Solar-powered microgrids in Northern California: an opportunity for resilience

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This Master's Project

Solar-powered microgrids in Northern California: an opportunity for resilience

by

Marina Riddle

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Outline

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Abstract

Planned and unplanned power outages have been increasing in frequency and duration, negatively impacting all public sectors, and threatening public safety. These outages are deadly to those who rely on medical devices. As climate change-fueled extreme weather events (wildfires, earthquakes, storms, etc.) also increase in frequency, our electrical grid must be prepared to bounce back. Microgrids provide necessary redundancy and reliability. Through a novel GIS suitability analysis, based on solar radiation, land use type, local energy demand, distance to transmission lines, distance to roads, and slope, optimal locations for solar-powered microgrids throughout Northern California were determined. The counties of Fresno, Sacramento, and Santa Clara were found to be the most optimal locations to implement these projects. Solar was chosen because of the competitive pricing and abundant nature of the renewable resource. Due to the emission-free power generation and resiliency, solar-powered microgrids serve as a technology that prevents and adapts to climate change. For public health, safety, and the environment, it is recommended that the California Energy Commission partners with utility companies and Independent Power Producers (IPPs) to implement solar-powered microgrids. IPPs may site their projects in disadvantaged communities to qualify for funding through the Microgrid Incentive Program and benefit from the Inflation Reduction Act tax credits for solar technologies and components.
1. Introduction

1.1 Importance of Electricity and Impact of Climate Change

Dependable electricity is crucial for educational institutions, medical facilities, transportation systems, telecommunication networks, and an overall functioning society. A wide range of sectors are impacted when power is down, either directly or indirectly (Mishra et al., 2020). As shown in the figure below, natural events have increased dramatically from 1960 to 2019. Extreme weather events, or natural events, have been the leading cause of power outages, with the most significant disruption compared to other causes (Dumas et al., 2019). As climate change progresses, extreme weather events like wildfires, floods, and storms are predicted to increase in frequency and severity (Seneviratne et al., 2021). Therefore, climate change-fueled extreme weather events threaten the reliability of electricity.

![Figure 1: The figure above shows the number of natural events from 1900 to 2019, adapted from Hamidieh et al., 2022.](image-url)
Extreme weather events can lead to power outages for many reasons. Fallen trees, branches, and other debris from intense storms can damage power lines. During thunderstorms, lightning can strike electric cables, causing them to catch fire. Floods can cause soil erosion that can compromise the foundation of roads which, in turn, compromises electrical infrastructure.

Microgrids, which can be simply defined as self-sufficient small electrical grids, have the potential to mitigate and prevent these power disruptions. De-centralizing the energy grid, through the implementation of microgrids, increases the reliability of energy.

1.2 Focus Area – Northern California

The focus area for this analysis is Northern California. To narrow the scope and simplify the analysis, the northern portion of the state was chosen. Many utility companies serve customers throughout the state of California, including San Diego Gas and Electric (SDG&E), Southern California Edison (SCE), Pacific Gas and Electric (PG&E), and many more. Most gas and electric customers in Northern California are served by the Pacific Gas and Electric (PG&E) utility company. For that reason, the analysis will go in-depth into the specifications of working with PG&E to implement microgrids.

In this portion of the state, earthquakes and wildfires are common extreme weather events. California had the greatest number of wildfires and acreage burned in 2021 compared to other states across the United States (National Interagency Fire Center, 2022). Wildfires can burn or even melt electrical infrastructure, which causes disruptions in utility services. California is home to two-thirds of the nation’s earthquakes (California Earthquake
Authority, 2014). Earthquakes impact the electrical grid by sustaining substantial damage to substations, causing isolators, breakers, and switchgear to fail which can cause a cascading effect of large power outages (Johnson et al., 2020).

Since extreme weather events like wildfires and earthquakes are common in California, and associated power outages, either planned or unplanned, are common as well, there is a substantial opportunity for outage mitigation through microgrids.

1.3 Impact of Wildfires

Human-caused climate change contributed to an additional 4.2 million hectares of burned area from 1984 to 2015 (Abatzoglou et al., 2016). The amount of land area that is impacted by wildfires is increasing. Therefore, the likelihood of power outages from wildfires is also increasing.

Two of California’s most destructive and deadly wildfires occurred due to electrical infrastructure complications. Camp, a wildfire that destroyed over 150 thousand acres and led to 85 civilian deaths, occurred in November of 2018. It was determined to be caused by electrical power, specifically faulty electrical transmission lines (California Department of Forestry and Fire Protection, n.d.). PG&E pleaded guilty to causing Camp and was fined 4 million dollars (Associated Press, 2022). This was not a one-time occurrence; PG&E has been blamed for over 30 fires since 2017 (Associated Press, 2022). Tubbs, a wildfire that destroyed over 35 thousand acres and led to 22 deaths, occurred in October of 2017. It was determined to be also caused by electrical power, specifically a private electrical system.
adjacent to a residential structure (California Department of Forestry and Fire Protection, 2019).

In response to this, PG&E has ordered emergency shutoffs of power to prevent the utility’s electrical equipment from sparking and fueling additional wildfires. In 2012, the California Public Utilities Commission (CPUC) ruled that utility companies could authorize Public Safety Power Shutoff (PSPS) events to prevent wildfires when conditions like heat events, strong winds, and other related environmental conditions occur. Both the shutoffs and the disruption of service caused by the fires themselves create power outages. There are dangerous consequences that arise during these outages.

1.4 Dangers of Power Outages

According to Ready.gov, at the municipality level power outages can disrupt telecommunications and transportation, close essential businesses like grocery stores, banks, and gas stations, and prevent the use of medical devices. At the community level, power outages can lead to food spoilage and disrupt household activities like cooking and heating/cooling of the home.

Many PSPS events occur for a long time. On average, PG&E customers experienced a PSPS duration of 46.8 hours (Murphy, 2021). PSPS events are inconvenient for all and deadly for some. For those who are attending school or working from home, PSPS events decrease productivity. For those who rely on mobility, medical, or other essential electrical-powered devices, PSPS events are life-threatening (Murphy, 2021).
1.5 Frequency of Power Outages

The dangers of power outages have been stated. To demonstrate the frequency of the outages, the State of California’s GIS data portal was queried for a daily report of power outages. The data comes from the California Governor’s Office of Emergency Services. To compare outage frequency between utility companies, both planned and unplanned outages for PG&E and SDG&E have been added to Table 1. The raw data for this table can be found in Appendix 1.5.

Table 1: Planned and unplanned power outages for two utility companies, Pacific Gas and Electric (PG&E) and San Diego Gas and Electric (SDG&E), between November 17th and 18th 2023.

<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Outage Type</th>
<th>Number of Outages</th>
<th>Number of Customers Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG&amp;E</td>
<td>Planned</td>
<td>23</td>
<td>333</td>
</tr>
<tr>
<td></td>
<td>Unplanned</td>
<td>109</td>
<td>9,044</td>
</tr>
<tr>
<td>SDG&amp;E</td>
<td>Planned</td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Unplanned</td>
<td>1</td>
<td>95</td>
</tr>
</tbody>
</table>

As shown in Table 1, PG&E was responsible for 129 outages between November 17 and 18 in 2023, resulting in 9,377 customers losing power. According to Statista, PG&E serves 5.6 million electric customers. This results in approximately 0.17% of their customers losing power during a single-day period. In comparison, SDG&E had 13 outages, resulting in 183 customers losing power. According to the utility’s website, SDG&E serves 3.7 million customers, which results in approximately 0.005% of their customers losing power.

On a randomly selected day in November, PG&E, proportionate to their service area, had 34 times more customers losing power than SDG&E. Since PG&E serves the majority of
Northern California, there is ample opportunity for IPPs to work with the utility company to add microgrids and prevent these power outages.

1.6 Opportunity for Energy Justice

Many households have purchased diesel generators to provide backup power during PSPS events. The average diesel-powered backup generator can cost anywhere between 5,000 and 18,000 dollars (Cramer, 2023). Therefore, only affluent households can afford to have reliable electricity during scheduled or emergency outages. Low-income households are subject to the dangers of losing power, as discussed in Section 1.4. This current situation lacks energy justice.

Energy justice consists of three different forms of justice: distributive justice, procedural justice, and recognition justice. In the energy context, distributive justice is defined as the relationship between the energy infrastructure’s distribution and both the associated environmental impacts and the benefits/costs to the local population (Pellegrini-Masini et al., 2020). In the energy context, procedural justice means ensuring all stakeholders are equally engaged in the judicial process and policymaking of energy infrastructure. In the energy context, recognition justice means recognizing the energy needs, rights, and dignity of socially disadvantaged groups to avoid conditions of deprivation (Pellegrini-Masini et al., 2020).

Renewable microgrids provide distributive justice by ensuring the energy that is generated is emission-free, benefiting the local environment, and reliable, benefiting the local community. Community-owned microgrids provide procedural justice by involving the
residents in the ownership and, therefore, the decision-making process. Microgrids provide recognition justice if they are sited in a disadvantaged community by recognizing and fulfilling the energy needs of the residents. Overall, renewably powered community-owned microgrids sited in underserved communities can provide energy justice, to allow all Californians to have power during outages, regardless of their income level.

2. Background

2.1 Transition to the “Modern Grid”

Historically, the United States’ energy grid operates by burning a fuel source, usually coal or natural gas, at an electric power plant (Energy Information Administration, 2023). After burning a fuel source, a turbine generator moves either air, combustion gases, water, or steam to push a series of mounted blades on a rotor shaft. The force of this rotates the rotor shaft of the turbine, turning the mechanical energy into electrical energy. Once the electrical energy has been generated, it must be transferred. This is done with a transformer to step up the voltage of the energy for transmission. Transmission lines carry high-voltage electricity long distances to the neighborhood of the intended end user. Next, a transformer steps the voltage down and transports the energy with distribution lines to the utility pole and ultimately the electric customer (Energy Information Administration, 2023). This type of energy distribution requires significant financing of infrastructure building and ongoing maintenance costs. One of the many benefits of microgrids is that the transmission towers and lines are not needed because the end user is much closer to the power being generated.
The United States is transitioning from a traditional grid to a modern grid. The figure below shows the difference between a one-way power flow system and a two-way power flow system. A one-way power flow system operates by power flowing from the source of generation (e.g., a power plant) to the utility customer. A two-way power flow system operates by power flowing both to and from the customer. An example of this would be residential solar panels. If the solar panels are generating more electricity than the household is using, the excess energy flows back to the main grid.

![Figure 2: The transition from a traditional energy grid to a new electrical grid with a two-way power flow. Adapted from Henderson et al., 2017.](image)

A renewable microgrid can be set up so that power is generated from either a mix or single source of renewable resources (i.e., wind, solar, geothermal, small-scale hydroelectric, etc.). When there is a mix of renewable sources, this is referred to as a hybrid microgrid. Regardless of the microgrid type, four main processes occur when a microgrid is in operation. Energy is generated from a renewable source, a photovoltaic (PV) panel for example, stored in a fuel cell, controlled by an Energy Management System (EMS), and
distributed directly to the end user. As shown in Figure 2, the microgrid can also be integrated with the energy system at large.

2.2 Aging Infrastructure

Although there have been incremental updates to the energy grid, the infrastructure is aging. Much like other infrastructure throughout the United States like roads, bridges, and highways; electrical infrastructure (e.g., transformers, underground cables, capacitor banks, etc.) is aging as well. According to a press release from the White House in February of 2023, over 70% of the electrical grid is more than 25 years old. This aging infrastructure needs to be supplemented with renewably powered microgrids to ensure citizens are never without power.

2.3 Why Solar?

The rationale behind choosing solar as opposed to other types of renewable energy for potential microgrid projects, such as wind, hydroelectric, tidal, geothermal, etc., is the abundance and affordability of the resource. Solar radiation is high in the state of California, like most of the western portion of the country. As shown in Figure 3, symbolized by either dark orange or red colors, solar irradiance is high throughout the entire state, with more irradiance concentrated in the southern and central areas of the state. Solar irradiance can be defined as the sun’s energy measured in kilowatt-hours per meter squared.
Typically, as a new technology matures and becomes optimized, the price for the new technology goes down. Solar is no exception. Solar PVs have decreased in price by 89% in the past decade (Roser, 2020). In 2009 the cost for solar was $359 per megawatt-hour and in 2019 the cost went down to $40 per megawatt-hour (Roser, 2020). The cost of renewables like solar is becoming so competitive that for 99% of all coal-fired power plants across the United States, it is more expensive to operate than to fully replace them with renewables (Solomon et al., 2023).

Lastly, the reason that renewable energy was chosen was because it is naturally occurring and replenishing, unlike fossil fuels like coal which do not replenish over a human time scale. However, there is an environmental impact associated with solar. The degree of the ecological impact is highly dependent on the sourcing of raw materials and whether recycled
materials are used or not. Solar PV cells require key metals such as silver and copper that require mining if they are not recycled. Mining precious and semi-precious metals can contaminate local waterways, permanently convert the land, and negatively impact biodiversity. For example, recent and historical silver mines in the US, Mexico, Peru, and Bolivia have contaminated local soil and water with heavy metals as well as created social conflicts in Guatemala (Dominish, et al., 2019). Nonetheless, the energy generated from the renewably powered system does not produce greenhouse gas emissions that fuel climate change.

2.4 Resilience

Resilience can be defined as the ability to survive and quickly recover from disruptions, both extreme and unexpected (Jasiūnas et al., 2021). Energy resilience can be thought of as the high reliability and availability of energy services, reliability as minimal outage frequency and duration, and availability as an energy supply that meets and exceeds demand.

In this analysis, resilience is considered through the 4Rs framework: robustness, redundancy, resourcefulness, and rapidity. Robustness is the ability of systems to withstand stress without loss of function or degradation (Bruneau et al., 2003). Redundancy is the presence of alternative processes that perform a system’s function. Resourcefulness is the ability to prepare and plan before a disaster to manage potential threats. Rapidity is the speed at which the functions of a system are recovered after an initial shock (Li et al., 2017).

Utilizing the framework mentioned, microgrids provide resilience to communities through robustness, redundancy, resourcefulness, and rapidity. Microgrids are robust in that
they can maintain power during extreme weather events such as wildfires and earthquakes.

Microgrids are redundant in that they are a backup system that can be utilized when the main utility grid is not functional. Microgrids fit within the resourceful framework because key personnel test to prepare the microgrid to “island” when the main energy grid is experiencing an outage, managing the threat of communities losing power and dangers associated with the outages. Islanding occurs when microgrids are fully self-sufficient (i.e. do not receive any power from the main grid). Finally, microgrids fit within the rapidity framework due to the speed at which an outage is detected and the microgrid can enter island mode.

Additional resilient aspects of microgrids are financial. Since transmission towers and lines are not needed to transport the electricity far distances, because the microgrid is located close to the end-user, there are reduced infrastructure requirements compared to traditional energy grids. This lowers the financial burden of upfront costs, as well as operating and maintenance costs. In instances where excess energy has been created, revenue can be generated by selling the excess energy to the utility company. Finally, local jobs are created for building and monitoring the microgrid. In those ways, microgrids offer economic resilience in addition to the 4Rs previously mentioned.

2.5 Research Questions

My research question is, can microgrids increase resilience in Northern California against climate change-fueled extreme weather events? The sub-questions are as follows:

What are the technical obstacles facing the implementation of microgrids in Northern California? A case study analysis was performed to answer the sub-question. This analysis
considered two solar-powered microgrids in Northern California: the Blue Lake Rancheria
tribal-owned microgrid and the Kaiser Permanente hospital microgrid.

What are the funding opportunities to support the implementation of microgrids in
Northern California? A policy review was conducted to answer the sub-question. This review
focuses on the Inflation Reduction Act, Electric Program Investment Change, Net Metering
3.0, and the Microgrid Incentive Program.

What counties in Northern California are most optimal for solar-powered microgrids? To
answer the sub-question question, a GIS suitability analysis was performed throughout
Northern California to determine potential locations for solar-powered microgrids to be built.

Microgrids offer Northern California residents many different benefits: reliable power
amid outages, jobs to operate and maintain the microgrids, emission-free energy, and
financial benefits of selling excess power back to the grid (although this benefit has been
impacted by the passing of Net Metering 3.0). For these reasons, microgrids as a technology
offer resilience to combat and adapt to climate change.

3. Case Study – Blue Lake Rancheria (BLR) Microgrid

3.1 Background of BLR Microgrid

The BLR microgrid is located on the coast of Northern California near the border of
Oregon in Humboldt County. Since BLR is a certified American Red Cross Evacuation
Shelter and provides emergency services for the tribal community in a disaster-prone and
remote area, resilience is the cornerstone of this system. In 2017, the BLR microgrid received
the Federal Emergency Management Agency (FEMA) award for Whole Community Preparedness.

The microgrid is composed of a 420-kW PV array, an 1150-kW battery storage system, a microgrid management system, and a legacy 1-MW diesel generator (Schatz Center, 2023). For a visual representation of the system, see Figure 4.

![Figure 4: Configuration of Blue Lake Rancheria solar-powered microgrid. Adapted from Schatz Center, 2023.](image)

To better understand Figure 4, some technical terminology will be defined. According to the Institute of Electrical and Electronic Engineers, a protective relay functions to detect faulty lines or abnormal/dangerous power system conditions to trigger an action on a control
circuit to protect the system. A point of common coupling is the point at which the utility infrastructure meets the customer infrastructure. A backup generator is a backup electrical system that will provide energy during times of intermittent conditions (i.e. when clouds cover the sun and decrease available solar radiation). Loads are defined as the local energy demand for the system, shown in the figure as a local building. PV is a photovoltaic solar array that is generating energy for the system. A battery is a storage system that can also provide energy during times of intermittent conditions.

The system is a publicly owned multi-property microgrid. The BLR tribe was able to buy a part of the distribution network within their jurisdiction directly from PG&E. Approval was required from CPUC. After approval was acquired, common regulatory barriers were able to be circumvented (Zinaman et al., 2022). Since the solar-powered microgrid is owned by the tribal community, the financial benefits stay within said community. Procedural justice, one of the three aspects of energy justice, is being met in this case study due to the community involvement and ownership of the microgrid.

The microgrid’s resilience was put to the test in 2017 and again two years later. In October of 2017, a wildfire started a quarter mile from BLR, and, because of the fire, the PG&E grid experienced an outage from 4:37 pm to 5:55 pm. This unscheduled blackout was quickly detected by the BLR microgrid and it was able to successfully island (Moreno et al., 2022). Rapidity, from the resilience framework discussed previously, was exemplified during the extreme weather event by the speed at which the outage was detected and the system was able to respond. In October of 2019, a scheduled outage was ordered by PG&E. The PSPS event lasted over 28 hours and the microgrid was able to provide uninterrupted power to the county of Humboldt. For eight residents who were on oxygen tanks, this was a matter of life.
or death. They would not have survived without the microgrid providing power (Neumann, 2020). Redundancy, the duplication of systems, from the resilience framework was exemplified during the PSPS event because the backup system, a microgrid, was utilized due to the failure of the main system, the main energy grid. This is resilience in action.

3.2 Key Personnel for Operating BLR Microgrid

To operate a successful microgrid, critical people must be employed. The table below details the title and the associated essential functions of key personnel. A licensed and experienced team is crucial to the success of the designing, building, testing, maintaining, optimizing, and operating of the microgrid.

**Table 2:** Key personnel for design, construction, and implementation of the microgrid. Adapted from Carter et al., 2019.

<table>
<thead>
<tr>
<th>Personnel Type</th>
<th>Personnel Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Management Team</td>
<td>Keep projects on schedule and under budget. Ensure environmental and permitting processes are closely managed.</td>
</tr>
<tr>
<td>Licensed Engineer</td>
<td>Lead integration process (empowered through contracts to direct work as needed).</td>
</tr>
<tr>
<td>Controls Expert</td>
<td>Program advanced protection relays with control functions. Participate in the development of real-time and optimization control programming. Coordinate the settings of the component-level controllers.</td>
</tr>
<tr>
<td>Licensed Electrical Engineer</td>
<td>Electrical design of the microgrid. Develop a power flow model to evaluate stability under various conditions.</td>
</tr>
<tr>
<td>Protection Engineer</td>
<td>Program protection relays. Complete short-circuit coordination studies. Responsible for the selectivity of the fault interruption systems in grid-connected and islanded modes.</td>
</tr>
<tr>
<td>Energy Modeler</td>
<td>Verify optimal component sizing. Consult with the controls team to ensure the necessary functions are in place to achieve optimal economic performance.</td>
</tr>
<tr>
<td>Role</td>
<td>Responsibilities</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Utility Interconnection</td>
<td>Evaluate requirements, inspect, and approve projects.</td>
</tr>
<tr>
<td>Engineers</td>
<td></td>
</tr>
<tr>
<td>Licensed Electrical</td>
<td>Experience with medium-voltage systems.</td>
</tr>
<tr>
<td>Contractor</td>
<td></td>
</tr>
<tr>
<td>Network Technology</td>
<td>Design communications network for microgrid control and data acquisition.</td>
</tr>
<tr>
<td>Expert</td>
<td></td>
</tr>
<tr>
<td>Cyber Security Team</td>
<td>Evaluate design plans, identify any vulnerabilities, and recommend mitigation</td>
</tr>
<tr>
<td></td>
<td>measures to harden the microgrid against cyberattacks.</td>
</tr>
<tr>
<td>Testing Team</td>
<td>Conduct hardware-in-the-loop testing controls in a digital simulation environment.</td>
</tr>
<tr>
<td>Construction Management</td>
<td>Document construction and mediate any disputes that arise.</td>
</tr>
<tr>
<td>Team</td>
<td></td>
</tr>
<tr>
<td>Commissioning Agent</td>
<td>Testing all functionality in the final Concept of Operations.</td>
</tr>
<tr>
<td>Data Analysis Specialist</td>
<td>Analyze large operation datasets during the system observation period.</td>
</tr>
<tr>
<td></td>
<td>Provide summary reports to the project management team.</td>
</tr>
</tbody>
</table>

### 3.3 Technical Obstacles for BLR Microgrid

Common challenges for the BLR microgrid were integration and communication. Communication between key personnel and between different departments/groups/teams was disconnected at times. There were instances in which IT software upgrades and changes to network infrastructure were not properly communicated which led to microgrid components not being able to signal back and forth between each other (Carter et al., 2019).

Integration between the microgrid and the main energy grid was challenging at BLR. Integration between the microgrid and legacy equipment was a significant obstacle as well (Carter et al., 2019). To streamline the main energy grid integration, a partnership with the utility company was established. A collaborative relationship between BLR key personnel and the utility was essential, due to the complexity of configuring an integration between the microgrid and the main grid.
To mitigate the technical obstacles mentioned above, an experienced team is needed. As detailed in Table 2, many key personnel like electrical engineers are licensed and experienced, but having people on the team who are experienced with microgrids specifically is most important.

3.4 Conclusions for BLR Microgrid

The BLR solar-powered microgrid is an example of a successful microgrid implementation. The project was completed with no safety incidents or equipment damage. In addition to the smooth completion of the project, there were significant carbon emissions and cost savings. The economic benefit of the system was approximately 164,000 dollars and is expected to increase to approximately 198,000 dollars in the upcoming years due to an improvement in the performance of the system (Carter et al., 2019). The economic benefit is quantified as the savings in energy costs. The carbon savings for the microgrid were approximately 175 metric tons of CO2 equivalent per year (Carter et al., 2019).

Although there were technical obstacles (coordination, communication, and integration), with the carbon savings, cost savings, and empowerment of the indigenous tribal community, the BLR microgrid is an example of the resilience that is provided by renewably powered microgrids. However, it may be difficult to replicate due to the unique aspects of the location that made it successful.
4. Case Study – Kaiser Permanente (KP) Microgrid

4.1 Background of KP Microgrid

The KP microgrid is located in the city of Richmond in Northern California. It was completed in partnership with the California Energy Commission (CEC) and Charge Bliss, Inc. The CEC awarded 4.78 million dollars of grant money to Charge Bliss, Inc. to build and operate the first renewable microgrid for a California hospital (Bliss, 2019).

The system is comprised of a 250kW PV canopy, 250kW battery, dual interconnection, and a Phasor Measurement Unit device, which measures the voltage and current synchrophasors of the system down to the microsecond (Gabbar, 2017).

The Kaiser Permanente Hospital is the only general hospital that serves the western portion of Contra Costa County, meaning it provides essential/emergency services to the surrounding community much like the BLR microgrid provides essential/emergency services like an American Red Cross Evacuation Shelter. Therefore, the reliability of electrical power for the hospital is vital to the wellness, security, and safety of the community. Due to the high electrical load of hospital equipment and air filtering requirements for the building, hospitals have high energy demand (Bliss, 2019). Their high demand coupled with the essential services they provide, make them an ideal candidate for supplemental and reliable power provided by microgrids.

4.2 Intersection of Environmental and Energy Justice

The city of Richmond has historically had issues with air quality. A microgrid that is renewably powered provides emission-free electricity generation. The KP microgrid prevents
an estimated 214 metric tons of carbon dioxide equivalent from being released into the atmosphere each year (Bliss, 2019). This is especially important in instances where hospitals use diesel-powered backup generators, directly negatively impacting air quality to operate the building. Thus, energy justice and environmental justice intersect.

Figure 5: This map shows the California Office of Environmental Health Hazard Assessment (COEHHA) of CalEnviroScreen 4.0. The red polygons symbolize a high score, which is associated with an unhealthy environment, and the green polygons symbolize a low score, which is associated with a healthy environment based on census tracts. The score is calculated based on air pollution and population. Adapted from COEHHA 2022.

As shown in Figure 5, symbolized in red and orange polygons, the city of Richmond has much worse air quality than surrounding areas like Orinda and Larkspur, which are mostly either light green or dark green. Since the hospital works to improve the health of its clients, it is aligned with its mission statement to also improve the surrounding air quality of the facility through emission-free energy generation that the microgrid provides. Judith Park, an MD who practices at the hospital stated, “Every day, our caregivers treat patients with asthma and other chronic health conditions related to environmental stressors. Our commitment to Richmond and the East Bay is not only to improve the health of our members but also the health of the communities that we serve.” Distributive justice, one of the three
aspects of energy justice, is being met in this case study due to the environmental benefits to the community related to the energy infrastructure.

4.3 Technical Obstacles for KP Microgrid

A unique challenge for the Kaiser Permanente (KP) microgrid was finding a host hospital, the original host declined to participate. Once the substitute host site was found, there was another location-related problem. Within the Kaiser facility, the microgrid needed to be placed with adequate space, depth, weight, and height requirements along with electrical connection capabilities. To meet the specifications mentioned, a canopy solar array was built on top of a parking structure with added structural components. This design allowed for proximity to the central utility plant for shorter distribution lines while maintaining fire and seismic safety regulations. Interconnection with the main grid was another major obstacle (Bliss, 2019).

4.4 Conclusions for KP Microgrid

All permits, inspections, California Environmental Quality Act (CEQA) regulations, and interconnection were approved for the KP microgrid. The solar-powered KP microgrid successfully: reduced greenhouse gas emissions, developed a novel microgrid controller, which is crucial to the Applied Research and Development grouping needed to qualify for EPIC funding (discussed more in 5.2), reduced strain on the utility, increased resilience of critical infrastructure, reduced cost, and allowed for the development and sharing of microgrid-specific knowledge.
As shown in Table 3, comparing the two case studies, both provide emergency services, are solar-powered, have saved a significant amount of carbon and costs, and can go into island mode. The BLR microgrid has many unique aspects to it, so replication may be difficult. However, the KP microgrid is easily replicable for other hospital locations. BLR is more rurally located, whereas KP is more urban. Since BLR is isolated, the reliability of energy is what adds the most meaningful aspect of resilience to the community. Since KP has historically poor air quality, the emission-free aspect of the energy is what adds the most meaningful aspect of resilience to the community.

**Table 3:** Comparison summary table of the BLR microgrid and KP microgrid.

<table>
<thead>
<tr>
<th>Microgrid Details</th>
<th>Blue Lake Rancheria Microgrid</th>
<th>Kaiser Permanente Microgrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Services</td>
<td>Red Cross Shelter</td>
<td>Hospital</td>
</tr>
<tr>
<td>Location</td>
<td>Rural Humboldt County, CA</td>
<td>Urban Contra Costa County, CA</td>
</tr>
<tr>
<td>CO2e Saved</td>
<td>175 metric tons per year</td>
<td>214 metric tons per year</td>
</tr>
<tr>
<td>Islandable?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Renewable Type</td>
<td>420kW ground-mounted solar</td>
<td>250kW rooftop solar</td>
</tr>
<tr>
<td>Storage System</td>
<td>1,150 kW battery</td>
<td>250kW battery</td>
</tr>
<tr>
<td>Economic Benefit</td>
<td>25 - 30% reduction in energy cost, provides local jobs</td>
<td>20% savings of baseline utility cost</td>
</tr>
<tr>
<td>Unique Issue</td>
<td>Isolated</td>
<td>Poor air quality</td>
</tr>
</tbody>
</table>
5. Policy Analysis

5.1 Inflation Reduction Act (IRA)

At the federal level, the passing of the IRA which came into effect on January 1st, 2023, has been estimated to reduce costs for microgrid components by 10 to 50 percent. The reduced costs come from the Investment Tax Credit (ITC) and Production Tax Credit (PTC). The ITC lowers tax liability. The PTC also lowers tax liability but is measured with the amount of kWh produced by the microgrid project. Typically, microgrids would use ITC because there are more relative savings, bigger systems typically use PTC. Microgrid controllers, like electronic management systems, qualify for the ITC. A microgrid controller controls the flow of energy and lets the operator optimize cost and carbon savings based on provided data on the system. Solar technologies, like solar-powered microgrids, qualify for both ITC and PTC (EPA, 2022). However, there are requirements for the microgrids to benefit from the tax credits.

The solar technologies must be alternating current (AC) as opposed to direct current (DC). AC occurs when electrons flow in both directions creating a sinusoidal wave. DC occurs when electrons flow in one direction.

There are differing tax credits based on the size of the microgrid. If the project is less than one megawatt, there is an ITC of 30% and a PTC of 2.75 cents per kilowatt hour. If the project is greater than one megawatt, there is an ITC of 6% and a PTC of 0.50 cents per kilowatt hour (EPA, 2022). Tax credits are more advantageous for smaller solar microgrid projects.
There are bonus tax credits available for US-manufactured products, which increases ITC by an additional 10%, as well as the siting location of the microgrid project. Siting increases ITC by an additional 10%, siting can be:

1. In an “energy community” (e.g. a locality that has mining operations).
2. In a low-income community.
3. In Native American land.

Siting in a qualified low-income residential building project or a qualified low-income economic benefit project increases ITC by an additional 20% (EPA, 2022).

5.2 EPIC Program

At the state level, the Electric Program Investment Charge (EPIC) was established in 2011 by the CPUC to fund technological advancements. The advancements were to support the transition from fossil fuels and to meet California’s clean energy goals. The focus was on ratepayer benefits such as safety, lowering costs, and increased reliability. The budget of EPIC 4, which spans from 2021 to 2025 is $147.26 million per year (Lew et al., 2021). The EPIC has a few goals:

- Increase resiliency and safety of the electrical system
- Increase the use of renewable energy
- Decentralize the grid
- Support local businesses and economies in California
- Improve affordability, comfort, and health of communities in California
There are a few requirements that IPPs must comply with to receive funding. To apply for EPIC, the business must be registered with the California Secretary of State. Additionally, the microgrid project must fall into at least one of three categories: “Applied Research and Development”, “Technology Demonstration and Deployment”, and/or “Market Facilitation” (Lew et al., 2021). The Applied Research and Development grouping means that the project is a novel technology. An example of this would be the KP hospital microgrid case study, where the team was able to create a new kind of microgrid controller. The Technology Demonstration and Deployment grouping means that the project is a non-commercially viable technology. The Market Facilitation grouping means that the project focuses on overcoming non-technical barriers.

The application for EPIC will need to have an executive summary, fact sheet, project narrative, project team resumes, scope of work, schedule of products and due dates, budget, CEQA compliance form, reference/work product form, contact list, and commitment/support letters. The CPUC will screen and score the application, the evaluation usually takes 6 to 8 months, and the IPP must score a 70 out of 100 to be accepted.

5.3 Net Metering 3.0

Net Metering 3.0 (NEM3) replaced Net Metering 2.0 in April of 2023. This program cut the value of solar energy credits by 75%. Since the passing of NEM3, selling excess energy back to the main energy grid is now worth less than before it was passed. Environmental groups, the Center for Biological Diversity, Environmental Working Group, and Protect Our Communities Foundation sued the CPUC over the ruling. The environmental groups argue that the ruling has not properly valued solar.
5.4 Microgrid Incentive Program

On October 11th, 2023, the Microgrid Incentive Program (MIP) was announced by PG&E. Focusing on vulnerable and disadvantaged communities, the program, approved by the CPUC authorized 79.2 million dollars for PG&E to help fund microgrids. To qualify for the MIP, the project must adhere to at least one requirement in column one, one requirement in column two, and all technical requirements in column three shown in Table 4.

Table 4: Requirements for MIP Proposed Projects. Adapted from PG&E’s website: Community Microgrids (pge.com)

<table>
<thead>
<tr>
<th>Vulnerable to Outages</th>
<th>Disadvantaged and Vulnerable Community</th>
<th>Technical Eligibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>o Tier 2 or 3 High-Fire Threat District</td>
<td>o Census tracts with median household incomes less than 60% of state median</td>
<td>o Meet the eligibility requirements of the Community Microgrid Enablement Tariff (CMET)</td>
</tr>
<tr>
<td>o Area that experienced prior PSPS outage(s)</td>
<td>o California Native American Tribal Community</td>
<td>o Be able to serve a minimum of 24 consecutive hours of energy in Island Mode as determined by a typical load profile within the microgrid boundary.</td>
</tr>
<tr>
<td>o Elevated earthquake risk zone</td>
<td>o Community with highest risk per CalEnviroScreen</td>
<td></td>
</tr>
<tr>
<td>o Locations with lower historical reliability</td>
<td>o A rural area</td>
<td></td>
</tr>
</tbody>
</table>

The technical requirements for meeting the eligibility of the Community Microgrid Enablement Tariff (CMET) are that the microgrid project must be:

1. Serving at least 2 PG&E customers.
2. Geographically within the PG&E service area.
3. No larger than 200 MW.
4. Able to connect to, disconnect from, and run in parallel with the main grid.

5. Pre-screened with a pre-application report.

6. Built by a team that has either completed a microgrid of a similar size or is currently building a microgrid of a similar size.

It’s important to note that eligibility of the microgrid project does not guarantee funding, since PG&E uses a competitive application process (Allen, 2022).

5.5 Conclusion

There are financial opportunities at both the federal level and state level for solar-powered microgrids. At the federal level, the IRA has ITC and PTC credits for solar microgrids. At the state level the EPIC program, which has the goal of funding technological advancements for clean energy, has a yearly budget of 147 million dollars for the next few years. MIP has 79.2 million dollars available for microgrids. IPPs can apply to these programs for funding assistance.

6. GIS Analysis – Methods

6.1 Suitability Criteria

The GIS suitability analysis was performed using the ESRI (Environmental Systems Research Institute) mapping software ArcGIS Pro, with version 3.1. The purpose of the suitability analysis is to find the optimal locations for new solar-powered microgrid
installations in Northern California. The criteria that will determine which counties in Northern California are “optimal” are as follows:

1. Amount of solar radiation.
2. GAP Status.
3. Local energy consumption.
4. Distance to transmission lines.
5. Distance to roads.

The first criterion is the amount of solar radiation. Since the analysis focuses on solar-powered microgrids, the amount of solar radiation is vital to determining the suitability of a proposed location. A high amount of solar radiation is considered “more optimal”, and a low amount of solar radiation is considered “less optimal” because solar radiation is directly related to the amount of energy output the PV panels can produce.

The second criterion is the protection status of the land. Microgrids are not permitted to be built in wildlife conservation areas. GAP (Gap Analysis Project) Status land areas have the designation of 1, 2, 3, or 4. GAP Status 1 lands are defined as an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management. GAP status 2 lands are defined as an area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management
practices that degrade the quality of existing natural communities including suppression of natural disturbance. GAP Status 3 is the permanent protection from the conversion of most of the land and some extraction is allowed (either low intensity, localized, or broad). GAP Status 4 is defined as having no known institutional mandates or legally recognized restrictions held by the managing entity to prevent the conversion of natural habitat types to manmade habitat types. Therefore, if there is a GAP Status of 1, 2, or 3 in any given location in Northern California, it is considered not optimal for microgrids. If there is no GAP designation or a GAP Status of 4, it is an optimal location for microgrids.

The third criterion is the energy demand from the locality. Microgrids in their nature are meant to be geographically close to the end customer, since one of the benefits of microgrids is that power doesn’t need to be transported long distances, saving on costs associated with transmission infrastructure. Therefore, if the local energy demand is low, then there is less of a need for a supplemental energy supply provided by the microgrid, and the location is considered “less optimal”. If the local energy demand is high, there is more of a need for a supplemental energy supply provided by the microgrid, and the location is considered “more optimal”.

The fourth criterion, distance to transmission lines, is crucial for the potential financial benefits of microgrids. Being close to a transmission line allows for the microgrid to be integrated with the main grid when the microgrid produces excess energy to sell to the local utility company. Therefore, the closer the microgrid is to the transmission lines, the “more optimal” the location is considered and the farther the area is to the transmission lines, the “less optimal” the location is considered.
The fifth criterion, the distance to the major roads, is important for the maintenance and operation of microgrids. If there are no access roads, repairs will not be able to be made and maintenance will be difficult. Therefore, the closer the area is to the major roads, the “more optimal” the location is considered, the farther the area is to the major roads, the “less optimal” the location is considered.

The sixth criterion, the slope degree of the land, was determined to be an important factor based on the assumption that a large degree of slope would be difficult to build on. A low amount of slope degree is considered “more optimal”, and a high amount of slope degree is considered “less optimal”.

To begin the suitability analysis, reputable sources for solar radiation raster data, GAP Status 1, 2, 3, and 4 polygons, energy demand polygons, transmission lines, major road lines, and elevation raster data, used to determine slope, were obtained. Figure 14 visualizes the six different data layers.

6.2 Converting Vector to Raster Data

After the initial data layers were found, tools from ArcGIS Pro were run to transform polygons or lines into raster data. For GAP status vector data and energy demand vector data, the tool “Polygon to Raster” was run to complete the conversion.
For major roads and transmission lines, the tool “Euclidean Distance” was run.

According to the National Institute of Standards and Technology, Euclidean distance is defined as the straight line between two points. The formula is as follows:

\[ p_1 = (x_1, y_1) \]
\[ p_2 = (x_2, y_2) \]

\[ \text{Euclidean Distance} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \]

The Euclidean distance was found for roads and transmission lines to transform the line vector data into a continuous raster dataset. The tool sets a value for each cell on the map, calculated based on the distance from the center of the source cell, shown in purple in the figure below, to the center of each of the surrounding cells, shown in light gray in the figure below. Figure 6 demonstrates a sample calculation.

Figure 6: This figure shows the Euclidean Distance calculation for the ArcGIS Pro tool based on cell orientation in relation to the source cell, symbolized on the left in purple.
6.3 Reclassification of Data Layers

After each dataset was transformed from vector data to raster data, reclassification was performed. The purpose of reclassification for this suitability analysis was to rank cells within the raster as 1, 2, 3, 4, or 5 to standardize initial values of the data layers so they can ultimately be combined in a weighted overlay for the final output.

![Reclassify](image)

**Figure 7:** This figure shows the parameters for the reclassification of the solar data layer. 4.1 to 5.8 kWh/m² were ranked least optimal. 5.8 to 6.5 kWh/m² were ranked less optimal. 6.5 to 7.01 kWh/m² were ranked moderately optimal. 7.01 to 7.6 kWh/m² were ranked optimal. 7.6 to 8.66 kWh/m² were ranked most optimal.

The input dataset was the solar raster provided by the National Renewable Energy Laboratory (NREL). The reclass field was the “VALUE” field. The values for the reclassification were ranked 1 to 5, with 5 being the least optimal and 1 being the most
optimal. The greatest value for solar radiation, 7.64 approximately to 8.66 approximately, was given the value of 1. The greater the amount of solar radiation, the more optimal the location is to build microgrids. The output raster was named “Reclass_SolarRadiation”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 1.

![Reclassification parameters for the GAP Status data layer](image)

**Figure 8:** This figure shows the parameters for the reclassification of the GAP Status data layer. No GAP Status or GAP Status of 4 were assigned a value of “Available” and were ranked as optimal locations for solar-powered microgrids. GAP Status 1, 2, and 3 were assigned a value of “OneTwoThree” and were ranked as not optimal locations for solar-powered microgrids.

The input dataset was the GAP Status raster provided by the United States Geologic Survey (USGS), converted from vector data to raster data. The reclass field was the “FeatClass” field. The values for the reclassification were ranked 1 to 2, with 2 being the least optimal and 1 being the most optimal. This is a binary matrix where the “Available” land has either no GAP Status classification or a GAP Status of 4 and the value “OneTwoThree” either had a GAP Status of 1, 2, or 3, which would mean that the land use
could not be converted to build a microgrid. The output raster was named “Reclass_GAPStatus”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 2.

**Figure 9:** This figure shows the parameters for the reclassification of the energy demand data layer. 17 to 750 GWh of yearly energy consumption were ranked least optimal, 750 to 2000 GWh of consumption were ranked less optimal, 2,000 to 4,000 GWh of consumption were ranked moderately optimal, 4,000 to 8,000 GWh of consumption were ranked optimal, and 8,000 to 17,102 GWh of consumption were ranked most optimal.

The input dataset was the energy demand raster divided by county provided by the California Energy Commission (CEC). The reclass field was the “VALUE” field. The values for the reclassification were ranked 1 to 5, with 5 being the least optimal and 1 being the most optimal. The greatest value for energy demand, 8,000 GWh to 17,102 GWh, was given the value of 1. The greater the energy demand, the more optimal the location is to build a
microgrid. The output raster was named “EnergyDemandReclass”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 3.

Figure 10: This figure shows the parameters for the reclassification of the transmission data layer. 0 to 0.05 miles from the road were ranked most optimal, 0.05 to 0.2 miles were ranked optimal, 0.2 to 0.4 miles were ranked moderately optimal, 0.4 to 0.65 miles were ranked less optimal, and 0.65 to 12.8 miles were ranked least optimal.

The input dataset was the Euclidean Distance for the transmission lines raster that converted the line vector data to raster data. The transmission data was provided by the CEC. The reclass field was the “VALUE” field. The values for the reclassification were ranked 1 to
5, with 5 being the least optimal and 1 being the most optimal. The lowest value for transmission lines, 0 to 10,145 feet approximately, was given a value of 1. The closer to transmission lines, the more optimal the location is to build microgrids. The output raster was named “Reclass_Transmission1”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 4.

**Figure 11:** This figure shows the ranking and parameters for the reclassification of the roads data layer. 0 to 0.05 miles from the road were ranked most optimal, 0.05 to 0.2 miles were ranked optimal, 0.2 to 0.4 miles were ranked moderately optimal, 0.4 to 0.65 miles were ranked less optimal, and 0.65 to 12.8 miles were ranked least optimal.
The input dataset was the Euclidean Distance for the major roads raster that converted the line vector data to raster data. The major roads data was provided by the Department of Commerce. The reclass field was the “VALUE” field. The values for the reclassification were ranked 1 to 5, with 5 being the least optimal and 1 being the most optimal. The lowest value for roads, 0 to approximately 0.053 miles, was given the value of 1. The closer the location is to roads, the more optimal the location is to build microgrids. The output raster was named “Reclass_Roads2”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 5.

![Geoprocessing](image)

**Figure 12:** This figure shows the ranking and parameters for the reclassification of the slope data layer. 0 to 4.3 degrees were ranked most optimal, 4.3 to 10.7 degrees were ranked optimal, 10.7 to 18.1 degrees were ranked moderately optimal, 18.1 to 27 degrees were ranked less optimal, and 27 to 78.3 degrees were ranked least optimal.
The input dataset was the slope degree raster. The data, based on elevation, was provided by the USGS. The reclass field was the “VALUE” field. The values for the reclassification were ranked 1 to 5, with 5 being the least optimal and 1 being the most optimal. The greatest value for slope degree, from 27 degrees to approximately 78 degrees, was given the value of 5. The greater the slope, the less optimal the location is for building microgrids. The output raster was named “Reclass_SlopeDegree”. The output was mapped in the GIS Analysis – Results section in Figure 15 Map 6.

6.4 Weighted Overlay for Final Output

After all reclassifications were completed, the tool “Weighted Overlay” in ArcGIS Pro was used to create the final suitability output. The Weighted Overlay tool allows different weights to be placed on multiple raster layers to determine the final suitability for solar-powered microgrid locations. “Reclass_ds491”, the solar radiation layer, was given a 20 percent weight, “Reclass_Roads2_Clip”, the roads layer, was given a 10 percent weight, “Reclass_Transmission1_Clip”, the transmission layer, was given a 10 percent weight, “Reclass_SlopeDegree_Clip”, the slope layer, was given a 10 percent weight, “Reclass_PAD2”, the GAP status layer, was given a 40 percent weight, and “EnergyDemandReclass”, the energy demand layer, was given a 10 percent weight.
Figure 13: This figure shows the weighted overlay parameters for the final suitability output. Reclass_ds491 is the solar radiation layer. Reclass_Roads2_Clip is the roads layer. Reclass_Transmission1_Clip is the transmission layer. Reclass_SlopeDegree_Clip is the slope layer. Reclass_PAD2 is the GAP status layer. EnergyDemandReclass is the energy demand layer.

The rationale for the assigned percent weights is that the roads, transmission, slope, and energy demand had similar importance, thus they were all assigned the same weight of 10 percent. The solar radiation layer is vital for the output of the solar cell of the microgrid; therefore, it was given a higher percentage of 20 percent. The GAP status layer was assigned the greatest percentage because it does not matter if all the other data inputs are optimal, if it is not legally permissible to build a microgrid, then the project cannot be built. The Weighted Overlay tool generated the final output of suitable locations shown in Figures 15 and 16.
7. GIS Analysis – Results

7.1 Initial Data Layers

Figure 14: This figure shows the six data layers as maps depicting different suitability criteria. The figure was last updated on October 22nd, 2023 by Marina Riddle.
7.2 Analysis of Initial Data Layers

In Figure 14, labeled as Map 1, the solar radiation raster data layer is shown. This 2018 dataset comes from the National Renewable Energy Laboratory (NREL). High amounts of solar radiation are symbolized in red, and low amounts of solar radiation are symbolized in dark purple. Overall, the lower right portion of the Northern California boundary has the highest amount of solar radiation. The counties located in this area include Inyo, Tulare, and parts of Fresno County. The upper left portion of the boundary has the lowest amount of solar radiation. The counties located in this area include Del Norte and Humboldt County.

In Figure 14, labeled as Map 2, the GAP Status polygons are shown. This 2022 dataset comes from the United States Geologic Survey (USGS). GAP Status 1 is symbolized in pink and most of this classification is found in the lower righthand portion of the map. GAP Status 2, symbolized in mint green, does not cover a large portion of the map, and is scattered across the more mountainous regions of Northern California. GAP Status 3, symbolized in periwinkle, covers a large portion of the upper region of the map, especially in the mountainous areas. There are generally fewer land use restrictions (no GAP Status or GAP Status 4 classification) in the central valley portion of Northern California.

In Figure 14, labeled as Map 3, the energy demand for both residential and non-residential in 2022 for counties in Northern California measured in GWh. This data came from the California Energy Commission. High amounts of energy demand, symbolized in yellow, are found in Alameda, Contra Costa, Fresno, Sacramento, and Santa Clara County. Low amounts of energy demand, symbolized in dark blue, are found along the eastern border and upper region of Northern California.
In Figure 14, labeled as Map 4, the transmission lines are symbolized as a line feature class in a bright red color. This data comes from the CEC. Most of the lines are concentrated in the central and lower middle portions of the map. There is a lack of transmission lines in the lower right-hand corner of the map.

In Figure 14, labeled as Map 5, the roads are symbolized as a line feature class in brown color. This data comes from the United States Census Bureau in the Department of Commerce. Most of the lines, as expected, are concentrated in more densely populated areas and less concentrated in more rural areas.

In Figure 14, labeled as Map 6, a high amount of slope is symbolized in a dark purple color, and a small slope degree is symbolized in yellow. This data comes from the USGS from 2008. The elevation data was transformed into slope data using the ArcGIS Pro tool “Slope (Spatial Analyst)” measured in degrees from 0 to 90. The Central Valley portion of Northern California is flat, while the mountainous areas of the map have a large slope degree, the steepest being approximately 78 degrees.

Overall, the central valley portion of the maps has a high concentration of transmission lines, a high concentration of major roads, little to no slope, high energy demand, a GAP Status of 4 or no designation (not a wildlife conservation area), and a moderate amount of solar radiation. Table 4 summarizes the source, rationale, and ranking for each of the six data layers.
Table 5: Summary of GIS initial data layers, the source of the data, and the rationale behind choosing and ranking the data for the solar-powered microgrid suitability analysis.

<table>
<thead>
<tr>
<th>Data Layer</th>
<th>Data Source</th>
<th>Rationale</th>
<th>Ranking for Weighted Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Radiation</td>
<td>National Renewable Energy Laboratory (NREL), 2018.</td>
<td>Increased radiation → increased output for photovoltaic (PV) panels</td>
<td>20%</td>
</tr>
<tr>
<td>GAP Status</td>
<td>United States Geologic Survey (USGS), 2018.</td>
<td>The microgrid cannot be built in a wildlife-protected area.</td>
<td>40%</td>
</tr>
<tr>
<td>Energy Demand</td>
<td>CEC, 2022.</td>
<td>High local energy demand → increased need for microgrids</td>
<td>10%</td>
</tr>
<tr>
<td>Transmission Lines</td>
<td>CEC, 2023.</td>
<td>Connection to the main energy grid.</td>
<td>10%</td>
</tr>
<tr>
<td>Roads</td>
<td>United States Census Bureau, Department of Commerce, 2019.</td>
<td>Operation and maintenance.</td>
<td>10%</td>
</tr>
<tr>
<td>Slope</td>
<td>Elevation data from USGS, 2008.</td>
<td>Easier to build on flat land.</td>
<td>10%</td>
</tr>
</tbody>
</table>
7.3 Reclassification of Initial Data Layers

Figure 15: This figure shows six maps of raster data that have been reclassified, ranking 1 through 5. For each of the six maps, 1 is symbolized as a dark green color and represents the most optimal location for solar-powered microgrids. 5 is symbolized as a red color and represents the least optimal location for solar-powered microgrids. The figure was last updated on October 22nd, 2023 by Marina Riddle.
7.4 Analysis for Reclassification of Initial Data Layers

In Figure 15, labeled as Map 1, the solar radiation reclassification is shown. The dark green color symbolizes the most optimal locations for solar-powered microgrids based on solar radiation in Northern California, the light green color symbolizes the optimal locations, the yellow color symbolizes the moderately optimal locations, the orange color symbolizes the less optimal locations, and the red color symbolizes the least optimal locations. The general trend for solar radiation is an optimally ranked classification in the lower right portion of the map and a non-optimally ranked classification in the northern left portion of the map.

In Figure 15, labeled as Map 2, the GAP status reclassification is shown. The dark green color symbolizes the optimal locations for solar-powered microgrids based on wildlife-protected land classification in Northern California and the red color symbolizes the not optimal locations. Light green, yellow, and orange symbology was not used in this map since the GAP Status reclass is binary, either the land is protected for conservation, or it is not. Either an IPP can build a microgrid based on land use or they cannot. The general trend is the Central Valley and the western coastal portions of the map have a GAP status that would make it legally permissible to build a solar-powered microgrid.

In Figure 15, labeled as Map 3, the energy demand reclassification is shown. The symbology is the same as in Map 1. The general trend is optimally ranked classification was found in Alameda, Contra Costa, Fresno, Sacramento, and Santa Clara County with
surrounding rural areas having lower energy demand and, therefore, a non-optimal ranking symbolized in red.

In Figure 15, labeled as Map 4, the transmission reclassification is shown. The symbology is the same as in Map 1. The general trend is that an optimally ranked classification was found in most of the map, only in the bottom right-hand corner is there a lack of transmission lines, symbolized in red.

In Figure 15, labeled as Map 5, the road reclassification is shown. The symbology is the same as in Map 1. Like the transmission reclassification map, the general trend is that an optimally ranked classification was found in most of the map, symbolized in dark green.

Finally, in Figure 15, labeled as Map 6, the slope reclassification is shown. The symbology is the same as in Map 1. The general trend is optimally ranked classification was found in the Central Valley and the upper right-hand portion of the map, symbolized in dark green.

Overall, the most optimal location for a solar-powered microgrid project is in the Central Valley of Northern California. To determine the exact counties that are the most optimal, a weighted overlay was performed, and the final output is shown in Figures 16 and 17.

### 7.5 Final Output

Once the reclassification of all six data layers was completed, a weighted overlay was performed, detailed in section 6.4. The final output was generated in the map below in Figure 16.
Figure 16: This map shows the final suitability output. The most optimal locations for solar-powered microgrids are symbolized as a bright yellow color, more optimal locations are symbolized in orange, moderately optimal locations are symbolized in magenta, less optimal locations are symbolized in dark purple, and least optimal locations are symbolized in dark blue. The map was last updated on October 22nd, 2023 by Marina Riddle.

The yellow pixels indicate that a particular location is the most optimal for a solar-powered microgrid in Northern California, the orange pixels indicate that a particular location is more optimal, the magenta pixels indicate that a particular location is moderately
optimal, the purple pixels indicate that a particular location is less optimal, the dark blue pixels indicate that a particular location is the least optimal for solar-powered microgrids. The blue stars symbolize the case study microgrids that were discussed in Sections 3 and 4.

Along the mountainous areas of Northern California, most of the pixels in the map are less optimal. Most of the map is orange and very little of it is dark blue, indicating that, in general, Northern California is an advantageous state for solar-powered microgrids having lots of “more optimal” locations and few “least optimal” locations. Specific counties stand out for having nearly all yellow pixels or having many yellow pixels. Those counties, Fresno County, Sacramento County, and Santa Clara County are shown in Figure 17.

The BLR microgrid and KP microgrid were added to the map to validate the suitability analysis. The BLR microgrid is shown in the northern portion of the map and is located on an orange pixel, meaning it has a value of 2 which is considered a “more optimal” location for a solar-powered microgrid. The county of Humboldt does not have a very high local energy demand, symbolized in orange in Figure 15 Map 3, and does not have as much relative solar radiation, symbolized in red in Figure 15 Map 1, which also could have decreased the ranking from 1 to 2 for the BLR microgrid. Although a ranking of 1 is the most optimal for a solar-powered microgrid, 2 is still considered optimal, therefore this case study supports the validity of the suitability analysis performed. The KP microgrid is shown in the central portion of the map and is also located on an orange pixel of the raster dataset, meaning it has a value of 2 which is considered a “more optimal” location for a solar-powered microgrid. Like the BLR microgrid, the area where the KP microgrid is located does not have as much relative solar radiation, symbolized in orange in Figure 15 Map 1, which also could have
decreased the ranking from 1 to 2. Again, 2 is still considered optimal, so the KP microgrid case study also supports the validity of the suitability analysis performed.

Figure 17: Final suitability output with the three top counties: Fresno County, Sacramento County, and Santa Clara County. The map was last updated on October 22nd, 2023 by Marina Riddle.
To verify the validity of the suitability analysis further, another map, Figure 18, shows the completed solar projects in Fresno County. The solar projects that have been completed, symbolized as a green check icon, are all located on the southwestern side of Fresno County. There are no solar projects located on the northeastern portion of the map. Like Figure 18, the southwestern side of the county in Figure 17 has most of its pixels symbolized in a yellow color, meaning that those areas are optimal for solar-powered microgrids. Additionally, like Figure 18, the northeastern side of the county in Figure 17 has most of its pixels symbolized in either a magenta or purple color, meaning that those areas are either moderately optimal or less optimal for solar-powered microgrids.

Figure 18: This map shows completed, withdrawn, under review, denied, under construction, and approved solar projects in the County of Fresno. The green check mark icons indicate that a solar project has been completed. The yellow dots indicate that the solar project has been withdrawn. The light blue information icons indicate that the solar project is under review. The red x icons indicate that the solar project was denied. The purple digging icons indicate the solar project is under construction and the green digging icons indicate that the solar project is approved. Adapted from the County of Fresno created with Google My Maps.
Cross-referencing and comparing the two maps, Figures 17 and 18, in addition to locating the two case study microgrids, KP and BLR shown in Figure 16, provides evidentiary support for the accuracy of the GIS suitability analysis that was conducted.

### 8. Conclusions

Climate change fuels increased extreme weather events severity and frequency, specifically earthquakes and wildfires in Northern California. These events create power outages, which are dangerous to local communities. Residents require a more resilient power supply, which can be accomplished with solar-powered microgrids. Solar was chosen due to the affordable and abundant nature of the natural resource. Renewable microgrids provide energy justice, modernization to an aging energy grid, resilience, and sustainability through emission-free power generation.

There is demonstrated success against extreme weather events and PSPS events at the BLR microgrid. The main technical obstacles to microgrid implementation are communication and coordination (with IT and other sectors) as well as integration, whether that is with legacy systems or the main grid. These technical obstacles can be mitigated with licensed and experienced key personnel. The main funding opportunities for microgrids are MIP, IRA, and EPIC. These programs all provide significant funding and tax benefits for solar-powered microgrids. The most optimal counties for solar-powered microgrids in Northern California are Fresno, Sacramento, and Santa Clara.
Microgrids can increase the resiliency of the energy grid in Northern California because of the environmental benefits of reduced CO2e, economic benefits of reduced energy costs and local job creation, and public health and safety benefits of reduced power outages.

9. Recommendations

As previously mentioned, based on the GIS analysis, solar-powered microgrids are most fit for the central valley portion of Northern California, specifically Santa Clara County, Sacramento County, and the southwestern portion of Fresno County. This suitability analysis can be taken a step further by considering cost. For example, building a ground-mounted 1 MW system in Sacramento County would cost 12,296 dollars for the proper permitting, see Appendix 11.1 for the details. In Santa Clara County, the building permit with the county would cost 13,346 dollars, see Appendix 11.2 for the details. For the breakdown of this calculation, see Appendix 11.3. In Fresno County, the permit would cost 15,112 dollars, see Appendix 11.4 for the details. Therefore, it is recommended to build a solar-powered microgrid in Sacramento County for the economical building permit costs. It’s important to note that this cost only covers the permitting, not the building, operation, or maintenance of the microgrid.

It is recommended that CEC funds solar-powered microgrids in Fresno, Sacramento, and Santa Clara utilizing EPIC funding. Projects should be under 1MW and AC to qualify for ITC and PTC from IRA. Overcoming the technical obstacles that may arise during a microgrid project requires experienced and licensed key personnel. It is recommended that disadvantaged communities (energy communities, low-income communities, and Native American communities) vulnerable to PSPS events leverage MIP funding and bonus ITC/PTC. Lastly and
most importantly, it is recommended that IPPs get buy-in from PG&E and maintain a cooperative relationship with the utility company. When a microgrid project is proposed, the utility has the ultimate authority to either approve or deny the project (Carter et al., 2019). Due to the complexity of microgrid integration with the main energy grid and the utility being the expert in implementation, a partnership must be made to ensure the success of the microgrid.
10. References


COEHHA. 2021, October. CalEnviroScreen 4.0. https://experience.arcgis.com/experience/11d2f52282a54ceebcac7428e6184203/page/CalEnviroScreen-4_0/.


The Associated Press. 2022, January 24. California’s embattled utility leaves criminal probation, but more charges loom. NPR.


11. Appendix

11.1 Fee Schedule for Sacramento County

**Table 6**: Solar permit fees for ground mount panels for commercial or residential projects in Sacramento County.

<table>
<thead>
<tr>
<th>System Size – Kilowatts</th>
<th>Fee (minimum fee based on current hourly BI-II rate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 10 kW</td>
<td>$812.00 (7 hourly units)</td>
</tr>
<tr>
<td>11 kW to 1.0 MW</td>
<td>$812.00 + 1 hourly unit for each additional 10 kW or portion thereof</td>
</tr>
<tr>
<td>1MW and greater</td>
<td>$12,296.00 + 25 hourly units for each additional MW or portion thereof</td>
</tr>
</tbody>
</table>

11.2 Fee Schedule for Santa Clara County

**Table 7**: Electrical System Only Permits (ESOP) for a solar project in Santa Clara County.

<table>
<thead>
<tr>
<th>Electrical System Type</th>
<th>Additional Information</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixtures, appliances; transformers; motors; panel</td>
<td>1 – 15 units</td>
<td>$163.00</td>
</tr>
<tr>
<td></td>
<td>Each additional</td>
<td>$9.65</td>
</tr>
<tr>
<td>Electrical Service / Transfer Switch</td>
<td>Up to 400 amps</td>
<td>$163.00</td>
</tr>
<tr>
<td></td>
<td>Over 400 amps</td>
<td>$200.55</td>
</tr>
<tr>
<td>Heather; electric welder (per kVA)</td>
<td>Up to 50 kVA</td>
<td>$163.00</td>
</tr>
<tr>
<td></td>
<td>Each additional kVA</td>
<td>$3.22</td>
</tr>
<tr>
<td><strong>Renewable Energy Systems (solar, wind, fuel cell)</strong></td>
<td>Up to 15 kV</td>
<td>$375.35</td>
</tr>
<tr>
<td></td>
<td>15 kV</td>
<td>$541.46</td>
</tr>
<tr>
<td></td>
<td>Each kV over 15</td>
<td>$13.00</td>
</tr>
<tr>
<td>UPS and Battery Banks</td>
<td>Under 400 pounds</td>
<td>$163.00</td>
</tr>
<tr>
<td></td>
<td>Over 400 pounds</td>
<td>$317.44</td>
</tr>
</tbody>
</table>
11.3 Calculation for 1 Megawatt Solar System Permit in Santa Clara County

\[
1 \text{ mW} = 1,000 \text{ kW} \\
15 \text{ kV} = $541.46 \\
1,000 \text{ kV} - 15 \text{ kV} = 985 \text{ kV} \\
\text{Total Cost} = $541.46 + (985 \text{ kV} \times $13.00) = $13,346.46
\]

11.4 Fee Schedule for Fresno County

Table 8: The specific breakdown of fees for an Unclassified Conditional Use Permit (UCUP) for a solar project in Fresno County.

<table>
<thead>
<tr>
<th>Filing Fees</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditional Use Permit Application (CUP)</td>
<td>$ 9,123.00</td>
</tr>
<tr>
<td>Initial Study Application (IS)</td>
<td>$ 5,151.00</td>
</tr>
<tr>
<td>Public Health Environmental Review</td>
<td>$ 992.00</td>
</tr>
<tr>
<td>Ag Department Review</td>
<td>$93.00</td>
</tr>
<tr>
<td>Minus the $247.00 Pre-Application Credit</td>
<td>- 247.00</td>
</tr>
<tr>
<td>Check payable to &quot;Fresno County&quot; for:</td>
<td>$ 15,112.00</td>
</tr>
</tbody>
</table>
## 11.5 Raw Data for Planned and Unplanned Outages from 11/17/23 to 11/18/23

<table>
<thead>
<tr>
<th>Utility Company</th>
<th>Start Date</th>
<th>Estimated Restore Date</th>
<th>Cause</th>
<th>Impacted Customers</th>
<th>County</th>
<th>Outage Status</th>
<th>Outage Type</th>
<th>Incident Id</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDGE</td>
<td>2023/11/18 16:20:00+00</td>
<td>2023/11/18 19:30:00+00</td>
<td>SDG&amp;E is assessing the outage to determine the cause.</td>
<td>95</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Not Planned</td>
<td>1054725</td>
</tr>
<tr>
<td>SDGE</td>
<td>2023/11/18 16:26:00+00</td>
<td>2023/11/19 00:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>1</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054726</td>
</tr>
<tr>
<td>SDGE</td>
<td>2023/11/18 16:26:00+00</td>
<td>2023/11/19 00:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>6</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054727</td>
</tr>
<tr>
<td>SDGE</td>
<td>2023/11/18 17:15:00+00</td>
<td>2023/11/18 22:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>33</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054728</td>
</tr>
<tr>
<td>SDGE</td>
<td>2023/11/18 14:56:00+00</td>
<td>2023/11/19 02:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>1</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054702</td>
</tr>
<tr>
<td>SDGE</td>
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<td>2023/11/19 02:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>2</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054703</td>
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<tr>
<td>SDGE</td>
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<td>2023/11/19 02:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>1</td>
<td>SAN DIEGO</td>
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<td>1054704</td>
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<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore</td>
<td>1</td>
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<td>Planned</td>
<td>1054711</td>
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<tr>
<td></td>
<td>Event Date</td>
<td>Event Time</td>
<td>Restoration Date</td>
<td>Restoration Time</td>
<td>Service Area</td>
<td>Status</td>
<td>Type</td>
<td>ID</td>
</tr>
<tr>
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<tr>
<td>SDGE</td>
<td>2023/11/18 15:56:00+00</td>
<td>2023/11/19 02:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>2</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054712</td>
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<td>SDGE</td>
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<td>2023/11/18 21:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>5</td>
<td>SAN DIEGO</td>
<td>Active</td>
<td>Planned</td>
<td>1054699</td>
</tr>
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<td>SDGE</td>
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<td>2023/11/19 01:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>12</td>
<td>SAN DIEGO</td>
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<tr>
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<td>2023/11/18 20:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>23</td>
<td>SAN DIEGO</td>
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<tr>
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<td>2023/11/18 23:00:00+00</td>
<td>Upgrading the electric system in your area requires us to turn off the power. Our crews are working to safely restore your electric service by the estimated restoration time.</td>
<td>1</td>
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<td>Active</td>
<td>Planned</td>
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<td>2023/11/18 20:00:00+00</td>
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<td>Active</td>
<td>Planned</td>
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<tr>
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<td>2023/11/18 02:00:00+00</td>
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<td>BUTTE</td>
<td>Active</td>
<td>Planned</td>
<td>2271460</td>
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<td>2023/11/20 18:00:00+00</td>
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<td>PLACER</td>
<td>Active</td>
<td>Planned</td>
<td>2271882</td>
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<tr>
<td>PGE</td>
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<td>2023/11/18 19:00:00+00</td>
<td>REPLACE TXFMR</td>
<td>1</td>
<td>SAN LUIS OBISPO</td>
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<td>PGE</td>
<td>2023/11/18 04:50:34+00</td>
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<td>EMERG REPAIRS</td>
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<td>2023/11/18 22:00:00+00</td>
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<td>97</td>
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<td>EMERG REPAIRS</td>
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<td>Not Planned</td>
<td>2271994</td>
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<td>BRKN POLE EQUIPMNT</td>
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<td>SANTA CLARA</td>
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<td>Not Planned</td>
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</tr>
<tr>
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<td>21</td>
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<td>2023/11/18 13:11:00+00</td>
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<td>2272033</td>
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<td>2023/11/18 13:11:00+00</td>
<td>STORM</td>
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<td>SAN LUIS OBISPO</td>
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</tr>
<tr>
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<td>2023/11/18 13:20:55+00</td>
<td>2023/11/18 04:00:00+00</td>
<td>PLNND SHUTDOWN</td>
<td>2</td>
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<td>Active</td>
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