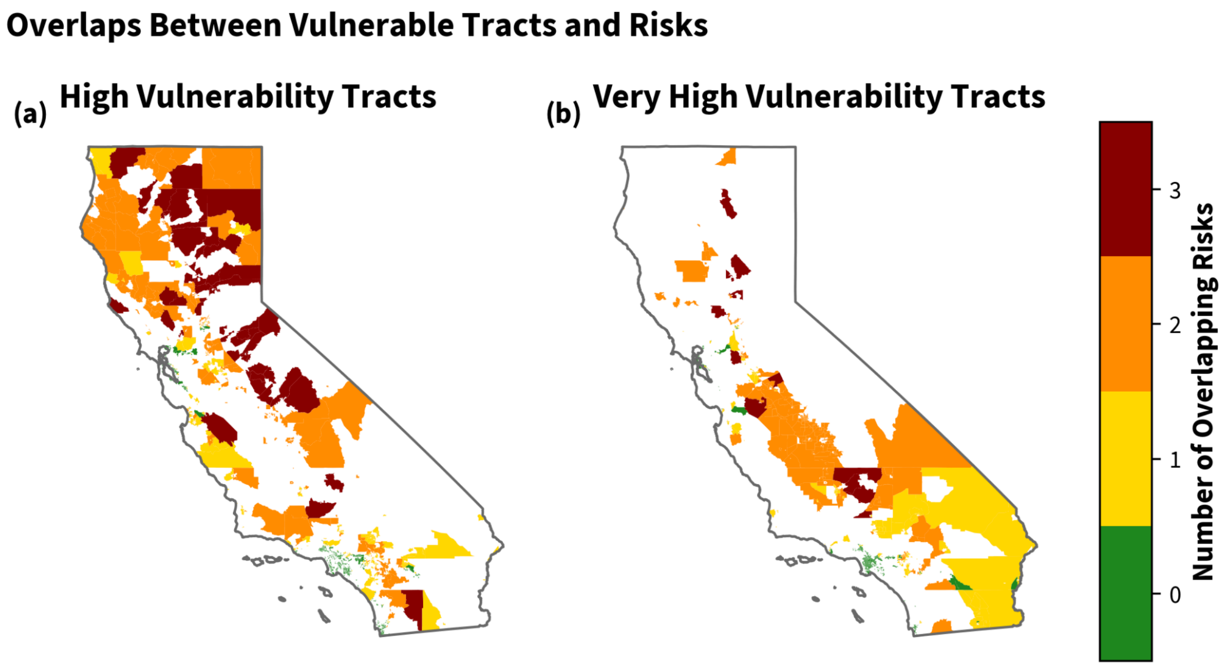


Figure 1.5: Overlaps Between Vulnerable Tracts and Risk. The number of significant climate risks faced by census tracts with (a) high or (b) very high vulnerability. For this figure, the top quartile of risk exposure was used to characterize significant climate risk, meaning more than 16.25 additional extreme heat days each year, wildfire smoke greater than ~1.34 $\mu g/m^3$, and two or more Public Safety Power Shutoffs.

Existing policy that allocates resilience funding based on a restrictive income or vulnerability thresholds does not effectively support all communities with high climate vulnerability and risk. For instance, only communities with a CalEnviroScreen score above the 75th percentile may qualify for certain tranches of incentives. This approach can hide a community's actual need, either by ignoring climate risks or obscuring pockets of much higher vulnerability within a census tract. Updating threshold-based criteria can help ensure funding is accessible where it is needed.

For example, a community Southeast of Chico near Paradise ranks in the 60th CVI (52nd CalEnviroScreen) percentile but faces numerous climate hazards. While they may not qualify for certain resilience funding, they might need it as much as a community in San Diego that ranks just above the 80th percentile in both metrics but faces far fewer climate risks.

Communities facing multiple overlapping hazards should also be able to easily combine resilience funding from multiple sources, which is currently difficult to do. (See ‘Additional barriers to resilient solar+storage adoption at hubs’ in **Section 2.3**.) For example, a hub may need to stack funding for social services with funding for capital improvements, but such funding is often only available from different sources on mismatched timelines.

COMMUNITY-DRIVEN DESIGN

Ensuring resilience hubs provide the right ongoing and emergency services requires careful consideration of a range of factors, including community needs and desires, solar+storage design trade-offs, and financial viability. For example, communities facing extreme heat or poor air quality may want enough resilient power to run their HVAC systems during an outage. However, these systems are energy intensive and may limit the time a solar+storage system can provide air filtration and cooling, or dramatically increase costs. On the other hand, not every hub will require a large backup power system. In some situations, smaller systems may provide enough power to provide nearby residents with a safe place to gather, charge electronics, store refrigerated medications, and more. Understanding community needs and priorities will help resilience hub designers determine which services need to have reliable backup power during an outage and which are better suited to meeting community needs before or after a crisis.

Another important reason that resilience hub services should be designed with and by the community is to ensure that hubs are trusted by the people they serve. The importance of community trust has been demonstrated with emergency cooling centers which, despite becoming more common, are often underutilized. Reporting shows this occurs in part because cooling centers are short-term facilities that are relatively unfamiliar, hard to get to, and which lack the underlying trust that exists within well-established and community-driven spaces.[11] What’s more, many emergency cooling centers do not have backup energy to ensure consistent services during a power outage. These limitations would not be true of a well-designed and resourced solar+storage resilience hub.

2.0 Solar+Storage Potential Across California

Regional differences in the cost of electricity, weather patterns, and the availability of trusted, solar-ready hub facilities can create barriers to solar+storage adoption at potential resilience hub sites.

2.1 Identifying Suitable Facilities

Typically, the most effective way to build resilience hubs is to use buildings that already provide community services, such as community centers, schools, community colleges, and houses of worship. We identified roughly 18,000 of these sites for this analysis and estimated the area available for solar on their rooftops. While this list is incomplete, it allows us to investigate how solar+storage can be deployed at existing sites to build resilience.

Based on the sites analyzed, we see that some communities have fewer choices to establish resilience hubs in existing buildings. In **Figure 2.1**, we map the percentage of people living further than three miles from the nearest site found in our inventory. In these primarily rural areas, many would need to travel far to gain access to hubs using existing sites. For these communities, it may be necessary to include a broader array of building types in resilience hub planning, such as multi-family homes, post offices, or groceries stores. Additionally, outreach and support may be needed to build the internal capacity of locally-trusted organizations in these regions. Transportation challenges will also need to be addressed. In some cases, other resilience investments may take priority over resilience hubs.

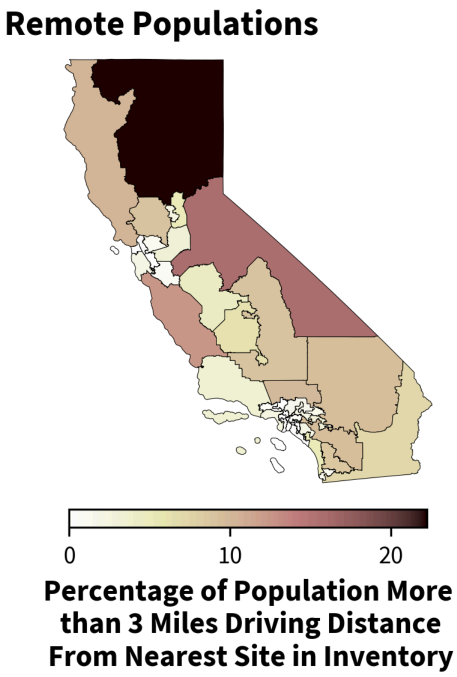


Figure 2.1: Remote Populations. Percentage of population living in census block groups whose centroids are greater than a three-mile driving distance from the nearest inventoried site. Regions represent California Senate districts and have populations of roughly one million persons each.

2.2 Policy Barriers to Resilience

The structure of utility rate designs can affect the affordability of resilient solar+storage systems, even in places with similar climates, energy needs, and available sunshine. One important example of this in California is utility Net Energy Metering (NEM) policy, which allows customers to sell the solar power they generate on their roofs back to the utility in return for credits on their electricity bills. Utilities that have higher electricity prices and who pay their customers more for solar power tend to make solar+storage investments more cost effective. In turn, this tends to increase the number of customers adopting solar+storage, the size of solar+storage systems built, and the overall resilience on-site. While more solar+storage is generally good for resilience, high electricity rates can also decrease energy affordability and some net metering schemes can reward wealthier solar+storage adopters at the expense of those who face barriers to adopting these systems, (e.g., renters and people with lower incomes or lack of credit).

Table 2.1 summarizes the impact that four features of rates have on solar+storage adoption (both on the number of sites that might adopt and the size of the systems implemented), and how the rate impacts energy costs for solar+storage adopters and non-adopters, assuming all other factors are equal. Most rates are designed such that when energy (measured in kilowatt hours or kWh) rates are higher, demand (power, measured in kilowatts or kW) charges are lower. Demand charges are based on the highest monthly and annual power use at a site, as the utility must build infrastructure to meet that peak demand, even if average energy use is much lower. Time-of-Use (TOU) rates tend to charge more for electricity when it is harder and more expensive to deliver (such as hot summer afternoons and warm evenings after solar power drops off), while non-TOU rates tend to provide electricity at the average cost of delivery.

Table 2.1: Utility Rate and Net Energy Metering Impacts on Solar+Storage

Electric Rate Type	Rate Range	Impact on System Capacity		Impact on Affordability		Notes and Issues to Consider
		Solar (kW)	Storage (kWh)	Adopters	Non-Adopters	
Average Cost per (kWh)	Low (≤ $0.30)	🟥 ↓	🟥 ↓	🟥 ↓	🟩 ↑	Low prices tend to be good for affordability, but disincentivize solar+storage.
	High (>$0.30)	🟩 ↑	0	🟩 ↑	🟥 ↓	Adopting solar can be cost-effective, but non-adopters may face affordability challenges. Storage adoption will be a function of TOU and demand rates.
Time-of-Use Rates ($/kWh)	None (Flat Rate)	🟥 ↓	🟥 ↓	0	0	While flat rates are simple, they do not charge for the cost to deliver electricity when it is hardest and most expensive.
	TOU w/ Day > Eve	🟩 ↑	🟩 ↑	🟩 ↑	🟨 ↓	Solar adopters can reduce the amount of energy purchased at the highest daytime TOU rates, but non-adopters with inflexible energy needs cannot.
	TOU w/ Eve > Day	🟩 ↑	🟩 ↑	🟩 ↑	🟨 ↓	Solar+storage adopters can reduce the amount of energy purchased at highest evening TOU rates, but non-adopters with inflexible energy needs cannot. Impact depends upon how much energy is used in the evenings.
Demand Charges ($/kW)	Low (≤ $10)	0	🟥 ↓	🟨 ↓	0	Low demand charges make batteries less cost-effective. Note that when these charges are not explicit, they are included as higher energy rates for everyone.
	High (>$10)	🟩 ↑	🟩 ↑	🟩 ↑	🟨 ↓	Presents affordability challenges, especially for inflexible power needs. Batteries can reduce these impacts.
Net Energy Metering Sellback Prices ($/kWh)	Low (wholesale)	🟥 ↓	🟥 ↓	🟥 ↓	0	Makes solar+storage systems less cost-effective and fails to promote climate impacts and ancillary benefits achievable from virtual power plants.
	Optimized	🟩 ↑	🟩 ↑	🟩 ↑	0	Can increase affordability of resilience for solar+storage adopters.
	High	🟩 ↑	🟩 ↑	🟩 ↑	🟨 ↓	Increases risk of cost-shift as adopters' bills shrink and non-adopters' bills must cover infrastructure.

Table 2.1. Utility Rate and Net Energy Metering Impacts on Solar+Storage. Summary of utility rate and Net Energy Metering impacts on solar+storage adoption, and on affordability for solar+storage adopters and non-adopters. Green boxes and up arrows indicate desirable outcomes, yellow boxes indicate risks and potentially undesirable outcomes, and red boxes

highlight the worst outcomes. Arrow size corresponds to the magnitude of the potential outcome.

While utility rates should not be used as the sole method to incentivize investments in resilient solar+storage, the impact of rates and NEM policies on solar+storage incentives must be taken into account to understand where resilience will need additional support from grants, green bank financing, or other mechanisms.

2.3 Regional Design Considerations

From California's mild coastal environments to its increasingly hot Central Valley, the characteristics of different regions shape how energy is used, how much solar energy can be produced, and what is required for establishing climate-resilient sources of electricity.

Using the Critical Load-to-Solar Ratio, we identify where solar+storage resilience hubs may face greater challenges in meeting essential energy needs (or critical load). The Critical Load-to-Solar Ratio is defined as the critical energy needs (energy out) over the potential solar generation (energy in). Using this calculation, we see that across much of California it is most difficult for solar+storage to meet the full energy needs of facilities during the winter. This is especially true in Northern coastal regions (Del Norte, Humboldt, Mendocino counties) where short, foggy days make sunlight poorest (see red region in **Figure 2.2**). Winter electricity resilience is likely to become even more difficult in the coming years as more buildings electrify space and water heating.

ADDITIONAL BARRIERS TO SOLAR+STORAGE

Hopeful solar+storage adopters often face numerous barriers, including difficulties in aligning funding from multiple sources, delayed interconnection timelines, and other technical challenges.

Aligning Funding. Organizations often rely on multiple funding sources to support different resilience hub needs, including building purchases or upgrades, solar hardware, battery hardware, staff, and year-round programming. These unique sources often have restrictive and sometimes conflicting rules and timelines. Coordinating and aligning numerous grants can force organizations to make design decisions that are not optimal.

Excessive Interconnection Timelines. Solar+storage installations can sit idle for months to years waiting for utilities to approve their connection to the grid, which in turn delays resilience services and bill savings. Some delays may result from inclusion of components (panels, batteries, inverters) that are not on the utility's pre-approved list, but often sites wait with little or no information on the reasons for delay. One bottleneck appears to be a lack of utility staff working to approve interconnections.

Technical Challenges. Many technical barriers exist that may slow interconnection timelines and limit the size of solar+storage installations, including utility grid hosting capacity (can the grid handle additional power in that location?) for distributed renewables, a lack of predictable NEM prices, and the availability and timing of funding. Sites are also often prohibited from combining solar+storage across multiple utility meters on a campus or adjoining buildings—or they incur additional expenses and/or permitting challenges by doing so. A number of technologies and policies can help overcome these barriers and expedite the deployment of solar+storage for resilience.

Virtual Power Plants (VPP). VPPs are aggregations of distributed energy resources that provide power and energy to the grid like a power plant. Rules and processes enabling solar+storage to be pooled into virtual power plants (VPP), including mechanisms to pay generators for energy and ancillary services, will enable more and larger solar+storage adoption. Aggregation need not be local, but rules that allow campus-level VPPs to virtually merge multi-parcel and multi-meter solar+storage systems can increase the capabilities of resilience hubs.

Microgrids. Allowing multi-parcel microgrids to "island" and operate independently from the electric grid could further increase resilience by allowing communities to network backup power across multiple facilities during power outages.

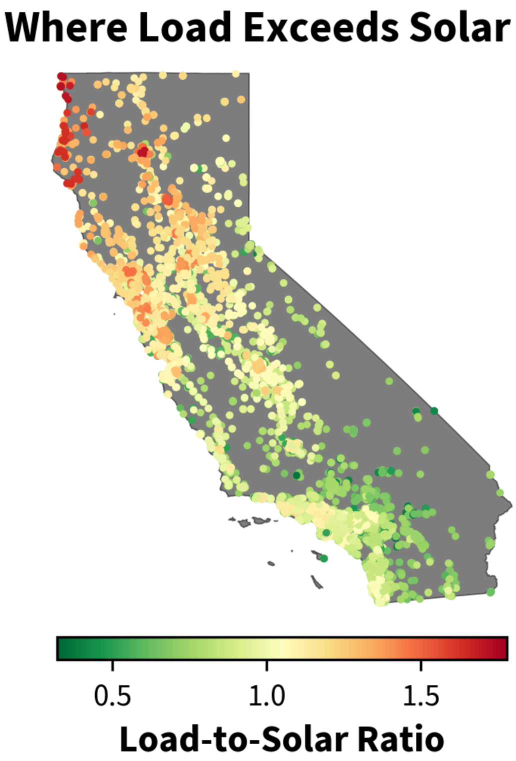


Figure 2.2: Where Load Exceeds Solar. Assuming half of a building's energy needs are critical services that must continue running during a 96-hour power outage, this map shows the ratio of critical energy needs to potential solar input for each candidate resilience hub site. Green indicates where, on average, plenty of sunlight is available to meet resilience needs in the day and charge up batteries to serve nighttime demand. Yellow shows where load matches solar input on average, and where more battery storage is needed to meet energy demand during power outages. Orange and red sites show where solar production cannot easily meet energy needs, and much more storage is necessary to make up the difference.

Urban areas present additional challenges. Major population centers have better sunlight than the North Coast, but their buildings tend to have more floors and greater floor area. This dynamic can result in rooftop-constrained solar installations, which have a harder time meeting energy needs. Urban areas along the Central Valley, in the Bay Area, and Los Angeles all show higher load-to-solar ratios than nearby suburban or rural regions. These areas will have a harder time overcoming the low solar radiation than their rural counterparts because they are less likely to have real estate available for off-roof solar.

An additional concern in urban areas are heat island effects from dense concentrations of buildings and pavement, along with a lack of tree cover, which can increase local temperatures by as much as 20°F, further increasing energy needs for cooling.[12,13]

2.4 Funding and Affordability Trends

The interaction of utility rates and climate zones drives both the costs and potential savings associated with solar+storage at resilience hubs. **Figure 2.3a** shows International Energy Conservation Code (IECC) climate zones (described in **Table 2.2**) next to **Figure 2.3b** which shows Investor Owned Utility (IOU) service areas and **Figure 2.3c** which shows additional utility service territories. The PG&E service area cuts across the most climate zones (six of them: 3B, 3C, 4B, 4C, 5B and 6C). Climate zone 3B intersects the most utilities (ten of them: PG&E, SMUD, MID, TID, SCE, LADWP, COR, COAPUD, SDG&E, and IID).

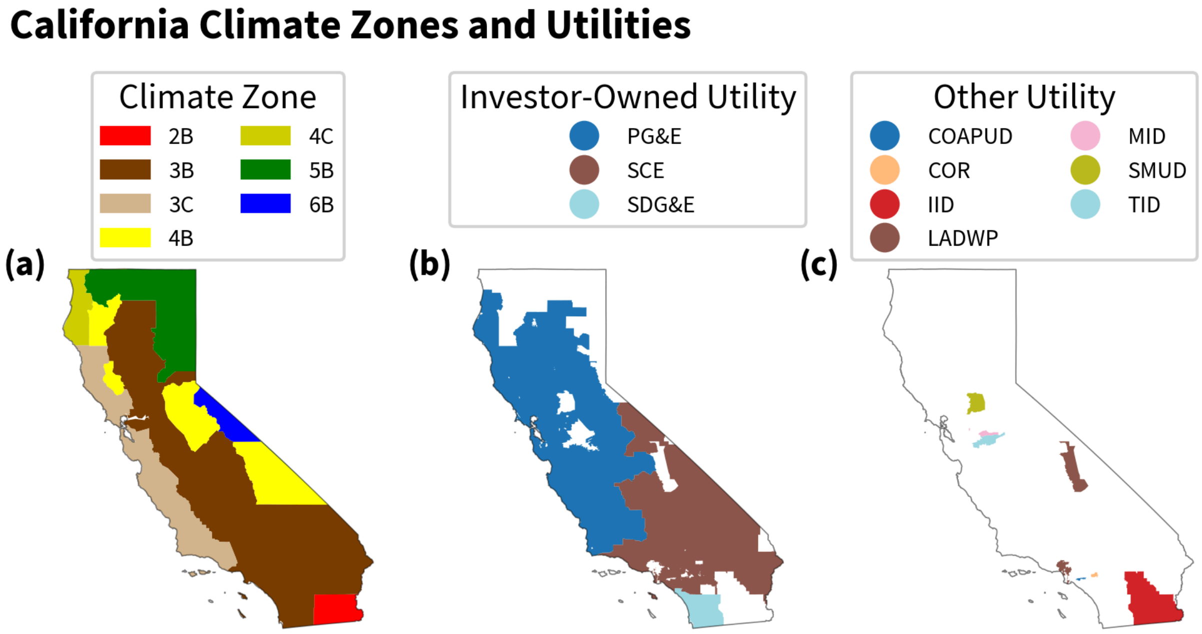


Figure 2.3: California Climate Zones and Utilities. IECC climate zones (a), investor owned utility service areas (b) and other utility services areas (c).

Table 2.2: IECC Climate Zone Descriptions

IECC Climate Zone	Description	IECC Example City	Characteristic California Regions	California Population (Thousand)
2B	Hot, Dry	Phoenix, AZ	Imperial Valley	180
3B	Warm, Dry	Las Vegas, NV	San Diego, Los Angeles, Inland Empire, Central Valley, Eastern Bay Area	29,570
3C	Warm, Marine	San Francisco, CA	Santa Barbara, San Francisco Bay Area	8,360
4B	Mixed, Dry	Albuquerque, NM	Sierra Foothills, Coastal Cascade Mountains	440
4C	Mixed, Marine	Seattle, WA	North Coast	160
5B	Cool, Dry	Boulder, CO	Northern Sierras, Cascade Mountains	210
5C	Cold, Dry	Helena, MT	Lake Tahoe, Eastern Sierra Mountains	15

Table 2.2. IECC Climate Zone Descriptions.

Climate zone-utility interactions can be observed in **Figure 2.4**, which shows boxplots of return on investment (ROI) for solar+storage owners in each utility/climate zone region. ROI is the ratio of net present value (NPV) to upfront capital costs. NPV is a financial metric that combines the cost of building and operating the system with the bill savings experienced over the lifetime of the system. Where NPV and ROI are greater than zero indicates a good financial investment, and solar+storage systems can likely be supported with access to financing rather than grants. Where NPV and ROI are negative, grants will be required.

Positive ROIs cover regions where more than 15.3 million Californians live and work, including all of SDG&E territory and most of PG&E territory. SDG&E has the highest ROI across the state, where the median ROI across the utility exceeds 0.5, indicating that every dollar invested in solar+storage results in total bill savings of more than $1.50 over the system lifetime. The positive ROI across all of SDG&E indicates solar+storage is cost-effective, due to a combination of high utility rates combined with warm, sunny weather year-round. Similarly, most of PG&E territory (other than climate zone 4C in Northern Coastal California) has positive ROI, earning back about $1.20 for each dollar invested in solar+storage.

Regions with negative solar+storage ROIs cover a population of 17.8 million people, representing more than half of Californians. These areas will require grant support for solar+storage systems at resilience hubs. Climate zone and utility rates both influence ROI. PG&E in climate zone 4C (North Coast) is the first negative ROI shown, illustrating that despite PG&E's high rates supporting solar+storage, the lack of sunlight in this region makes solar+storage less cost-effective. Despite having the same climate zone as SDG&E (zone 3B), ROI in IID drops to below zero because of IIDs lower electricity rates. ROI drops further in the hottest climate zone in California—zone 2B—where despite plentiful sunlight, high temperature driven cooling needs exceed the capacity of rooftop solar, and additional storage is necessary for resilience. However, the rooftop solar limitation should be relatively easy to overcome with ground-mount, parking lot, or other off-roof solar options in these mostly-rural areas.

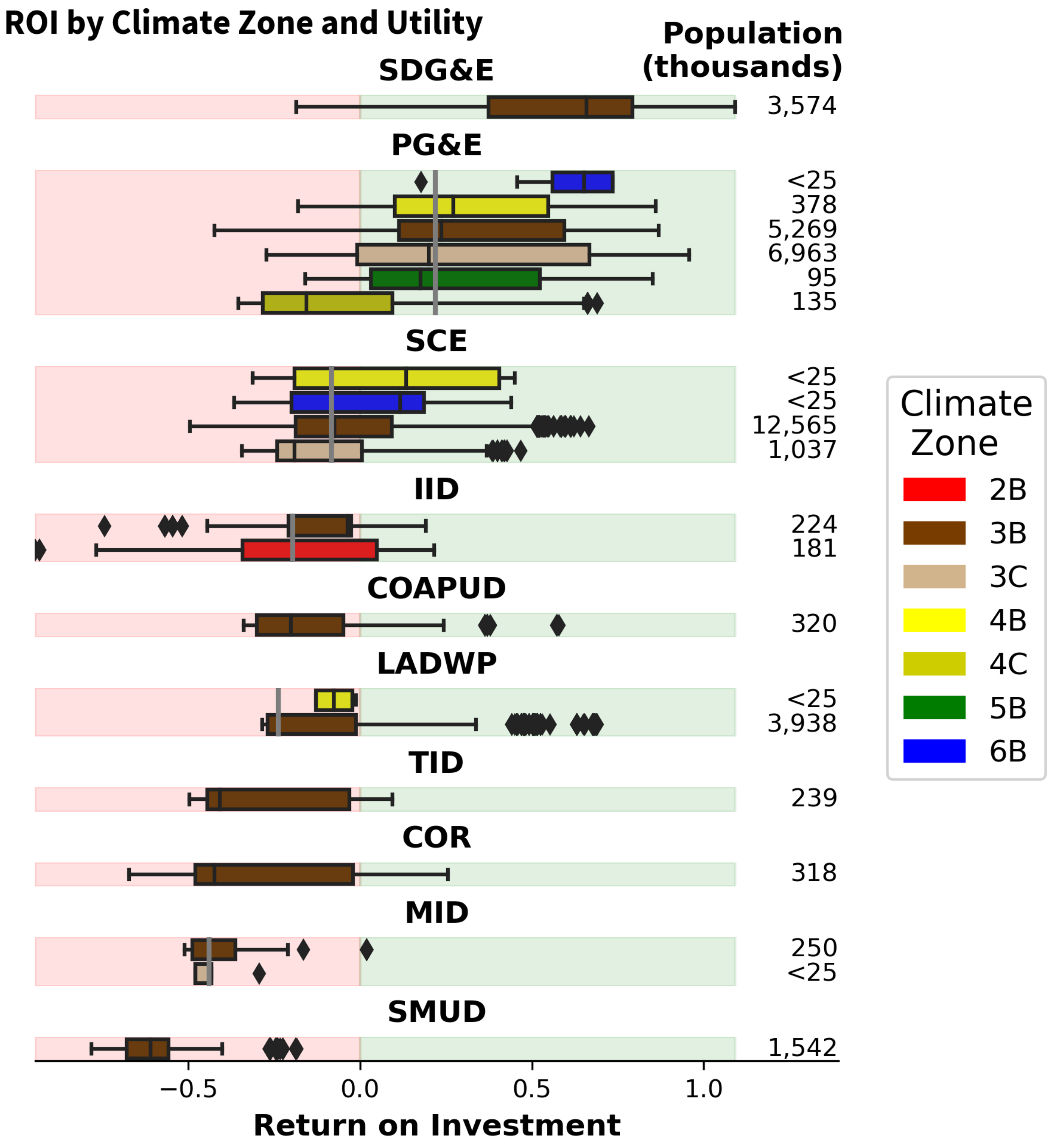


Figure 2.4: ROI by Climate Zone and Utility. Boxplots are sorted by median ROI across the utility (gray line across each utility), and then by median ROI in each climate zone for that utility. Population in each utility/climate zone combination is shown next to the Y-axis. SCE, COAPUD, LADWP, and COR service territories include climate zones 4B and 6B in the Sierras, 3B in greater Los Angeles and in the Southern Central Valley, and 3C along the coast North West of Los Angeles. MID, TID and SMUD all serve customers in climate zone 3B in the

Central Valley, all with negative ROI for solar+storage driven by utility rates. SMUD has the worst ROI across the state, losing $0.70 per dollar invested in solar+storage, indicating significant portions of solar+storage funding would have to come from grants.

2.5 Emissions Benefits

One of the important benefits of solar+storage deployments will be reductions in greenhouse gas emissions, along with other co-pollutants. **Table 2.3** summarizes the total potential reductions for systems optimized for everyday operations and for the resilience scenario presented here, if all 18,000 identified candidate sites were outfitted with solar+storage. Total installed solar and battery capacity for each scenario is shown for reference.

Table 2.3: Emissions Reduction Potential

	Everyday Operations Design	Resilience Design (50% of Normal Load)
Total Solar Power	5.5 GW	8.7 GW
Total Percent of Rooftop Solar Potential	59%	93%
Total Storage Power	1.8 GW	3.8 GW
Total Storage Energy	11 GWh	41 GWh
CO_2 Annual Emissions Reduction	3.3 million tons	5.4 million tons
NO_x Annual Emissions Reduction	200 tons	360 tons
$PM_{2.5}$ Annual Emissions Reduction	190 tons	300 tons

Table 2.3. Emissions Reduction Potential. Emissions reduction potential across 18,000 candidate sites if outfitted with solar+storage designed to meet everyday operational needs and designed to meet resilience operational needs (50 percent of normal load for 96 hours).

2.6 Policy and Design Recommendations

Policy measures to address the factors limiting solar+storage deployment at potential resilience hub sites across California include:

- **Incentivize Larger Solar Installations.** Remove policy barriers to larger solar installations, including export limits and challenges for microgrids permits. In areas where larger solar arrays are impossible on-site, policies that support microgrids, VPP, campus VPP, and multi-parcel islanding may help increase solar installation sizes, and thus increase energy available to resilience hubs at these sites.
- **Support Investments in Efficiency and Other Renewable Technologies.** In addition to solar+storage, investments in energy efficiency and alternative resources (e.g. district heating, geothermal heat pumps) should also be explored, especially in low-sunlight regions.
- **Explore Different Funding Models for Solar+Storage Resilience Hubs.** Funding for solar+storage at resilience hubs can come from both grants and loans. Across much of California, solar+storage can have a positive ROI by lowering a site’s utility bills. Thus, hubs can be supported with loans and loan guarantees, without requiring state or federal grant support, although low-interest government financing could be valuable. Grants can then be used to expand the size and scale of solar+storage systems to increase resilience capabilities where needed. Some regions, where utility rates

RESILIENCE AT HOME

Building solar+storage resilience hubs is only one method of improving energy resilience. Another essential strategy is to improve resilience at home. Outfitting housing with solar and battery storage can provide a range of benefits that contribute to holistic community resilience, including access to clean backup power, lower energy bills, and increased home values. These benefits may be particularly important for people with electricity-dependent medical devices, elderly or disabled residents who can’t or shouldn’t travel, or households in areas with limited access to potential hubs.

Home-based resilience strategies should be prioritized in areas that face both significant resilience challenges and barriers to effective resilience hub design. California's Self-Generation Incentive Program (SGIP), which supports at-home resilience solutions, has carve-outs for low-income households in climate-vulnerable areas. These programs can be improved, however, by making this funding easier to access. This could be done by reducing onerous burden-of-proof requirements and providing up-front funding rather than reimbursements, which require that a household has the money and/or credit to purchase a storage system on their own before being paid back.

and NEM rules don't incentivize solar+storage, may still need to rely completely on grant funding.

2.7 Strategies for Widespread Resilience Hub Access

Statistical models can help estimate the resources needed to meet resilience targets and investigate trade-offs between policy designs. In this section, we use models to investigate how prioritizing vulnerability, geographic spread, and multiple financial metrics impacts access to resilience hubs. While models alone are insufficient for decision-making, they can illuminate trends that may be helpful in program and policy design.

2.8 Hub Accessibility for Prioritized Communities

In this section, we model three hypothetical scenarios to investigate how different strategies for prioritizing climate-vulnerable communities may impact access to resilience hubs. Communities with high and very high vulnerability are defined in **Section 1.1**. Each model aims to use the fewest sites possible, while placing them within a three-mile driving distance of nine million people. The difference between the three scenarios are as follows:

- **No Vulnerability Constraints.** This model chooses sites regardless of the climate vulnerability of the population nearby.
- **Only Very High Vulnerability.** This model requires that the minimum population within range live in census tracts with very high climate vulnerability. This is similar to some existing policies that target disadvantaged communities.
- **Stepped Vulnerability with Geographic Dispersion.** This scenario requires hubs to be within range of at least three million and six million people in tracts with high and very high climate vulnerability, respectively. Furthermore, it adds a similar constraint for each Senate district to encourage a geographically-dispersed distribution of hubs.

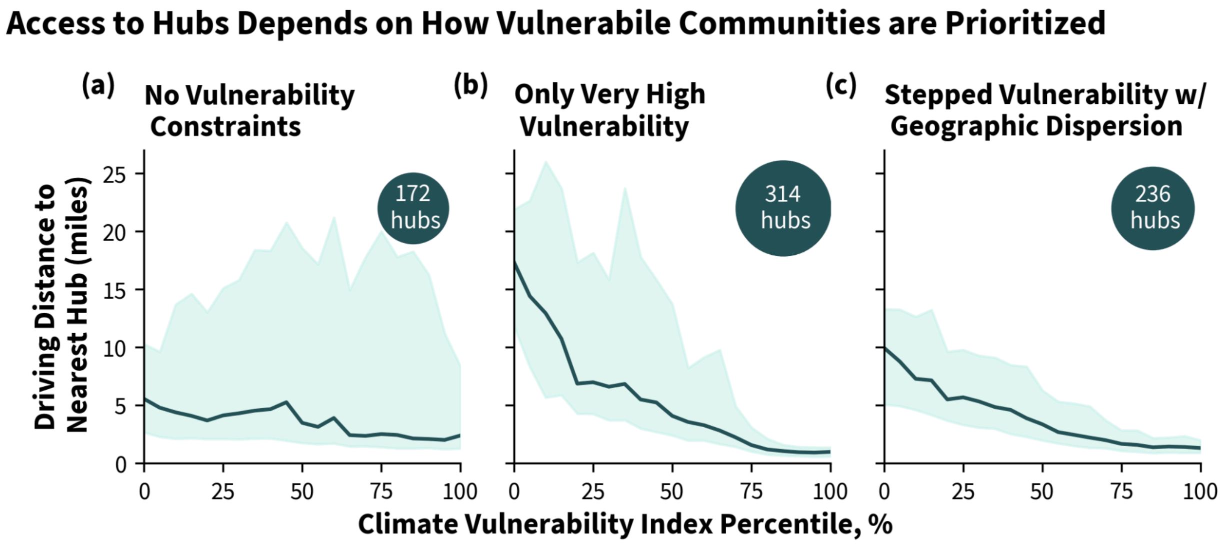


Figure 2.5: Access to Hubs Depends on How Vulnerable Communities are Prioritized. The distribution of driving distances to the nearest hub by the CVI percentile under three scenarios described in text. Black lines indicate the median travel distance while the blue shaded areas span from the 25th to the 75th percentiles.

The resulting driving distances to the nearest hub for each scenario are shown in **Figure 2.5**. A few trends emerged from these scenarios:

- Using a single hard cutoff to designate vulnerability leads to a steep increase in travel distance for those who are just below the very high climate vulnerability threshold **(Figure 2.5b)**. By incorporating an additional requirement to site hubs near communities with high vulnerability as well **(Figure 2.5c)**, the model mitigates the unintended consequences of a single strict cutoff.
- Communities with very high vulnerability are more often in densely populated areas, however, more remote pockets of very high climate-vulnerable communities exist. In the second scenario, many more hubs are needed to reach these rural areas.
- Compared to the first scenario, the third scenario that incorporates vulnerability and dispersed hubs throughout California requires 37 percent more hubs.
- In the third scenario, we find that community centers are disproportionately chosen as hub locations. This suggests that these facilities are more often located within range of high and very high climate vulnerable communities **(Figure 2.6)**. We note that without the geographic dispersion constraints included in the third scenario, sites are nearly always concentrated in only a few densely-populated areas of California, such as Los Angeles.

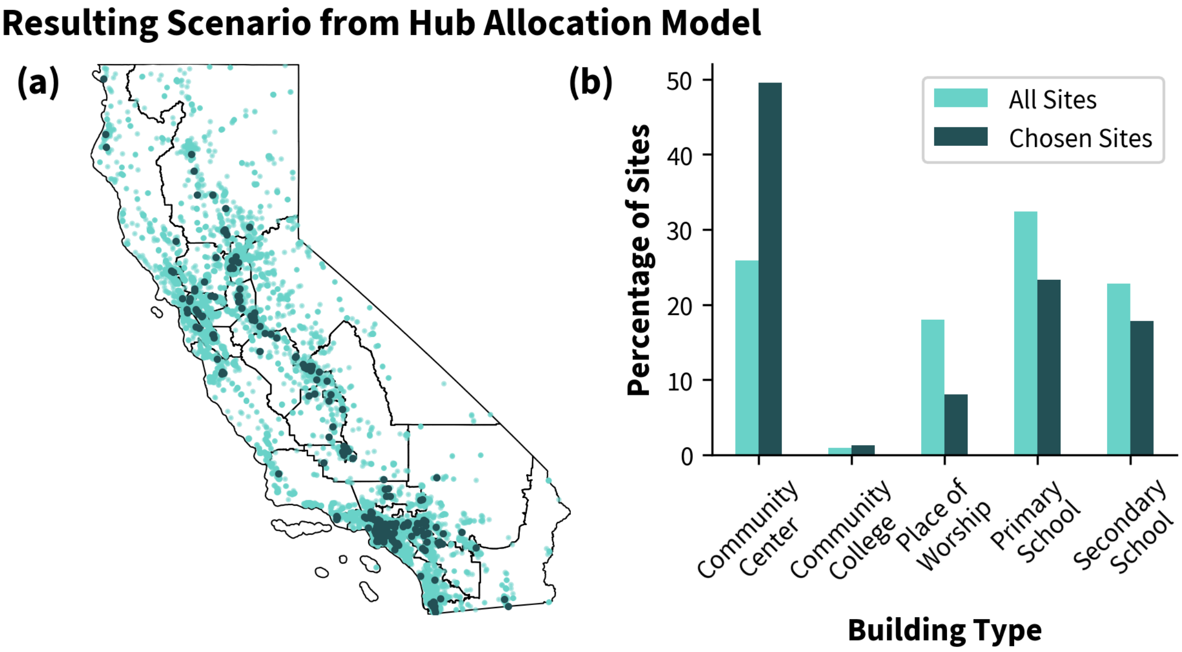


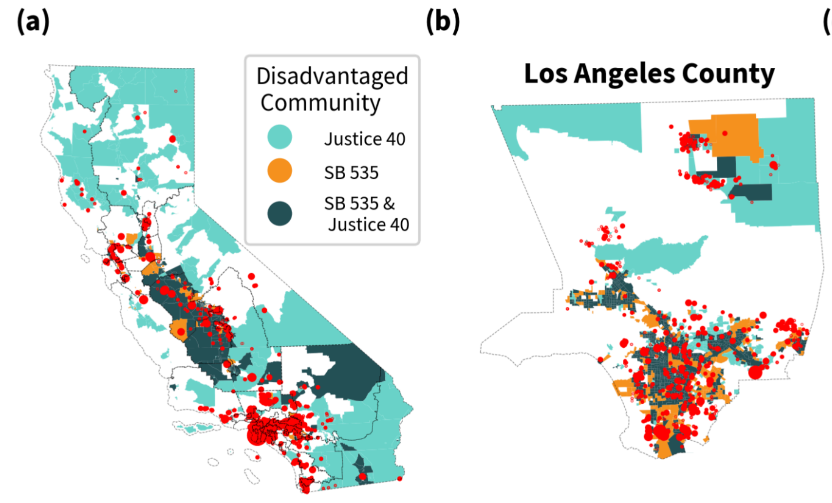
Figure 2.6: Resulting Scenario from Hub Allocation Model. Results from the third scenario with stepped vulnerability prioritization and geographic dispersion. (a) All inventoried sites (light green) and sites chosen by model (dark green). Black lines indicate Senate districts. (b) Percentage of all sites in inventory (light green) and chosen sites (dark green) categorized by building type.

Further elements should be considered that were not in the scope of this model. For example, after resilience hubs are built, it will become more important to consider where hubs already exist in order to fill geographic gaps that remain. This will require an inventory of existing hubs that, to our knowledge, currently does not exist. Furthermore, the model itself is not aware of whether a given site already serves vulnerable populations, such as community centers serving low-income seniors or populations with limited English proficiency. These sites may be worth prioritizing due to the demographics of the people they serve, even when they are not near vulnerable census tracts according to the CVI.

2.9 Total Costs for Resilient Energy Access

Another consideration for deploying resilience hubs is the cost of a solar+storage back-up energy system. In this section, we use models that favor the lowest spending on solar+storage to examine how differences in costs and projected bill savings factor into model results. Our initial scenario requires that at least 50,000 and 100,000 individuals residing in tracts with high and very high vulnerability be served with backup power at nearby hubs over a 96-hour outage. The same constraint used in **Section 2.6** to ensure geographically-dispersed hubs is also used here. The results for this scenario are shown in **Figure 2.7**. As shown by the maps, the vast majority of hubs are built near targeted populations in Los Angeles, the Central Valley, and the Bay Area. The table in **Figure 2.7** also quantifies the financial metrics, solar+storage capacity, and resulting climate benefits in offset air pollution associated with these backup energy systems.

Minimizing the Cost for Backup Energy:
Serving 150,000 People in Climate Vulnerable Tracts Through 96-Hour Outage



(c) Statistics of Chosen Hubs

Metric	Total
Number Hubs	1,585
Capital Cost, $M	555
NPV, $M	49
Grants, $M	30
Solar, MW	319
Storage, MWh	1,245
Offset CO_2, 1,000 tons	206
Offset NO_x, tons	14
Offset $PM_{2.5}$, tons	12

Figure 2.7: Minimizing the Cost of Backup Energy. (a) Red circles are sites chosen by a cost minimization model that also prioritizes vulnerable populations and geographic dispersion. Sizes of circles are proportional to the number of hub seats. Shading indicates disadvantaged community designations by the federal Justice 40 program and California Senate Bill 535. (b) Zoomed in view of Los Angeles county. (c) Table of metrics totaled across all sites chosen by the model.

In addition to the upfront cost, we also consider the net present value (NPV), as defined in **Section 2.4**. Where the NPV is positive, we assume the solar+storage system can be financed with loans. For solar+storage systems with negative NPV, the NPV represents the amount of funding in the form of grants needed in order to pay for the rest of the project with financeable loans. **Figure 2.7** shows that most hubs overlap with disadvantaged communities as designated by California Senate Bill 535 or Justice 40, indicating the potential availability of existing funding. While the total capital cost of these systems is roughly $555 million, the NPV is a positive $49 million. However, since each project would need its own financing, approximately $30 million would be needed in the form of grants for buildings with negative returns on investment.

To understand how access to grants versus loans impacts where hubs are feasible, we ran a second scenario where the access to grants decreased from $30 to just $5 million and measured the change in hub investments in each utility. In **Figure 2.8** we see that, as a result of limited grants, hubs are moved from utilities with lower returns on investments, largely in the Los Angeles area and Sacramento, to utilities with higher returns on investments. Moreover, in neither scenario are hubs chosen in the smaller TID electric cooperative, where utility rates do not incentivize solar+storage. The same is true of California's far northern areas, such as Humboldt County, where climate and limited sunlight make energy resilience challenging. To avoid prejudices against areas with less favorable utility rates, access to grants may need to be higher where backup power is more difficult to finance.

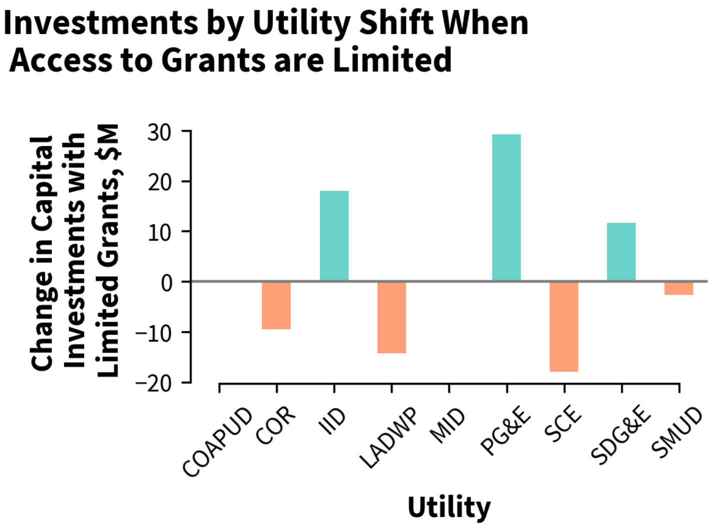


Figure 2.8: Investments by Utility Shift When Access to Grants are Limited. The solar+storage investments under a scenario with grants limited to $5 million minus the investments with unlimited grants mapped in **Figure 2.7** by utility.

Ultimately, these models provide us with estimates that ignore certain costs and rely on certain assumptions, such as utility rates and solar+storage costs. However, they may also provide us with lower bound estimates for the funding needed to construct clean and resilient backup energy on existing buildings. These estimates therefore demonstrate that solar+storage investments have the potential to cost-effectively provide targeted energy resilience while reducing emissions.

3.0 Case Studies

3.1 Building Resilience in Wilmington, Los Angeles

Communities for a Better Environment (CBE) has been working in California for nearly 50 years to advance environmental justice and build healthy and sustainable communities, including in Wilmington, Los Angeles. Wilmington has a strong legacy of intergenerational youth and adult organizing. For years, CBE has had a core youth membership from local high schools, including Port of Los Angeles High School, Banning High School, Harbor Teacher Prep Academy, and Los Angeles Harbor College. Wilmington is a largely low-income community of color impacted by pollution from the Port of Los Angeles, diesel trucks, five refineries, hundreds of oil wells, and numerous other industrial facilities. Much of Wilmington is considered more disadvantaged than over 90 percent of California by CalEnviroScreen 4.0 and as having very high climate vulnerability based on the CVI we developed. Like most of California, it also faces increasing climate risks from extreme heat, flooding, and wildfire smoke, in addition to compounding risks from earthquakes. High housing costs, large renter populations, old buildings, many households with limited-English proficiency and limited availability of multilingual emergency notifications, among other factors, make it difficult for Wilmington residents to adapt to growing climate risks and respond to emergencies. CBE's broad range of work includes organizing community leaders to phase out air pollution, envisioning and building resilience through trainings and mutual aid, strengthening relationships with trusted community centers and local governments to develop resilience hubs, and fostering a sense of community and social cohesion via ancestral healing practices such as gardening, decolonized food workshops, herbal medicine, and art.

CBE began the Climate Adaptation and Resiliency Enhancement (CARE) Program in 2013. Its objectives, which were rooted in community visioning, were to build a foundation of community leadership, to strengthen near-term resilience in the face of environmental and climate emergencies, and to expand the resilience of Wilmington in the long term. CBE's iterative process includes first running staff trainings and building curricula around resilience and adaptation, ensuring sufficient dedicated time is allocated so staff deepen their knowledge of issues, such as how the energy grid operates or how energy storage can provide backup power to buildings. Next, CBE holds discussions with community leaders and volunteers to ground truth climate impacts with local lived experiences, thereby building individuals' understanding of the global climate crisis. Consistent community visioning with members provides the opportunity to spread awareness of potential climate impacts and to cultivate creative problem solving rooted in traditional and holistic practices that build long-term change. CBE trained a Resilience Squad of four to six canvassers on issues related environmental justice, resilience, just transition, and housing—work that CBE has found to be more impactful when these interconnected issues are addressed holistically.

Wilmington community members participating in community visioning and mapping in 2016.

The Resilience Squad helped develop, conduct, and share findings from a community survey that identified resilience needs. Additionally, the Resilience Squad held community events to disseminate resilience kits, identified and engaged with potential resilience hub sites, and began to build a resilience hub network. The surveys identified environmental and climate concerns, with the top five being: earthquakes, air pollution, refinery flaring, wildfires, and extreme heat. The community also suggested goals for a resilience hub would include backup solar+storage, Wi-Fi, air conditioning and clean air, charging stations, food and water, friendly staff, first aid, and support for financial resources. These community goals, however, were complemented by mutual aid in the community itself, such as food and clothing drives, distribution of resilience kits with first aid and personal protective equipment, first aid training, and distribution of do-it-yourself box fan air filters. CBE integrated these findings into educational materials, community dialogues, blogs, toolkits, workshops, and other engagement efforts with its members and the Wilmington community, and conducted presentations and held meetings with city officials to inform long-term resilience policy.

CBE has worked with two sites—the Wilmington Senior Center and the Tzu Chi Clinic—to build out resilience hubs. The timeline for hub development is shown in **Figure 3.1**. These provide examples of the kinds of community-serving buildings that might be locally identified to provide resilience hub services, above and beyond those identified in the PSE site analysis. Supported through community visioning efforts, the Senior Center integrates transportation, programming, and food distribution, alongside a 100-panel solar system. Currently, CBE is working with the Senior Center and Clinic to develop an operation plan that would allow the hub to operate for the larger public. The Clinic incorporates health and wellness and community emergency preparedness trainings, food distribution, outreach, and transportation. The Clinic is equipped with a solar+storage system that can provide an average of 1-2 days of backup energy; as of early April 2024, the system is pending permission to operate from LADWP.

CARE Program Timeline

Figure 3.1: Care Program Timeline. CARE program timeline for community engagement and hub development at the Tzu Chi Clinic and Wilmington Senior Center.

These efforts have faced a broad array of challenges. These include the difficulty of identifying and stacking funding for solar+storage systems alongside all-year programming; accessing funding for roof upgrades to support solar panel installations; expanding staffing for resilience hub sites with limited current staff capacity and open hours; accessing grants with challenging requirements, such as multi-decade site leases or government partnerships; contracting delays; and identifying partners to effectively share information with other communities working on similar efforts.

3.2 Developing a Resilience Hub in Richmond, Despite Obstacles

RYSE Commons in Richmond is a community center and resilience hub that strives to create a safe space, grounded in social justice, building the power of youth to learn, educate, heal, and transform lives and communities. In Richmond, disasters like refinery fires, oil spills, and power shut offs are a constant threat. Communities face decades of disinvestment from schools and public services, live in close proximity to big polluters, navigate criminalization and over-policing, and are increasingly being pushed out of their homes. As converging economic, political, and climate disasters become more frequent and intense, it is even more critical that we are ready, resourced, and organized. During this project's collaboration, RYSE consisted of two buildings on two separate parcels in Richmond. Richmond is a community of primarily low-income people of color. The city and its residents have been deeply impacted by decades of economic and environmental blight. Stressors such as high unemployment and lack of access to health care, affordable housing, green open space, and healthy food exacerbate the environmental burdens, creating severe cumulative impacts. Richmond is home to the 3,000-acre Chevron Richmond Refinery, the largest stationary source of greenhouse gas (GHG) emissions in the State of California. Richmond residents suffer from high rates of asthma, respiratory illness, and cancer. RYSE has been a hub for a healing-centered community for a long time, answering youth demands for mental health and crisis services, culturally relevant art, culture, and connection. Its growth into a climate resilience and liberation hub evolved with wildfire relief coordination in 2017, followed by a funding campaign for the youth-led design and build of a community center in 2018. RYSE then bought the adjacent lot, breaking ground on a second building in 2019 and discussions about connecting the full campus to one solar+storage system. In 2020, APEN renewed work with the young people of RYSE on climate resilience, emergency preparedness, and energy democracy. Climate risk and resilience planning eventually led to a request for proposals for solar+storage design and build in November 2021, with an original estimated timeline for commissioning, testing, and inspection by August 2022.

This estimate turned out to be wildly optimistic. While the initial goal was a combined solar+storage microgrid for the campus, worries about permitting and cost led to the decision to keep the two buildings electrically separated, with designs for 43.2 kW of solar on the older building and 86.4 kW of solar and 110 kWh of battery for the new building. While a microgrid could have supported both buildings, integrating more solar generation with the backup battery, multiple contractors advised that the process would be long and complex. The extended process might even cause delays to the project, making it ineligible for more cost-effective Net Energy Metering 2.0 rules, and subject to NEM 3.0 with lower energy export payback prices, making the entire system less affordable.

The solar installation was complete by October of 2022 and the batteries were installed in February of 2023. There were some maintenance issues due to historic winter storms and pigeons, but RYSE was able to submit for interconnection permission to PG&E in February of 2023. In September 2023, seven months later, the old building received permission to operate its solar installation but only for partial operations of 30 kW of their solar. Utility system upgrades are necessary before the system can connect at full power. RYSE and APEN fought for permission to operate for the new building’s solar system, using advocacy tactics against the lack of accountability and transparency at the utility. The solar was finally interconnected on March 20, 2024, more than a year after the request to connect, the battery system still has not been approved for connection as of April 2024.

With more than a year of delays in interconnection permission, the site missed out on energy bill savings on the order of $20,000. The site still lacks energy resilience from battery backup until they have permission to operate.

APEN staff tour the RYSE Center during construction.

4.0 Policy Recommendations

Our analysis identified a number of policy and programmatic measures which may help accelerate resilience hub deployment in California communities that need them most. In addition, we outline further research and data collection efforts which could improve the effectiveness and efficiency of resilience hub development over time.

Prioritizing Populations and Communities for Resilience Hub Development

- **Include Adaptive Capacity.** While existing tools, such as CalEnviroScreen, are useful for capturing some potentially vulnerable populations, additional indicators to capture adaptive capacity will likely be required to identify the state's at-risk populations. This is particularly true for rural regions.
- **Consider Compounding Climate and Environmental Factors.** Data on existing and emerging hazards, and where they're projected to overlap, can be used to help prioritize necessary services and funding, particularly in historically disinvested communities.
- **Avoid a Single Vulnerability Cutoff Threshold.** Using a single vulnerability threshold risks missing potentially vulnerable populations in areas below that threshold. Using a gradient approach and considering both a community's vulnerability and risk of climate hazards may be better at capturing priority populations across a broad range of areas and types of vulnerability. An alternative is to set resilience targets for communities under the threshold, particularly in areas facing climate or environmental risks.
- **Set Resilience Targets.** Smart resilience targets, such as resilience hub access for a minimum number of people in vulnerable areas, will help identify future sites to invest in and maximize their equity and impact.

Deploying Equitable Resilience Hubs at Scale

- **Develop Targeted Strategies for Rural Areas.** Rural regions may need smaller and more distributed sites to ensure people live within a reasonable travel distance of resilience hubs. These areas may benefit from a particular focus on increasing adaptive capacity, as well as investments in at-home resilience (e.g. solar and storage at people's homes) in remote areas far from potential resilience hub sites.

- **Pair Resilience Investments with Energy Efficiency, Particularly in Areas Where Sunlight Cannot Provide Enough Energy.** Investments in energy efficiency and alternative resources (e.g., district heating, geothermal heat pumps) should also be explored, especially in regions where sunlight cannot be expected to provide enough power to recharge batteries. Cost-effectiveness tests used by agencies to determine whether a project is "worthwhile" should reflect local climate challenges and whether climate change will make it necessary to build larger solar+storage installations to achieve resilience.
- **Enable Resilience Services by Removing Barriers for Larger Solar+Storage Systems.** Regulators should remove disincentives for larger solar installations (e.g., net export limits) at sites that provide resilience. More energy will enable more services for more people, and sites serving public resilience needs should not be constrained by export limits.
- **Enable Easy and Rapid Interconnection.** Current timelines for solar+storage interconnections can be needlessly long, wasting money and delaying the impact of resilient investments. In addition to a need for accelerating all interconnection processes, it may be beneficial to prioritize resilience hub interconnections, particularly for vulnerable populations. Moreover, it may be beneficial to consider compensating solar+storage adopters for the loss of use of their systems if there are interconnection delays.

Equitable Financing and Design

- **Provide Planning Grants.** The least-resourced communities likely need up-front planning grants (such as those provided by the California Strategic Growth Council to support Resilience Center planning) to support their ability to develop projects and apply for full project funding.
- **Don't Rely on Utility Rates.** Utility rate design should not be the primary tool for promoting resilience, in part because rates that tend to incentivize solar+storage also tend to make energy more expensive. But rate designs do significantly and directly impact the lifecycle cost of solar+storage such that different rate structures can make solar+storage investments pay for themselves over time, even without considering the resilience value they provide.
- **Provide Combinations of Targeted Low-Interest Loans and Grants.** Systems are potentially financeable where rates give solar+storage systems positive paybacks that make bill savings greater than capital and maintenance costs. Low-interest loans and

loan guarantees can increase renewables and resilience, without requiring individuals, communities, or governments to provide initial capital. Where utility rates are less favorable for solar+storage investments, grants from federal, state, and local governments as well as philanthropic organizations will be necessary. Additional grant funding will also be required to expand system size to address significant extreme heat days, smoke events, and other energy-intensive challenges and extreme weather events.

- **Make Funding Less Siloed.** Offering sources of intersectional funding and allowing grantees to more easily stack funding from different sources will enable organizations to design resilience hubs that meet community needs. This might be enabled through efforts such as a one-stop-shop for multiple funding sources or bridge funding to cover the period between receiving an award and money actually hitting the bank.
- **Design Accessible Funding Requirements.** Easier reporting requirements and more upfront funding, rather than reimbursement-based funding, would make grants more accessible to resource-strapped communities and organizations.

Future Research and Data Need

- **Track How Existing Hubs are Being Used.** While many hubs are under development, there is limited information on how they will be used over time. Tracking the number of people visiting hubs, energy demand and trade-offs during outages, and other operations at hubs can help inform better future designs. Instrumenting hubs with energy data collection devices would provide the opportunity to collect and share planning, building, and operating data to help each hub learn from the others, and help the next generations of hubs learn from these early sites.
- **Track How Existing Resilience Hub Funding is Being Distributed.** Transparent sharing of hub funding, across agencies, can enable identification of funding gaps for certain regions or communities.
- **Develop Inventories of Existing Resilience Hubs and Resources.** As hubs become more common, an inventory of existing hubs would help identify gaps to prioritize outreach and resources. This inventory could also serve as a resource, connecting organizations just starting their hub-design process with those who are further along and can offer guidance.
- **Identify More Resilient and Efficient Methods for Heating, Cooking, Water Heating, and Electrification.** Decarbonizing heating, water heating, and cooking through electrification will decrease greenhouse gas emissions and improve indoor air

quality, but will also pose additional challenges for home and hub energy resilience. Increased reliance on electricity for these services will increase the amount of resilient energy needed for hubs, and the number of people who will need hub services, often when solar power is at its lowest (e.g. during winter). Requirements for energy production and storage to meet these needs, while still achieving public health, climate, and sustainability goals, must be studied and methods other than rooftop solar+storage to meet them will likely be necessary, including district heating, off-roof solar, and geothermal heat pumps.

- **Quantify the Potential Benefits of Community and Multi-Building Solar+Storage.** Lack of sufficient sunlight to power resilience needs can be overcome with off-roof and off-parcel solar. Community solar provides energy affordability benefits during non-outage times, and can also increase the amount of energy available for resilience hubs and energy services from resilience hubs during outages. The design and engineering for community microgrids is well understood, but the techno-social challenges of getting such systems permitted and connected to utility grids remains a significant challenge. Research to quantify the potential benefits, along with analysis and demonstration of potential solutions to address utility concerns, will accelerate adoption and increase resilience.

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