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Decentralizing the Electric Grid: Giving Power Back to the People

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DECENTRALIZING THE ELECTRIC GRID:
GIVING POWER BACK TO THE PEOPLE

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ABSTRACT

DECENTRALIZING THE ELECTRIC GRID: GIVING POWER BACK TO THE PEOPLE

by Nicole Chen

Societies across the globe are shifting away from fossil fuels and towards clean energy, resulting in significant changes to the electric grid. This clean energy transition is accompanied by transformative opportunities. However, the benefits of clean, reliable energy do not equitably accrue to all communities. In order to challenge and overcome the persistent social disparities that exist in the energy transition, energy justice must be a driving factor in energy planning and decision making. This research highlights metrics and parameters that should be included when considering deployment of community solar microgrids to advance a just energy transition. The results of this study provide insight for understanding the potential for deployment of community solar microgrids in Santa Clara County, particularly for underserved communities who could benefit the most from increased reliability and resilience in their electric grid.

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LIST OF ABBREVIATIONS

ACS - American Community Survey
CalEPA - California Environmental Protection Agency
CIF/CIFs - Critical Infrastructure Facilities
CSI - California Solar Initiative
DAC - Disadvantaged community (defined by the Environmental Protection Agency)
DER - Distributed Energy Resource
DER-CAM - Distributed Energy Resources Customer Adoption Model
DIT - Diffusion of Innovations Theory
EV - Electric Vehicle
GIS - Geographic Information Systems
HIFLD - Homeland Infrastructure Foundation - Level Data
HOMER - Hybrid Optimization of Multiple Energy Resources
ICA - Integration Capacity Analysis
kWh - Kilowatt-hour
kWp - Kilowatt peak
MW - Megawatt
MWh - Megawatt hour
OEHHA - Office of Environmental Health Hazard Assessment
PG&E - Pacific Gas and Electric
PRQ - Preliminary Research Question
PV - Photovoltaic
ReOPT - Renewable Energy Optimization
SEIA - Solar Energy Industries Association
SOC - State of Charge
SVPI - Silicon Valley Pain Index
TAM - Technology Acceptance Model

Introduction

Motivation and Scope

Traditionally, the electrical system is based around centralized transmission and large-scale generation facilities that are largely monopolized, owned and operated by large state- or investor-owned entities. This has long led to a power system structure that is supply-oriented, with major players and decision-making power being dominated by utilities. However, in recent decades, growing efforts with climate change initiatives and policies to promote clean energy have led to the rapid development and uptake of clean energy technologies and distributed energy resources (DERs), facilitated by supportive technological and social innovations, leading to rapid changes in the global electricity industry landscape. The National Renewable Energy Lab defines DERs as "small, modular, energy generation and storage technologies that provide electric capacity or energy where you need it" (Bonneville Power Association, n.d.). DERs decentralize the energy system and allow power to be locally generated, consumed, and stored, as opposed to being generated at a power plant and distributed over long-distance transmission lines to where it is needed.

The modernization of the electrical grid and evolution of the power systems away from fossil fuels and centralized sources and shift towards DERs - a pathway widely referred to as the "energy transition" - has created large-scale, complex waves in technological, social, and economic infrastructures (Perez-DeLaMora et al., 2021; Romero-Agüero et al., 2017); this shift has caused the verticality of the electricity industry to be disrupted, and calls for collaborative, cohesive, and comprehensive efforts by all stakeholders including utilities, legislators, as well as consumers and communities (Droubi et al., 2022; Roege et al., 2014;

Szulecki, 2018). Users, such as households and communities, who were previously seen as passive consumers in the energy market are becoming more actively engaged and involved in electricity consumption, distribution, and management, with involvement at many levels from generating their own energy (such as rooftop solar), investing in carbon markets (such as peer-to-peer [P2P] trading), asset-owning (such as owning or leasing solar systems), and involvement in decision-making (such as influencing policy through political backing).

The energy transition is largely motivated by greenhouse gas emissions mitigation and the need to shift towards a decarbonized society is to adapt to anthropogenic impacts on the planet. Equal importance should also be placed upon examining the equity dimension of the energy transition, which is where the concept, framework, and tool of "energy justice" comes into play. Energy justice examines energy systems through the lens of social and economic equity. In the context of the energy transition, energy justice refers to socioeconomic and/or sociotechnical disparities that exist or are caused by the energy transition; these result in disproportionate benefits and costs in affordability and accessibility to sustainable energy (Hazrati & Heffron, 2021; Jenkins et al., 2016; Knox et al., 2022; Sovacool et al., 2017). The term "just energy transition" is widely used to research the specific overlap of equity and justice issues arising from the rapidly evolving energy transition. Energy justice is also being integrated into policy and decision-making processes, such as the United States Department of Energy's Justice40 Initiative.

Literature Review

A Just Energy Transition

The rise of energy costs and fall of energy reliability most heavily impacts vulnerable communities. On average, low-income households spend a higher proportion of their income on energy bills than other income groups (Berry et al., 2018; Drehobl et al., 2018) even though they consume less per capita and spend less on energy per square foot of living space (Drehobl et al., 2018). The transition towards clean energy reveals adamant wealth and racial disparities in the United States (Reames, 2016; Sunter et al., 2019), and thus necessitates focus on a just energy transition, where society moves towards a post-carbon society guided by equity and fairness regardless of racial, ethnographic, geographic, economic, and social positions.

Social Disparities in Clean Energy Access

The accelerating uptake of clean energy technology paired with increasingly frequent natural disasters such as wildfires and hurricanes reveal society's dependence on the electrical grid (Roege et al., 2014; Wu et al., 2016). Energy is the backbone of daily life, and access to reliable energy and emerging clean energy technologies is often a key differentiator between an advanced and a developing society (Williams et al., 2015). This directly ties into energy autonomy, which can be summarized as the ability to have control over energy decision making, which often leads to cost benefits such as short term and long-term bill savings (Kühnbach et al., 2020; Weinand et al., 2020). Energy autonomy is a privilege afforded to wealthier households and often majority white communities (Wang et al., 2021), as these groups tend to have more exposure to clean energy technologies and have more available and disposable resources to put towards energy-related efforts such as installing solar and battery systems for their homes, buying smart appliances, investing in the carbon market, or participating in local energy projects, as opposed to lower income and minority groups that tend to be more focused on financial savings (Knox et al., 2022; Lukanov & Krieger, 2019). As these higher income groups have more access and exposure to technology and policy, they are also the ones that are able to be more active participants in the decision-making process and the ones who reap the benefits that accompany this transition. Conversely, lower income groups face major barriers in accessibility and affordability of clean energy, leading to less exposure and slow adoption rates (Lukanov & Krieger, 2019; Sunter et al., 2019), creating the basis for injustice in the energy transition.

In addition to facing persistent social disparities in the energy transition due to upfront capital costs (McNamara et al., 2022), disadvantaged communities (DACs) such as low-income communities and communities of color also face inequitable barriers to adoption of DERs due to limitations in grid infrastructure in California (Brockway et al., 2021). Common examples of DERs include rooftop solar photovoltaic (PV) units, fuel cells, natural gas turbines, wind turbines, battery storage, and electric vehicles (EV) and EV chargers. Deployment of DER projects are driven by many factors such as demand response, cost optimization, or technology architecture (Gilani et al., 2020; Panwar et al., 2012; Perez-DeLaMora et al., 2021; Wu et al., 2016), but another important consideration is local hosting capacity; hosting capacity can be defined as the ability of existing electrical infrastructure to support DERs without upgrades. Brockway et al. (2021) find that Black-identifying and DACs have increasingly low hosting capacities for DERs, meaning that DER projects such as microgrids or even rooftop solar PV panels would be more resource intensive and complex projects in these communities, necessitating more electrical infrastructure upgrades and increasing construction time and costs. If left unaddressed, this poses to be another major inequity in the energy transition, precluding these communities more often than other groups as targets for clean energy projects in order for project decision makers to minimize project costs and prevent project delays.

Theories Explaining the Energy Transition

As society shifts away from fossil fuels and towards clean and decentralized energy resources like microgrids, there are several theories that explain this transition and why microgrids and other DERs have become increasingly popularized. The Technology Acceptance Model (TAM) (Davis, 1989) and Rogers' (2003) Diffusion of Innovations Theory (DIT) have both been extensively used to explain sustainable energy adoption (B. Chen & Sintov, 2016; Korjonen-Kuusipuro et al., 2017; Silk et al., 2014). The TAM theory helps explain society's shift towards DERs and the rapid growth of clean energy technology, as perceived usefulness and perceived ease-of-use for these technologies increase (Billanes & Enevoldsen, 2021; B. Chen & Sintov, 2016). Similarly, another theoretical underpinning of the energy transition is the DIT, as the adoption of residential and commercial solar PV, microgrids, and other clean energy technology happens in waves, starting with innovators (the first 2.5% of a given population to adopt the technology), then early adopters (the next 13.5%), early majority (the subsequent 34%), late majority (the subsequent 34%), and laggards (the final 16%), with each wave having a different perceptions of the new technology, in hand with increased penetration levels of the technology as later waves of adopters emerge (Billanes & Enevoldsen, 2021; B. Chen & Sintov, 2016; Rogers, 2003). Another approach to analyzing the energy transition is examining the movement as a sociotechnical transition of the energy system. A widely used theoretical framework in this context is the Multi-Level Perspective (Cherp et al., 2018; Geels, 2011; Hess, 2014), which examines how different factors affect microgrid adoption and how niche-technologies like microgrids uproot the current sociotechnical landscape.

Microgrids Can Drive a Just Energy Transition

A microgrid is a DER that localizes energy generation and consumption. The United States Department of Energy defines a microgrid as

> a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or islandmode. (Ton & Smith, 2012)

Microgrids present the opportunity to challenge social barriers that befall the traditional centralized electrical grid (Ajaz & Bernell, 2021; Hussain et al., 2019; Parag & Ainspan, 2019) and shift towards community-based, demand-side energy management (Brown et al., 2020). A microgrid consists of an energy generation source, a storage system, and an intelligent software-based control system. Microgrids can be a purely renewable energy and storage system (such as solar plus battery) or hybrid storage system (such as diesel generator and solar plus battery) that provides backup power during grid outages. These systems can provide both short-term reliability, long-term reliability (by avoiding a blackout and avoiding resilience-need), long-term resilience, reduce electricity costs, boost energy autonomy, and increase penetration rates of DERs, amongst numerous other quantifiable social and economic benefits (Galvan et al., 2020; Soshinskaya et al., 2014; Stadler et al., 2016; Zhou et al., 2018). If designed, deployed, and managed with continuous, community-centric focus on improving reliability, resilience, safety, cost-efficiency, and customer flexibility (Romero-Agüero et al., 2017), microgrids can play a strategic role in the socio-economic-technical transition of the energy system (Ajaz & Bernell, 2021).

Because harms of climate change fall disproportionately upon DACs such as lower income communities and communities of color (Banzhaf et al., 2019; McCauley & Heffron, 2018; McNamara et al., 2022) who are least able to prepare for and recover from impacts such as power outages, pollution, flooding, and heatwaves, these communities should be prioritized in the planning and decision-making process. Furthermore, with climate-enhanced extreme weather and natural disasters becoming increasingly disruptive, grid reliability and a community's energy resilience should be at the forefront of strategies for microgrid and other clean energy deployments (Galvan et al., 2020). Current business cases for microgrids are largely related to military and research related applications, and microgrid projects in the United States are not deployed strategically with social justice and community needs in mind (Kelly-Pitou et al., 2017; Perez-DeLaMora et al., 2021). Microgrids can play an important role in advancing energy justice in the energy transition by providing economic, resilience, health, and environmental benefits for underserved communities (Anderson et al., 2022; Benander et al., 2017; Szulecki, 2018; Weinrub & Fairchild, 2017). This is where the concept of a community solar microgrid shines.

Community Solar Microgrids

The United States Department of Energy defines community solar "as any solar project or purchasing program, within a geographic area, in which the benefits of a solar project flow to multiple customers such as individuals, businesses, nonprofits, and other groups. In most cases, customers are benefitting from energy generated by solar panels at an off-site array." The shift from the concept of "community solar" to a "community solar microgrid" is the addition of an energy storage system such that the system can operate independently in addition to being connected to the grid during power outages (it provides backup power even if the grid is not restored).

The critical role community solar microgrids play in building social capacity is two-fold. First, on average, underserved communities, including low-income, Black, Hispanic/Latino, multifamily households, and women in the United States consume less energy but have higher energy burden compared to other groups (C. Chen et al., 2022; Drehobl et al., 2018), meaning energy costs (such as cost of energy delivery) put more strain on their income and energy options (such as an additional budget to invest in energy technology such as solar) are significantly limited. Historically, adoption of traditional residential rooftop solar skews towards higher income, home-owning, majority-white communities, which also means these communities reap and retain associated benefits of solar, such as reduced electric bills (Horne et al., 2021; Lukanov & Krieger, 2019). Community solar microgrids allow people to "own" a portion of the generated solar energy and the electricity is credited towards their electricity bill, similar to if they had the traditionally installed rooftop solar panels. Community solar microgrids provide economic and environmental benefits to a diverse range of customers, making solar more affordable so more people can participate; this is an alternative solution that also makes the electric grid more reliable by providing backup power when there are grid intermittencies.

Second, the electric grid is becoming increasingly vulnerable and unreliable due to the combination of weather-related events and disasters and aging electrical infrastructure, with increased frequency of short term and long-term power outages are on the rise (Ciscar & Dowling, 2014; Dugan et al., 2022). Utility companies often prioritize power restoration based on the number of outages and the size of affected populations, an approach that overlooks how impacted populations are differentially experiencing these power losses (Pacific Gas and Electric [PG&E], n.d.; Southern California Edison, n.d.). It is clear that lower income and racial-ethnic minority households communities suffer disproportionately from direct impacts and long-term consequences compared to other groups (C. Chen et al., 2022; Dugan et al., 2022; Lin et al., 2021). Community solar microgrids provide these vulnerable communities with critical backup power so they can respond properly and recover effectively, strengthening their resilience.

Barriers to Adoption for Microgrids

One major theme in current research on microgrids focuses on electrification applications in rural areas, or areas with no centralized grid at all (Kirubi et al., 2009; Marqusee et al., 2021). Further research is needed that explores urban applications of microgrids (Hussain et al., 2019; Pullins, 2019). Additionally, barriers in universal deployment and adoption of microgrids exist and can be categorized into four categories: technological, financial, regulatory, and stakeholder (Galvan et al., 2020; Soshinskaya et al., 2014). No singular, standardized solution can be applied across varying microgrid projects, as local factors such as resources and weather patterns create limitations (Galvan et al., 2020). Divergent needs and unique applications of microgrids lead to highly specified system designs, operational scopes, and business models that create hesitation in widespread adoption of microgrids, as it is difficult to correlate results across multiple projects (Panwar et al., 2012; Stadler & Naslé, 2019; Wu et al., 2016). Nonetheless, it remains clear that microgrids can significantly improve the resilience of power distribution systems, and to a greater extent, their communities (Ajaz & Bernell, 2021; Galvan et al., 2020; Parag & Ainspan, 2019; Syed & Morrison, 2021).

Microgrid Design

Much of the current literature surrounding microgrid research evaluates microgrid design, deployment, and feasibility from a technological and/or economic perspective, as many researchers aim to create microgrid systems that balance optimal technological system architecture with optimal economic value. In order to achieve this balance, many researchers use technoconomic tools such as REopt (Renewable Energy Optimization) (Marqusee et al., 2021), HOMER (Hybrid Optimization of Multiple Energy Resources) (Ribó-Pérez et al., 2021), and DER-CAM (Distributed Energy Resources Customer Adoption Model) (Stadler & Naslé, 2019). While these tools support economic and investment decision making processes, they often leave out energy justice components. A relatively new subfield that has become popularized in the last decade studies equity dimensions of microgrids in the context of a just energy transition (McCauley & Heffron, 2018; Sovacool & Dworkin, 2015). There is ongoing research in quantifying social benefits associated with microgrids, including calculating and quantifying the social cost of carbon, the value of job creation, the value of avoided outage costs, public health costs (Anderson et al., 2022; Farthing et al., 2021; Laws et al., 2018; Nock et al., 2020), as well as the value of increased quality and reliability of energy supply and the social value of viewing and utilizing the electrical system as a common-pool resource controlled by the demand-side, rather than relinquishing power to a centralized entity (Brown et al., 2020; Milis et al., 2018; Parag & Ainspan, 2019). Rather than evaluating microgrids solely on technological and economic cost/benefits, these researchers adapt technoeconomic models or create their own models, matrices, or methodologies to identify, quantify, and incorporate social justice values into microgrid planning and decision making. These are methods that inform the design portion of microgrids; another equally important step is deployment of these projects.

Microgrid Deployment

There are tools for identifying higher risk and higher vulnerability communities, to better inform where to deploy environmental justice projects, such as CalEnviroScreen (Lukanov & Krieger, 2019) and the Environmental Justice Screening and Mapping Tool (Ross et al., 2022). These are spatial tools that help identify DACs suffering from legacy environmental pollution and pinpoint those disproportionately burdened by multiple sources of pollution and are often used in the decision-making process to identify communities to target for environmental justice projects. In order to fully incorporate energy justice into the decision-making process, further research must be conducted in combining tools that evaluate the technoeconomic feasibility of microgrid projects, with tools that identify energy justice communities. Much of the research in this area makes the assumption that if a microgrid is deployed in a community, the benefits of a microgrid will automatically accrue to the disadvantaged residents (Anderson et al., 2022; McNamara et al., 2022; Wallsgrove et al., 2021). However, that may not be the case; thoughtful and purposeful site selection needs to be conducted when deploying a microgrid project.

Justice Frameworks in the Energy Transition

In order to capture the fullest depth of a just energy transition, the energy system must be recast in a way that addresses energy justice via distributive, procedural, recognition, and restorative justice (Anderson et al., 2022; Hricko et al., 2014; McCauley & Heffron, 2018; Sovacool et al., 2017; Wallsgrove et al., 2021). Distributive justice considers the accrual of the benefits and burdens of energy systems, and specifically whether impacts from decisions disproportionately affect marginalized communities. Procedural justice calls for equitable and nondiscriminatory processes and procedures during engagement with all stakeholders in the planning, decision making, and management process of energy investments. Recognition justice calls for acknowledging the historic and ongoing marginalization of certain communities in energy-related decisions, and how these communities and their perspectives are often underrepresented, misrepresented, or ignored despite the fact that they may be most heavily impacted in the short and/or long term. Restorative justice serves to not only recognize but to rectify past and ongoing injustices that stem from energy systems, and to proactively be inclusive and prevent these injustices moving forward in the transition towards clean energy (Hazrati & Heffron, 2021). Distributive and procedural justice are often discussed in framing a just energy transition, but both recognition and restorative justice are particularly important dimensions that must be expanded on further in the literature surrounding this topic. Distribution of outcomes (distributive justice) and an unprejudiced decision-making process (procedural justice) are interconnected and vital pieces to empowering marginalized communities in the energy transition, but without also recognizing and rectifying historical and/or systemic injustices (recognition and restorative justice, respectively), such empowerment may be figurative and hinder or cripple society's advancement toward holistic, long term justice.

Problem Statement

The transition towards clean energy reveals entrenched wealth and racial disparities in the United States (Reames, 2016; Sunter et al., 2019), and thus necessitates focus on a just energy transition, where society moves towards a post-carbon society guided by equity and fairness regardless of racial, ethnographic, geographic, economic, and social positions. The harms of climate change fall disproportionately on DACs, such as low-income communities and communities of color (Banzhaf et al., 2019; McCauley & Heffron, 2018; McNamara et al., 2022), who are least able to prepare for and recover from impacts such as power outages, pollution, flooding, and heatwaves. Unfortunately, these are the communities that also face persistent barriers in accessibility and affordability in clean energy technologies such as microgrids and other DERs.

Although it is widely acknowledged across the literature that DERs can build capacity and upward mobility in communities, providing benefits such as energy reliability and resilience, energy security, decreased energy costs for the consumer, increased energy autonomy, increased penetration of clean energy sources, and retention of economic benefits in the community (Gui & MacGill, 2018; Soshinskaya et al., 2014; Szulecki, 2018; Wu et al., 2016), DACs consistently experience low levels of adoption for clean energy and adjacent technologies (Brockway et al., 2021; Keady et al., 2021; Sunter et al., 2019) due to a variety of barriers such as affordability (because integrating these technologies often comes with high upfront capital costs) and accessibility (such as exposure to these technologies, general knowledge and educational resources). These injustices also lead to an inequitable distribution of the benefits that accompany clean energy such as job creation, economic benefits, and decreased levels of pollution, inhibiting society's capacity to achieve an equitable energy transition.

Additionally, in the decision making and investment process for microgrids, there are tools that analyze the technoeconomic feasibility and optimize design of microgrids, and then tools that help identify communities that are disproportionately impacted by impacts of climate change. There remains a gap in combining the two and formulating a decision-making tool that incorporates energy justice values into the planning and deployment of microgrid projects. Much of the current literature comes to the consensus that in order to advance a just energy transition, energy planning and decision making must be guided by distributive, procedural, recognition, and restorative justice. Many studies and reviews have been conducted in order to further stress the importance that each of these forms of justice - whether researched alone or in combination - has in recasting the energy system. However, there has yet to be research that both recognizes communities that face persistent social disparities that arise in the energy transition and utilizes a methodology that specifically targets these vulnerable communities for community solar microgrid projects in an effort to incorporate energy justice into microgrid deployment.

Research Questions

Research Objective

It is critical to recognize and incorporate energy justice into the planning and decision-making processes that surround energy-related issues. Many existing microgrid design methodologies consider energy justice values in their process, but there is yet a methodology that uses energy justice as a main driver to determine optimal areas for microgrid deployment. This research uses GIS (geographic information systems) to identify optimal areas in which to target community solar microgrid deployment to advance a just energy transition in Santa Clara County. The objective of this research is to leverage energy justice as a main driver in the planning process for microgrid deployment.

Research Questions

Preliminary Research Question 1 (PRQ1): What are the geographic patterns of current microgrids deployed in California?

Preliminary Research Question 2 (PRQ2): Are median household income and predominant race associated with deployment of these microgrids?

Research Question 1 (RQ1): Where are the most suitable locations to deploy community solar microgrids in Santa Clara County to advance a just energy transition?

Methodology

Introduction

This research leverages GIS to explore microgrid deployment trends in California and produce a final map of Santa Clara County that identifies optimal locations for community solar microgrid deployment, incorporating energy justice values as a driving factor in scoring these areas. An exploratory analysis is performed to obtain base level understanding of where current microgrid projects exist in California, and to preliminarily observe any overlaps between current microgrid deployment and socioeconomic factors. Then, a suitability analysis is performed to identify the most suitable sites for microgrid deployment in Santa Clara County.

It is important to work with a commonly accepted definition of a DAC and a corresponding dataset. The California Environmental Protection Agency (CalEPA, 2021) has a tool called CalEnviroScreen 4.0, which bases its designations of DACs on “geographic, socioeconomic, public health, and environmental hazard criteria” (p. 1) that are closely aligned with the research objectives of this thesis. This includes but is not limited to, “areas disproportionately affected by environmental pollution and other hazards that can lead to negative public health effects, exposure or environmental degradation,” as well as “areas with concentrations of people that are of low income, high unemployment, low levels of home ownership, high rent burden, or low levels of educational attainment” (CalEPA, 2021, p. 5).

Study Site

The selected study area is Santa Clara County, California. This area was selected because it is widely recognized as the core of the Silicon Valley, and is experiencing stark and growing inequities. According to the five-year estimates from the 2014 to 2018 American Community Survey (ACS) by the United States Census Bureau (2019), Santa Clara County has one of the highest median household incomes in the nation at $124,055, ranking third on a country-wide scale following Loudon County, Virginia and Fairfax County, Virginia. Even more shocking is the five-year change in median household income in Santa Clara County, which is 32.2%; this means that within the last five years, the median household income in Santa Clara County has increased by 32.2%, which is the third highest change value following San Mateo County, California and San Francisco County, California, which are at 34.1% and 43.5% respectively. However, even as median household income skyrockets, income overall is increasingly less evenly distributed. Also commonly called the "Silicon Valley," Santa Clara County is a globally recognized center for high technology and innovation, but the gains driven by high tech industries have created a widening gap between high earners and middle- to low-income workers. According to analyses completed in the 2020 Silicon Valley Index - a comprehensive report of indicators that measure the strength and health of the local economy and community - local trends indicate that income inequality has increased over the past three decades, with surges beginning in 2011 and intensifying since. In 2018, 30% of households had annual incomes over $200,000 and hold an estimated 75% of the region's overall wealth; on the other hand, 70% of non-affluent households have less than $25,000 saved.

Indicators show Santa Clara County is a place with significant inequality. Another illustrator of persistent social disparities in Santa Clara County is the Silicon Valley Pain Index (SVPI). SVPI is a metric that analyzes racial and income/wealth disparities in Santa Clara County and illustrates the persistent racial discrimination and income/wealth inequality that runs rampant in this area. The SVPI is authored by Dr. Scott Myers-Lipton and Dr. William Armaline of San Jose State University's Human Rights Institute. The report is comprised of over 80 statistics generated from 60 of the most recent studies and reports conducted in the area, that showcase persistent inequities that Black, Latinx, and various Asian American communities (Filipino, Vietnamese, Pacific Islanders) face in Santa Clara County.

Santa Clara County is an ideal study area given strong data surrounding social inequities, thus creating more urgency and stronger inclination to create opportunities to build capacity in the most DACs by increasing penetration of clean and resilient energy in the form of microgrids. These persistent inequities are also reflected in the energy transition as well, as low-income communities and predominantly Black and Latinx communities consistently face lower levels of adoption of clean energy due to greater barriers in affordability and accessibility of these technologies.

It is vastly acknowledged across the literature that low-income communities and minority groups experience disproportionately lower solar PV penetration and adoption rates compared to socioeconomic and income level other groups, and minority households are disproportionately vulnerable to energy poverty in the United States (Brockway et al., 2021; Lukanov & Krieger, 2019; Sunter et al., 2019; Wang et al., 2021). While there are federal, state, and local policies, incentives, and programs designed to spur equity in solar PV adoption, such as Single-family Affordable Solar Homes and Solar for Multi-family Affordable Housing, these groups still face consistently low adoption and penetration rates (Barbose et al., 2020; O'Shaughnessy et al., 2021).

California Distributed Generation Statistics is the official public reporting site of the California Solar Initiative (CSI), presented jointly by the CSI Program Administrators, GRID Alternatives, the California Investor-Owned-Utilities, and the California Public Utilities Commission. Using their Statistics and Charts feature, an analysis of solar PV adoption in Santa Clara County in 2021 is performed, comparing residential solar PV deployment for DACs to that of the remaining population. In Figure 1, it is determined that the total solar capacity for residential solar PV projects deployed in Santa Clara County is 204 MW. In Figure 2, it is determined that the total solar capacity for residential low-income solar PV projects in Santa Clara County is 964.96 kW, which is 0.96 MW. This means that just 0.005% of residential solar PV deployments in Santa Clara County in 2021 were for low-income customers. With California experiencing rapid growth in DERs, it is critical to address equity dimensions of the energy transition in order to ensure that accessibility, affordability, and distribution of benefits and costs of these technologies are just.

Preliminary Research Questions 1 and 2

Study Design

The PRQ1 and PRQ2 serve as an exploratory analysis to obtain base level understanding of where current microgrid projects exist in California, and to preliminarily observe any overlaps between current microgrid deployments and socioeconomic factors. California is

Figure 1
Total Solar Capacity for Residential Solar PV Projects Deployed in Santa Clara County in 2021

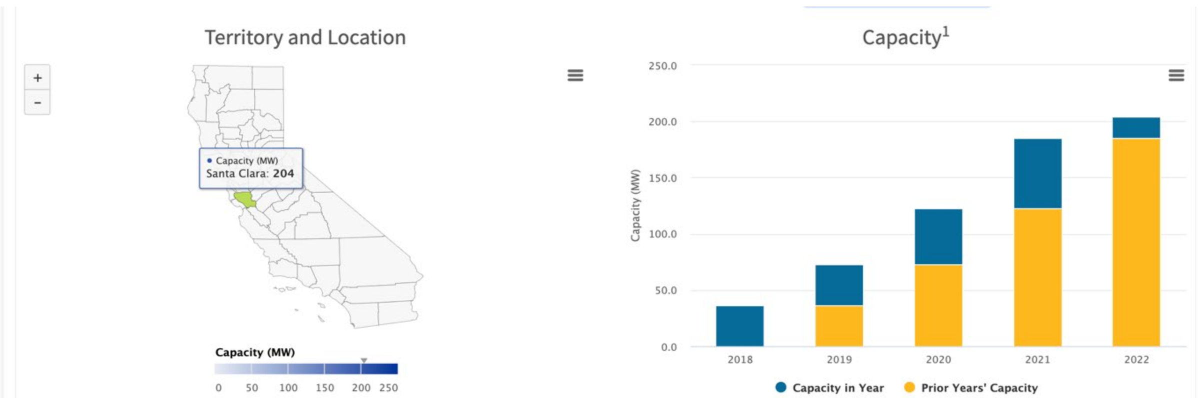
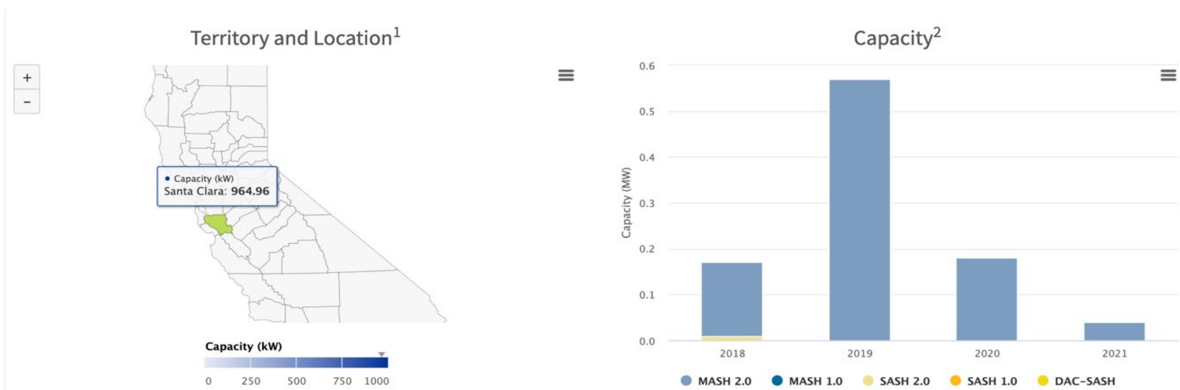


Figure 2
Total Solar Capacity for Residential Low-Income Solar PV Projects in Santa Clara County in 2021



widely recognized as a leader in solar energy generation and a champion of energy-transition policy (Hess & Lee, 2020; Horne et al., 2021; Zanocco et al., 2021), often referred to as a "solar state." According to California Distributed Generation Statistics, as of March 2022, California leads the nation in distributed generation, with over 1,400,000 solar projects deployed and 34,950 MW installed. Growth of DERs in California is rapid and constant, thus making this energy transition and energy justice outcomes even more pertinent, and it becomes increasingly critical to support justice outcomes within the energy transition.

Data Collection

The United States Department of Energy provides a comma-separated values (CSV) file containing data on 63 operational microgrid locations in California. The file contains some location data but is not robust enough to create a visualization easily in ArcGIS Pro. In order to create a map of operation microgrids in California, the Google Places API was used to add specific locational attribute data such as latitude, longitude, and full address to the CSV file. The Google Places API is an application programming interface that returns information about establishments, geographic locations, or prominent points of interest using HTTP requests. With more accurate and precise location data, the CSV was fed into ArcGIS Pro to create a map of representing locations of microgrids in California, as shown in Figure 3.

Data Analysis

Next, analysis was completed to observe trends between microgrid deployment and median household income and predominant race by census tract. Figure 4 shows predominant race data by census tract layered with the map for operational microgrid locations. Race data was obtained from the United States Census Bureau ACS, and predominant race by census tract was calculated and overlaid with operational microgrid locations map. Race groups classified by the ACS are: White alone, Hispanic or Latino alone, Black or African American alone, Asian alone, American Indian and Alaskan Native alone, two or more races (not Hispanic or Latino), Native Hawaiian and other Pacific

Figure 3
Operational Microgrid Locations in California (2021)

Islander alone, some other race alone. Figure 5 shows median household income by census tract layered with the map of operational microgrid locations. Median household income is divided into five classes, grouped by the "Natural Breaks" method in ArcGIS Pro, which creates classes based on natural grouping of the data. Classes are represented using a graduated color scale: > $170,000 - $250,001 (highest income, lightest red); > $118,481 - $170,000; > $85,295 - $118,841; $56,417 - $84,295; $7,461 - $56,417 (lowest income, darkest red).

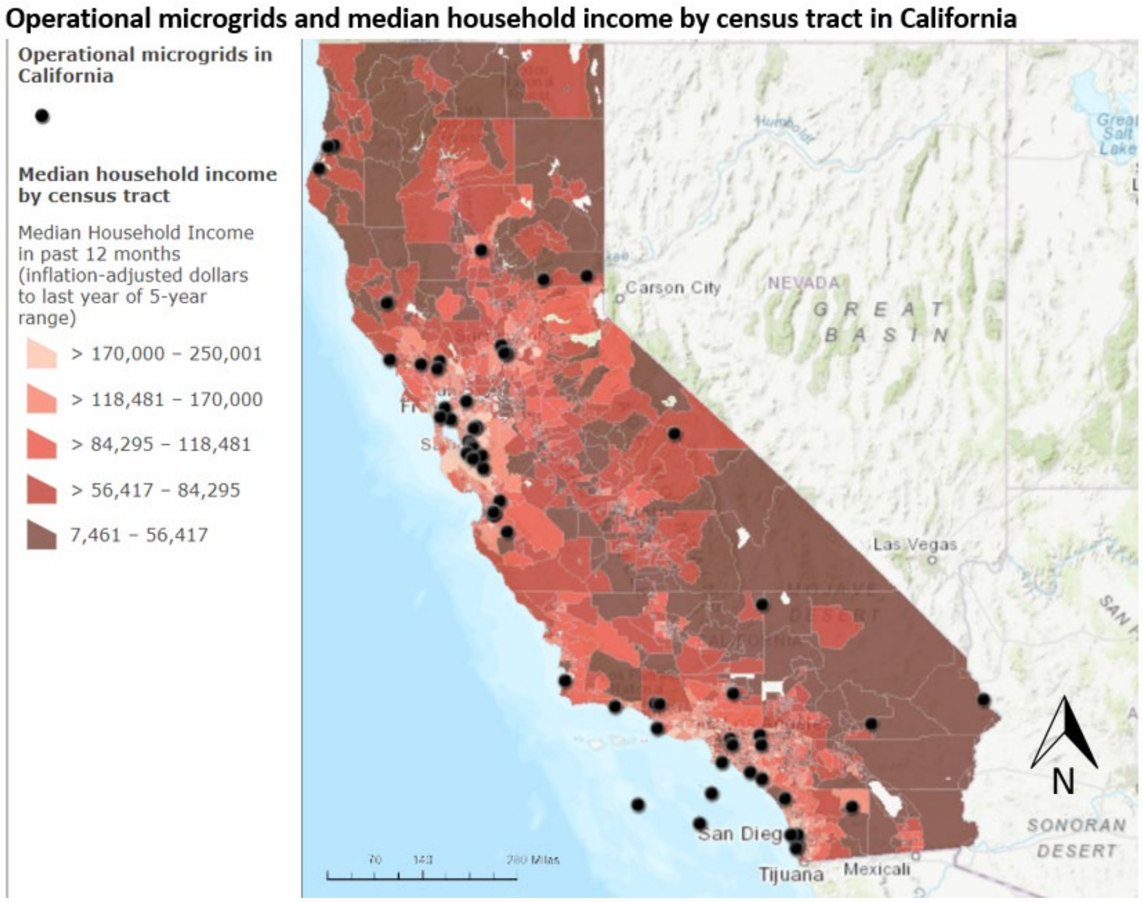
Figure 4

Operational Microgrid Locations and Predominant Race by Census Tract Map

Using the "Join" geoprocessing tool in ArcGIS Pro, the microgrid location map was joined to the median household income by census tract map layer as well as the predominant race by census tract layer to identify which census tracts contained microgrids. Then, for each microgrid location, median household income and predominant race was extracted to observe any skews or trends in the data.

Figure 5

Operational Microgrid Locations and Median Household Income by Census Tract Map



Research Question 1

Study Design

A suitability analysis is performed to identify the most suitable sites for microgrid deployment in Santa Clara County. Suitability analyses allow users to qualify, compare, and rank candidate areas based on how closely they adhere to criteria the user selects and defines.

In this study, the suitability analysis to identify optimal census tracts for community solar microgrid deployment is completed in two stages: Phase One and Phase Two. Phase One is completed in ArcGIS Pro; the Suitability Analysis tool weighs and ranks census tracts to preliminarily identify optimal locations to deploy a microgrid in Santa Clara County based on three criteria: classification of DACs by census tract, count of CIFs per census tract, and count of power outage events by city. Phase Two of the suitability analysis takes the results from Phase One and calculates estimated rooftop solar potential by census tract using Helioscope and Excel. The final output of this research is a map that identifies the most suitable census tracts in which to deploy a community solar microgrid based on the completed analyses.

Data Collection

The Homeland Infrastructure Foundation - Level Data (HIFLD) is a public domain that provides national foundation-level geospatial data. Geospatial data is obtained from HIFLD to map and count the location of critical infrastructure facilities (CIFs); the data is sorted to obtain the count of CIFs per census tract. In this study, CIFs are public schools, fire stations, police stations, community centers, and hospitals. The aggregate count of CIFs per census tract is calculated and used as a criterion in the suitability analysis.

CalEPA's Office of Environmental Health Hazard Assessment (OEHHA) CalEnviroScreen is a screening methodology that can be used to help identify California communities that are disproportionately burdened by multiple sources of pollution. This study uses data from CalEnviroScreen 4.0. DACs are identified by census tract, sorted by score, and classified into four groups based on percentiles calculated in CalEnviroScreen 4.0.

Historical PG&E power outage data from October 1, 2017 to October 28, 2022 is obtained from PowerOutage.us, a site that collects, records, and aggregates power outage data from utilities all over the United States. The city of Santa Clara falls into Silicon Valley

Power's utility territory and historical power outage data was not available, so power outage data is excluded for tracts in the city of Santa Clara.

Estimated rooftop solar potential on the census tract level is the final criteria in the suitability analysis. This metric is calculated using data obtained from Helioscope, a web-based solar PV design software that designs solar systems and simulates their efficiency. Rooftop solar potential for individual CIFs is measured in Helioscope, and then this data is exported to Excel to aggregate estimated rooftop solar potential on the census tract level.

Solar Energy Industries Association (SEIA) is the national trade association for the solar energy industry in the United States, working to expand markets, strengthen and develop research, and improve education for the employment of solar energy. SEIA provides data on the average number of homes powered by one MW of solar in some of the main solar markets across the country. The estimated number of homes that could be powered by the microgrids designed in this study is calculated using this data; read more about their methodology in their paper cited in references.

The PG&E Integration Capacity Analysis (ICA) map shows conditions on the utility's distribution grid that reflect its ability to "host" additional DERs, such as rooftop solar, energy storage and/or EV charging stations, at specific locations on the grid. The purpose of the map is to help reveal the operational limits of the grid, which might impact the ability of new DERs to interconnect quickly or affordably. These tools can also identify areas where DERs may be able to provide beneficial services by addressing existing grid constraints, informing more strategic grid investments over the long term. In addition, the information gleaned from an ICA map can help regulators, utilities, developers, and customers make more proactive, cost-effective and efficient decisions about DER investments.

A tract's hosting capacity will not serve as a criterion in the suitability analysis because current grid limits and existing electrical infrastructure are historically a limiting factor in clean energy integration projects, and have systemically precluded majority-Black and Lantinx communities from being targets for such projects (Brockway et al., 2021). Therefore, the ICA map will serve as a peripheral layer on the final map that identifies optimal tracts in which to deploy microgrids, serving as a supplemental information source rather than a weighted criterion.

Data Analysis

In this study, the suitability analysis is completed in two stages: Phase One and Phase Two. In Phase One, three criteria are weighted:

1. Number of CIFs within an area:

Six CIF types are selected in this research: public schools, fire stations, police stations, community centers, public libraries, and hospitals. These are public service facilities, meaning they are facilities owned, operated, or occupied by a government agency that provides governmental service to the public. CSV files of point features representing building locations of fire stations, police stations, community centers, public libraries, and hospitals in the United States were downloaded from the HIFLD. A CSV file of point features representing building locations of public schools was downloaded from the Santa Clara County Open Data Portal. Data cleaning work of CSV files was completed in Excel: data was trimmed to only retain data from Santa Clara County, key fields identified were the name of each CIF (column named “PLACENAME” in the CSV), the classification of CIF type (column named “PLACETYPE” in the CSV), street address (column named “LOCATION1” in the CSV), and geographical coordinates in latitude and longitude (column named “GPS COORDINATES” in the CSV), and Excel’s PowerQuery feature was used to transform location data into usable points, and then to append multiple files into one master file that was then uploaded into ArcGIS Pro for further analysis and mapping.

In ArcGIS Pro, point data representing CIF locations was joined to the CalEnviroScreen 4.0 group classification layer to obtain an aggregate count of CIFs per census tract. The higher the count of CIFs contained in a census tract, the higher the score the census tract is assigned in the suitability analysis, as shown in Table 1.

Table 1
Summary of Scoring Criteria for CIFs from Suitability Analysis Tool in ArcGIS Pro

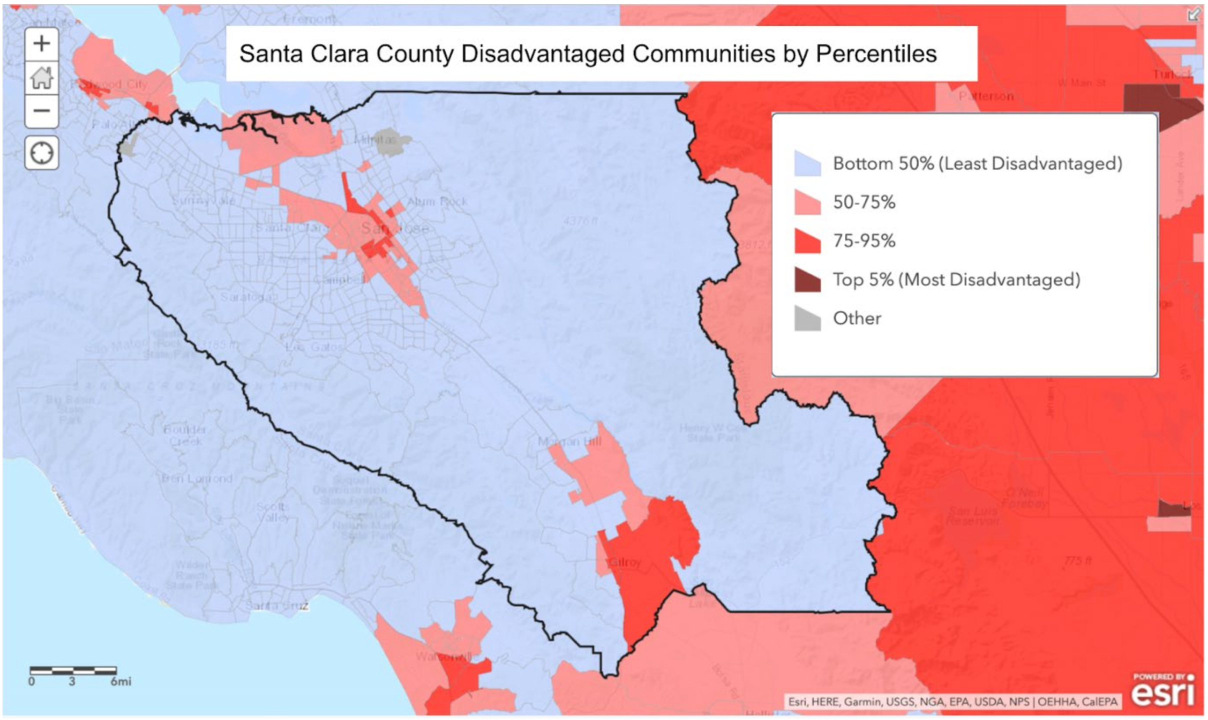
Count of CIFs (per census tract)	Score of Count of CIFs
9	1
8	0.888889
7	0.777778
6	0.666667
5	0.555556
4	0.444444
3	0.333333
2	0.222222
1	0.111111
0	0

2. Disadvantaged community percentile:

In Figure 6, the black border represents the geographical boundary for Santa Clara County as determined by the United States Census. CalEPA's OEHHA is the provider of

Figure 6

Map of Classification of Census Tracts Based on CalEnviroScreen 4.0 Percentiles, Classified into Four Main Groups



CalEnviroScreen and with the newest revision (CalEnviroScreen 4.0), the agency also released a spreadsheet showing raw data and calculated percentiles for individual indicators and combined CalEnviroScreen 4.0 scores for individual census tracts with additional demographic information. In the data, each census tract is assigned a CalEnviroScreen 4.0 score, which reflects the tract's SB53 Disadvantaged Communities Designation, or its "DAC" Status. Based on this score, the tract is then placed at a percentile; the percentile represents a relative score for 21 indicators used in the model. Then, tracts are assigned a percentile range in increments of five percent (90-95%, 85-90%, 85-90%, etc.).

Residents in DACs are disproportionately impacted by environmental and socioeconomic burdens such as air pollution, poverty, or high incidence of asthma. Using the scores provided in the dataset, census tracts were further classified into 4 categories for this study: Top 5% (Most Disadvantaged), 75-95%, 50-75%, and Bottom 50% (Least Disadvantaged). In ArcGIS Pro, census tracts are assigned to a color scale based on their group classifications, see table below. The group classification (Bottom 50% Least Disadvantaged, 50-75%, 75-95%, etc.) is used as a visual component in this map.

OEHHA also provides a Shapefile containing CalEnviroScreen 4.0 results by census tract, which was uploaded into ArcGIS Pro and trimmed to only show census tract boundaries in Santa Clara County. This layer serves as the base map for which other layers are joined to in order to relate datasets by census tracts.

The Suitability Analysis tool in ArcGIS Pro weighs the CalEnviroScreen 4.0 percentile range, which are grouped in descending increments of five percent (90-95%, 85-90%, 85-90%, etc.). Table 2 shows a sample of the data, showing only the upper five percent in each range to provide a brief overview of the scoring; for the more detailed table, see Appendix.

1. Count of power outages:

Historical power outage data for PG&E from October 1, 2017 to October 28, 2022 was obtained from PowerOutage.us. Precise geographic locations (such as street address and/or GPS coordinates) were not available in the original dataset from PowerOutage.us so in order to map the incidents for use in the suitability analysis, each power outage event is counted by city rather than census tract. Then, suitability scores are assigned and weighted by city name, based on the total count of incidents. Cities with higher counts of power outage events are weighted more highly compared to those with a lower count of power outage events, as shown in Table 3. Then, CIFs that are contained within a city are assigned the associated

Table 2

Summary of Sample of Scoring Criteria for CalEnviroScreen 4.0 Data from Suitability Analysis Tool in ArcGIS Pro

CalEnviroScreen 4.0 Group Classification	CalEnviroScreen 4.0 Percentile Range	Score of CalEnviroScreen 4.0 Percentile
75-95%	90-95%	0.927093
50-75%	70-75%	0.70027
Bottom 50% (Least Disadvantaged)	45-50%	0.463046

Table 3

Summary of Scoring Criteria for PG&E Power Outage Events from October 1, 2017 through October 28, 2022 Data from Suitability Analysis Tool in ArcGIS Pro

Count of power outage events by city	Score of Count of power outage events by city
622	1
149	0.23955
132	0.212219
131	0.210611
102	0.163987
95	0.152733
91	0.146302
81	0.130225
75	0.120579
74	0.118971
70	0.11254
63	0.101286
42	0.067524
31	0.049839
26	0.041801
13	0.0209
10	0.016077
4	0.006431
3	0.004823
1	0.001608
0	0

score and weighted score. For example, Yerba Buena High School is a CIF located in census tract 6085503122, which is in the city of San Jose; therefore, Yerba Buena High School is assigned a score of one in the suitability analysis for this category.

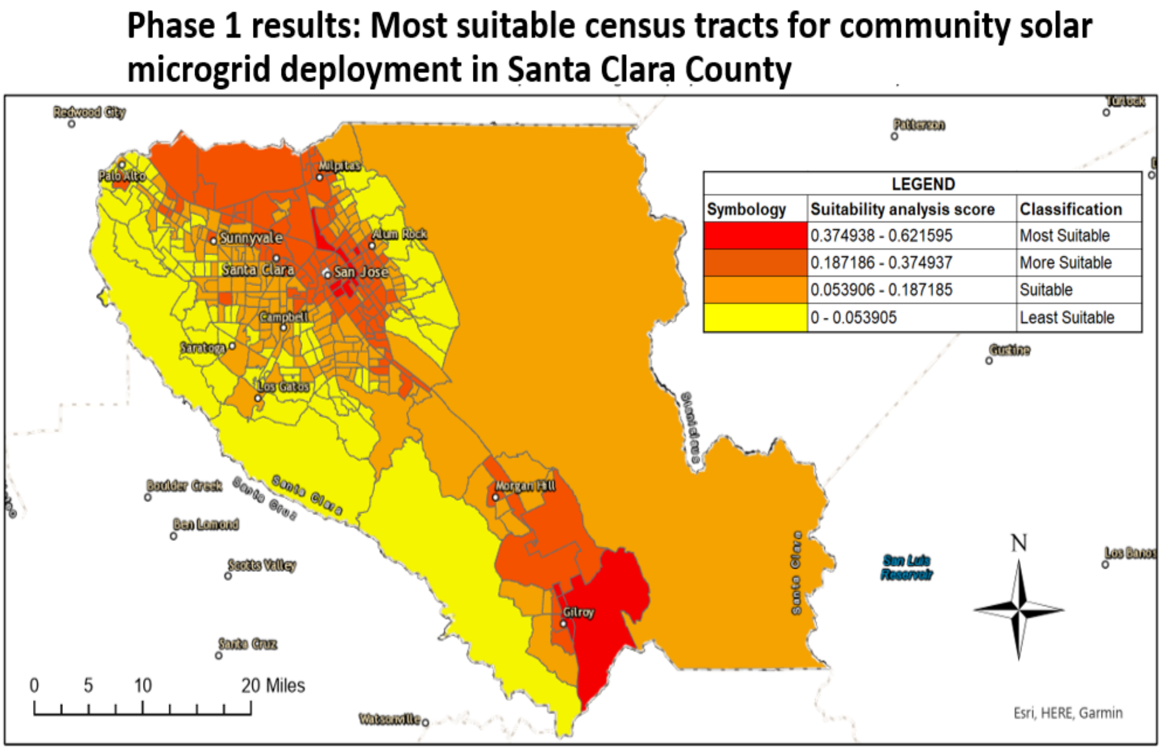
Phase One Analysis. Based on the three criteria set in the Suitability Analysis tool in ArcGIS Pro (classification of DACs by census tract, count of CIFs per census tract, count of power outages by city), census tracts are assigned a score to identify most suitable sites based on analysis completed in Phase One, as shown in Figure 7. Scores are classified into four natural breaks on a graduated color scale of red to yellow, with an upper value of 0.621595 ("Most Suitable", symbolized with bright red) to a lower value of zero ("Least Suitable", symbolized with yellow). 19 census tracts are classified as "Most Suitable" during Phase One.

The next step in this study's suitability analysis is Phase Two, which uses Helioscope and Excel to calculate the final criteria, a census tract's estimated rooftop solar potential (estimated in kilowatts). This analysis is performed by taking all tracts that scored in the "Most Suitable" category (19 tracts) and calculating their estimated rooftop solar potential. Tracts are then assigned their final suitability rank and displayed on the final map, as shown in Figure 8.

Phase Two Analysis. The final criteria in the suitability analysis is estimated rooftop solar potential. The rooftop solar potential is estimated for each CIF is measured using Helioscope and then entered into an Excel spreadsheet to calculate the total rooftop solar output estimate of a census tract. CIFs that rank in the top 19 census tracts from the suitability analysis performed in ArcGIS Pro were exported as a CSV file to Excel. The

Figure 7

Map of Results from Phase One, Showing Most Suitable Locations to Deploy Microgrids Based on 3 Criteria Input into the Suitability Analysis Tool in ArcGIS Pro

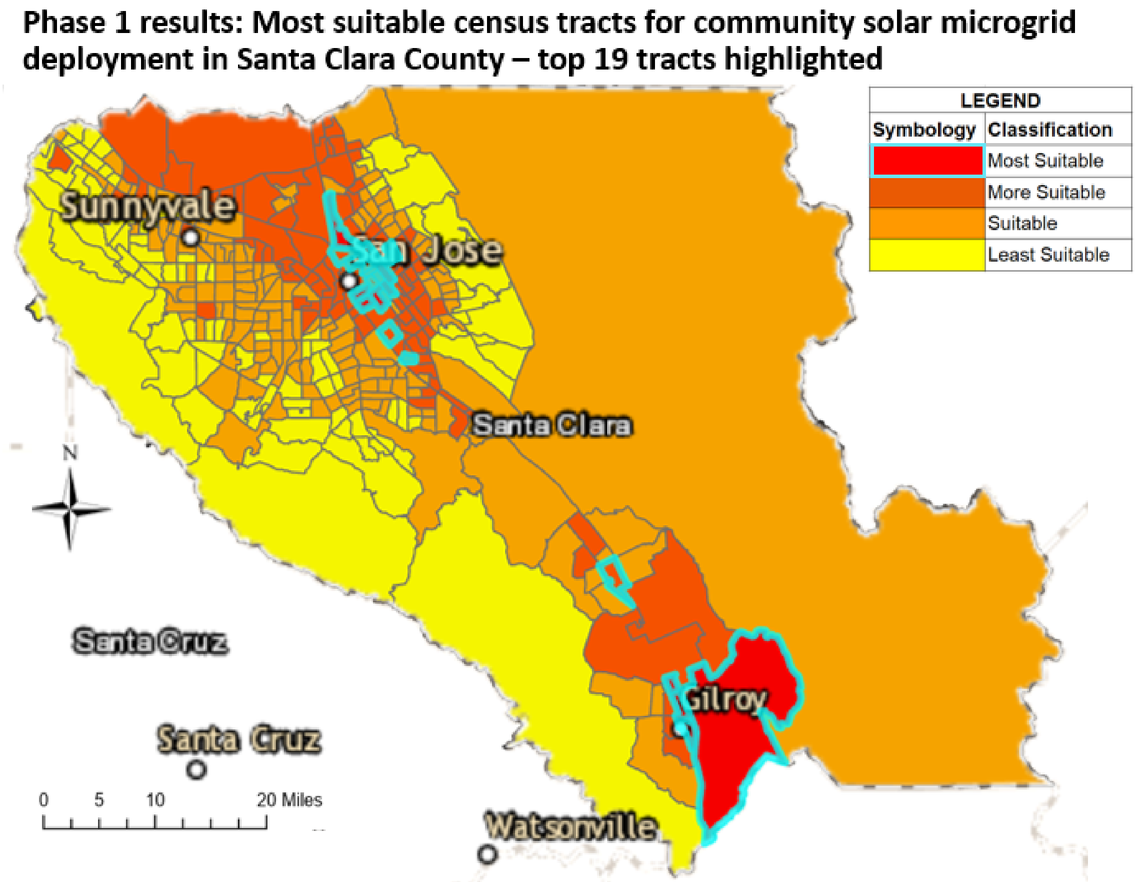


suitability analysis identified 19 census tracts that fall in the "Most Suitable" category, which are tracts that have a final weighted score between 0.37498 to 0.621595 (inclusive), with 0.621595 being the highest score possible (meaning "Most Suitable"). Each of the 19 census tracts is assigned a numerical ranking based on their score, as shown in Table 4; a tract that scores 0.621595 is ranked as number one, and so on, on a decreasing scale until a score of 0.37498 which is ranked as number 19.

There are multiple CIFs in each census tract; CIFs are grouped by census tract and then each CIF is individually entered into Helioscope to estimate rooftop solar generation. Using the Helioscope solar PV system designer, street addresses of CIFs are entered individually;

Figure 8

Map of Results from Phase One, Highlighting 19 Census Tracts that Fall in the "Most Suitable" Category, Which Are Tracts that Have a Final Weighted Score between 0.37498 to 0.621595 (Inclusive), with 0.621595 Being the Highest Score Possible ("Most Suitable")



a satellite view of the CIF is used to evaluate rooftop space and design the solar PV system. A street address or single building may not represent an entire facility; for example, a middle school may have multiple buildings, but the street address is pinned only at the building with the administrative office. To ensure the entire facility is captured, street addresses were cross checked in the Santa Clara County Technology Services and Solutions web mapping application, SCCMap. This map allows users to search for addresses and will show a satellite

Table 4
Summary of Scoring Criteria from Phase One (Completed with the Suitability Analysis Tool in ArcGIS Pro)

ArcGISPro Rank	Census Tract	Score
1	6085501000	0.621595
2	6085504318	0.526119
3	6085501401	0.498316
4	6085512508	0.484391
5	6085512604	0.443211
6	6085503711	0.43591
7	6085512401	0.432109
8	6085507001	0.428118
9	6085500200	0.427576
10	6085503903	0.427543
11	6085502102	0.413275
12	6085504602	0.408408
13	6085500500	0.405841
14	6085503504	0.404507
15	6085503601	0.39564
16	6085512310	0.388606
17	6085512603	0.383105
18	6085503122	0.378971
19	6085505100	0.378738

map view along with parcel boundaries, which confirms which buildings should be part of the CIF.

The entire rooftop area is used for solar PV module placement to estimate solar potential. Obstructions on rooftops are not accounted for in this estimate, such as HVAC systems, roof drains, vents, or other physical barriers; tree cover and shading is also not accounted for in this estimate. Buildings are all assumed to not have any solar PV system previously installed (for example, if a building already has solar installed, the existing system is ignored and a new system is designed for the purpose of this study). Solar carports are also not considered in this study.

A rooftop solar PV system design is created for each CIF. Solar PV system sizes are measured in kilowatt peak, kWp (measure of kilowatts Direct Current, abbreviated as DC, produced by a solar PV system). This is called the nameplate rating of solar PV systems and refers to the amount of power produced in bright sunshine or under standard laboratory test conditions. A design consists of the solar PV systems mounted on buildings' rooftops, which are modeled by creating field segments (meaning valid areas to place modules). Field segments in Helioscope use the parameters listed in Table 5.

The end product of a Helioscope design shows the total count of panels and the total power for a CIF. These two data points are then entered into an Excel spreadsheet to calculate estimated rooftop solar generation for each of the 19 census tracts. Tracts are then provided with their final suitability rank. Final ranks are entered into ArcGIS Pro to create a map that visualizes the most suitable census tract to the least suitable.

In addition to presenting the data points associated with the four criteria of these suitability analysis calculated in Phase One and Phase Two, the deep dive results present two additional calculations that are not scoring criteria but are relevant calculations that make the results more robust. The first is an estimate for battery size associated with each microgrid (only calculated for the top three most suitable tracts). Table 6 shows definitions of variables used in the calculation. The estimated size of the battery storage system is calculated using the equation below:

Battery size (kWh) = Daily energy use (kWh) x Number of days of autonomy / (1 – SOC)

Table 5

Summary of Field Segment Parameters for System Design in Helioscope

Parameter	Value	Description
Panel model	Silfab Solar SIL-500 HM Silfab	See specification sheet in Appendix.
Racking	Fixed tilt racking	Modules are tilted up in rows along a flat surface.
Height (feet)	0	Height of modules set to 0 (default).
Azimuth (degrees)	Varies	Orientation of modules are set to align to the face of the building edge.
Tilt (degrees)	10	Tilt of modules is set to 10 degrees (default).
Frame size	1x1	Blocks of modules are laid out in a single plane (default).
Orientation	Landscape (horizontal)	Modules are set in landscape orientation (default).
Row spacing (feet)	2	Because modules are on fixed tilt racking, row spacing much be sufficient to prevent high shading loss.
Module spacing (feet)	0.04	Row spacing is based on a zero-tolerance shading rule from 10am to 2pm on the winter solstice (default).
Frame spacing (feet)	0	Lateral spacing between frames for thermal expansion (default).
Setback (feet)	4	Perimeter setback around the array is set to 4 feet (default).
Alignment	Centered	Alignment of modules is centered to optimize placement on irregularly shaped rooftops.

Note. In alinement with Executive Order 14017 "America's Supply Chains" - President Biden's Executive Order to help the United States federal government facilitate greater domestic production, acceleration in clean energy, and generally build more secure and diverse United States energy supply chains - the United States Department of Energy's Solar Energy Technologies Office (n.d.) published their "Solar Photovoltaics Supply Chain Review Report" which finds that "the solar supply chain is global and reliant on products from China or companies with close ties to China, a country with documented human rights violations and an unpredictable trade relationship with the United States." Due to findings in the report regarding growing industry concerns with supply chain sustainability and supply chain responsibility, Silfab Solar was strategically selected as the panel manufacturer in this study. Silfab Solar is the North American manufacturing leader in the industry and all of their panels are manufactured in the United States. The solar PV module model selected for the design is the Silfab Solar SIL-500 HM Commercial solar PV module, a high- efficiency solar panel optimized for large to small commercial projects, with a module output of 500 Watts, 38.8 Volts, and 21.0% efficiency; see manufacturer's datasheet in the Appendix.

Constants in this calculation are the desired number of days of autonomy for the battery, battery state of charge (SOC), and average daily usage per home (kWh). The desired number of days of autonomy for the battery is set to 0.17 days; the average event length (in hours) for all PG&E power outage events from October 1, 2017 through October 28, 2022 was calculated to be 4.08 hours, which converted into days is equal to 0.17 days. Battery SOC shows the charging capacity available for a battery (100% SOC is a full charged battery,

Table 6
Summary of Battery Size Estimate Calculation

Average daily usage per home (kWh)	18 kWh	According to data from SEIA (based on data provided by the United States Energy Information Administration), the average annual electricity consumption per household in California is about 6.5 MWh per home, which approximates to a daily usage of 18 kWh per day per home.
Number of housing units in the census tract	Varies by tract	Data obtained from the Census Reporter, which presents data collected by the United States Census Bureau. Data is from the 2016-2020 5-year American Community Survey.
Desired number of days of autonomy for the battery	0.17	Number of days that the battery can receive no power from solar panels or other sources. Derived from PowerOutage.us data.
State of charge (SOC)	5%	The minimum capacity for the battery before it stops discharging power (to prevent serious damages).

whereas an SOC of 0% indicates it is completely discharged). The SOC selected for this calculation is 5%, which means the battery can discharge power until it reaches the minimum limit of 5%; then, the battery will stop dispensing power and disconnect from the solar PV system to prevent battery damage. Reaching an SOC that is too low can cause damage to the battery; Manlun and Hofstee (2021) define the minimum limit of a microgrid to be 5% SOC.

Variables in the estimation for battery size is daily energy use (kWh), which is calculated by multiplying average daily energy usage per home (kWh) by the number of homes in a census tract, which is data obtained from the Census Reporter (data obtained from the United States Census Bureau). The count of housing units only considers single unit homes and multi-unit homes only (such as mobile homes, vans, etc. are excluded).

The second calculation provided is an estimate for the number of homes the designed microgrid could power. According to research completed by the SEIA, as of Q2-2022, the average number of homes powered by a MW of solar in California is approximately 260 homes; SEIA does not specify if “homes” means single-family homes, multi-family homes, or a mix. 260 homes is the data point used to estimate how many homes could be powered by the microgrids designed in this study. This is calculated by multiplying estimated MG generated by a system by 260 homes:

Estimated number of homes = Estimated megawatts generated by a system x 260 homes

Average daily energy usage per home (kWh) is calculated with data from research by the SEIA (based on data provided by the United States Energy Information Administration) which shows that the average annual electricity consumption per household in California is about 6.5 MWh per home, which approximates to a daily usage of 18 kWh per day per home.

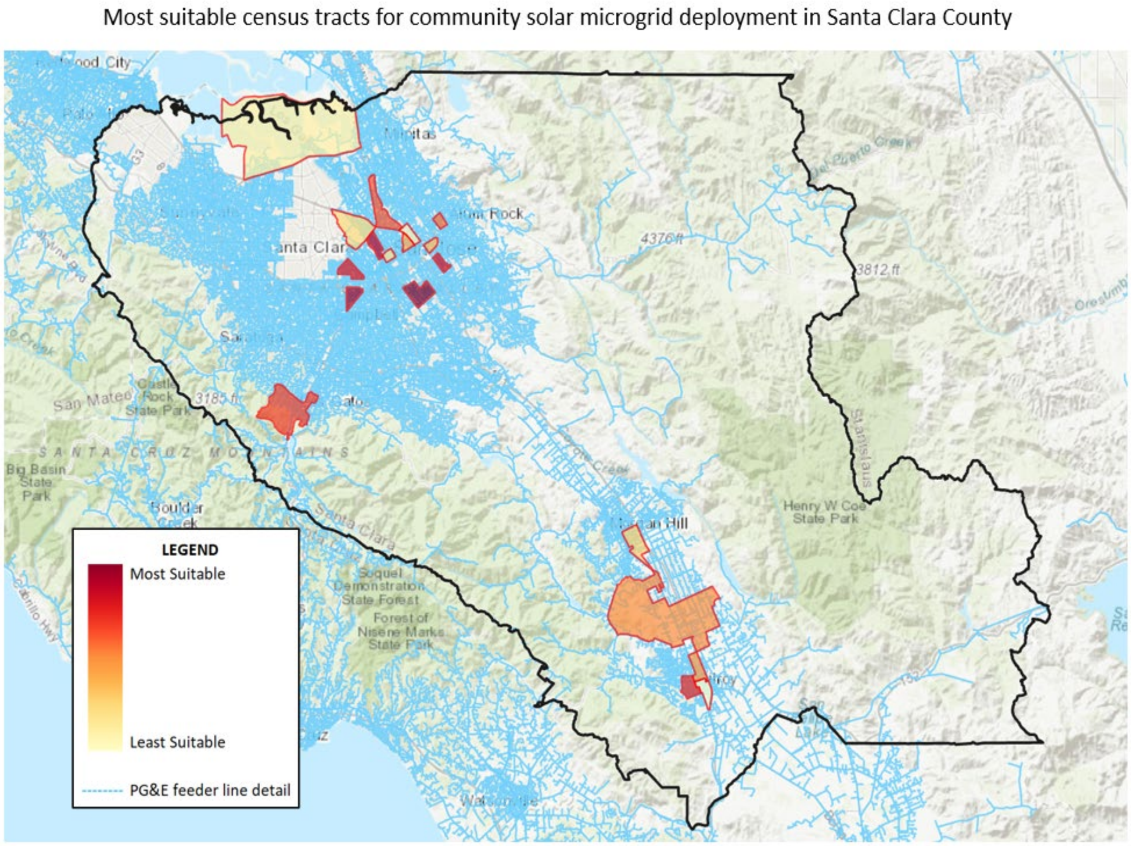
Results

Based on the analysis completed in the PRQs and the existing body of literature on the topic, no trend or pattern related to socioeconomic drivers can be detected for where microgrid projects are deployed. According to the United States Census, the median household income in 2021 was $70,784. 52% of microgrids in California are deployed in census tracts whose median household income is greater than the national median. 62% of current microgrids in California are deployed in census tracts where the predominant race is "White alone, not Hispanic or Latino." This exposes a significant missed strategic opportunity in microgrid deployment; even though the economic and social benefits that microgrids can contribute to a community are widely acknowledged across the literature, the vast majority of microgrid projects in California and across the United States are deployed for military, research, education, and related purposes (Kelly-Pitou et al., 2017; Perez-DeLaMora et al., 2021), rather than to build capacity in vulnerable communities. This disparity may be due to the resource intensive and cost prohibitive nature of microgrid design, deployment, and management, but is exemplary of the inequity that persists in the energy transition.

The following section provides an in-depth review of the top three most suitable census tracts for microgrid deployment in Santa Clara County. Figure 9 shows the final map identifying the most suitable sites for community solar microgrid deployment in Santa Clara County, layered with feeder line detail from PG&E's ICA map.

Figure 9

Final Suitability Map of Most Suitable Sites for Community Solar Microgrid Deployment in Santa Clara County, Layered with Feeder Line Detail from PG&E's ICA Map

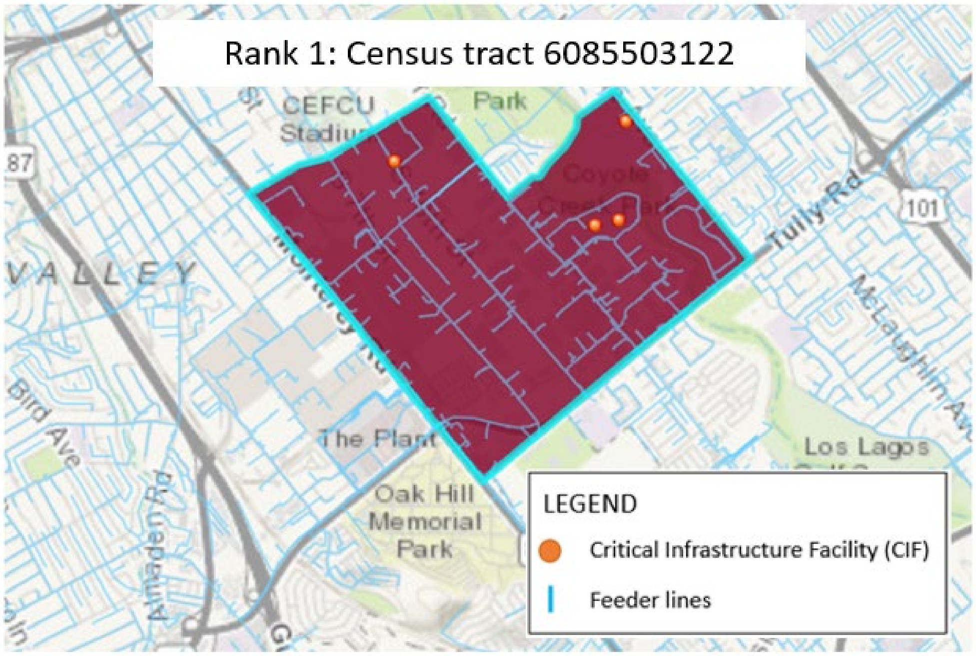


Rank 1: Census Tract 6085503122

The most suitable census tract for microgrid deployment in Santa Clara County is census tract 6085503122, shown in Figure 10. This tract contains four CIFs; Figure 11 shows details of Helioscope designs for these CIFs. The estimated rooftop solar generation of a microgrid system mounted on these CIFs is 6,662 kW (6.66 MW). Based on the SEIA's estimated average number of homes powered by one MW of solar in California, this system could power approximately 1,730 homes. This census tract scores in the 69th percentile, meaning census tract 6085503122 scored a higher CalEnviroScreen 4.0 score than 69% of other

Figure 10

Enhanced View of Final Suitability Map Output Showing the Most Suitable Site, Tract 6085503122, with Locations of CIFs and Feeder Line Details



census tracts in California. This tract is also located in San Jose, which is serviced by PG&E and has experienced 622 power outage events from October 2017 to October 2022. Table 7 summarizes these results. The estimated battery size for this microgrid system is 4.13 MWh. Table 8 shows the summary for the calculation for estimated battery size. Estimated battery size is calculated using the equation:

Battery size (kWh) = Daily energy use (kWh) x Number of days of autonomy / (1 – SOC)

Rank 2: Census Tract 6085502102

The second most suitable census tract for microgrid deployment in Santa Clara County is census tract 6085502102, shown in Figure 12. This tract contains seven CIFs; Figure 13 shows details of Helioscope designs for these CIFs. The estimated rooftop solar generation of

Figure 11

Helioscope Designs for the CIFs Contained in Census Tract 608550312

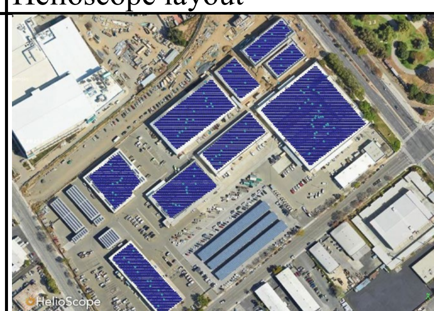
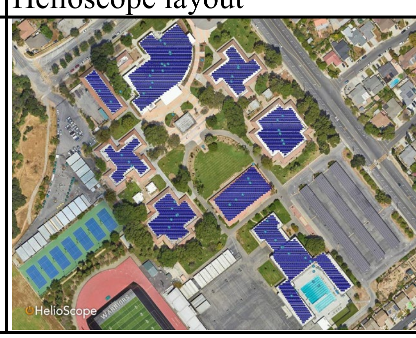
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: ACE Franklin McKinley District Address: 645 Wool Creek Dr. San Jose, CA 95112 Estimated system size: 925 k	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Shirakawa George, Sr. Elementary Address: 655 Wool Creek Dr. San Jose, CA 95112 Estimated system size: 428 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: San Jose Police Department Service Yard Address: 1580 S 10th StSan Jose, CA 95112 Estimated system size: 3512 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Yerba Buena High Address: 1855 Lucretia Ave San Jose, CA 95122 Estimated system size: 1797.5 kW	

Table 7

Summary of Suitability Analysis Results for the Most Suitable Site, Tract 6085503122

Census tract	6085503122
City	San Jose
Count of CIFs	4
CalEnviroScreen 4.0 percentile	69.25
CalEnviroScreen 4.0 group classification	50-75%
Count of power outages	622
Estimated rooftop solar generation (MW)	6.66
Estimated number of homes that could be powered	1,732

Table 8

Summary of Estimated Battery Size Calculation for the Most Suitable Site, Tract 6085503122

Average daily usage per home (kWh)	18
Number of days of autonomy	0.17
Number of housing units	1,281
State of Charge (SOC)	5%
Battery size (MWh)	4.13

Note. Daily energy usage is calculated by multiplying the average daily usage per home (18 kWh) by the number of housing units in the census tract (1,281 units).

Figure 12

Enhanced View of Final Suitability Map Output Showing the Second Most Suitable Site, Tract 6085502102, with Locations of CIFs and Feeder Line Details

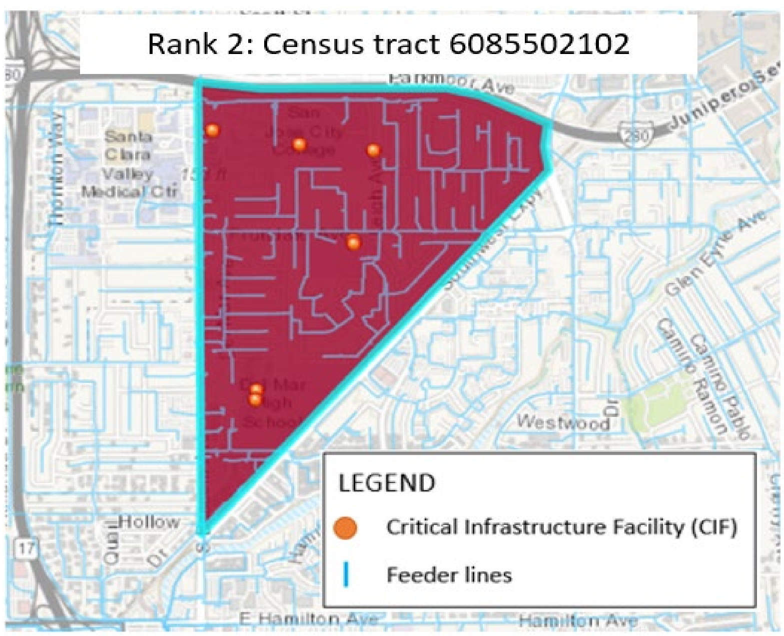
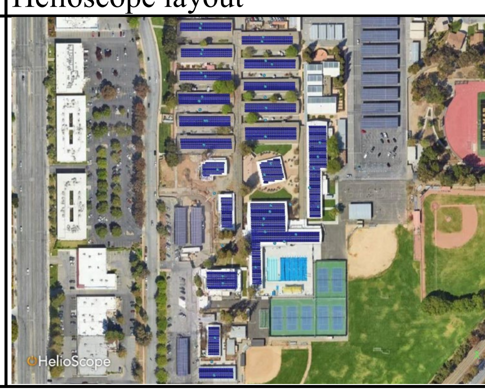
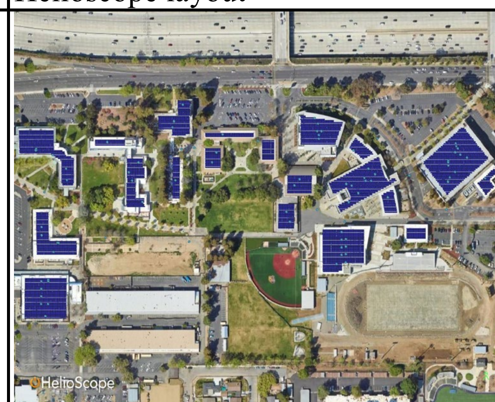
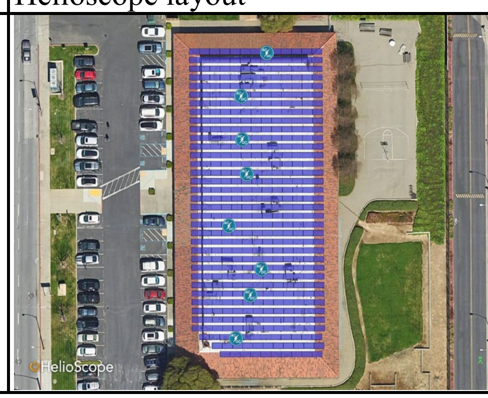


Figure 13

Helioscope Designs for the CIFs Contained in Census Tract 6085502102

Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Sherman Oaks Community Center Address: 1800 Fruitdale Ave. San Jose, CA 95128 Estimated system size: 323 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Sherman Oaks Elementary School Address: 1800 Fruitdale Ave. San Jose, CA 95128 Estimated system size: 323 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: San Jose Fire Station Four Address: 710 Leigh Ave. San Jose, CA 95128 Estimated system size: 119 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Campbell Adult and Community Education Address: 1224 Del Mar Ave. San Jose, CA 95128 Estimated system size: 725 kW	

Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Del Mar High School Address: 1224 Del Mar Ave. San Jose, CA 95128 Estimated system size: 725 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Middle College High School Address: 2101 Moorpark Ave. San Jose, CA 95128 Estimated system size: 2720 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Adolescent Day Treatment Center Address: 650 S. Bascom Ave. San Jose, CA 95128 Estimated system size: 260 kW	

a microgrid system mounted on these CIFs is 5,195 kW (5.2 MW). Based on the SEIA's estimated average number of homes powered by one MW of solar in California, this system could power approximately 1,350 homes. This census tract scores in the 46th percentile, meaning census tract 6085502102 scored a higher CalEnviroScreen 4.0 score than 46% of other census tracts in California. This tract is also located in San Jose, which is serviced by PG&E and has experienced 622 power outage events from October 2017 to October 2022. Table 9 summarizes these results. The estimated battery size for this microgrid system is 3.38 MWh. Table 10 shows the summary for the calculation for estimated battery size. Estimated battery size is calculated using the equation:

Battery size (kWh) = Daily energy use (kWh) x Number of days of autonomy / (1 – SOC)

Table 9
Summary of Suitability Analysis Results for the Second Most Suitable Site, Tract 6085502102

Census tract	6085502102
City	San Jose
Count of CIFs	7
CalEnviroScreen 4.0 percentile	46.21
CalEnviroScreen 4.0 group category	Bottom 50%
Count of power outages	622
Estimated rooftop solar generation (MW)	5.2
Estimated number of homes that could be powered	1,350

Table 10
Summary of Estimated Battery Size Calculation for the Second Most Suitable Site, Tract 6085502102

Average daily usage per home (kWh)	18
Number of days of autonomy	0.17
Number of housing units	1,048
State of Charge (SOC)	5%
Battery size (MWh)	3.38

Note. Daily energy usage is calculated by multiplying the average daily usage per home (18 kWh) by the number of housing units in the census tract (1,048 units).

Rank 3: Census Tract 6085500200

The third most suitable census tract for microgrid deployment in Santa Clara County is census tract 6085500200, shown in Figure 14. This tract contains seven CIFs; Figure 15 shows details of Helioscope designs for these CIFs. The estimated rooftop solar generation of a microgrid system mounted on these CIFs is 3,929 kW (3.93 MW). Based on the SEIA's estimated average number of homes powered by one MW of solar in California, this system could power approximately 1,020 homes. This census tract scores in the 51st percentile, meaning census tract 6085500200 scored a higher CalEnviroScreen 4.0 score than 51% of other census tracts in California. This tract is also located in San Jose, which is serviced by PG&E and has experienced 622 power outage events from October 2017 to October 2022. Table 11 summarizes these results. The estimated battery size for this microgrid system is 7.14 MWh. Table 12 shows the summary for the calculation for estimated battery size. Estimated battery size is calculated using the equation:

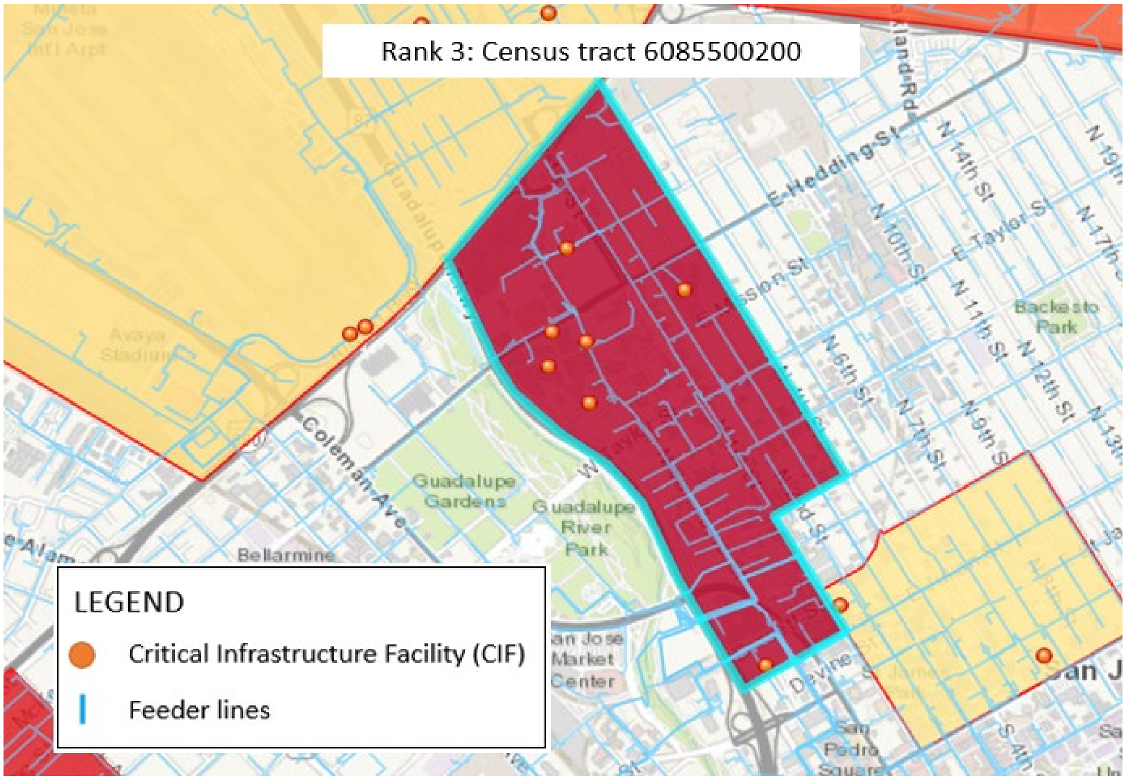
Battery size (kWh) = Daily energy use (kWh) x Number of days of autonomy / (1 – SOC)

Summary of Deep Dive Results

Census tracts 6085503122, 6085502102, and 6085500200 are identified as the most suitable sites in which to deploy community solar microgrids in Santa Clara County because they show the strongest balance of both demonstrated need and technical feasibility. These sites show need because they contain vulnerable populations, as exemplified by the CalEnviroScreen 4.0 scoring, as well as the high frequency of power outages in the area.

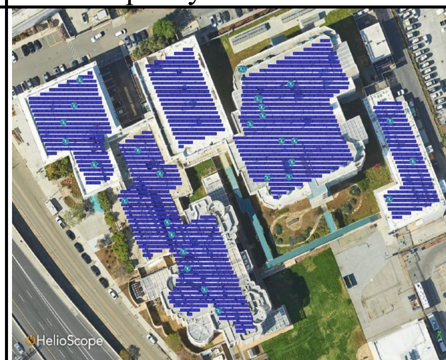
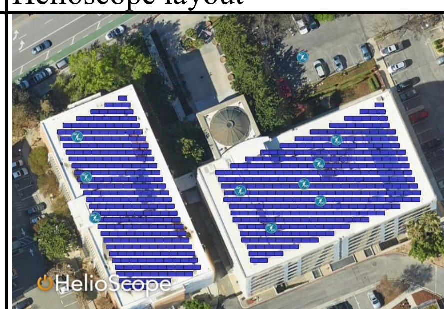
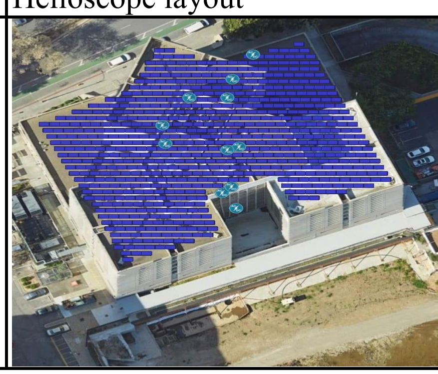
Figure 14

Enhanced View of Final Suitability Map Output Showing the Third Most Suitable Site, Tract 6085500200, with Locations of CIFs and Feeder Line Details



These are also technically feasible sites, as they have enough facilities that can serve as the mounting infrastructure for the rooftop solar system portion of the microgrid, and these systems can supply an adequate amount of energy for community customers.

Figure 15
Helioscope Designs for the CIFs Contained in Census Tract 6085500200

Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Osborne Juvenile Center Address: 840 Guadalupe Pkwy. San Jose, CA 95110 Estimated system size: 912 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Santa Clara County Sheriff's Office Address: 555 W Younger Ave. . San Jose, CA 95110 Estimated system size: 297 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Main Jail North Address: 150 W Hedding St. San Jose, CA 95110 Estimated system size: 340 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Main Jail South Address: 885 N San Pedro St. San Jose, CA 95110 Estimated system size: 289 kW	

Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: San Jose Police Department Address: 210 W Mission St. San Jose, CA 95110 Estimated system size: 429 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: San Jose Police Department Impound Garage Address: 330 Terraine St. San Jose, CA 95110 Estimated system size: 1038 kW	
Critical Infrastructure Facility (CIF) details	Helioscope layout
CIF name: Peter Burnett Middle School Address: 850 N Second St. San Jose, CA 95110 Estimated system size: 625 kW	

Table 11

Summary of Suitability Analysis Results for the Third Most Suitable Site, Tract 6085500200

Census tract	6085500200
City	San Jose
Count of CIFs	7
CalEnviroScreen 4.0 percentile	50.5
CalEnviroScreen 4.0 group classification	50-75%
Count of power outages	622
Estimated rooftop solar generation (MW)	3.92
Estimated number of homes that could be powered	1,020

Table 12

Summary of Estimated Battery Size Calculation for the Third Most Suitable Site, Tract 6085500200

Average daily usage per home (kWh)	18
Number of days of autonomy	0.17
Number of housing units	2,215
State of Charge (SOC)	5%
Battery size (MWh)	7.14

Note. Daily energy usage is calculated by multiplying the average daily usage per home (18 kWh) by the number of housing units in the census tract (2,215 units).

Discussion

California has invested significantly in accelerating solar energy adoption and has the largest solar PV system capacity in the United States (U.S. Energy Information Administration, 2023). In this rapidly accelerating energy transition, there are critical questions that need to be considered at every stage to ensure that this transition is achieved equitably: who is able to participate and why? Who directly benefits? To whom do the benefits accrue? The inverse of these questions is even more critical: who is excluded or has more barriers to entry? What are the costs associated w this transition and to whom do costs accrue? What are the costs to all of these inequities?

Social disparities in grid reliability and energy security are severe. However, it is not until relatively recently that power outages were included in the narrative of vulnerability to severe weather and natural disasters across literature (Dugan et al., 2022). The impacts of longer lasting and more frequent power outages are unequally distributed among socioeconomic and sociodemographic groups, thus impacting an individual's or groups' social vulnerability (Casey et al., 2020; Dugan et al., 2022; Molinari et al., 2017). Many studies show that low-income communities and communities of color often experience more frequent (Rodríguez et al., 2022) and/or longer power outages compared to other groups (Azad & Ghandehari, 2021; Liévanos & Horne, 2017; Rodríguez et al., 2022); these groups also often face longer recovery times and more direct and indirect consequences (Coleman et al., 2020; Dugan et al., 2022; Mitsova et al., 2019).

From October 2017 to October 2022, the number of power outage events in PG&E's service area in Santa Clara County has steadily increased, as has the number of customers impacted by these events, which exemplifies a need for communities to have plans for when the current grid proves to be unreliable. It is also clear that socioeconomic disparities are growing at an alarming rate throughout the county (Myers-Lipton & Armaline, 2021), which mirror socioeconomic disparities in the energy transition. This highlights the need to identify and prioritize socially vulnerable groups and communities so when there are power supply intermittencies, information, assistance, and resources can be deployed in a more targeted manner and have more impactful results.

To date, there are four operating microgrids in Santa Clara County located at: JSR Micro, Inc.in Sunnyvale (commercial application), PG&E's Yerba Buena Research and Development facility (research application), Santa Clara University (university application), and Extreme Networks Headquarters (commercial application). These microgrids are private projects and were deployed as a response to private, internal needs and do not provide service to the greater community. This differs from community microgrids, which are typically designed to serve the portions of communities that include community resources and supply these communities with critical energy resilience during extreme weather, Public Safety Power Shutoff events, or other events that cause intermittencies in power supply. Deployment of community microgrids would not only provide more reliability in the power supply system but may also lead to growing levels of adoption of other clean energy technologies in these and adjacent communities (Shittu & Weigelt, 2022). As exposure and accessibility grow, associated benefits like local job creation, reduced air pollutants due to cleaner energy generation source, and increased energy autonomy will also be realized in these communities, working towards closing the equity gap in the energy transition.

Energy justice outcomes should be considered at every step and every level of the energy planning, decision-making, and execution process to ensure that energy security and energy resilience are not benefits reaped only by those who are privileged enough to afford and have access to resources. In this study, energy justice is leveraged as a tool to identify communities best suited for deploying a community microgrid; the three census tracts presented in the results deep dive portion of this study highlight tracts that balance both need for technology and have technical feasibility. This study demonstrated this need through CalEnviroScreen 4.0 scores and vulnerability to power outages is weighed in the suitability analysis, as well as technical feasibility of sites in terms of the number of CIFs (public service/community resources) available and the estimated rooftop solar generation for these facilities, which are important to understand to ensure the tract has enough infrastructure to support a microgrid system and that the system can supply a large amount power. Identified tracts from this study could serve as part of an evaluation in allocating and distributing resources and funding for community microgrid projects or other community-centric energy resilience projects.

The methodology of this research can inform concerns regarding equity in the energy transition. One application could be in the public policy sector in relation to the Justice40 Initiative, which is the Biden administration's initiative to "bring resources to communities most impacted by climate change, pollution, and environmental hazards" in an effort to "confront and address decades of underinvestment in disadvantaged communities" (U.S. Department of Transportation, n.d.); this initiative directs 40% of the overall benefits of certain Federal investments to flow to DACs. Although undoubtedly progressive and a big step forward, how can we ensure the benefits actually accrue to DACs? What metrics are being used to measure success? Are the metrics community-centric or results-centric? The prioritization of local, community-specific data from this research is an approach that would ensure benefits of these microgrids would accrue to the targeted DACs, and adopting a similar approach in execution of Justice40-related efforts would ensure proper resources and associated benefits accrue to communities that need it most.

Conclusion

This study provides information for understanding the potential for deployment of community solar microgrids in Santa Clara County, particularly for underserved communities that could benefit the most from increased reliability and resilience in their electric grid. The results of this study could support the planning and decision-making process and highlight metrics and parameters that should be included when considering deployment of community solar microgrids. To achieve a just energy transition, access to clean energy technologies must be equitable, and energy justice must be leveraged not only as a concept but also a tool in the energy decision-making process.

Limitations and Future Research

Barriers of financing microgrid projects are beyond the scope of this study but would be important to understand for the long-term trajectory and successful life cycle of a project like this. Deep technical details regarding microgrid control structure, system design, location of battery, and details of the battery management system are also beyond the scope of this study.

Further research could be conducted on the economics, policy, and program implementation side of microgrid projects in order to further analyze barriers to deployment in DACs, as these are critical factors in energy justice outcomes. A deeper dive into regulatory and bureaucratic obstacles to microgrid development in local communities (such as options for local control over distribution), would be interesting to further analyze barriers in deployment.

In a future study, another interesting facet to consider would be analyzing avoided emissions for a diesel generator versus a solar-based microgrid. Diesel generators are very popular around the world, largely because of their well-recognized reliability and durability, efficiency, and safety (lower volatility) compared to other longstanding generator types such as natural gas generators. In the United States, demand for diesel generators is becoming increasingly popular - with the market projected to grow from $4.89 billion in 2021 to $6.94 billion in 2028 (Fortune Business Insights, 2021) - in residential, commercial, and industrial markets. This growth is largely related to the increased frequency of power outage events. However, the impacts of diesel generators are extremely harmful to the environment and humans; diesel exhaust contains harmful environmental pollutants and more than forty toxic air contaminants, including nitrogen oxide which is currently the single most important ozone-depleting emission, as well as benzene, arsenic, formaldehyde, and many other known or suspected cancer-causing substances (Awofeso, 2011). Although they do have a higher upfront cost compared to diesel generators, solar-based generators are a 100% clean energy source that produce zero carbon emissions during operation. An analysis of avoided emissions in the scenario of deploying a solar-based generator versus a diesel generator could provide clear data on the favorability of solar-based generators and contribute to favorable policymaking and funding. Another interesting layer to add could be estimating the impact on DACs, such as the estimated number of premature deaths avoided due to decreased air pollutants.

In this study, the estimate for the number of homes the designed microgrid could power is calculated using SEIA's calculated average household electricity consumption, which is based on "whole house power" rather than "partial house power." Whole house power considers all electrical loads for a house, including both critical loads and non-critical loads. Critical loads are typically defined as loads that are crucial to essential operation; examples of common critical loads in a household are: refrigeration, lighting, well pumps, and outlets to run small 120 volt appliances (such as charging devices). Non-critical loads are loads that, if not supplied with power, will not put households at risk; common examples of non-critical loads in a household are air conditioning, washer and dryer units, and EV charging. Partial house power considers allocating only enough power to support critical loads. In this study, microgrids are designed as a community resource designed to increase reliability of the local grid particularly in an emergency capacity, such as any power supply intermittencies from unexpected weather events or Public Safety Power Shutoffs. In the context of emergency events, the distinction between whole house power and partial house power is important because usage per house should only be calculated using critical load power, meaning only load needed to power basics like a fridge, lights, or small 120 volt appliances. With partial house power usage, homes will not be able to use air conditioners or washer and dryer units during an outage, but they will be able to keep fridges running and some lights on. Calculating partial house power and conducting calculations using partial house power could be an interesting area for future research, particularly in terms of battery sizing.

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Appendix

Datasheet for the Silfab Commercial SIL-500 HM

ELECTRICAL SPECIFICATIONS		500 HM	
Test Conditions		STC	NOCT
Module Power (Pmax)	Wp	500	369
Maximum power voltage (Vpmax)	V	38.80	35.69
Maximum power current (Ipmax)	A	12.89	10.34
Open circuit voltage (Voc)	V	45.78	42.11
Short circuit current (Isc)	A	13.48	10.82
Module efficiency	%	21.0%	19.4%
Maximum system voltage (VDC)	V	1500	
Series fuse rating	A	25	
Power Tolerance	Wp	0 to +10	

Measurement conditions: STC 1000 W/m² • AM 1.5 • Temperature 25 °C • NOCT 800 W/m² • AM 1.5 • Measurement uncertainty ≤ 3%
Sun simulator calibration reference modules from Fraunhofer Institute. Electrical characteristics may vary by ±5% and power by 0 to +10W.

MECHANICAL PROPERTIES / COMPONENTS	METRIC	IMPERIAL
Module weight	26.2kg ±0.2kg	57.8lbs ± 0.4lbs
Dimensions (H x L x D)	2098 mm x 1133 mm x 35 mm	82.6 in x 44.6 in x 1.37 in
Maximum surface load (wind/snow)*	2400 Pa rear load / 5400 Pa front load	50.1 lb/ft² rear load / 112.8 lb/ft² front load
Hail impact resistance	ø 25 mm at 83 km/h	ø 1 in at 51.6 mph
Cells	132 Half cells - Si mono PERC 10 busbar - 182 mm x 91 mm	132 Half cells- Si mono PERC 10 busbar - 3.58 x 7.16 in
Glass	3.2 mm high transmittance, tempered, DSM antireflective coating	0.126 in high transmittance, tempered, DSM antireflective coating
Cables and connectors (refer to installation manual)	1350 mm, ø 5.7 mm, EVO2 from Staubli	53.15 in, ø 0.22 in (12AWG), EVO2 from Staubli
Backsheet	High durability, superior hydrolysis and UV resistance, multi-layer dielectric film, fluorine-free PV white backsheet	
Frame	Anodized Aluminum (Silver)	
Bypass diodes	3 diodes - GF5045 (45V max DC blocking voltage, 50A max forward rectified current)	
Junction Box	UL 3730 Certified, IEC 62790 Certified, IP68 rated	

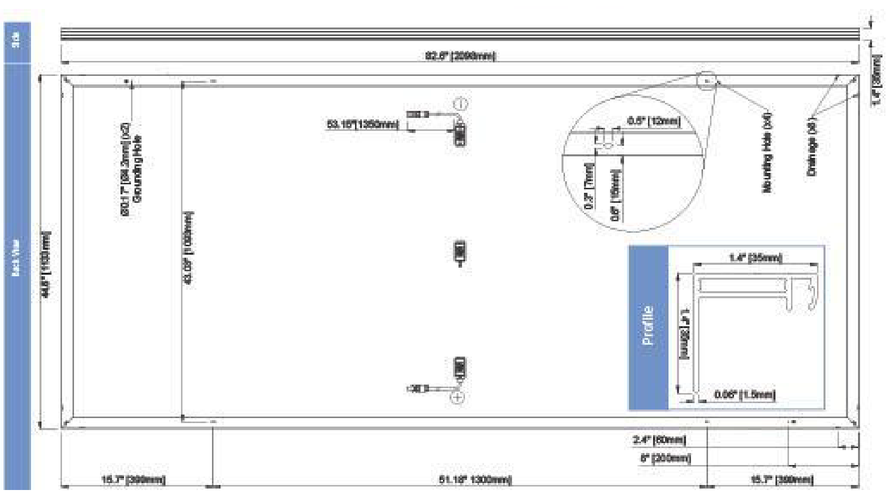
TEMPERATURE RATINGS	
Temperature Coefficient Isc	+0.064 %/°C
Temperature Coefficient Voc	-0.28 %/°C
Temperature Coefficient Pmax	-0.36 %/°C
NOCT (± 2°C)	45 °C
Operating temperature	-40/+85 °C

WARRANTIES	
Module product workmanship warranty	25 years**
Linear power performance guarantee	30 years
	≥ 97.1% end 1st yr ≥ 91.6% end 12th yr ≥ 85.1% end 25th yr ≥ 82.6% end 30th yr

CERTIFICATIONS	
Product	UL 61215-1:2017 Ed.1, UL 61215-2:2017 Ed.1, UL 61730-1:2017 Ed.1, UL 61730-2:2017 Ed.1, CSA C22.2#61730-1:2019 Ed.2, CSA C22.2#61730-2:2019 Ed.2, IEC 61215-1:2016 Ed.1, IEC 61215-2:2016 Ed.1, IEC 61730-1:2016 Ed.2, IEC 61730-2:2016 Ed.2, IEC 61701:2020 (Salt Mist Corrosion), IEC 62716:2013 (Ammonia Corrosion), CEC Listing, UL Fire Rating: Type 1
Factory	ISO9001:2015

SHIPPING SPECS	
Modules Per Pallet:	29 or 29 (California)
Pallets Per Truck	24 or 23 (California)
Modules Per Truck	696 or 667 (California)

* ⚠ Warning. Read the Safety and Installation Manual for mounting specifications and before handling, installing and operating modules.
** 12 year extendable to 25 years subject to registration and conditions outlined under "Warranty" at silfabsolar.com
PAN files generated from 3rd party performance data are available for download at: silfabsolar.com/downloads



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