Title
The Promise of Power & Resilience: Mapping Optimal Locations for Microgrids Across a Range of Grid Modernization Goals in California

Author
Kwoka, Bethany

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Mapping Optimal Locations for Microgrids Across a Range of Grid Modernization Goals in California

Bethany Kwoka
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ADVISORY COMMITTEE

Ryan Hanna, PhD
Center for Energy Research, UC San Diego
Capstone Chair

Mark Merrifield, PhD
Center for Climate Impacts & Adaptation, Scripps Institution of Oceanography, UC San Diego
Committee Member

Craig Lewis
Clean Coalition
Committee Member

Mike Ferry
Center for Energy Research, UC San Diego
Committee Member

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ABSTRACT

The State of California is working to bolster local electricity resilience by accelerating the adoption of microgrids, notably through its Microgrid Incentive Program (MIP). This Program allocates the State's three largest electric utilities $200 million to build community microgrids that support disadvantaged communities, specifically in fire and outage prone areas of their service territories.

This work presents a new tool built to analyze microgrid suitability in the service territories of these utilities. It then applies this tool in a study that locates areas potentially eligible for California's new MIP and maps optimal sites for microgrids under MIP objectives as well as a range of other grid modernization goals. It identifies and ranks where microgrids could be most beneficial by seeding an ArcGIS suitability model with criteria chosen by the utilities and informed by the California Public Utilities Commission, California's Office of Planning and Research, and MIP workshop participants. These criteria reflect utility efforts to bolster resilience for key populations in areas vulnerable to disruption and include Tier 2 and 3 High Fire Threat Districts, locations of previous Public Safety Power Shutoffs, circuits with historically low levels of reliability, and disadvantaged / vulnerable populations. Other criteria speak to additional benefits that microgrids can provide, such as reducing pollution, arbitraging locational marginal electricity prices, and integrating renewable energy.

Results indicate that 70% of incorporated and census designated places within the three utilities' service territories likely have at least one location that's eligible for MIP funds. Historically marginalized communities are the most likely to lack the capital, technical/regulatory expertise, and institutional support required to pursue this funding. As such, this result indicates that capacity building in these communities to develop the skills and resources necessary to undertake adaptation projects may be necessary to reach the Program's equity goals.

Modeling suitability under different secondary goals, in which various aims beyond resilience are weighted and scored, changes the distribution of the most suitable locations—with the percentage of individual places featuring high suitability scores ranging from 6% to 26% for different portfolios of benefits. In some areas, three goals are often aligned (those of lowering pollution, improving equity, and achieving incremental decarbonization). This suggests that realizing multiple microgrid co-benefits is feasible, but that doing so marks a distinctly different approach from the current focus on wildfire resilience. Ultimately, policy choices that prioritize different sets of microgrid goals in different locations—depending on the unique burdens and threats facing local communities—and shift power from utilities to communities may offer the most viable path forward to realizing potential co-benefits.

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ACRONYMS

BIA	*Federal* Bureau of Indian Affairs
CalEPA	California Environmental Protection Agency
CARB	California Air Resources Board
CAISO	California Independent System Operator
CDP	Census Designated Place
CEC	California Energy Commission
CMEP	Community Microgrid Enablement Program
CPUC	California Public Utilities Commission
FEMA	Federal Emergency Management Agency
FORHP	Federal Office of Rural Health Policy
GIS	Geographic Information Systems
HFTD	*CPUC-designated* High Fire Threat District
ICA	Integration Capacity Analysis
ICARP	Integrated Climate Adaptation & Resilience Program
IOU	Investor-Owned Utility
LMP	Locational Marginal Price
MIP	Microgrid Incentive Program
OPR	*California's* Office of Planning and Research
NREL	National Renewable Energy Laboratory
PG&E	Pacific Gas & Electric
PSPS	Public Safety Power Shutoff
RCAM	Redwood Coast Airport Microgrid
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCE	SoCal Edison
SDG&E	San Diego Gas & Electric
PV	*Solar* Photovoltaic
USGS	United States Geological Survey
WGCEP	Working Group of California Earthquake Probabilities
WPC	Worst Performing Circuits

INTRODUCTION & BACKGROUND

Climate Impacts in the Electric Power Sector. The rate and severity of wildfires in California has increased dramatically over the past decade [1]. Some of the most devastating fires have been linked to aging electrical equipment, leading utilities to institute Public Safety Power Shutoffs (PSPS) where they proactively de-energize at-risk power lines during dry conditions with high winds [2][3]. This lowers wildfire risk but can have dramatic negative impacts on local residents and California's economy.

The consequences of public safety power shutoffs. PSPS events can cause billions in losses and both physical and psychological damage in those who experience them [4][5]. The impacts are particularly pronounced for low-income and historically disadvantaged communities. Those who rely on electricity for medical equipment, are food insecure, or cannot afford to miss work are hit harder by and have a tougher time bouncing back from long periods without power [6][7].

To mitigate the public health and safety consequences of PSPS events, the California Air Resources Board (CARB) has authorized an increase in the use of diesel generators for backup power in PSPS-prone areas [8]. While this keeps the power on, it also increases local pollution and emissions—a step away from California's clean air and climate goals.

California's quest for climate resilience. Given the increasing severity of climate impacts in California—including widespread wildfires and record heat waves—State agencies are considering future climate conditions in infrastructure investment and planning [9][10]. Through its Integrated Climate Adaptation and Resiliency Program (ICARP), California is also developing strategies to bolster resilience at state, regional, and local levels.[1]

The State's approach emphasizes equity—recognizing that numerous economic, social, and political factors determine how hard different people will be hit by climate impacts as well as their capacity to recover [11][12]. In consideration of State mitigation efforts, ICARP and the guides it develops prioritize solutions that protect the most vulnerable and actions that both reduce emissions and build resilience to climate change's effects [13][14].

Climate adaptation in the electric power sector. Updating the energy system is critical for both climate mitigation *and* adaptation. Public health, California's economy, and people's day-to-day functioning are all tied to having reliable power [15][16]. But the extreme weather that's becoming more common as climate change progresses threatens the safety and reliability of California's grid [17].

A quarter of California's population lives in a high fire risk area, putting millions of people—and their homes, livelihoods, and communities—at risk [18]. Climate change is exacerbating the issue, lengthening wildfire season by increasing the amount of dry vegetation that can fuel a fire while driving strong winds that can help spark one [1][19].

Addressing the need to adapt to these changing conditions, the California Public Utilities Commission (CPUC) has set climate adaptation planning standards for energy utilities and directed them to conduct vulnerability assessments that focus on climate risks [20]. With the risks and consequences of wildfires

[1] While related, climate adaptation and climate resilience are distinct concepts. Adaptation refers to changing the built environment (or people's behaviors) to reduce climate risks. For example, relocating roads or other infrastructure to avoid damage from sea level rise. Resilience is how prepared people are to face these risks, and how well they can recover after experiencing them. For instance, can a family afford to relocate or rebuild after their home is destroyed?

so high, the Commission also created the Office of Energy Infrastructure Safety, which now reviews annually-updated wildfire mitigation plans from each utility [21][22]. Echoing ICARP, the Commission has also directed the utilities to ensure the State's most vulnerable residents are not left behind [23].

While utilities spent years resisting regulation on wildfire management, they're now undertaking numerous measures to reduce the risk of their infrastructure igniting further conflagrations [24][25][26][27]. Physical measures include undergrounding electrical lines so they're not vulnerable to high winds, increasing vegetation management to reduce the risk of trees or branches falling on power lines, and setting more sensitive fault protections so that downed lines have less chance of sparking fires on the ground. Utilities are also building out meteorology teams, partnering with universities and research institutes to model fire risk given different weather conditions.[2]

Utilities are facing multiple, overlapping challenges. They're torn between keeping the grid reliable with business-as-usual techniques and the need to modernize operations to address the unique characteristics of renewable energy, the rising demand for power as the State electrifies its economy, and increasingly severe climate impacts.

Using Microgrids to Boost Local Resilience. It may be a decade before utilities can stop using PSPS to lower wildfire risk [28]. To reduce impacts in the meantime while simultaneously modernizing the power grid, the State is exploring the potential of microgrids.

A brief explanation of microgrids. A microgrid is a combination of local energy generation sources, storage, and load that can operate interconnected with or isolated from the main electric grid. It sits behind a point of common coupling with the distribution system and can island from the grid when needed. While microgrids can involve myriad configurations of size, energy sources, and connections, for this work they're considered a single critical facility and at least one other utility customer.[3]

The main goal of a microgrid is to make a community more resilient to impacts elsewhere on the grid that would leave them without electricity. The hope is that microgrids can reduce the social and economic impacts of PSPS events by powering critical services during these or other outages [29].

Potential co-benefits of microgrids. Microgrids can provide benefits beyond resilience, too. When paired with solar and energy storage systems that sell power to the grid, they can reduce greenhouse gas emissions and local pollution by replacing fossil fuel generation with clean power.[4] Since they're islands of decentralized generation, they can also delay expensive grid upgrades by strategically deferring the need to increase line capacity in congested areas and offer further value by providing ancillary services such as voltage and frequency regulation to the grid. This means they can potentially address numerous power sector needs [32][33][34][35].

However, the value of these benefits varies substantially by location [36]. And the ability of single microgrid deployments to provide multiple benefits simultaneously also raises an important question: which communities in California would benefit most from a microgrid and where should microgrids be located to achieve the greatest combination of benefits?

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[2] This includes an ongoing partnership between Scripps Institution of Oceanography at UC San Diego and SDG&E.
[3] This follows the definition of a microgrid currently used by utilities as part of the Microgrid Incentive Program.
[4] While decarbonization is a secondary aim for microgrids, California needs an 'all-hands-on-deck' approach to reach its goal of reducing greenhouse gas emissions 40% below 1990 levels by 2030 and carbon neutrality by 2045 [30][31].

Current policy context. In 2018, Senate Bill 1339 directed the CPUC, the California Energy Commission (CEC), and the California Independent System Operator to develop policies that would accelerate the commercialization of microgrids [37]. Addressing the growing prevalence of California's resilience issues, core portions of this proceeding became dedicated to directly mitigating the effects of PSPS events within this context [38]. One of the first measures was establishing PG&E's Community Microgrid Enablement Program (CMEP), which provides technical support for communities to develop microgrids serving critical facilities. Approved at $27 million, CMEP was set to run through 2022 and designed as a short-term solution to help communities with their most urgent resilience needs [39][40].

Expanding on this idea, the CPUC then authorized $200 million to fund the development and installation of clean microgrids in vulnerable communities throughout the State. California's three large investor-owned utilities (IOUs)—Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E)—were then directed to work with community leaders and other stakeholders to create the Microgrid Incentive Program (MIP) and allocate these funds (Figure 1) [41].

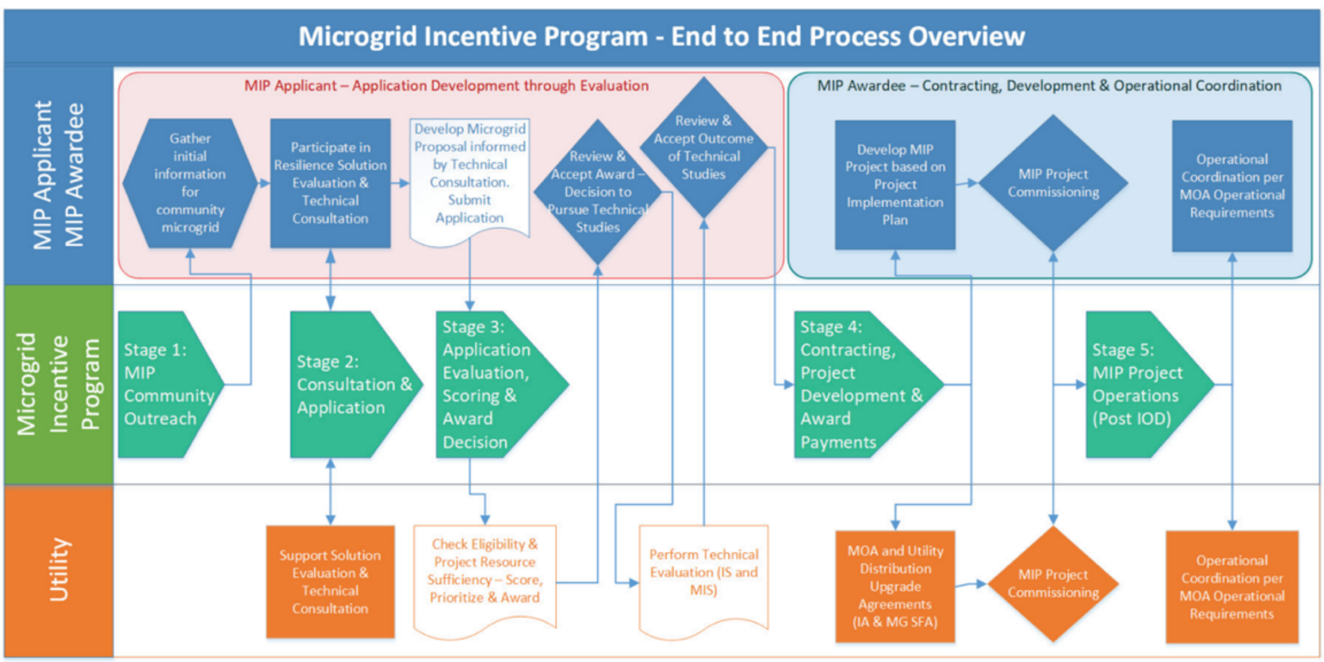

Figure 1. The end-to-end process of the proposed MIP. From the Proposed MIP Implementation Plan submitted by PG&E, SCE, and SDG&E to the CPUC.

The Microgrid Incentive Program. The MIP is designed to advance microgrid technology while ensuring resilience benefits flow to disadvantaged communities [42]. To achieve this, the proposed Microgrid Incentive Program Implementation Plan outlines a range of criteria communities must meet to be eligible for microgrid funding and a framework for prioritizing projects. Criteria include indicators of disadvantage and/or vulnerability, such as being low income, rural, or tribal community, or scoring in the top 25th percentile of the most recent CalEnviroScreen.[5] These indicators accompany criteria that reflect a community's vulnerability to electrical outages, for instance having low historic levels of reliability, having experienced previous PSPS events, and having high fire and/or earthquake risk.

[5] CalEnviroScreen scores census tracts based on how affected by and vulnerable they are to the effects of pollution-based disparities. As of this writing, CalEnviroScreen 4.0 is the most recent version [13].

Eligibility also involves a technical component, which includes criteria around the number of customers served, the amount of generation included, projected emissions, and more.

The application process is involved and may require hiring a technical consultant. To address concerns that this will prevent disadvantaged communities from accessing MIP funds, the utilities plan to undertake community outreach, provide technical consultations to determine the best resilience solution for a community's specific needs, and offer an application development grant for qualified applicants with eligible projects [42][43]. The IOUs are spearheading the MIP. Without their support, no community microgrid project in their service territories' will be able to move forward.[6]

While the MIP is "aimed at funding multi-customer clean energy microgrids that support the critical needs of vulnerable populations impacted by grid outages," it's also designed to inform future policy [42]. Because although there are many potential benefits to microgrids, design of policy to achieve them is still in question. As is whether all potential co-benefits can be aligned.

Modeling suitable locations for microgrids across a range of goals. The focus of this study was locating Places[7] that are eligible for community microgrids given the community eligibility criteria of the MIP, identifying communities that may be particularly well suited for these projects, and demonstrating how optimal locations change when policy prioritizes different non-resiliency aims.

Specifically, this project sought to answer the following questions:

I. What jurisdictional areas—both incorporated and census designated places[8]—in California are eligible for state funding for community microgrids under the community eligibility structure embedded within the Microgrid Incentive Program?[9]
II. What areas are the most suitable for microgrids under current program criteria and given different criteria or policy incentives? How does prioritizing different microgrid co-benefits change the distribution of most suitable locations?
III. What changes would be needed to implement these projects, and to ensure they achieve potential co-benefits such as improving resilience in historically disadvantaged communities and aligning with state decarbonization goals?

Why California is well suited for this analysis. The growing prevalence of wildfires, regulators' push for microgrids, and the State's ambitious climate policies make California an ideal place to explore whether various aims for microgrids are complementary or opposed, what tradeoffs might need to be made between co-benefits, and what is necessary to facilitate climate resilient development in the electricity sector.

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[6] Utility-owned microgrids are currently the only viable community-level option under California law, as Public Utilities Code 218 stipulates that selling power across a public right of way subjects an entity to CPUC regulation [44, p. 2].
[7] Places denote incorporated and census designated places from the 2020 census. This indicator is used as a rough proxy for communities to facilitate analysis. (Projects may also require sign off from a local government.)
[8] Census designated places represent unincorporated but settled communities with recognized names. They are used in the census for statistical population counts, though lack legally designated boundaries and active local governments [45]. While they lack the jurisdictional authority of an incorporated place, they are included in this analysis since they represent locations that could apply for MIP funding so long as the applicant obtained any necessary approvals.
[9] This only applies to the community eligibly piece of MIP eligibility, as a corresponding evaluation of technical eligibility was beyond the scope of this study. For more on the technical eligibility requirements, refer to the proposed plan in [42].

METHODS

General Approach. The project constructed two distinct but related models—a binary eligibility model and a weighted suitability model. Based in ArcGIS, these models allowed the overlay of numerous geospatial datasets that corresponded to criteria reflecting favorable locations for a microgrid.

In this work, the results of the eligibility model were overlayed with the locations of census designated and incorporated places to determine which communities might be eligible for the Microgrid Incentive Program under its 'community eligibility' criteria. Subsequently, consideration of other goals for microgrids beyond resilience, for example lowering pollution or achieving incremental decarbonization, were incorporated to form a series of suitability models. The ArcGIS Suitability Modeler was then used to determine optimal geographic locations for microgrids given these various aims. Results were again overlayed with the locations of census designated and incorporated places to compare suitability scores between these differing secondary priorities.

To make eligibility and suitability projections, models must be informed by one or more datasets. The models in this work used data that reflected the different goals. For instance, CalEnviroScreen 4.0's pollution score percentile represented high-pollution locations when the secondary aim of the microgrid was lowering local pollution. And integration capacity for solar photovoltaic (PV) generation was used to simulate an increased likelihood that new distributed resources would be able to connect to the power grid without the cost of upgrading distribution infrastructure becoming a barrier to the project when the secondary goal was reducing emissions or lowering energy costs.

Roughly half of the criteria and associated data were identified by the CPUC, California's Office of Planning and Research (OPR), the State's major utilities, and participants of the working groups that developed the MIP Implementation Plan [46][47]. These criteria include Tier 2 and 3 High Fire Threat Districts (HFTD),[10] locations of previous PSPS events, areas prone to outages due to poorly performing circuits, high earthquake risk zones, and disadvantaged / vulnerable communities based on income, [11] CalEnviroScreen score percentile, tribal designation, and rural location. Other criteria, including CalEnviroScreen pollution percentile score, flood risk, potential for utility interconnection of uniform or PV generation, average locational marginal prices of energy, and population, were identified through a review of additional goals for microgrids [33][34][51][52]. Core criteria reflect efforts to quickly bolster resilience for key populations in areas vulnerable to disruption.[12]

Model Resolution. Identifying appropriate locations for microgrids requires a high level of precision. Microgrids are often designed to encompass a single facility or a few co-located buildings, and buildings within a single neighborhood can be served by multiple circuits whose electrical lines meander in close proximity. To address this while still accounting for computing constraints and the size of California, the eligibility model was run at a 10-meter resolution and the suitability models were run at a 100-meter resolution.[13] Determining more precise locations would have necessitated a level of detail beyond the scope of this study.

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[10] CPUC-designated HFTDs are specific to areas at higher risk of wildfire due to utility infrastructure like power lines [48].
[11] The MIP designates low income as census tracts with median household incomes less than 60% of state median income. As the current method for designating communities for climate investments, CalEPA's priority populations data specifying low-income census tracts—which uses less than 80% of state median income—was used to represent this criterion [49][50].
[12] See Appendix A for a full list of criteria and reasoning for inclusion and Appendix B for a full list of data and sources.
[13] See "Project Limitations & Refinements" in the Future Work section for more on this.

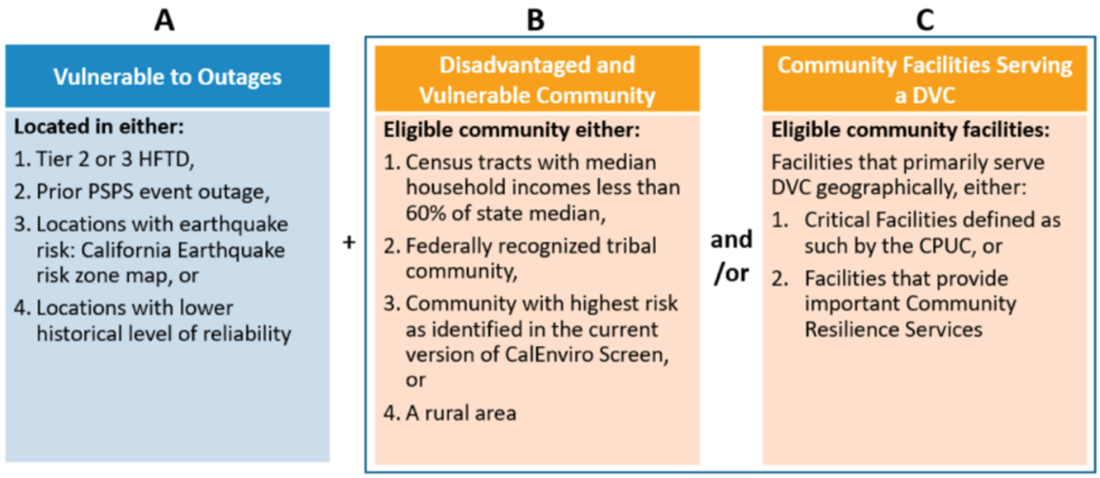

Figure 2. MIP community eligibility structure. From the Proposed MIP Implementation Plan.

The Eligibility Model. As outlined in the MIP Implementation Plan, eligibility for the program requires meeting at least one criterion from two discrete buckets (Figure 2). The first indicates whether customers are receiving electric service that is below historic norms. The second indicates whether customers are located in a disadvantaged or vulnerable community.

To determine eligible areas, the appropriate data was collected and brought into ArcGIS, with data specific to different utility service territories stitched together to cover the full analysis area. Data sets were categorized by their place in the eligibility structure and fed into the model, which superimposed and combined them to show which areas were eligible. The third eligibility bucket in Figure 2—critical facilities serving disadvantaged / vulnerable communities—is directly linked to the second. So, it was set aside for an overlay after eligible areas were identified.

Results of this eligibility model only apply to the community eligibility piece of the MIP. They do not indicate that a community in these areas will have an eligible project or receive funding, as there are further technical eligibility and program scoring factors to consider that are not included in this model.[14] And while many of the same criteria were used, actual eligibility for the MIP was not considered in the suitability analysis.[15]

The Suitability Model. Suitability modeling combines multiple variables into a single suitability score. It goes beyond simple eligibility by assigning values within individual criteria to a suitability scale and then combining numerous criteria with different weights. This adds nuance to each criterion and allows the modeler to explore the effects of emphasizing different criteria differently.[16]

In that context, this work identified nine iconic use cases for microgrids, each varying in their portfolio of criteria and weights (Table 1). Portfolio 0, called Current Approach, represents the current MIP approach in California. It emphasizes resilience against wildfires and only uses criteria chosen by the State's three major utilities. Portfolio 1, labelled Pure Resilience, represents a focus on resilience generally (not just against wildfires), though still uses the utility resilience metrics as its foundation.

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[14] For more on technical eligibility requirements and project scoring, refer to the Proposed MIP Implementation Plan in [42].
[15] For a list of eligible communities paired with their suitability scores across portfolios, see Appendix E.
[16] For more on suitability modeling within ArcGIS Pro, see [53]

Seven additional cases pair resilience—the core function of any microgrid—with secondary functions that microgrids are often cited as providing.

Portfolio	Iconic Case	Central + Secondary Benefit	General Reasoning
P0	**Current Approach in California**	**Wildfire Resilience** Protecting vulnerable and PSPS-prone communities from losing power due to wildfire mitigation measures	This reflects what California and the utilities are working towards
P1	**Pure Resilience**	**General Electricity Resilience** Providing resilience from PSPS impacts and climate/natural disasters to the largest number of people	The core function of microgrids
P2	**Disaster Response**	Using microgrids to create local resilience hubs to improve disaster response and recovery in vulnerable and historically disadvantaged communities	Making disaster scenarios less bad for those worse affected and making disaster recovery faster
P3	**Lowering Pollution**	Using resilience-providing microgrids to lower pollution via distributed clean resourecs	Improving public health and meeting state goals around pollution
P4	**Improving Equity**	Protecting vulnerable and historically disadvantaged communities by improving energy resilience in their neighborhoods	California has climate and equity goals that match well with microgrid aims for equity
P5	**Decarbonization**	Using resilience-providing microgrids to lower emissions via distributed clean resourcecs	Meeting state climate + clean energy goals
P6	**Lower Energy Costs**	Using resilience-providing microgrids to lower energy costs by locating distributed generation in places that can best provide grid services	Delaying expensive grid expansions and reducing congestion can lower energy costs for consumers
P7	**Meeting State Goals**	**Electricity Resilience + Clean Energy + Protecting Vulnerable Communities** Using resilience-providing microgrids to meet state goals around clean energy and equity by powering microgrids with distributed clean resources and locating them in historically disadvantaged communities	Meeting state goals around increasing the amount of clean energy on the grid and improving pollution in historically disadvantaged communities
P8	**Doing Everything**	**Resilience + Everything Else**	People want microgrids to do it all. Where do we put them if we prioritize everything at once?

Table 1. The nine 'iconic case' portfolios used in the suitability model. Each case represents an aim for microgrids beyond resilience.

Based on the combination of criteria and associated weights assigned to the portfolio, the model outputs a suitability score for each cell in the map that represents the three utility service territories included in the analysis. This score is based on a weighted sums calculation of the values of all cells in that specific location within each geospatial data set that's informing the model.

In other words, each criterion is its own map—a layer of data sectioned into a grid that covers the full service territories of the State's three major utilities. Each grid cell contains a value that reflects something about this criterion, which have been reclassified onto a common suitability scale before analysis. (For example, a cell that falls within a census tract with a CalEnviroScreen score in the 95^{th}-100^{th} percentile range would be assigned a 10 when the suitability scale is 1-10.) Each criteria layer is then assigned a weight—which in this work was a percentage representing its relative importance to the portfolio objective. The model multiplies each cell in each map layer by the layer's assigned weight. The model then stacks these individual layers and adds the values of all cells that cover each location on the grid. The result is a new map with a value between 1 and 10 for each grid cell. Lower values represent less suitable areas and are colored red while higher values reflect more suitable areas and are shaded green. Orange and yellow represent middling suitability scores.

Ultimately, running the model for each iconic case outputs a map of the analysis area—PG&E's, SCE's, and SDG&E's service territories—that reflects the suitability of every 100-meter square for a microgrid, given the use case in question. These maps form the basis for this work's suitability determinations.

The Criteria. The criteria used in this study reflect diverse views about the functions and people microgrids should serve. Some criteria represent a community's likelihood of power outages, such as previous PSPS events and worst performing circuits. Others reflect a community's status as a vulnerable or disadvantaged population. And some criteria, such as pollution levels and the marginal price of power, speak to goals beyond resilience. Criteria come from the MIP implementation plan and the literature focusing on different potential benefits of microgrids. The models use these criteria, represented by the appropriate datasets, to generate projections.

The first four criteria and accompanying six datasets in Table 2 reflect the criteria outlined in the MIP and were used to determine the Current Approach portfolio. As the indicators of vulnerability to electricity disruptions, the top three criteria were also used in each model run.[17] Because CalEPA's 2022 priority populations data draws from CalEnviroScreen 4.0 and is already used to identify disadvantaged / vulnerable communities for climate investments, it serves as a stand in for the combination of CalEnviroScreen score percentile, low-income, and rural communities' in all model runs after Current Approach [49][50]. See Appendix B for a full list of criteria and Appendix A for the data and sources.

Criteria	The Data that Reflects the Criteria
Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations (median outage duration over all experienced PSPS by census tract)
Reduce vulnerability to losing power in areas with lower historical levels of reliability	Areas prone to outages (defined by 2020 worst performing circuits)
Reduce vulnerability to losing power in areas at risk from climate and environmental impacts like wildfire	High Fire Threat Districts (defied by CPUC High Fire Threat Districts Map)
Provide resilience to the communities that will be hardest hit by, and least able to bounce back from, PSPS events	CalEnviroScreen score percentile
	Low income populations
	Rural communities
Reduce vulnerability to losing power for the largest number of people	Population (by census bloc)
Increase community resilience in or near areas most at risk of experiencing a disaster	High earthquake risk area
	High flood risk area
Provide local resilience to the communities that will be hardest hit by, and least able to bounce back from, losing power and increase the amount of clean, distributed generation sources in areas most likely to be heavily burdened by pollution	Priority Populations (defined by CalEPA for California Climate Investments)
Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid	Interconnection capacity for uniform generation (via utility Interconnection Capacity Analysis data)
Increase the likelihood that, and speed at which, new distributed resources like solar and battery storage can connect to the power grid	Interconnection capacity for PV generation (via utility Interconnection Capacity Analysis data)
Increase distributed zero-carbon energy sources in areas most affected by pollution in order to retire fossil fuel power plants	CalEnviroScreen pollution percentile score (by census tract)
Lower energy prices by putting new distributed resources in places that can help alliviate grid congestion	Average Locational Marginal Price at CAISO pnodes

Table 2. Data reflecting the eligibility and prioritization criteria from the MIP. This data, as well as data reflecting other goals for microgrids, was collected, cleaned, and used to inform the models.

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[17] Given that these resilience indicators were chosen by the major utilities, they may or may not reflect the full range of resilience indicators that should be incorporated into an analysis of this type. See 'Project Refinements' for more.

Data and Data Processing. Data reflecting criteria outlined by the utilities, as well as criteria that otherwise reflected the goals of each portfolio, was collected and transformed so that it could be used to inform the models. The data source, the form it took, and how it would be used to inform the results directed how it was transformed before being fed into the model.

Government data. Most of the data from government agencies—for instance, CalEnviroScreen 4.0, priority populations, CPUC High Fire Threat Districts, FEMA flood hazard layers, and population by census bloc—was available in a geodatabase or shapefile format that was immediately useable in ArcGIS. These datasets required little cleanup beyond ensuring each one covered the full area of California. They were simply reclassified to a common suitability scale after being transformed from a vector type to the raster type required by ArcGIS's suitability modeler. (Three exceptions were rural areas, earthquake hazard zones, and locational marginal prices with associated nodes, discussed below.) As the official California border extends offshore, the CEC's building climate zones data was used to create an onshore boundary of the State.

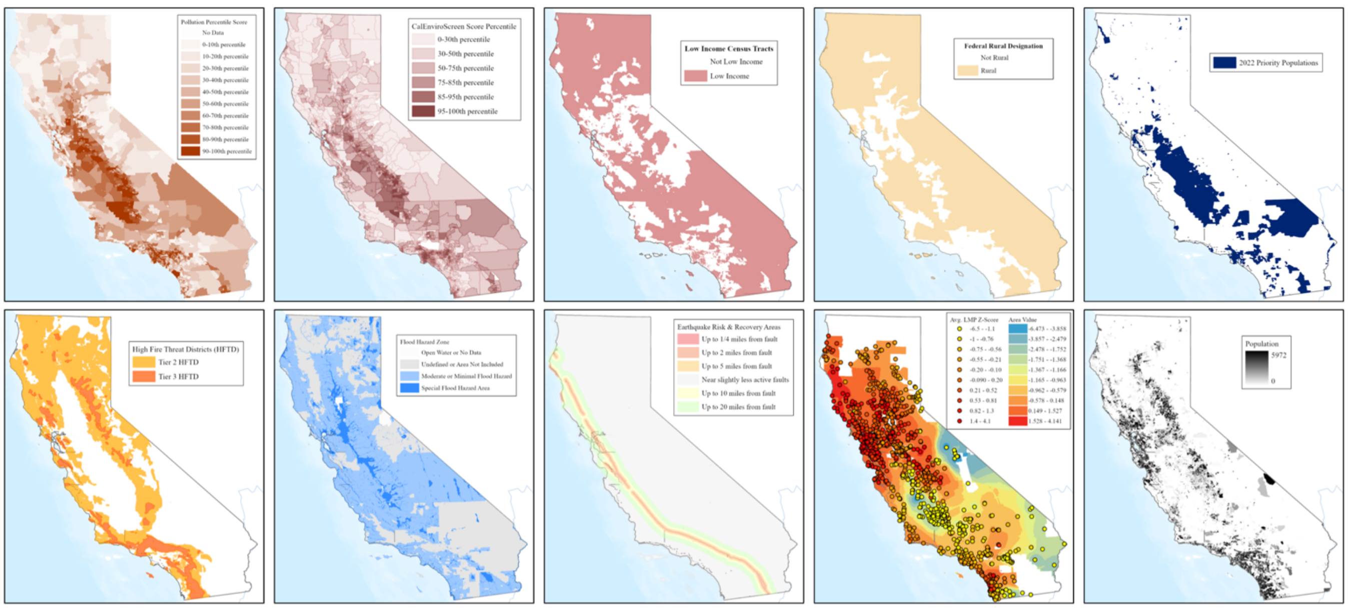

Figure 3. Criteria layers represented by government data. Top row: pollution percentile score, CalEnviroScreen 4.0 score, low-income census tracts, rural census tracts, and priority populations. Bottom row: CPUC High Fire Threat Districts, FEMA Flood Hazard Zones, buffered highest earthquake risk zone, locational marginal electricity price zones, and population numbers.

Rural areas. In the case of rural areas, the data provided by the Federal Office of Rural Health Policy (FORHP) listed a combination of counties where all census tracts were eligible and census tracts within counties where the full county was not rural. Since rural designations are formally done at the census tract level, a sub model was created to collect all census tracts within fully rural counties and combine them with census tracts in counties with mixed rural/non-rural areas.

Earthquake hazard zones. Two different datasets were used to determine earthquake hazard areas. The highest risk area in the 2018 Long-Term National Seismic Hazard Map was used for the eligibility model because it is called out within the MIP implementation plan [54]. However, the zones in this dataset are overly broad and include areas directly on top of major fault lines. A microgrid located on top of a badly rupturing fault is unlikely to provide much community support, while a resilience hub some distance from the main damage could significantly benefit disaster response and recovery efforts. So, the Uniform California Earthquake Rupture Forecast Version 3 was used to locate fault lines with a

10% or greater likelihood of experiencing a 6.7 magnitude or greater quake in the next 30 years [55]. These faults were then buffered out to distances of .25, 2, 5, 10, and 20 miles, which each zone and the rest of the state given a corresponding suitability score for use in the suitability model.

Electricity price zones. California's Independent System Operator (CAISO) provides access to historical Locational Marginal Pricing (LMP) Data. This data represents the wholesale price of electricity at different pricing nodes throughout the state. Data is downloadable by day and includes both the LMP and the factors that make up the price at each node. A series of simple python scripts were used to download a year's worth of LMP data, extract only the base LMP, and average the LMP for each node over the course of that year. This was done to avoid daily and seasonal variations in price. This data was then matched with node locations from CAISO's price map [56]. To normalize prices for each node, Z-scores were calculated before being used to create a price surface across the state using an Inverse Distance Weighted method within ArcGIS. Creating this price surface with normalized average locational marginal prices allowed the model to simulate where new electricity generation could potentially be most profitable and/or provide useful services to the grid.

Utility data. The CPUC mandates that the IOUs make their PSPS, worst performing circuits, and Integration Capacity Analysis (ICA) data publicly available [2][57][58]. PG&E has its PSPS and worst performing circuits data searchable from its website and a simple process to register to access its ICA web portal. SCE's PSPS and worst performing circuits data was best found via filings made at the CPUC and their ICA web portal did not require registration. SDG&E had PSPS data available on its site while worst performing circuits data was best obtained via the CPUC. Registration to access SDG&E's ICA data required both an email sign up and approval process.

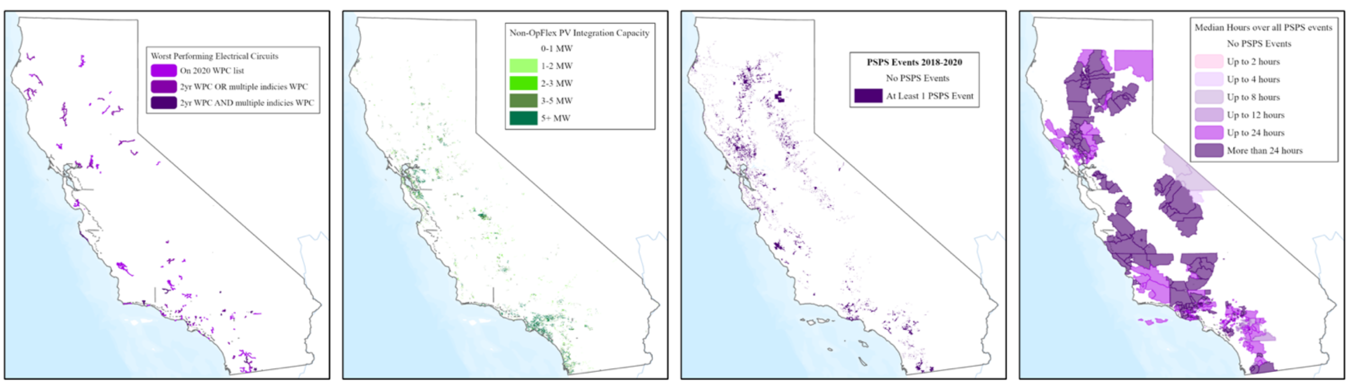

Figure 4. Criteria layers represented by utility data. From right to left: worst performing circuits, integration capacity for PV generation, circuits that experienced PSPS events between January 2018 and December 2021, and census tracts that experienced PSPS events in 2021.

Worst performing circuits data is available as part of each utility's 2020 Annual Electric Reliability Reports. The relevant data for this work was embedded within those report PDFs. Metrics, presentation styles, and naming conventions were different between utilities—e.g. PG&E used the term 'feeder' while SCE and SDG&E used the term 'circuit' to refer to the same type of infrastructure. Once transcribed into excel and cleaned such that each utility dataset matched, it could be transferred into ArcGIS and combined with the portion of the ICA data that indicates where circuits are located to enable a geospatial analysis. Data was then classified into three buckets to be ranked: a circuit that was simply on a utility's 1% worst performing circuits list, a circuit that appeared as worst performing under multiple reliability indices (e.g., both circuit SAIDI and circuit SAIFI) or was deficient (meaning worst performing two years in a row), or a circuit that was both poorly performing under multiple indices and deficient. Finally, circuits were buffered out to 60 meters. This represented areas that would potentially draw power from that circuit and ensured that the circuits could be seen at the 100-meter cell resolution of the suitability models.

For PSPS data, each utility has geospatial shapefiles available that depict PSPS events by census tract for 2021. Utilities also file post-event reports for each PSPS event, which include the names of impacted circuits, when they were de-energized, and when they regained power. Prior to mid-2021 this data is listed as circuit names, without a geospatial component, in these individual reports. In the interest of time, the suitability models used the 2021 census-track level shapefiles from each utility—classified by median outage hours experienced over the course of the year—to represent previous PSPS locations. The eligibility model used areas likely to be served by impacted circuits dating back through 2018.[18] This was done by matching the names of impacted circuits with the corresponding circuit name in the utility ICA data, which includes the necessary geospatial component.

PG&E's full ICA dataset was downloadable in a geodatabase format. SCE and SDG&E asked users to download the data by circuit—which would have meant individually downloading thousands of circuits to cover the full service territories. When asked for an easier solution, SDG&E pointed to their API widget and documentation, neither of which enabled a different download option. Ultimately, full ICA files for SDG&E were obtained via the ICA layer's service definition file hosted online and SCE's full files were gathered through a hosted ArcGIS portal.[19] Once accessed, ICA files required reformatting before being stitched together given different names, labels, and field types.[20]

ICA data was ultimately used to identify the locations of worst performing circuits, to illuminate which circuits had integration capacity in each service territory, and to identify the locations of circuits that had suffered PSPS events in the eligibility analysis. There were more than 2.3 million line segments once data from the three IOUs was combined. To simplify the analysis, integration capacity was averaged at the feeder / circuit level before the circuits were buffered to a total distance of 45 meters to represent areas that would likely be served by those circuits.

For further accounting of data, sources, transformations, and suitability scale reclassifications, see Appendices A and B.

Setting Up and Running the Models. After appropriate datasets were identified, collected, and brought into ArcGIS, they were internally reclassified onto a common scale. For the eligibility model, this was a binary 1 or 0 representing "yes" or "no" for areas that fit one of the criteria buckets. For example, areas in a Tier 2 or 3 HFTD were given a 1 and areas not in those districts were given a 0. Criteria from each eligibility bucket—vulnerability to outages and disadvantaged / vulnerable communities—were then combined and reclassified back to that binary scale. The results of these combined and reclassified buckets were then combined a final time, with results indicating which areas included at least one criterion from each.

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[18] The eligibility model used PSPS-impacted circuits from 2018 onwards as the majority of reported PSPS impacts began in that year. (Only SDG&E reported on PSPS events prior to a 2018 ruling allowing all utilities to conduct PSPS and expanding the reporting requirements around these events.)

[19] SCE and SDG&E's ArcGIS portals have been updated for easier data access since this data was first collected.

[20] Maintaining field type consistency is important for combining data within the model. For example, if one utility used a short integer while another used doubles, intermediate model outputs would not include information from that field. Additionally, PG&E and SCE had their ICA data as lines while SDG&E formatted as polygons. These types cannot be combined, so PG&E and SCE data was ultimately buffered to form polygons that could be combined with SDG&E's data.

For the suitability model, internal reclassifications were done on a 1-10 suitability scale. This allowed the criteria to "speak" with each other so that the dataset with the highest values didn't overpower the results. Once all data was set to a common scale, criteria were fed into the model and weighted to reflect policy choices that prioritized the secondary benefit the iconic case represented. As resiliency is the core function of a microgrid, resiliency-oriented criteria such as poorly performing circuits and areas subject to PSPS events were included in each model parameterization.

The suitability model was then run for each iconic case. The resulting suitability maps contain scores between 1 and 9.5.[21] A vector dataset containing census designated and incorporated places from the 2020 census was then overlaid on the final suitability map for each portfolio and zonal statistics were run to calculate the mean, max, and other score statistics of these Places.[22] This focused the final analysis on communities that could theoretically build and benefit from one or more microgrids, rather than comparing every 100-meter square of California.

To compare results between portfolios, suitability scores for Places within PG&E, SCE, and SDG&E's service territories were grouped into three categories: high, medium, and low. This was done by splitting the average range of scores into thirds.[23]

One goal was to illustrate the shifting distributions, if any, of high-, medium-, and low-suitability locations when prioritizing different secondary goals. Another goal was to locate communities where electricity resilience solutions may be particularly desirable so that a closer analysis—including an overlay and cluster analysis of community services like fire stations, hospitals, and schools—could be conducted in the most appropriate locations.

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[21] No suitability scores were higher than 9.5, as no areas included values in the highest category for all criteria.

[22] To avoid confusion, the word 'places' is capitalized when it refers to census designated or incorporated places and isn't immediately preceded by that qualifier.

[23] The average of all lowest minimum scores was 1.10 while the average of all highest maximum scores was 9.07. This gave a range of 7.97, which was then split into thirds. This helped account for outlying minimum or maximum scores.

RESULTS

The study located Places eligible for the proposed Microgrid Incentive Program and modeled the most suitable locations for microgrids that provide the functions that define the nine iconic cases outlined in Table 1. Each portfolio considered resilience its core criterion in addition to various secondary goals.

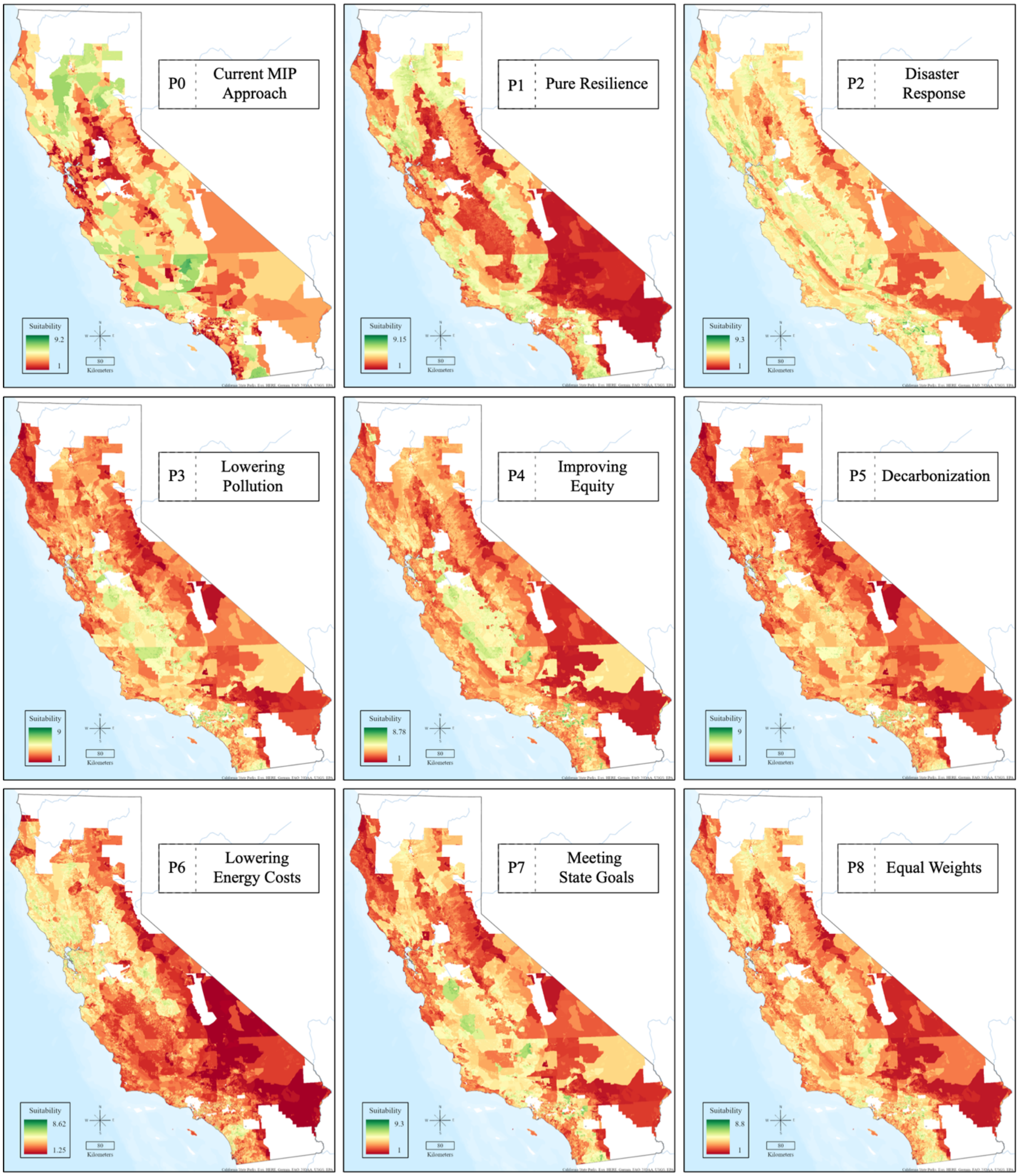

Figure 5. The final suitability maps across all nine portfolios Each used resilience as its core criterion while prioritizing different secondary goals (Table 1). As PG&E, SCE, and SDG&E are the focus of the MIP—and only their worst performing circuit and PSPS event data is included—results only reflect their service territories. To that end, clear areas within the maps represent the service territories of other electric utilities operating in California.

A key finding is that although some locations remained consistently suitable sites for microgrids across portfolios, results were dynamic between model runs—illustrating that optimal sites shift when policy prioritizes different secondary goals. Figure 5 illustrates the broad trends in suitability for each iconic case. Notably, the Current MIP Approach (P0) and Pure Resilience (P1) cases have a similar pattern of suitability—which reflects the fact that the MIP is resilience-centric. The Lowering Pollution (P3), Improving Equity (P4), and Decarbonization (P5) portfolios also showed similar patterns to one another. This concurrence speaks to the secondary aim of powering microgrids with clean energy sources that could then replace polluting fossil fuel generators—which are often located in disadvantaged / vulnerable communities—and reflects these portfolio's prioritization of locations with higher pollution scores. There is a rural-to-urban shift, particularly around Los Angles, when emphasis in the suitability model shifts from pure resilience to weighting incremental decarbonization or lowering pollution.

Community Eligibility for the Microgrid Incentive Program. The eligibility model determines which geographic areas in PG&E, SCE, and SDG&E's service territories are potentially eligible for the Microgrid Incentive Program (Figure 6).[24] Overlaying this result with incorporated and census designated places shows which communities are eligible—an important piece of the puzzle given that projects may require a letter of interest from a local authority [42].[25] Of the 1,611 Places in California, 1,384 (86%) are served by one of the big three utilities. Of these, 965 have at least one 10-meter-squared location within their boundaries that is potentially eligible for the MIP, based on the community eligibility criteria.[26]

More than half of all Places (60%) in California are theoretically eligible for the MIP under its community eligibility criteria. This reflects the breadth of PG&E, SCE, and SDG&E service territories—which represent roughly 75% of the State by area and include 86% of all Places in California—as well as the large number of low-income census tracts and federally designated rural areas in High Fire Threat Districts and/or Places that have experienced a PSPS event since 2018 [60][61][62].

[24] This only applies to the community eligibly piece of MIP eligibility, as a corresponding evaluation of the technical eligibility requirements was beyond the scope of this study. It also does not indicate that these areas will have eligible projects, as there may not be critical facilities or other suitable locations for microgrids within them.

[25] There may be communities that could benefit from resilience solutions that don't reside in either incorporated or census designated places [59]. But for the purpose of this analysis, these boundaries were used to classify locations in a replicable way, which could then be looked at in greater depth.

[26] See Appendix D for a full list of places potentially eligible for the MIP and the "Eligibility Statistics" table therein for a complete view of these and the following percentages.

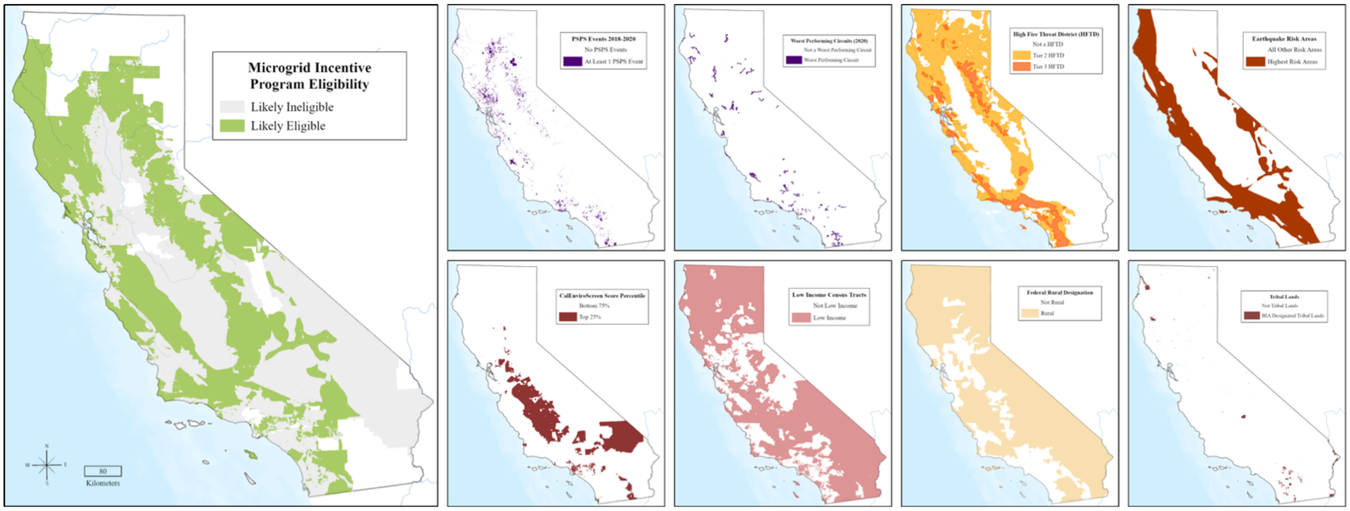

Figure 6. Areas eligible for the MIP and associated criteria. Community eligibility (left) is the intersection of areas eligible per vulnerability-based criteria (top row) and disadvantaged-community criteria (bottom row). (Top from left: previous PSPS events, worst performing circuits, high fire threat districts, highest earthquake risk. Bottom from left: CalEnviroScreen 4.0 score percentile, low-income census tracts, rural census tracts, federally designated tribal lands.)

The analysis indicates that more census designated places are eligible than incorporated ones (654 census designated places compared to 311 incorporated) and that generally, more populated areas are less likely to be eligible for the program. This is unsurprising, as rural areas—which are less densely populated—are included in the definition of disadvantaged communities [63][64]. There are also simply more census designated places in the IOU service territories (and in California) than incorporated places.

The percentage of Places with at least one 10-meter square that's eligible for the MIP reflects the roughly 70/30 breakdown of census designated places to incorporated places within the IOUs' service territories. However, census designated places are more likely to be fully eligible (89% of census designated places versus 11% of incorporated)—meaning all of the grid cells that make up the area score as eligible within the model. This indicates that the entire jurisdiction could potentially be a good location for a microgrid. This may reflect, in part, the fact that incorporated places are roughly 40% larger by land area than census designated ones.

The distinction between census designated and incorporated places may become important to accessing MIP funds because utility outreach efforts will primarily target local governments [42]. Certain community facilities may also need local government approval to be included in a microgrid. For a proposed project in a census designated place this means relying on the County government, an entity the local community may have little or no working relationship with.

Suitability of Locations Under a Range of Grid Modernization Goals. Prioritizing different secondary goals for microgrids changes the distribution of their most suitable locations. The contrast is starkest when comparing the Current MIP Approach (P0) and Pure Resilience (P1) portfolios with the Improving Equity (P3), Lowering Pollution (P4), Decarbonization (P5), and Lowering Energy Costs (P6) portfolios (Figure 7). For example, 15% of places in the Pure Resilience (P1) portfolio contained a 100-square-meter area with a high suitability score, while 26% of places did so in the Decarbonization (P5) portfolio. While Pure Resilience (P1) visually appears to have more area with high suitability scores, other portfolios often had more communities with locations highly suitable for microgrids. For further comparisons, see Figure 5, Table 3, and Appendix E.

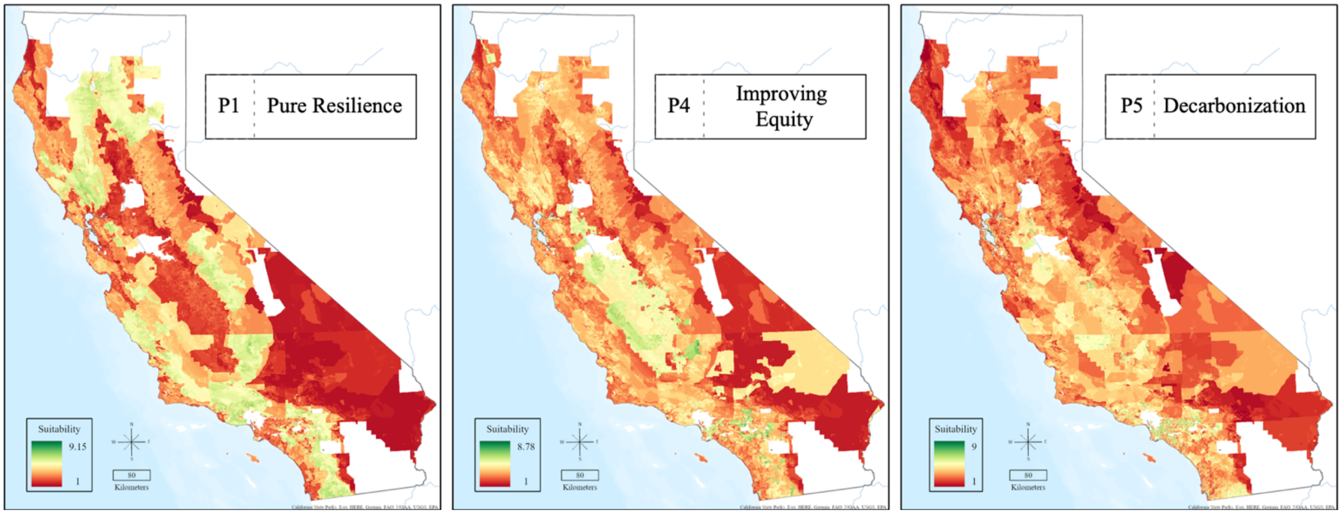

Figure 7. Suitability scores across three of the nine microgrid portfolios representing iconic cases for secondary benefits. Here, the general electricity resilience or 'Pure Resilience' (P1) portfolio is contrasted with the co-benefits of the Improving Equity (P4) and Decarbonization (P5) portfolios.

The distribution of suitability across portfolios. The frequency of high, medium, and low suitability scores—with each tier representing one third of the range of all scores—for each portfolio was divided by the total number of Places to find the percentage of Places in each tier for each portfolio. This was done for both the mean and single maximum score for each Place.

Doing so allowed a general comparison between portfolios, as it painted a rough picture of how often a microgrid might be considered a strong (or poor) solution under each secondary policy objective.[27]

The 'Mean Score' in Table 3 reflects the average suitability score across the entire Place—how likely a full census designated or incorporated place is to be highly, middlingly, or poorly suited for a microgrid. It's a potentially useful metric for assessing a full community's needs, as a high mean suitability score represents a Place where a community may struggle to recover from disruptions and most infrastructure is vulnerable to outages and could benefit from a microgrid. However, the mean score does not reflect the suitability of any specific location within a Place, as it's the average suitability score across the entire community and utilities are not currently planning microgrids at that scale.

The 'Max Score' indicates the single highest score found within a Place. It represents the most potentially suitable 100 square meter location for a microgrid in that community. Unlike the mean score, it doesn't indicate whether a broader Place is vulnerable, just whether any single location within a Place has a confluence of vulnerability criteria. A microgrid is, at present, unlikely to cover more than a few buildings.[28] So the 'max score' in Table 3 may be a more accurate depiction of the percentage of different communities potentially suitable for a microgrid. (That said, it still does not illustrate the total microgrid potential for each portfolio, as a single Place could contain numerous highly scoring locations and build multiple microgrids to cover different sets of critical facilities.)

[27] This does not consider how a microgrid might compare to other resilience solutions—a worthwhile analysis that was beyond the scope of this study.
[28] While microgrid sizes and configurations are growing, most microgrids are still sized for a single building or scoped for a few facilities. A microgrid covering a full community would face significantly more technical and regulatory challenges.

Portfolio	Iconic Case	Percentage of Places with a high suitability score		Percentage of Places with a medium suitability score		Percentage of Places with a low suitability score	
		Mean Score	Max Score	Mean Score	Max Score	Mean Score	Max Score
P0	**Current Approach in California**	3%	6%	30%	47%	67%	47%
P1	**Pure Resilience**	1%	15%	31%	52%	68%	33%
P2	**Disaster Response**	2%	24%	79%	73%	19%	3%
P3	**Lowering Pollution**	1%	22%	41%	60%	59%	17%
P4	**Improving Equity**	0%	14%	39%	72%	60%	15%
P5	**Decarbonization**	0%	26%	38%	58%	62%	16%
P6	**Lower Energy Costs**	0%	23%	56%	63%	44%	13%
P7	**Meeting State Goals**	1%	9%	38%	69%	61%	22%
P8	**Doing Everything**	0%	15%	30%	70%	70%	15%
-	***Average Across All Portfolios***	1%	17%	42%	63%	57%	20%

Table 3. Percentage of Places in PG&E, SCE, and SDG&E service territories with high, medium, and low suitability scores in each portfolio.

Table 3 indicates that a limited number of Places have locations that would be considered highly suitable for a microgrid, particularly under the current approach. It also illustrates that across portfolios, most locations (roughly 50-75%) are only somewhat suitable for this resilience solution.

Shifts in suitability around Los Angeles. Under the Current MIP (P0) and Pure Resilience (P1) approaches, areas adjacent to L.A. that are in SCE's service territory are frequently unsuitable as they are often not in a HFTD and did not experience a PSPS event in 2021.[29]

Areas around L.A. stand out for a significant increase in suitability when boosting the importance of other goals, such as equity and lowering pollution, compared to just electricity resilience (Figure 8). In the Pure Resilience (P1) portfolio, suitability scores range from 1.45 to 5.2, out of a possible range of 1–9.15. This indicates that most of the area is not ideal for microgrids when prioritizing pure electricity resilience or likely when using the current MIP approach. That said, some pockets—e.g., low-income communities served by poorly performing circuits—would still be reasonable candidates. When the model increased the importance of equity—represented by prioritizing disadvantaged communities

[29] Geospatial information was only available for the most recent year of PSPS events, so only 2021 is included in the suitability model. See "Project Refinements" for more.

identified by CalEPA in its 2022 priority populations data—these neighborhoods' suitability scores increased. A similar change happened when the model prioritized lowering pollution, which was represented by CalEnviroScreen 4.0's pollution percentile data. This is likely due to the high concentration of gas peaker plants in the area, which are also often located in disadvantaged communities and would raise pollution scores for these neighborhoods [65][66].

The non-resilience goal of the Decarbonization (P5) portfolio depends on a combination of local pollution data and local interconnection capacity for PV generation, which indicates where new solar PV could displace fossil fuel generation. This also increased the suitability of neighborhoods around L.A. compared to a pure resilience approach, as shown in Figure 8. Many of these communities are disadvantaged and/or low income. Moreover, along with higher levels of pollution, disadvantaged communities often have lower integration capacity than their wealthier counterparts [67].

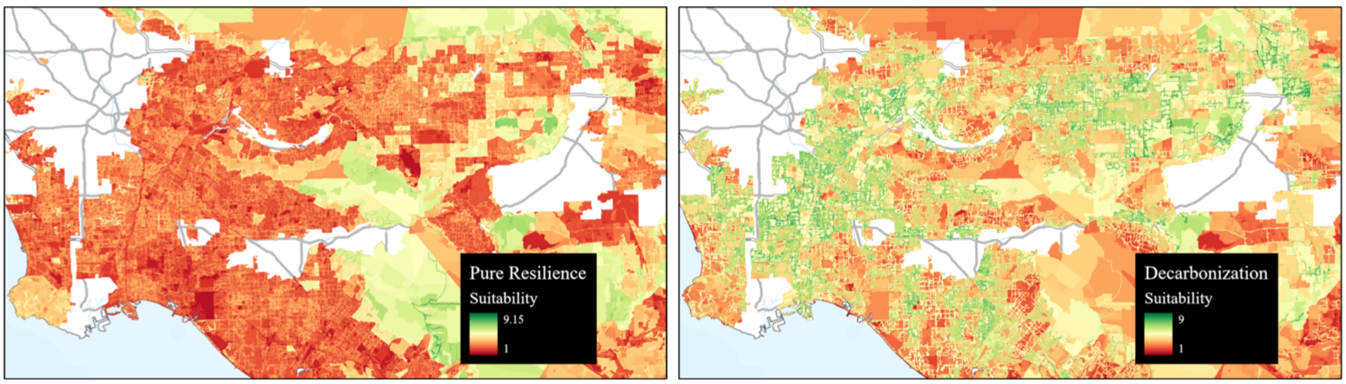

Figure 8. Suitability around Los Angeles in the Pure Resilience (P1) versus Decarbonization (P5) portfolios. In general, areas around L.A. have higher suitability scores in the portfolios that more heavily weight protecting disadvantaged communities and lowering pollution. Areas without color lie outside SCE's service territory and were not included in the analysis. The portions of each map near the legend without the crosshatch pattern (green on the left and orange on the right) are mostly state parks and a nature preserve.

The Lowering Energy Costs (P6) portfolio also raised suitability scores around L.A. This reflects the area's higher-than-average electricity prices, as the normalized average locational marginal price of energy was included in this portfolio to represent where new distributed generation could help lower costs [68][69]. This result held true whether integration capacity was for PV or baseload generation.[30]

Suitability in the Bay Area. In the Current Approach (P0) and Pure Resilience (P1) portfolios, areas directly bordering the San Francisco Bay were unsuitable while areas outside the inner Bay Area (in Livermore, Tassajara, Central Contra Costa, Napa, Sonoma, and Petaluma) had higher suitability scores. This is due to the former being considered less vulnerable to wildfire, while the latter are in High Fire Threat Districts and experienced long duration PSPS events in 2021. However, in the Lowering Pollution (P3), Decarbonization (P5), and Lowering Energy Costs (P6) portfolios, communities in the inner Bay Area have circuits with suitability scores up to 7.76. This is likely because pollution scores are higher in South San Francisco, Oakland, and San Jose, and wealthier communities along the bay might have more recently updated distribution circuits with higher capacity to integrate new distributed energy

[30] While both PV and baseload (e.g. traditional fossil fuel) generation were both tested, final results for the Lowering Energy Costs (P6) portfolio used PV generation given California's clean energy and decarbonization goals.

resources. Additionally, high power demands in the area may be leading to constrained transmission circuits and thus higher marginal prices for power, which would increase suitability scores in communities with these higher energy costs. As these results are based only on the 2021 PSPS data and PG&E's service territory experienced widespread outages in 2019, suitability scores along the Bay are likely to rise considerably in an analysis that updates this dataset.

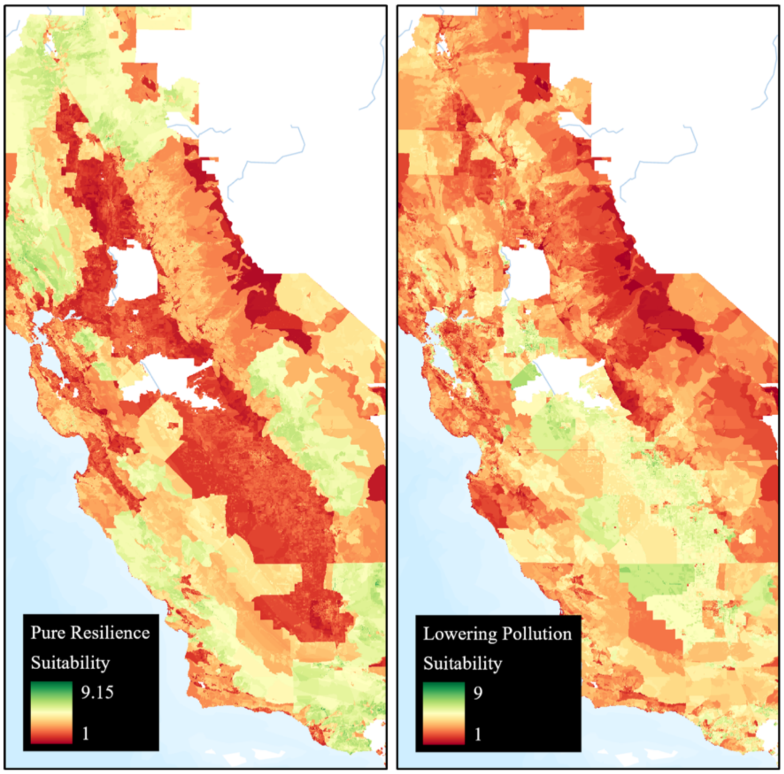

Figure 9. Suitability in the Central Valley in Portfolio 1 (Pure Resilience) versus Portfolio 3 (Lowering Pollution). The Central Valley's suitability scores were higher in portfolios that prioritized lowering pollution, reflecting the region's poor air quality.

Shifts in suitability in the Central Valley. Clear shifts in the suitability of the Central Valley are also apparent when moving from the Current Approach (P0) and Pure Resilience (P1) portfolios to portfolios that prioritized disadvantaged communities or lowering pollution (Figure 9). In the Current Approach (P1) case, the Central Valley's suitability score only exceeds 2 on circuits with integration capacity and in the portions of Kern, Tulare, and Fresno County that intersect with either high flood risk zones or HFTDs. This reflects the portfolio's focus on utility vulnerability to outages, as the Central Valley boasts a backbone of significant transmission infrastructure that isn't currently considered vulnerable to wildfires [70].

In contrast, in the Lowering Pollution (P3) and Improving Equity (P4) portfolios, Places located in the Central Valley were among the most suitable areas for microgrids. While population centers were pockets of low suitability, with scores as low as 1.7, the Central Valley on average appears suitable. This reflects the fact that high levels of vehicle- and farming-related pollution are easily trapped within the valley and severely degrade air quality, which is picked up in two criteria—CalEPA's priority populations data and CalEnviroScreen 4.0's pollution percentile scores [49][71][72].[31]

The Central Valley also increased in suitability in the Decarbonization (P5) portfolio, likely due to pollution acting as a stand-in for local emissions as well as reasonably high integration capacity in the region. In this scenario, locations with the highest suitability—with scores up to 7.76—contained distribution circuits with ample hosting capacity.

[31] High pollution areas are considered more suitable because a clean energy microgrid could reduce fossil power generation. However, much of the Central Valley's pollution is from agriculture, not electric power. See "Project Refinements" for more.

Places with consistently high suitability scores. While there are general shifts in suitability between portfolios, a few locations have consistently high mean suitability scores regardless of which secondary benefit is prioritized.[32] A high mean suitability score indicates a confluence of vulnerabilities that are represented by geographically broad datasets. So, beyond the 60-meters surrounding a poorly performing circuit, the entire area is likely covered by HFTDs or overburdened by pollution. The pollution data in this work covers full census tracts, which can be geographically large in sparsely settled rural areas [73]. This would help raise suitability scores across a full Place rather than only a small portion of it, leading to a higher mean score.

Bodfish, a census designated place (CDP) roughly an hour northeast of Bakersfield, was the most consistently suitable place in this analysis (Figure 10). It had the highest mean suitably score across all portfolios and the eighth highest average max suitability score. Similarly perched at the edge of Sequoia National Forest, the neighboring community of Lake Isabella CDP had the second highest mean suitability score and fourth highest max suitability score across all portfolios. They're both old gold-mining towns and home to priority populations (disadvantaged, low income communities) [74][75][76]. They also both experienced at least one longer duration PSPS event in 2021, sit within a Tier 3 HFTD, and are served by worst performing circuits.

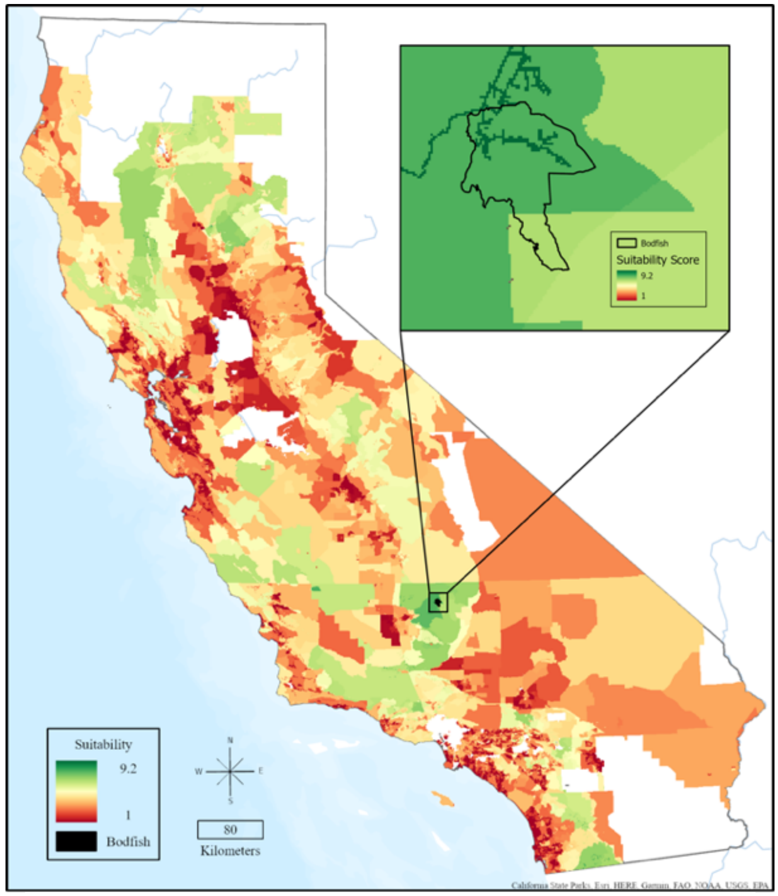

Figure 10. Suitability in Bodfish CDP. Bodfish and the neighboring community, Lake Isabella CDP, were the most consistently suitable Places in this analysis by full area, reflecting low levels of electric reliability alongside their high fire risk and status as disadvantaged / vulnerable communities.

While these two Places top the chart for average mean suitability score, only Bodfish ranked in the highest tier.[33] This is partially because the highest suitability scores will only fall on the actual locations of poorly performing circuits that overlap with other prioritized criteria and communities are likely to be served by multiple circuits—meaning a single poorly performing circuit is unlikely to cover the full area of a Place.

A few Places in Riverside County and the southwestern portion of San Bernadino County also have consistently high suitability scores across portfolios. San Bernadino City has the highest average maximum suitability score at 8.56, with neighboring communities Crestline CDP and Lake Arrowhead

[32] See Appendix E for highest mean suitability scores and highest single suitability scores (e.g., max score) by portfolio.
[33] The highest tier representing the top third of the average range of all suitability scores.

CDP in the 2nd and 3rd spots with maximum suitability scores of 8.55 and 8.38 respectively. This is due to the overlap of key resilience criteria like high wildfire threat and PSPS events with disadvantaged communities in those areas. As pollution burden is often highest in disadvantaged communities, incorporating pollution indicators would then further raise suitability scores in these neighborhoods [77].

Places that rank highly across portfolios on either mean or max suitability, and particularly Places that rank highly on both measures like Bodfish, Lake Isabella, and Crestline, are worth exploring with a deeper analysis. These areas would likely benefit significantly from resilience solutions and would be good candidates for MIP funds, given this analysis' grounding in those criteria.

In general, census designated places were more likely to have high mean suitability scores than incorporated ones. This may reflect the fact that these Places are frequently more rural, which in some areas correlates with higher wildfire vulnerability. For instance, most of San Bernadino City is not in a HFTD. But the communities of Crestline CDP and Lake Arrowhead CDP, both a 10–20-mile climb into the forested mountains northeast of the city, are entirely within HFTDs. Census designated places are also smaller. On average, the incorporated places in the three IOU service territories are almost 40% larger by land area, potentially making it easier for a CDP to achieve a high suitability score across a whole Place. That said, more than half of the top 20 Places with the highest average max suitability score across all portfolios were incorporated. This speaks to pockets of disadvantaged communities experiencing high pollution levels in cities, particularly in locations that overlap with PSPS events and high fire threat in Southern California.[34]

The overlap of eligibility and suitability. While MIP eligibility was not considered during the suitability analysis, comparing the results of each offers a shortlist of communities that may be good candidates for MIP funds. Of the 965 Places eligible for the MIP, 76 of them have at least one potential location that could be considered highly suitable for a microgrid in the Current MIP Approach (P0) portfolio. (While MIP project scoring is more specific than eligibility for certain criteria, these locations are worth exploring further as potential MIP candidates.) And of the 129 Places where the average max suitability score across all portfolios was in the highest tier, 111 are eligible for the MIP. This further illustrates that some communities may be good candidates for microgrids regardless of which secondary benefits are prioritized. These Places may be the most likely to achieve multiple microgrid co-benefits.

[34] This number will likely rise in an updated suitability analysis that incorporates more years of PSPS data.

The Microgrid Incentive Program: Eligibility & California's Goals. The MIP uses a range of vulnerability criteria as the core indicators of whether a community can receive MIP funding for a microgrid project. These include whether a community is served by a worst performing circuit, is in a Tier 2 or 3 HFTD, and has at least one indicator of being a disadvantaged community such as having a high CalEnviroScreen score. Given the various aims of the Program—testing new technology, catalyzing the microgrid industry, and ensuring disadvantaged communities receive microgrid benefits—these criteria must walk a fine line [41][42]. They need to be broad enough to attract a diverse array of proposals but narrow enough to ensure the program doesn't deepen existing inequities.

While the chosen criteria are defensible, they neither address the full array of threats facing communities nor pinpoint few enough locations to overcome the institutional barriers that historically block the most disadvantaged communities from accessing funding [78][79]. Certain locations have limited eligibility (and suitability) under MIP metrics even when other indicators, for instance vulnerable transmission infrastructure, suggest they might be good candidates for a microgrid. However, enough locations are likely eligible for the MIP that communities with more resources may monopolize program funds—if only because these communities have the time, money, expert knowledge, and institutional power needed to quickly apply for funding and get a community microgrid project off the ground.

This isn't to say the criteria are poorly chosen. Instead, it speaks to the structural issues inherent in how infrastructure projects are developed and the number of communities that currently need resilience solutions. In doing so, it indicates that other elements of the MIP design, notably project scoring, will need to step in to ensure the Program can accomplish its goals. It also suggests that this Program will need to be accompanied by further measures to shift institutional structures towards broader microgrid adoption; namely, increasing access to the knowledge, funding, and leverage required to implement adaptation and resilience projects in the energy sector.

Community eligibility for the Microgrid Incentive Program. Having a clear set of criteria to determine which projects can access funding is necessary to administer a program like the MIP—particularly to ensure resilience benefits are directed to disadvantaged communities. However, reliance on a narrow set of reliability indicators may not be the best way to judge the needs of a given place.

For example, the transmission lines that serve the southern strip of Santa Barbara County are vulnerable to wildfires and mudslides, making the entire region vulnerable to outages [80]. Limiting the area's eligibility to a few pockets for potential projects (Figure 11) —which may not meet the technical eligibility requirements or have appropriate community facilities—could miss multiple communities' actual needs.

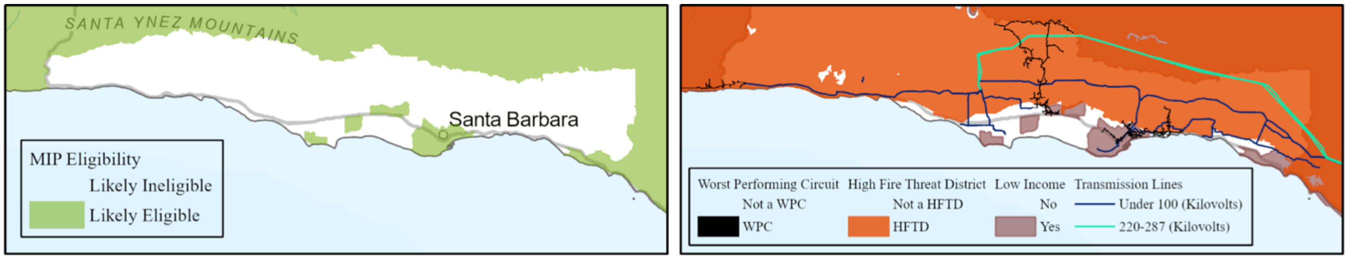

Figure 11. MIP eligibility in the southern strip of Santa Barbara County. The entire area is vulnerable to transmission outages, while eligibility is limited to a few places where MIP criteria overlap.

Additionally, the eligibility data—particularly the utility worst performing circuits and historical PSPS data—isn't the most straightforward. Restrictive or confusing criteria can prevent disadvantaged communities from accessing funds, in part because they may be unable to navigate the application process.[35] The MIP works to counter these issues through early technical consultations, a detailed MIP handbook, and an application development grant for eligible communities. But determining if it's worth applying for MIP funds and doing so within the necessary windows will still take considerable effort. MIP applications may also require contracting a technical consultant before the grant can be awarded, while a project's eligibility isn't confirmed until that work is done. For a community with limited resources, this could be a non-starter.[36]

That said, 70% of Places within PG&E, SCE, and SDG&E's service territories—accounting for 60% of all incorporated and census designated places in California—have at least one location that's potentially eligible for the MIP. There isn't funding for even a fraction of these to build a microgrid.[37] The combination of eligibility criteria with the MIP's proposed method of prioritizing projects for funding could result in money flowing towards those with more resources and/or towards projects that benefit fewer people. The MIP scoring formula is *Project Score = Benefit Score (points) / Application Incentive Request ($)*. Notably, the *Benefits Score* is capped. This could skew project scores towards those that request less funding.

Meeting California's equity goals while commercializing the microgrid industry. With the inclusion of eligibility criteria and application grants, the MIP takes steps towards prioritizing disadvantaged communities and considering their capacity to pursue a microgrid. But the MIP struggles to reconcile this with the parallel goal of industry commercialization.

The more projects the MIP can catalyze, the quicker this industry can take off. Project development strategies, interconnection timelines, and business models will begin to standardize, bringing down costs down for everyone and enabling more communities to afford a microgrid. Incorporating the amount of funding a project is asking for in the prioritization metric may be a nod towards this goal, as it can help stretch the Program's budget. But doing so works against the Program's equity goal since it prioritizes communities with more of their own resources to devote to the project. Capping the benefits score has a similar limiting effect since it incentivizes smaller projects or those that require less funding, potentially helping fewer people even if the incremental costs of a larger, more beneficial project are small.[38]

Preferencing communities with less access and greater need aligns with California's adaptation goals. Yet it could be at odds with the MIP's commercialization objectives. The MIP may ultimately have disappointing results—not serving the most disadvantaged communities while also not funding enough microgrids to truly jumpstart this nascent industry. It's not that the criteria or program design are irredeemably flawed, but that the problem of reconciling the work it takes to develop a microgrid with

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[35] The CPUC's stated intent for MIP design was to ensure "available incentives are not immediately booked by parties with advance knowledge and the means to navigate the application process" [41].

[36] For more specifics on equity concerns surrounding the MIP criteria and application process, please refer to comments submitted by the Microgrid Equity Coalition in [43].

[37] After administrative costs, the MIP has $180 million to spend with a cap of $14 million in incentive award—and up to $4 million in interconnection and special facilities costs—per project. If successful applicants are awarded $7 million (less than half of what they could theoretically use) and each Place is capped at one microgrid, MIP funds will cover 2.66% of Places deemed eligible in this study and 33.8% of eligible Places with high suitability scores in P0 (Current Approach).

[38] This concern has also been pointed out by the California Energy Storage Alliance and Clean Coalition in their opening and reply comments on the proposed MIP [81][82].

the communities California wants to prioritize with the goal of commercializing an industry is larger than this program.

An opportunity to integrate other resilience objectives. This work may show certain areas as ineligible and/or unsuitable for microgrids. That isn't to say a particular area *is* unsuitable—just that this study's methodology and the MIP criteria deem it so. In reality, other benefits not reflected in the current criteria could make a microgrid valuable to any community. So while Figure 8 illustrates that microgrids are only middlingly suitable for 50-75% of Places regardless of secondary aim, the resilience benefits a community would receive from a microgrid are still very high.

As part of the MIP, the IOUs have committed to undertaking technical consultations with disadvantaged communities. These will, in many cases, be used to steer communities away from microgrids—which are expensive—if there's another potential solution. In this scenario, consultations are a golden opportunity to not only explore what other potential options a community has that would offer the same level of benefit, but to immediately start working towards these solutions beyond the MIP framework.

It would not require much additional process to integrate the results of these technical consultations with other resilience programs, which would be more efficient than having new programs start from scratch. If the data is shared appropriately, MIP consultations could then help inform adaptation measures that address a range of vital services. Utilities are taking the time and effort to meet with community leaders and collate the data necessary to decide if a microgrid is the right solution. If a microgrid is not the right fit, this information could still be used to advance whatever solution the community does deem best. It could also be used to build an accessible catalogue of what solutions may work well for other Places with similar needs, burdens, and environmental threats.

Moreover, these consultations are an opportunity to make connections and foster local knowledge bases about different resilience and funding options. This could help build the capacity for historically marginalized communities to implement solutions in the future. (Even if a community installs a microgrid, further adaptation measures will likely be needed. The upfront work both utilities and communities are doing as part of the MIP can then form the foundation of future resilience efforts.)

Microgrid Suitability (and Policy) Given a Range of Grid Modernization Goals. While this analysis is limited by its focus on vulnerability indicators outlined in the MIP, it offers an interesting look at distributional changes based on differing policy goals and which co-benefits seem to walk in step. A key takeaway is that certain secondary aims for microgrids are not well aligned. In particular, the Pure Resilience (P1) and Decarbonization (P5) portfolios highlight suitable locations in very different areas, suggesting that it may be difficult to implement a policy that optimally achieves both (Figure 7).

However, certain aims *are* complementary in specific locations, so achieving multiple microgrid co-benefits is feasible for certain subsets of goals. This implies that one could design policy that groups microgrid goals based on optimal location. For instance, if policymakers want microgrids to help lower pollution, contribute to decarbonization, and support State equity measures, a policy that fund projects in disadvantaged communities around Los Angeles may achieve the most numerous benefits. The model suggests high suitability and the reality of gas peaker plants in underserved communities in the area confirms potential benefit. It comes down to prioritizing different co-benefits in different locations, depending on the unique burdens of the communities in those areas and which benefits are most aligned. This would signal a different approach from the MIPs focus on wildfire resilience and would require different strategies to achieve.

Designing policy around groups of goals. It's sensible that regulators want microgrids to simultaneously advance multiple objectives. The handful of locations that appear consistently suitable across portfolios indicate that, in some locations, microgrids can easily hit the mark. But overall, the site-specific factors that determine an area's needs, burdens, and potential benefits can vary wildly between utilities and even within an IOU service territory. So a flexible, experimentalist approach to policy design that treats each utility—and potentially different regions within each utility service territory—differently may be warranted.

Designing around these site-specific factors may also require more local control of energy resilience solutions than is currently on offer. A community knows what it needs but lacks the technical experience and dominion over potential solutions. So if state- or utility-level microgrid policy is attempting to realize multiple secondary benefits that are not aligned, giving communities more self-determination along with support may facilitate microgrid development in the most optimal locations. (That is so long as California also implements policy that ensures the often public benefits of a microgrid are valued highly enough by private developers to incentive microgrid construction.)

Lessons learned from funding demonstrations. Many of California's existing microgrids were built as demonstrations—designed to prove out early technologies and concepts [83][84][85]. However, not all CEC-funded projects are in locations that would be eligible under the MIP.[39] And despite clear potential benefits, there are numerous highly suitable Places that were not the focus of early demonstrations.

This speaks to the inherent social, economic, and political factors that influence how projects are sited and developed. Locations with institutional power—along with need for what's being built—are inherently more likely to gain funding and support for any type of new project. This is particularly true of community microgrids, which are complex, technical undertakings that are still in a formative phase of development with uncertain markets, ownership, and business models [86].

The Redwood Coast Airport Microgrid (RCAM)[40] is an example of this institutional power at play. Now serving as the model for PG&E's CMEP—the precursor to the MIP—technical work was led by the Schatz Energy Research Center, which is local to the area and had previous experience implementing another CEC-funded microgrid project with PG&E. But to succeed, RCAM still required years of dedicated collaboration between multiple public and private institutions including the Redwood Coast Energy Authority, the County government, and PG&E as well as significant technical and regulatory legwork from various partners [84]. So beyond the technical and business lessons learned from this demonstration, a key takeaway is the importance of local knowledge, existing relationships, and how willing utilities and others are to work on a complicated, multi-year project with a community.

Community microgrids will continue to require significant collaboration to execute, even with the new protocols and best practices developed from the RCAM project [88]. But some of the most suitable sites, which would enable microgrids to achieve numerous, diverse goals, are likely to be in communities that lack the institutional resources required to successfully pursue them. (E.g., rural, low-income, disadvantaged communities like Bodfish and Lake Isabella.) So as regulators and developers push microgrids from an emergence to diffusion stage of development, shifting the institutional structures that control their current implementation may become critical to accelerating their wider adoption [89].

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[39] See Appendix F for a sample list of existing or proposed projects compared with likely MIP eligibility.
[40] RCAM is the first front-of-meter, multi-customer, renewable-energy microgrid in California. It uses solar and energy storage to provide resilience to critical facilities in a transmission-vulnerable region of California's rural north coast [87].

California's evolving approach to microgrids. With Senate Bill 1339, the State is moving beyond the phase of pure demonstration projects. By focusing on commercialization and prohibiting cost shifting, the bill attempts to address the fact that the core resilience benefits of microgrids are extremely local while the costs of electrical infrastructure are generally spread over an entire utility service territory. But resolving this conflict requires demonstrating a clear value to the system for having microgrids and then providing avenues to earn back costs.

Many of the secondary aims for microgrids speak to their value, if not to the electricity system, then to accomplishing state goals and to the communities they serve. But given the shifts in suitable locations under the various portfolios modeled in this work, realizing these different aims may require flexible policy approaches like integrating general community resilience-building measures into microgrid policy, as well as multiple market mechanisms to value different benefits. In terms of accomplishing secondary goals involving energy costs and grid services, the CPUC may need to focus on shifting incumbent business models and power structures rather than continue asking the IOUs to design policy.

Limitations of a utility-led approach. Tapping the incumbent utilities to spearhead microgrid programs and policy development makes sense—they own the distribution infrastructure and have a duty to provide reliable power. And while they currently lack on-the-ground knowledge of which solutions would best help particular communities, they have the access to and expertise to use all other data relevant to designing and building a microgrid, including privacy-protected lists with information about customers and critical facilities.[41]

They also have almost complete control. The major IOUs that designed the MIP could choose how to incorporate feedback and have final discretion over which projects are chosen. They're under no obligation to build a certain number of microgrids or benefit a specific number of customers. This approach leans on their expertise and responsibility to act, which hasn't always had the best results. Utility failures have resulted in PG&E's bankruptcy and a utility credit downgrading, which threatened to destabilize the energy sector in California [90]. And after years of safety issues and evidence of utility malfeasance, many may not trust the IOUs as legitimate leaders of this effort [91][92].

One of the co-benefits modeled in the Lowering Energy Costs (P6) portfolio is deferring the need for the sort of expensive infrastructure projects that are core to a utility's business model [93]. This secondary aim for microgrids makes the IOUs imperfect partners to accelerate microgrid adoption, as an IOU's objective, first and foremost, is to generate the revenue needed to pay back its investors. The very nature of an IOU means they would be, at best, disinterested in facilitating this long-term change that would reduce their revenues.[42]

Achieving multiple microgrid co-benefits. Microgrids have huge potential to bolster resilience, reduce pollution, and provide services to the grid that can both lower costs and help the State reach its' emissions goals. But while microgrids can theoretically do all of these things, ensuring they will requires putting them in the right areas—an endeavor that may be best undertaken in collaboration with utilities but with empowered community leaders at the helm.

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[41] When asked for lists of critical facilities (scrubbed of sensitive information) to incorporate into this analysis as the basis for potential resilience hubs, only SDG&E was willing to share a file. However, the file was ultimately not accessible.

[42] While the MIP is funded by all customers in the three IOU service territories, the CPUC has also been looking for ways to ensure the utilities don't cost-shift the expenses of microgrid projects [37]. This adds another reason for utilities to be uninterested in spurring on the microgrid industry.

Project Limitations & Refinements. This project set out to build an ArcGIS-based modeling tool and use it to analyze microgrid suitability in the service territories of California's three largest IOUs. These utilities cover roughly 75% of the state by land area and 86% of Places. Thus, the project often used census tract-level data and generalized more granular data to fit the analysis scale. Time was limited, so data was sometimes bound to the most accessible formats and certain datasets were used as reasonable proxies for multiple criteria. Updating these factors would lead to a more refined and accurate analysis.

Government data. This analysis identified low-income communities based on data from California's 2022 priority populations data, which is currently used by the State to identify communities for climate investments [49]. This data reflects census tracts with a median household income of less than 80% of state median income. However, the MIP eligibility requirement is based on less than 60% of state median income, so eligibility results could have flagged certain ineligible communities as eligible. An updated eligibility analysis would reflect this stricter range.

CalEnviroScreen 4.0's pollution percentile score offers a comparative look at pollution levels between census tracts and served as a core criterion in both Portfolio 6 (Decarbonization) and Portfolio 3 (Lowering Pollution). It was used to represent areas where building a microgrid could potentially lower emissions—which are also a source of local air pollution—by replacing power from fossil fuel plants with clean generation and storage. However, this score includes numerous types of pollution beyond emissions, such as pesticides and children's lead risk from housing. It also doesn't geographically pinpoint pollution sources or hotspots. This means the data becomes less accurate for siting microgrids in rural areas where census tracts are large and different communities within the same tract might experience different levels of exposure to different types of pollution. Replacing this data with more granular emissions and air quality data could improve the accuracy of final suitability scores.

This analysis also used normalized Locational Marginal Prices (LMPs)—averaged over the course of a year—at power pricing nodes across California to simulate where new generation projects could lower energy costs by decreasing the marginal price for power or delaying expensive upgrades. Averaging LMPs over more than a single year would help account for intra-yearly cost fluctuations. Using projected future power prices could also help future-proof the analysis.[43] This forward-looking approach would more closely match the long timelines for investment in and construction of energy generation projects. Incorporating other relevant data into the Lowering Energy Costs portfolio, for instance Locational Benefit Analysis and Distribution Deferral Opportunity Report data, could also make for a more accurate picture of where installing distributed generation could lower costs by delaying or mitigating the need to update the transmission or distribution system [95][96, p. 14][97][98][99].

Utility data. For the suitability model, only the most recent year (2021) of PSPS event data was used. This should be updated to included data spanning further back in the record. The 2021 PSPS data is also shown by census tract rather than specifically impacted areas.[44] Using the impacted circuits from individual PSPS event reports—and for more recent events where circuits were sectionalized to de-energize fewer people, using those specific areas—would offer a more accurate representation of suitable locations than a full census tract, as the latter would be served by multiple circuits. (This update

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[43] Potential future power prices for zones in the Western Interconnection have already been calculated by the Renewable Energy and Applied Mathematics Lab at UC San Diego [94].
[44] Data was provided in this format by the utilities in their 2021 PSPS Post Season Report files.

was partially made for the eligibility model, which replaced the 2021 impacted census tracts with geographic areas around circuits that have been impacted by PSPS events from 2018 onwards. However, specific circuit sectionalization was not included.) Incorporating utility data about which circuits have already undergone, or will soon undergo, measures like undergrounding to avoid the need for PSPS events would also improve the accuracy of results.

Similarly, only 2020's worst performing circuits data was used. The MIP indicates eligibility based on worst performing circuits from the past two years. So, a worst performing circuits criteria layer with the 2021 data—which was not available at the time of this project—would improve accuracy. A forward-looking model would also need to forecast which of these circuits was likely to be repaired in the near future. Where possible, incorporating other information about planned resilience measures would ensure these locations are not identified as highly suitable for an additional long-term resilience project.[45]

Utility Integration Capacity Analysis (ICA) data was used to model potential interconnection speed and the likelihood of a project moving forward. (Given the cost of upgrading grid infrastructure, projects in places that lack existing interconnection capacity are less likely to move forward in the near future.) For this work, the ICA data was generalized to the circuit level, with average line capacity used as the value for the full circuit. This could lead to line segments with little or no capacity falsely marked as suitable if other portions of the circuit had significantly more capacity available. Given the 100-meter resolution and overlay of census designated and incorporated places, this was unlikely to meaningfully impact the results of this work. However, a more targeted analysis run at a smaller resolution should use the line-level data directly. As ICA data is known to reflect existing inequities, finding ways to model this variable without inadvertently reinforcing these injustices would also be a valuable refinement [67].[46]

Other datasets. While California's 2022 priority populations data, which highlights priority communities for climate investments, is an accurate representation of disadvantaged and vulnerable communities, the State has compiled multiple other indicators of community vulnerability to climate change [13]. Cal-Adapt, the California Heat Assessment Tool, and the Urban Heat Island Index could all be used to further evaluate climate risk [100][101][102]. And the Healthy Places Index, Regional Opportunity Index, and Climate Change & Health Vulnerability Indicators for California can all help analyze the potential adaptative capacity of different populations and locations [103][104][105]. An updated analysis could incorporate data from some of these sources. However, each should be carefully considered for factors it could contribute without duplicating other vulnerability indicators.

Incorporating further data around vulnerability to electrical outages—for example, debris flow risk that reflects transmission exposure to environmental impacts—would make the comparative suitability analysis more accurate beyond the current Microgrid Incentive Program approach. As California is earthquake country, including additional earthquake risk and damage factors reflected in landslide and liquefaction zone maps would also offer a stronger look at microgrid suitability overall.

Soliciting feedback from policymakers, microgrid developers, and communities impacted by frequent power outages would also offer a more complete picture of what criteria could and should be included in the analysis to accurately reflect real world conditions. Then incorporating further knowledge from

[45] This would also align with MIP application scoring.
[46] For this reason, ICA data was treated carefully in this work. To avoid reinforcing systemic inequities, data reflecting other equity considerations was given slightly more weight in portfolios that prioritized integration capacity.

experts, such as emergency management specialists trained in disaster response and recovery and those who model future climate and environmental impacts, would also improve the analysis.[47]

For MIP application scoring, the Program will validate and award points for low-income customers served based on how many California Alternate Rates for Energy (CARE) and Family Electric Rate Assistance (FERA) Program customers are included within the microgrid boundaries. If possible, incorporating this data into future analyses—particularly those run at high resolution or when looking at individual Places—would be valuable.[48]

Dataset and model resolution.[49] This study included data provided at multiple scales. For example, pollution data was at the census tract level, where a pollution score value applied to the full geographic area of a census tract, while integration capacity was provided for individual segments of electrical lines. In the case of high-resolution utility data, values were aggregated to the circuit-level and the geographic areas covered by circuits were expanded slightly to account for buildings fed by each circuit. Models were then run at 10- and 100-meter resolutions to balance the high degree of accuracy required to assign circuits to buildings with the lower resolution datasets.

Model results are only as accurate as their lowest resolution data. Since certain MIP eligibility criteria are based on census-level data—the lowest spatial resolution used for this study—using data at different scales likely had no adverse impact on the eligibility model. However, it does affect the suitability results. As discussed above regarding the pollution score, that data is only accurate at the census tract level since it doesn't account for differences within these occasionally large geographic areas. For more precise results, a more refined analysis would replace census tract-level data with more granular options.

Alternatively, this work's suitability results are best considered a first pass, used to identify areas for closer inspection. A future analysis could home in on locations this work or real-world proposals have highlighted as particularly suitable, running a model updated with higher-resolution, site-specific data focused on those areas. If the model was then run with high resolution data at a smaller cell size to account for the likely size of microgrid projects, it would offer a more accurate picture of optimal locations around individual circuits and allow a look at line-level integration capacity.

Critical Community Facilities. Adding an overlay of critical community facilities, particularly in a finer resolution analysis or after the most optimal locations for general suitability had been determined, would improve the accuracy of the results and offer deeper insight into where microgrids could improve community resilience. Locating clusters of critical facilities on the same electrical feeder would highlight hotspots of community services that could serve as the basis for a resilience hub power by a microgrid, offering both community and developer benefits [106][107][108]. Hubs offer potentially huge benefits because they realize economies of scale, combine efforts and institutional know-how, and reduce duplication in hardware and soft costs. There's also precedence for a hubs approach. Numerous state agencies, local governments, and nonprofits have already pursued demonstration projects that focus

[47] A few field-specific experts were consulted around various datasets, but further work with climate, environment, and energy modelers as well as risk analysts and equity researchers would benefit this work.
[48] Due to privacy concerns, this data may be inaccessible without non-disclosure and anonymization agreements.
[49] For the purpose of this section, it's helpful to think of resolution as a matter of accuracy. Here, it refers to the smallest discrete chunk of accurate information available. The term is generally applied to less spatially precise raster data. But while data used for this study started in vector formats with highly accurate boundary lines, the size of certain vectors themselves—aka, the size of a discrete chunk of accurate information—is the point of discussion.

on resilience hubs [109][110][111][112]. (Hubs are also the focus of federal efforts to demonstrate large-scale regional carbon capture and hydrogen gas production [113][114].)

This refinement would speak to multiple state adaptation and resilience goals, as promoting clean-energy powered resilience hubs designed and planned by trusted community groups would offer more benefits than temporary power tents or mobile resilience centers organized by utilities [115][116][117][118]. A permanent resilience hub would already be operational and known to the community during a disaster. And beyond offering a place to charge devices during an emergency, a permanent hub can act as a focal point for the community even during 'blue sky' days. If residents trust those running a hub, they may also be more likely to use it.[50]

Comparable metrics. Finally, the development of other metrics that quantify the similarities and differences in suitability results across portfolios would allow a more quantitative analysis of the shifts between modeled scenarios. For instance, it could help clarify the rural / urban swing as well as the shift in suitability from within to outside of High Fire Threat Districts.

Expanded Work Areas. This work was limited by the time available and there are innumerable ways it could be expanded upon—such as incorporating costs, benefits, and various microgrid configurations to address policy questions more completely or refining the models and turning them into tools available for local governments, community organizations, or microgrid developers to use. A few potential areas for expanded future analyses are sketched out below.

Expanding the eligibility model. The eligibility model focused only on the community eligibility piece of the MIP. Specifically, it located areas that met both a vulnerable to outages indicator and a disadvantaged community one. Future work could incorporate the third 'bucket' within the community eligibility structure (Figure 2) by overlaying critical facilities as discussed above.

A proposed microgrid project's technical eligibility is also critical to determining whether it can receive MIP funds. The technical eligibility requirements are generally more project-specific—focusing on emissions, the amount of generation necessary to power a microgrid for at least 24 consecutive hours in island mode, and interconnection permissions [42]. Future work could build another layer into the eligibility model using the technical eligibility criteria. Alternatively, it could construct a second eligibility model, concentrating on locations that have already been identified as potentially eligible under the community criteria. This could be further expanded to incorporate project scoring criteria to identify the communities and potential project elements most likely to receive MIP funding.

Expanding the suitability model with costs and benefits. This work's suitability analysis focused on identifying optimal areas for microgrids without considering the actual costs or quantified benefits of microgrids deployed in those locations. Future work could conduct a full engineering-economic analysis of potential microgrid sites that have been identified as highly suitable across the state.

Quantifying costs would involve determining the costs for different sized microgrid projects in different areas, including by collecting solar siting and other energy generation data to determine the feasibility of different renewable resources. It would also include calculating the energy needs for different critical facility types to estimate new generation and storage requirements. To quantify benefits, the analysis

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[50] The importance of building trust with communities was mentioned in multiple stakeholder workshop comments regarding the MIP design, and resilience hubs were brought up at least twice. (See Attachment 2 in [42].)

would develop a quantitative resilience metric, which could then be translated into one piece of a comparable 'benefits score' for different locations [119]. This benefits score would also involve estimating the avoided infrastructure and public health costs from increasing clean energy and avoiding PSPS events. Additionally, wholesale power market and ancillary services market prices in the relevant locations would be paired with the estimated generation and storage potential for the modeled projects.

To address concerns around future wildfire impacts on infrastructure, wildfire risk projections matching electricity infrastructure investment timelines could be developed using existing moisture, heat, rain, soil, vegetation, and other climate data [120][121]. Further site-specific costs, benefits, and refining layers could be included, depending on the expanded work's ultimate goals.

Modeling suitability for non-microgrid resilience options. Building off an expanded microgrid suitability analysis, future work could also compare the costs and benefits of a microgrid with the expenses and advantages of other resilience solutions. Understanding what co-benefits, if any, are aligned or at odds for other adaptation solutions and comparing their suitability with that of a microgrid could help inform future adaptation policy. This analysis could also help communities determine the optimal resilience solution for their unique context. Ideally, it would expand into a menu of potential resilience solutions, tailored to different challenges facing communities across the State.

Examining suitability for microgrids of various sizes. An additional avenue to explore would be modeling suitability for microgrids of a much larger size. This work followed the definition of microgrids as outlined in the MIP, which are unlikely to be larger than a few buildings. However, others have proposed islanding grid segments at a much larger scale [122][123]. (This size microgrid would be particularly valuable for areas like Santa Barbara, as discussed above.) A full community-sized microgrid has been successfully implemented by SDG&E in Borrego Springs [85]. And large-scale energy storage systems have been interconnected at utility substations in locations where the grid struggles to provide enough power, further confirming the feasibility of such projects [124][125]. Following this logic, a suitability analysis could be developed for either circuit-level or substation-based microgrids based on various grid factors such as challenges with local resource adequacy requirements, solar or wind curtailments, and grid congestion [126]. This analysis could pair well with a policy examination of California's clean energy goals, which will require a significant increase in energy storage over the next few decades [127, p. 100].

Incorporating further utilities. This study only included areas served by PG&E, SDG&E, and SCE, as together they cover 86% of Places in the State and are the IOUs involved in the MIP. An expanded future analysis could incorporate data from other utilities to form a more complete picture of microgrid suitability across California.

Building a sharable tool. The eligibility model results have real-world applicability for communities interested in pursuing MIP funds. Updating the eligibility model to add a critical facilities layer and an adjustable component that forecasts technical eligibility given different parameters such as project size and solar feasibility in different locations could enhance the utility of this work. Turning this expanded model into a web-based tool for public use could then expand the overall impact of this study.

Similarly, refined suitability model results may be useful for communities exploring their resilience options. An interactive tool that includes quantified costs and benefits and/or other potential resilience options and applicable funding sources could be a practical resource to help underserved communities determine their optimal climate adaptation solutions without hiring an expensive outside consultant.

APPENDIX A | DATA & SOURCES

Strategy	Final Criteria Data	Data Set	Source	Justification	Link
Reliability metric	Previous PSPS locations *(median duration by census tract for full 2021 or by circuit for January 2021 and by affected circuit area for post-January 2021)*	Locations of PSPS events in 2021: PG&E	PG&E	MIP eligibility criteria (vulnerable to outages)	1
		Locations of PSPS events in 2021: SCE	SCE		2
		Locations of PSPS events in 2021: SDG&E	SDG&E		3
		Circuits impacted by PSPS events 2018-2020	PSE*		4
Reliability metric	Areas served by the top 1% worst performing circuits (WPC)	Top 1% WPC in 2020: PG&E	PG&E	MIP eligibility criteria (vulnerable to outages)	5
		Top 1% WPC in 2020: SCE	SCE via CPUC		6
		Top 1% WPC in 2020: SDG&E	SDG&E via CPUC		7
Reliability metric	Tier 2 & 3 High Fire Threat Districts	CPUC High Fire Threat Districts Map	CPUC	MIP eligibility criteria (vulnerable to outages)	8
Disadvantaged communities metric (as defined by California Office of Planning and Resources)	CalEnviroScreen score percentile *(by census tract)*	CalEnviroScreen 4.0	CAL EPA	MIP eligibility criteria (disadvantaged and vulnerable community)	9
	Low income populations *(by census tract)*	Priority Populations 2022; low-income field	CAL EPA		10
	Rural communities *(by census tract)*	Federal Office of Rural Health Policy Data Files	FORHP		11
	Tribal Lands	American Indian and Alaskan Native Land Area Representations (LAR)	BIA		12
Disadvantaged communities indicator. (Metric caluclated by the state to determine climate investments, based on CalEnviroScreen4)	Disadvantaged communities selected for California climate investments *(by census tract)*	Priority Populations 2022	CAL EPA	Acts as a stand in for CalEnviroScreen score percentile, low-income populations, and rural communities from MIP eligibility criteria	13
Reliability indicator	High flood risk area	National Flood Hazard Layer	FEMA	High environmental risk in California	14
	High earthquake risk areas and associated zones	Uniform California Earthquake Rupture Forecast (Version 3)	WGCEP		15
		2018 United States (Lower 48) Seismic Hazard Long-term Model	USGS		16
Indicator for utility interconnection capacity + geospatial distribution infrastructure data	Interconnection space for uniform and PV generation *(by circuit)*	PG&E ICA data	PG&E ICA site	If a distribution line lacks integration capacity, expensive grid upgrades will be required to add generation in that area. Those costs can make a microgrid project too expensive for a community and/or can slow down a project	17
		SCE ICA data	SCE via ArcGIS online portal		18
		SDG&E ICA data	SDG&E ArcGIS online service definition file		19
Indicator for electricity cost and potential need for near future grid upgrades	Peak pricing locations (via normalized LMP score surface) **	Locational marginal price for each listed California pnode from May 2021 through May 2022	CAISO OASIS site	Defines areas where new distributed energy generation projects would make the most profit	20
		X,Y coordinates of pnodes	CAISO LMP web map		21
Indicator for pollution levels	CalEnviroScreen pollution percentile score *(by census tract)*	CalEnviroScreen 4.0	CAL EPA	Acts as an indicator of local pollution levels. Acts as a stand in for potential local emissions levels	22
Indicator for number of people served	Population *(by census bloc)*	Population by 2020 Census Bloc	US Census Bureau	All else equal, helping more people is often a goal	23
Locational Overlay	California Jurisdictional Places	Incorporated Places	US Census Bureau	MIP projects require a letter of interest from a local jurisdictional authority	23
		Census Designated Places	US Census Bureau		
Used to define study area	Utility Service Territories	Electric Load Serving Entities (IOU & POU)	CEC	The MIP and this project are focused on California's three largest utilities	24
Used to define California's onshore boundaries	California Boundaries	California Energy Commission's building climate zones	CEC	California's official boundary extends offshore, a consistently unsuitable location for a micgorid project	25

**This was made possible through the work of Patrick Murphy at Physicians, Scientists, and Engineers for Healthy Energy (PSE), who generously sent a spreadsheet of previous PSPS data collected for a different analysis.*
***Scripts used to collect and transform the data (before being brought into GIS) can be found here: https://github.com/beekwoka/caiso-scripts/tree/main/CAISO_LMP*
****Further datasets, such as power plants and transmission infrastructure, were used from the CEC GIS portal to explore final results*

Link Number[51]	Data Set	Link	Citation
1	Locations of PSPS events in 2021: PG&E	https://www.pge.com/en_US/residential/outages/public-safety-power-shuttoff/psps-reports.page	[128]
2	Locations of PSPS events in 2021: SCE	https://www.sce.com/wildfire ("PSPS Reports to the CPUC" including https://on.sce.com/PSPSposteventreports and https://on.sce.com/PSPSPostSeasonReporting)	[129]
3	Locations of PSPS events in 2021: SDG&E	https://www.sdge.com/wildfire-safety/psps-more-info#reports	[130]
4	Circuits impacted by PSPS events 2018-2020	Email. Originally from the links above.	[131]
5	Top 1% WPC in 2020: PG&E	https://www.pge.com/pge_global/common/pdfs/outages/planning-and-preparedness/safety-and-preparedness/grid-reliability/electric-reliability-reports/CPUC-2020-Annual-Electric-Reliability-Report.pdf	[132]
6	Top 1% WPC in 2020: SCE	https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/infrastructure/electric-reliability-reports/2020-sce-annual-electric-reliability-report.pdf	[133]
7	Top 1% WPC in 2020: SDG&E	https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/infrastructure/electric-reliability-reports/2020-sdge-electric-reliability-report.pdf	[134]
8	CPUC High Fire Threat Districts Map	https://www.cpuc.ca.gov/industries-and-topics/wildfires/fire-threat-maps-and-fire-safety-rulemaking	[48]
9	CalEnviroScreen 4.0	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40	[135]
10	Priority Populations 2022; low-income field	https://calepa.ca.gov/envjustice/ghginvest/	[50]
11	Federal Office of Rural Health Policy Data Files	https://www.hrsa.gov/rural-health/about-us/what-is-rural/data-files	[136]
12	American Indian and Alaskan Native Land Area Representations (LAR)	https://biamaps.doi.gov/bogs/datadownload.html	[137]
13	Priority Populations 2022	https://calepa.ca.gov/envjustice/ghginvest/	[50]
14	National Flood Hazard Layer	https://www.fema.gov/flood-maps/national-flood-hazard-layer	[138]
15	Uniform California Earthquake Rupture Forecast (Version 3)	http://wgcep.org/UCERF3.html	[55]
16	2018 U.S. (Lower 48) Seismic Hazard Long-term Model	https://www.usgs.gov/programs/earthquake-hazards/science/2018-united-states-lower-48-seismic-hazard-long-term-model	[54]
17	PG&E ICA data	https://www.pge.com/en_US/for-our-business-partners/distribution-resource-planning/distribution-resource-planning-data-portal.page	[139]
18	SCE ICA data	https://drpep.sce.com/drpep/	[140]
19	SDG&E ICA data	https://www.sdge.com/more-information/customer-generation/enhanced-integration-capacity-analysis-ica	[98]
20	Locational marginal price for California pnodes	http://oasis.caiso.com/mrioasis/logon.do	[141]
21	X, Y coordinates of pnodes	http://www.caiso.com/TodaysOutlook/Pages/prices.html	[56]
22	CalEnviroScreen 4.0; pollution percentile score field	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40	[135]
23	Population by 2020 Census Bloc; Incorporated Places; Census Designated Places	https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.2020.html	[142]
24	Electric Load Serving Entities (IOU & POU)	https://cecgis-caenergy.opendata.arcgis.com/datasets/electric-load-serving-entities-iou-pou/explore?location=37.059572%2C-119.273187%2C7.01	[143]
25	CEC building climate zones	https://gis.data.ca.gov/datasets/CAEnergy::california-building-climate-zones/explore	[144]

[51] "Link number" here corresponds to the number in the "Link" column in the table on page 31. In doing so, this table acts as an extension of the one above it.

APPENDIX B | CRITERIA LAYERS

Criteria	The Data that Reflects the Criteria	Data Transformations	Interal Criteria Layer Values (1-10 Suitability Scale)	Justfications + Notes
Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations (2021 PSPS events, median duration by census tract)	For the shapefile containing 2021 PSPS events by census tract, each tract was defined by its median duration and these were then classified into the suitability scale buckets. (The process was different for the eligibility model, which matched circuit names from an excel/csv file with locations from the relevant ICA dataset.)	No PSPS | 1 .4-2 hrs | 5 2.001-4 hrs | 6 4.001-8 hrs | 7 8.001-12 hrs | 8 12.001-24 hrs | 9 24+ | 10	2 hours was used as a consideration for food spoilage times (.4hrs was the shortest PSPS duration. Longest in 2021 was ~139hrs)
Reduce vulnerability to losing power in areas with lower historical levels of reliability	Top 1% worst performing circuits (WPC) in 2020	Pulled list of WPCs from utility reports, matched with circuit location via utility ICA data, and combined the data from the three utilities into a single criteria layer	Not covered | 1 On WPC list | 8 WPC by multiple indicies or deficient | 9 WPC by multiple indicies and deficient | 10	All areas servd by WPCs are highly suitable, but circuits that are either deficient, poorly performing under multiple indicies, or both should be prioritized for upgrades as they have already had the most issues.
Reduce vulnerability to losing power in areas at risk from climate and environmental impacts (e.g. wildfire)	Tier 2 & 3 High Fire Threat Districts	The only transformation needed was to create a full surface of California where the High Fire Threat Districts had the suitability scale values to the right of this cell.	Not tier 2 or 3 | 1 Tier 2 | 9 Tier 3 | 10	Tier 2 and 3 are cited by the CPUC/utilities as high fire threat districts, with 3 being the highest. Tier 2 is given a close suitability score given the worsening of wildfires due to climate change.
	High earthquake risk areas (>10% participation probability of >M6.7+ in next 30 years)	Pulled the mean 'participation probability' of a >M6.7+ for each fault line segment and selected those with a greater than 10% probability. These fault line segments were then buffered out to different distances, and the spaces between each buffer assigned a value, to create risk zones.	0-1/4 mi from fault. | 1 1/4-2 mi from fault | 2 2-5 mi from fault | 4 All other CA | 5 5-10 mi from fault | 6 10-20 mi from fault | 10	The zones closest to the fault were assigned low suitability scores to account for damage to the microgrid in the case of a large quake. The 10-20 miles zone was given a just-over-middling score, as it would be a suitable location in the case of a small quake but still too close if there was a massive earthquake along that fault. The 10-20 mile zone was assigned the highest score, as it sits far enough away from the fault to avoid damage in all but the worst case scenarios, but close enough to provide help. The rest of California was assigned a middle suitable score, as the State is crisscrossed by lower risk faults that nonetheless offer a non-insignificant potential of an earthquake.
	National Flood Hazard Layer: Flood Hazard Zones	Grouped different types of flood hazard classifications by risk level (e.g. all minimal flood hazard types together)	Open water/no data | 1 Undefined/not included | 3 Moderate or minimal hazard | 6 Special Flood Hazard Zones | 10	While the National Flood Hazard Layer has numerous classifications for types of flood hazards, many of these classifications are given the same risk level. Undefined/not included areas were given a low but not no suitability level to account for the low but not zero potential of unknown flood hazards. Grouping by risk level made calculations less computationally intensive for the model.
Provide resilience to the communities that will be hardest bit by, and least able to bounce back from, losing power	CalEnviroScreen score percentile	Delineated continuous percentile data into the blocks shown in the next column	0-29.999 | 1 30-49.999 | 2 50-74.999 | 4 75-84.999 | 8 85-94.999 | 9 95-100 | 10	A score percentile 75% or greater denotes eligibility in the disadvantaged community bucket of the MIP, so anything above 75% is weighted as highly suitable (with priority given to the highest 5% of scores). However, a score between 50% and 75% still indicates an above-average burden, so those scores are given 4x the suitability of the least burdened group. Scores between 20% and 50% are given 2x the lowest burdened group, as they denote some but not significant burden.
	Low income populations (via priority populations data)	Priority populations data set included a field for whether each census tract was considered low income. Used this field to classify each census tract and assign a yes/no number.	Not low income | 1 Low income | 10	Low income communities are called out in the MIP as being more suitable for microgrid investments. Low Income census blocks are assigned the highest suitable score (and non low income the lowest score) to reflect this prioritization and California's general focus on disadvantaged communities for priority investments.
	Rural communities (by census tract)	Data came as a list of fully rural counties and designated rural census tracts in non-rural counties. Generated a list of the census tracts in each fully rural county and added it to the list of designated rural census tracts. Then used census beurau data to add the geospatial location of these rural census tracts.	Not rural | 1 Special rural Designation | 9 Rural | 10	Rural areas are called out in the MIP as being more suitable for microgrid investments. The suitability determinations follow the Goldsmith Modification for rural areas and areas that are, essentially, borderline rural. (E.g. they're not fully rural but may be far enough from certain services to earn a special rural designation.) [61]
	Disadvantaged communities (priority populations data)	Pulled just the disadvantaged communities census tracts from the priority populations data to create a new layer showing areas that were either designated as home to disadvantaged communities or not.	Not a DAC | 1 DAC | 10	Following the logic from the other disadvantaged communities criteria, priority populations are given the highest suitability score (while not disadvantaged communities are given the least) to align with California's current climate investment goals.
Increase the likelihood that, and speed at which, new distributed energy resources can connect to the power grid	Interconnection space for uniform generation	ICA data from PG&E, SCE, and SDG&E was combined. Non-Opflex integration capacity was averaged for each feeder/circuit and circuits were then buffered to a distance of 45 meters (150 ft).	0-.999 MW | 1 .999-2 MW | 6 2-3 MW | 8 3-5 MW | 9 5+ MW | 10	Integration Capacity was generalized to the feeder/circuit level to account for the large number of individual lines and the scale of analysis (across the full state). Circuits were buffered to indicate areas that were likely to be fed from this circuit. The suitability scores were chosen to represent the suitability of different sizes of generation necessary for a microgrid. E.g., projects are likely to need at least 1 MW of generation, though a microgrid that encompasses more (or more power intensive) critical facilities will need 2 MW. Having a higher integration capacity available than strictly necessary also addresses concerns that by the time a project is ready to interconnect that capacity will have already been filled. Different layers were created for both uniform generation and PV generation to account for pure resilience as a goal (where no consideration is given to the type of generation) and for the State's goals of putting more clean energy on the grid.
	Interconnection space for solar photovoltaic (PV) generation	Same as above but using the data for PV capacity.	0-.999 MW | 1 .999-2 MW | 6 2-3 MW | 8 3-5 MW | 9 5+ MW | 10	
Increase distributed zero-carbon energy sources in areas most affected by pollution in order to lower pollution from power plants and improve public health in those areas	CalEnviroScreen 4.0 pollution percentile score	Used just the pollution percentile score from CalEnviroScreen 4.0 and classified it into tiers based on percentile.	0-9.999 | 1 10-19.999 | 2 20-29.999 | 3 30-39.999 | 4 40-49.999 | 5 50-59.999 | 6 60-69.999 | 7 70-79.999 | 8 80-89.999 | 9 90-100 | 10	As the suitability scale is a simple 1-10, the study simply broke pollution percentile scores into 10 equal segments, with the locations experiencing the most pollution ranked the most suitable.
Lower energy prices by putting new distributed resources in places that can help alliviate grid congestion	Peak pricing locations (via normalized LMP score surface)	Used the locations of pnodes from the CAISO online map [53] and matched them to the LMP score (averaged over the course of a year) for the corresponding pnode. Then normalized these LMPs and used their z-scores within the Geostatistical Wizard tool (via an Inverse Distance Weighted method) to create a general LMP surface across the entire state.	-6.5- -1.1 | 1 -1- -.76 | 2 -.75- -.56 | 3 -.55- -.21 | 4 -.2- -.1 | 5 .09- .2 | 6 .21-.52 | 7 .53-.81 | 8 .82-1.3 | 9 1.4-4.1 | 10	A price surface with normalized average locational marginal prices allows the model to simulate where new electricity generation could potentially be most profitable by prioritizing locations where the prices are higher. A geostatistical method was used to create a full data surface over the state to help simulate price liklihoods in areas that didn't have nearby pnodes.
Provide services for the largest number of people	Population by census bloc	Used only the population by census block data layer from the full 2020 Census dataset		Population numbers was never a huge piece of the model, so a simple surface weighting towards densely populated locations served well.

APPENDIX C | MODEL PORTFOLIOS

Portfolio Number	Iconic Case	Criteria	The Data that Reflects the Criteria	Final Weights in Suitability Model	Model Weight Justifications
0	Current Approach in California (Wildfire Resilience)	Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/median durations	20	Track 2 of SB 1339 is focused on funding microgrids in locations that are most likely to suffer outages. Given the utility-led nature of the program, vulnerability to outage indicators are given more weight.
		Reduce vulnerability to losing power in areas with lower historical levels of reliability	Areas served by the top 1% worst performing circuits	20	
		Reduce vulnerability to losing power in areas at risk from climate and environmental impacts like wildfire	Tier 2 & 3 High Fire Threat Districts	20	
		Provide resilience to the communities that will be hardest bit by, and least able to bounce back from, PSPS events	CalEnviroScreen score percentile	20	As an indicator of intersecting types of vulnerability, CalEnviroScreen Score is weighted higher than other vulnerable populations indicators. Disadvantaged communities indicators make up 40% of overall model weight because the MIP is designed to prioritize these populations, but also includes an eligibility component where communities who don't already meet these indicators are already ineligible.
			Low income populations	10	
			Rural communities	10	
1	Pure Electricity Resilience	Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	20	Significantly weighted as it's a clear indicator of electrical reliability (which is the main function of a microgrid, particularly in a pure resilience scenario).
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/median durations	25	Previous PSPS locations are likely to experience further PSPS events unless lines have already been undergrounded (which is unlikely for most places). This is the key resilience conern when it comes to microgrids in California, so given a quarter of all total weight in the model.
		Reduce vulnerability to losing power for the largest number of people	Population by census bloc	10	A pure resilience approach would look to help the largest number of people possible. So population number is included, but given only a small piece of the model's overall weight since the criteria that reduce resilience are by far the largest concern. This simply nudges projects in the direction of more people.
		Reduce vulnerability to losing power in areas at risk from climate and environmental impacts	High earthquake risk area	5	Included as California is 'earthquake country.' Small weight because fire risk is currently the greatest concern and there is other earthquake-focused legislation, but contributes to overall 30% weight of climate/environmental vulnerabilities.
			High flood risk area	5	Included as a climate risk factor. Small weight because fire risk is currently the greatest concern, particularly in regards to microgrids, but contributes to overall 30% weight of climate/environmental vulnerabilities.
			Tier 2 & 3 High Fire Threat Districts	20	With PSPS as a key measure for reducing wildfire risk from utility infrastructure and wildfire risk increasing with climate change, high fire risk areas are double the weight of the combined other climate/environmental risk factors.
		Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, losing power	Priority Populations*	5	A pure resilience approach doesn't care about who is being served. However, priority populations (e.g. disadvantaged communities) get a small weight in the model as more likely to recieve funding for climate adaptation/resilience projects in California and the ones who would benefit most from increased resilience.
		Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid	Interconnection space: uniform and PV generation (uniform was used for final result)	10	A pure resilience approach will slightly prioritize locations with interconnection space because it's quicker and less expensive to connect new generation to the grid in these locations. Not given a higher weight because but the criteria that reduce resiliency are by far the largest concern within this portfolio. (Uniform generation was used because for pure resiliency purposes, generation type is whatever is easiest. For example, utilities have already trucked in generators to address the impacts of PSPS outages. However, both uniform and PV generation were tested for this portfolio and results were essentially the same.)
2	Disaster Response	Increase community resilience near areas most at risk of experiencing a disaster scenario	High earthquake risk area	20	While fire risk is currently California's biggest electrical reliability concern, in a full disaster scenario, all climate/environmental imapcts are of grave concern. Each brings a special threat to the table, too. (Fire risk connects to PSPS and destroying power line poles, flooding is particularly bad for substations, and high-magnitude earthquakes are particularly destructive.) Therefore they're given equal weight and constitute 60% of the total model weight.
			High flood risk area	20	
			Tier 2 & 3 High Fire Threat Districts	20	
		Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disaster events	Priority Populations*	20	Historically, disadvantaged populations are the hardest hit by, least able to bounce back from, and least able to relocate from, disaster events. Micrgrids in these areas can significantly improve immediate disaster response efforts and long-term disaster recovery. Therefore these locations are given a not-insignifcant portion of total model weight.
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	5	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a small weight because the portfolio is a large disaster scenario. Combines with previous PSPS locations criteria to equal 10% for non-environmental resilience indicators.
		Provide services for the largest number of people	Population by census bloc	10	Included, but given a relatively smaller weight, as a way to indicate helping the largest number of people under the conditions of the other criteria.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/duration	5	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a small weight because the portfolio is a large disaster scenario. Combines with 1% WPC locations criteria to equal 10% for non-environmental resilience indicators.
3	Lowering Pollution	Increase distributed zero-carbon energy sources in areas most affected by pollution in order to lower emitting power plants there	CalEnviroScreen pollution percentile score	30	Given a significant amount of total model weight as the core indicator for the goal this portfolio is addressing.
		Provide services for the largest number of people	Population by census bloc	10	Included, but given a relatively smaller weight, as a way to indicate helping the largest number of people under the conditions of the other criteria.
		Increase the likelihood that, and speed at which, new distributed resources like solar and battery storage can connect to the power grid	Interconnection space: PV generation	15	Given half of highest criteria (pollution) weight, as higher integration capacity can streamline getting new PV projects on the grid, contributing to lowering pollution more quickly.
		Reduce vulnerability to losing power in areas that are most likely to experience outages so as to avoid the most likely or frequent use of heavily polluting diesel generators	Areas served by the top 1% worst performing circuits	10	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller weight because the portfolio is focused on lowering pollution.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events so as to avoid the most likely or frequent use of heavily polluting diesel generators	Previous PSPS locations/duration	10	Included as it speaks to both resiliency and ensuring emissions don't continue to rise from using diesel generators to improve local wildfire resilience. (Combines with similar indicator below to reach 20% total.)
		Reduce vulnerability to losing power in areas that are at risk from climate or environmental impacts so as to avoid the most likely or frequent use of heavily polluting diesel generators	Tier 2 & 3 High Fire Threat Districts	10	Included as it speaks to both resiliency and ensuring emissions don't continue to rise from using diesel generators to improve local wildfire resilience. (Combines with similar indicator above to reach 20% total.)
		Increase the amount of clean, distributed generation sources in areas most likely to be heavily burdened by pollution (e.g. disadvantaged/vulnerable communities)	Priority Populations*	15	Given half of highest criteria (pollution) weight, as priority populations are likely to be more overburdened by pollution issues (and the state has goals to lower pollution in these neighborhoods).
4	Improving Equity	Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disasters and PSPS events	Priority Populations*	30	Given significantly greatest single percentage of overall model weight because Priority Populations have been decided on by the State as the communities that most need climate investment because of historical injustices and structural inequities in our system. These are the communities this portfolio is targetting.
		Increase community resilience near areas most at risk of experiencing a climate- or environment-driven emergency or disaster	High earthquake risk area	8	Included and given a weight that's roughly half of the priority populations weight as these are areas where disadvantaged communities are more likely to be hit by a disaster, which is why a microgrid would be considered.
			High flood risk area	8	
			Tier 2 & 3 High Fire Threat Districts	12	Given 1.5x the weight of either earthquake or flood risk (the other climate/environmental indicators) as fire threat is currently the biggest threat in California and this criteria also speaks to the electricity resilience criteria of California's current approach.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/duration	10	Included as an indicator of resilience, which is the core function of a microgrid—PSPS events also hit priority populations the hardest. Given a relatively lower weight to ensure priority populations come through strongly.
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	10	Included as an indicator of resilience, which is the core function of a microgrid—outages from poorly performing circuits also hit priority populations the hardest. Given a relatively lower weight to ensure priority populations come through strongly.
		Provide services for the largest number of people	Population by census bloc	12	Included, but given a relatively smaller weight, as a way to indicate helping the largest number of people under the conditions of the other criteria.
		Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid	Interconnection space: uniform and PV generation (uniform used in final result)	10	Included as a way to shift results towards quickly getting projects online in places that really them. Not given a higher weight so as not to inadvertantly skew results towards whiter, wealthier neighborhoods that historically have more integration capacity availalbe. Uniform generation used based on reaoning from portfolio 2.

6	Decarbonization	Increase distributed zero-carbon energy sources in areas most affected by pollution in order to lower emitting power plants there	CalEnviroScreen pollution percentile score	**25**	Pollution percentile score was as stand-in for emissions and gets a quarter of overall model weight because prioritizing these areas for a clean energy microgrid can offset and ultimately replace the use of nearby fossil fuel plants.
		Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid without needing costly grid upgrades	Interconnection space: PV-specific	**25**	Given a quarter of overall model weight because this existing integration capacity for PV will make it much quicker and less expensive to get new energy generation onto the grid.
		Provide services for the largest number of people	Population by census bloc	**10**	Included, but given a relatively smaller weight, as a way to indicate helping the largest number of people under the conditions of the other criteria. Additionally, more people in a particular area may increase the potential for locating useful distributed generation and storage that can potentially be used for peak load shaving, avoiding the use of the dirtiest peaker plants.
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	**10**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/frequency	**10**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Reduce vulnerability to losing power in areas that are at risk from climate or environmental impacts so as to avoid the most likely or frequent use of heavily polluting diesel generators	Tier 2 & 3 High Fire Threat Districts	**10**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disasters and PSPS events and who are historically the most burdened by pollution	Priority Populations*	**10**	Included as Priority Populations are targeted for California's climate investments in its cap-and-trade program and within ICARP, but given a relatively smaller portion of overall weight because decarbonization is achieved in other ways.
7	Lower Energy Costs	Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid without needing costly grid upgrades	Interconnection space: uniform and PV generation (PV used for final result)	**25**	Given a quarter of total model weight because existing integration capacity significantly decreases the overall cost of a microgrid (or any energy generation) project and getting more clean energy paired with battery storage onto the grid can help reduce the need for fossil fuel plants that must ramp up when solar (without energy storage) is producing less power.
		Lower energy prices by putting new distributed resources in places that can help alleviate grid congestion	Peak pricing locations (via normalized LMP score surface)	**25**	Given a quarter of total model weight because locations with high energy prices indicate potential profit for generators who can sell power there at slightly lower rates—which would both motivate developers and decrease costs. These locations also indicate potential grid congestion as a reason rates are high, so locating distributed generation can potentially alleviate some congestion and lower prices.
		Provide services for the largest number of people	Population by census bloc	**16**	The more people who live in a particular area, the more potential there is for locating useful distributed generation and energy storage that can potentially be used for various grid services that will lower overall system costs.
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	**8**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/frequency	**8**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Reduce vulnerability to losing power in areas that are at risk from climate or environmental impacts so as to avoid the most likely or frequent use of heavily polluting diesel generators	Tier 2 & 3 High Fire Threat Districts	**8**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas, but given a relatively smaller portion of overall weight because the portfolio is targeting decarbonization. Not given lower because areas that suffer from resiliency challenges are more likely to use polluting deisel generators, which moves in the opposite direction.
		Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disasters and PSPS events and who are historically the most burdened by pollution	Priority Populations*	**10**	Included as Priority Populations are targeted for California's climate investments in its cap-and-trade program and within ICARP, but given a relatively smaller portion of overall weight because lowering energy costs is achieved in other ways.
8	**Meeting State Goals (Electricity Resilience + Clean Energy + Protecting Vulnerable Communities)**	Increase distributed zero-carbon energy sources in areas most affected by pollution in order to retire fossil fuel power plants	CalEnviroScreen pollution percentile score	**20**	Given a significant weight since California has goals to reduce pollution, particularly as certain areas are in non-containment with pollution regulations.
		Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disasters and PSPS events and who are historically the most burdened by pollution	Priority Populations*	**20**	Given a significant weight since California has goals to increase resilience for disadvantaged populations.
		Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid without needing costly grid upgrades	Interconnection capacity: PV-specific	**10**	California has goals to increase the amount of renewable energy generation such as solar PV. Paired with the pollution percentile score as a stand-in for emissions raises the overall weight of clean energy as a state goal within this portfolio.
		Provide services for the largest number of people	Population by census bloc	**10**	While targeting specific goals and/or populations, California is still looking to help the largest number of people possible.
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	**10**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas.
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/duration	**20**	Given a significant weight since California is currently looking to reduce the impacts of PSPS events. (This criteria also speaks to resiliency, the core function of microgrids.)
		Reduce vulnerability to losing power in areas that are at risk from climate or environmental impacts so as to avoid the most likely or frequent use of heavily polluting diesel generators	Tier 2 & 3 High Fire Threat Districts	**10**	Included as resiliency is the core function of a microgrid and this is a core indicator for less resilient areas. Responding to increased fire risk also corresponds to the State's climate adaptation goals.
9	**Doing Everything**	Provide local resilience to the communities that will be hardest bit by, and least able to bounce back from, disasters and PSPS events	Priority Populations*	**16.66**	Equal weights given to different indicators that speak to the various aims for microgrids. Nothing prioritized over the other (with the exception of resilience indicators together making up a significant portion of total weight, as resilience is the core function of a microgrid).
		Increase community resilience near areas most at risk of experiencing a climate- or environment-driven emergency or disaster	High earthquake risk area	**16.66**	
			Tier 2 & 3 High Fire Threat Districts	**16.66**	
		Reduce vulnerability to losing power in areas that are most likely to experience PSPS events	Previous PSPS locations/duration	**16.7**	
		Reduce vulnerability to losing power in areas that are most likely to experience outages, based on recent historical outage data	Areas served by the top 1% worst performing circuits	**16.66**	
		Provide services for the largest number of people	Population by census bloc	**16.66**	
		Increase the likelihood that, and speed at which, new distributed resources can connect to the power grid	Interconnection space: PV specific (accounting for decarbonization, and in some ways resilience, goals)	**16.66**	

***Priority Populations** *acts as a stand in for the combination of CalEnviroScreen score percentile, low-income populations, and rural communities from the MIP eligibility criteria as it has already been defined by CalEPA as a means to prioritize disadvantaged communities for California Climate Investments.*

APPENDIX D: MICROGRID INCENTIVE PROGRAM ELIGIBLE PLACES

There are 965 Places potentially eligible for the Microgrid Incentive Program under the community eligibility criteria. This represents roughly 70% of all Places in the three major IOU service territories.

For the full list of Place names, whether the full Place is eligible, as well as eligible Places paired with their suitability scores in each portfolio and further eligibility statistics, please reach out to bkwoka@ucsd.edu and request the *Appendix D: MIP Eligibility Stats* Excel file.

APPENDIX E: SUITABILITY SCORES BY PLACE

For the full list of mean and max suitability scores for each portfolio by Place, mean and max tier frequencies, and all zonal statistics for each Place included in the work, please reach out to bkwoka@ucsd.edu and request the *Appendix E: Suitability Stats* Excel file.

APPENDIX F: DEMONSTRATION PROJECT COMPARISONS

To validate results, the study also homed in on a few real-world microgrid demonstration projects and proposals. The chosen projects had either received funding from the California Energy Commission's Electric Program Investment Charge (EPIC) grant program, were developed by one of the State's major utilities, or are being advocated for by a local community. Because of this state agency, utility, or community support, these projects were assumed to have gone through a rigorous, site-specific suitability assessment. As such, they could serve as indicators of suitable locations and therefore validate the model results.

Project	Utility	Support	Theoretical MIP Eligibility
Blue Lake Rancheria Microgrid (Humboldt)	PG&E	CEC, CPUC, PG&E, Local Stakeholders	Eligible
Redwood Coast Airport Microgrid (Humboldt)	PG&E	CEC, CPUC, PG&E, Local Stakeholders	Eligible
Sonoma County Junior College District microgrid (at Santa Rosa Junior College campus)	PG&E	CEC, PG&E, Local Stakeholders	Eligible
Fremont Fire Stations Microgrids project	PG&E	CEC, PG&E, Local Stakeholders	Ineligible *(Pockets of Fremont are eligible, but the locations of the chosen fire stations are not)*
Proposed San Jose community microgrid	PG&E	CEC, Local Stakeholders	Partially Eligible
Proposed Goleta Load Pocket community microgrid near Santa Barbara	SCE	Local Stakeholders	Partially Eligible
Proposed East LA Library community microgrid	SCE	Local Stakeholders	Eligible
Proposed Oak View Huntington Beach community microgrid	SCE	CEC, Local Stakeholders	Ineligible
Ramona Air Attack Base Microgrid	SDG&E	CalFire, SDG&E, Local Stakeholders	Ineligible *(Romona is largely eligible, but the airport where the Calfire station is located is not)*
Borrego Springs microgrid	SDG&E	NREL, SDG&E, Local Stakeholders	Eligible

Table 4. Real world microgrid projects with theoretical MIP community eligibility. The study compared the locations of the above demonstration projects (completed or proposed) with the MIP community eligibility map.

Half of the above microgrid projects were in locations considered suitable for a microgrid, based on MIP eligibility. Two proposed projects—the Goleta Load Pocket community microgrid in Santa Barbara and Google's Downtown West development microgrid in San Jose—partially overlap with MIP eligible areas but would not be completely eligible [80][145]. This could ultimately lead to small microgrids in eligible locations but preclude attempting larger demonstration projects using MIP funds. While Google may not need state funding to build a microgrid, Santa Barbara likely would.

Two completed projects—the Fremont Fire Stations microgrids and the Ramona Air Attack Base microgrid—would only be eligible for MIP funds if these facilities were considered serving disadvantaged populations specifically [146][147]. Their locations may help explain why critical facilities are listed in a separate column from disadvantaged/vulnerable communities in Figure 2. (Where eligibility requires that the microgrid either be in a disadvantaged community or serve one.) This 'and/or' potentially offers more flexibility to choose the best locations, though risks confusing or delaying local stakeholders who are trying to determine whether it's worth applying for MIP funds. Sifting through eligibility data and comparing different requirements takes time—whether it's critical facilities and the areas they serve, historical PSPS data, or the latest earthquake risk assessment. As previously discussed, applying for the MIP will take significant time, effort, and funds on the part of the applicant. Uncertainty around eligibility could discourage communities without the resources to devote to this effort.

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