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Supporting Equitable Healthcare Through Solar Energy Assessment Tools

A group project submitted in partial satisfaction for the degree of
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The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the Bren School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions. The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

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1. Project Description

Federally Qualified Health Centers (FQHC) serve 32.5 million low-income and marginalized patients across the U.S. (HRSA, 2025). They provide essential healthcare services to underserved communities, often operating under resource constraints and in areas prone to power disruptions. Enhancing these centers' operational resilience and sustainability is vital to ensure uninterrupted care and community support. This project aims to create an evaluation system based on a cost-benefit approach to analyze the viability of implementing solar and storage systems at FQHCs. This evaluation system will provide our client, Collective Energy (CE), with a comprehensive tool to conduct a cost-benefit analysis to aid in all FQHCs' assessment of adopting solar and storage solutions to improve their resilience and capacity to serve their communities effectively. By implementing solar energy and storage, FQHCs can reduce their reliance on the traditional power grid, mitigate the impact of natural disasters, and continue operations during power outages, preserving revenue and critical healthcare services.

2. Objectives

2.1 General objectives:

This project aims to develop a **dual-purpose evaluation system** to support CE's efforts in expanding solar and battery adoption at FQHCs.

- **Cost-Benefit Analysis** (CBA) – Evaluate the feasibility of implementing solar energy systems and battery energy storage systems (BESS) at Federally Qualified Health Centers (FQHCs).
- **Prioritization Framework** – Creating a data-driven tool to help CE prioritize FQHCs that play critical roles in their communities for effective and impactful resource allocation.

2.2 Specific objectives:

a. Evaluate the financial feasibility of installing solar energy and/or battery storage systems at FQHCs through a CBA.
b. Build a model incorporating social equity and financial components for CE to prioritize impactful resource allocation.
c. Create two (2) interactive shiny dashboards for both FQHCs and CE displaying key metrics and data for informed decision-making.

3. Background

FQHCs are community-based healthcare providers that receive federal funding through the Health Resources and Services Administration (HRSA) Health Center Program to deliver primary care services in underserved areas. They serve as critical healthcare access points for low-income, uninsured, and medically vulnerable populations. Community Health Centers, Migrant Health Centers, Health Care for the Homeless, and Health Centers for Residents of Public Housing are all part of the FQHC network (HRSA, 2025).

According to the HRSA (2025) in 2023 alone, more than 31 million people relied on FQHCs, including 1 in 8 children in the U.S., 4.7 million uninsured, Medicaid, and Medicare patients, 1.4 million people experiencing homelessness, and more than 1.1 million students served at school-based health centers.

About 90% of these patients had incomes at or below 200% of the federal poverty level, highlighting the essential role FQHCs play in bridging healthcare access gaps. However, these clinics often operate under strict budget and resource constraints and face frequent disruptions due to power outages, severely impacting their ability to deliver care. Power outages—caused by extreme weather events, grid failures, or natural disasters—threaten healthcare access in underserved communities. FQHCs rely on electricity for medical equipment, refrigeration for vaccines and medications, electronic health records, and life-saving procedures. A single blackout can result in canceled appointments, financial losses, and even loss of life for patients dependent on powered medical devices. Without electricity, they can't serve their patients.

Solar energy and battery storage systems offer a sustainable and resilient energy solution to partially mitigate these risks. These systems reduce reliance on the traditional grid, allowing FQHCs to maintain operations even during outages. Collective Energy (CE), the client for this group project, is dedicated to equipping FQHCs with on-site solar panels and battery storage to enhance their energy resilience. By doing so, these health centers can continue providing uninterrupted care while lowering operational costs and reducing carbon emissions.

4. Significance

This project will enable more strategic resource allocation and support FQHCs in enhancing their resilience, reducing their reliance on fossil-fuel-based generators, and maintaining essential healthcare services even during crises. However, the project has broader impacts.

Many FQHCs rely on diesel backup generators, contributing to greenhouse gas (GHG) emissions and air pollution. Transitioning to solar and battery storage reduces reliance on fossil fuels, lowering emissions while ensuring reliable power. This shift aligns with broader sustainability and environmental justice goals by making clean energy accessible to underserved communities.

Power disruptions lead to substantial financial losses for FQHCs, including spoiled vaccines, canceled appointments, and damaged medical equipment. This project quantifies those costs and highlights the financial benefits of renewable energy adoption. By maintaining operational continuity, solar and battery systems help retain revenue and reduce unexpected expenses from grid failures and disturbances.

Blackouts directly threaten patient care by shutting down or even shorting critical medical equipment, interrupting medication refrigeration, and limiting access to electronic health records. Our evaluation system prioritizes the most heavily impacted clinics, ensuring that patients in underserved areas retain access to care even during emergencies.

This project supports environmental justice by addressing energy poverty, improving healthcare access, and ensuring resilience in low-income areas. The prioritization framework helps CE focus on the clinics and communities that need it most.

By identifying FQHCs that serve the most critical roles in their communities, CE can maximize its impact and ensure that the clinics supporting the most vulnerable populations are equipped first. This targeted approach strengthens the overall healthcare system resilience in underserved regions across the nation.

5. Methods

Our approach consisted of two main components: data processing and dashboard development. Both components involved building data-driven models.

The data component involved four main steps: (1) selecting relevant variables, (2) collecting data (3) processing and cleaning the dataset to ensure consistency and accuracy, and (4) building the models.

The dashboard component focused on transforming the processed data into an interactive visualization tool. This included (1) selecting the most relevant variables for display for each dashboard, (2) integrating data and equations to enable reactive outputs, and (3) designing the dashboard's layout and user interface for clarity and accessibility.

We dedicated the quarters of Spring 2024 and Fall 2024 to reviewing, sourcing, and processing the data, and the Winter 2025 and Spring 2025 quarters to building the dashboards and outputs.

5.1 Data processing

Our client, CE, provided initial data, such as FQHC locations, patient characteristics and demographics by site, and solar generation potential for 40 sites which were mostly used as training data for Solar API calculations. Beyond this data, we identified 12 key variables necessary for our models. These were divided into three categories according to the outputs they would provide:

A) Site risk: This category assesses the vulnerability of FQHCs to external disruptions, including the frequency and duration of power outages and the risk of natural disasters at the county level.
B) Financial costs and benefits (referred from now on as "financial data"): This includes factors influencing the financial feasibility of solar energy and BESS adoption, such as energy production potential, consumption costs, installation expenses, available incentives, and the financial impact of power outages on patient services.
C) Social vulnerability: This category captures the broader social and health context, considering health disparities which affect energy needs and resilience planning.

The variables are further explained in the following table, followed by an explanation of the analysis process for each and the methods to integrate the results into the dashboard:

Table 1. Categories and Variables

Category	Variables	Description
Site-risk	Power outage risk	Power outage frequency and duration based on historical data at the county level.
	Natural disaster risk	Risk of natural disasters (e.g., hurricanes, floods, wildfires, etc.) at the county level.
Financial data	Solar energy production	The amount of energy an FQHC can generate. Based on site-specific factors such as geographic location, rooftop area and panel efficiency.
	Energy consumption & utility costs	The amount of energy an FQHC consumes, and the cost of usage from their utility supplier
	Financial incentives for solar	Local and federal incentives, including the Investment Tax Credit (ITC).
	Solar installation costs	Costs associated with the purchase, installation, and maintenance of solar panels.
	Hourly revenues (Patients per hour)	Hourly revenues obtained from patients seen per hour
	Value of vaccines stored	The monetary value of vaccines stored in refrigeration
	Battery Energy Storage System (BESS)	Based on energy use, capacity $/kWh via client estimates
Social vulnerability	Medically Underserved Populations	Identifies is the clinic serves a Medically Underserved Area (MUA) or Population (MUP).
	Health disparities	Combined metric that presents health disparities and marginalization rate at the county level.
	Rural/Urban designation	Identifies whether an FQHC is located in a rural or urban area

5.1.1 Site-risk

Power outage risk:

The power outage data was sourced from Brelsford, C., Tennille, S., Myers, A. et al. *A dataset of recorded electricity outages by United States county 2014–2022*. (2024). We used the annual outage data files and their data around modeled customers per county (MCC). The MCC file was estimated for 2022 and allows for calculating some important metrics related to this topic. In all, there is roughly 8 gigabytes (GB) of data. The outage dataset contains the county FIPS code, county name, state name, number of customers, and time of outage. It presents observed outages, monitored every 15 minutes.

To use the data, it was necessary to address two anomalies in the dataset:

a. 5-10% of the entries record an outage for any given year without any customers affected. Oftentimes, utility companies serve areas that are not confined by county boundaries. Although an outage may only affect customers in one of the utility's service counties, it gets recorded as an entry for each county that the utility serves. Since these outages have no impact outside of counties where customers were impacted, these entries were removed from our analysis.
b. On a few occasions, outage events were reported as impacting more customers than were actually reported in the MCC. To address this, our data cleaning process records the maximum number of customers impacted in an outage for each county. Maximums that exceed the values in the MCC will replace the prior value to improve accuracy.

These anomalies were brought to the paper's author, Christa Brelsford, who provided context and noted that these two items were the most significant issues with the data. Once the data was cleaned and processed, we took the following steps to determine the average annual outage risk per county:

To determine when a new outage occurs, we sort the data by county and time so that all entries are in order. If an outage has the same number of customers out as the one before it, is 15 minutes apart from the previous entry, and is in the same county, it is a continued outage. Otherwise, we begin recording for a new outage event. Now that the data is grouped by outage event, we can summarize these events by calculating the duration.

As outages are monitored every 15 minutes, the point of acknowledgment for any given outage could range from 1 second to 14 minutes and 59 seconds. An outage could have started the exact second after the previous monitoring time or right before the current one. This range of uncertainty occurs both before and after every outage period. There was no literature surrounding the duration distribution for short-term power outages, so it is assumed that all outages with only one observed instance of outage last 15 minutes.

This assumption comes from the mean of a uniform distribution that ranges from 0 to 30 minutes, representing the average uncertainty around the endpoints of an outage event. With the monitoring period of 15 minutes, we expect to capture only ⅔ of all 10-minute outages, ⅓ of all 5-minute outages, and so on. This is unavoidable but likely results in a somewhat sizable gap in data. Roughly half of all outages in the data had only one observation period, so there may be significantly more outages that went unnoticed.

For 2022 and 2023, the script will save data once the outage event summarizes it. This data is still quite large, about 450 megabytes (MB) annually, because of the millions of national outages observed. This data will be useful in showing individual county trends more granularly and generating histograms of outage duration for each county in the dashboard.

We summarized the data further so there is a single entry per county. All outage events in a county will be combined into summary statistics. These include the number of outages, the total number of customers affected, the total duration of outages, and SAIDI and SAIFI. SAIDI and SAIFI should be interpreted as the average number of power outages and the average duration of outage for the average customer of a given county for that calendar year. These statistics are only comparable when the timespan they refer to is consistent.

System Average Interruption Duration Index (SAIDI) measures service reliability. The following equation can express it:

$$\mathrm{SAIDI} = \frac{\sum_{i=1}^{n} U_i * N_i}{N_t}$$

Where U_i is the duration of utility interruption for each of the n interruptions experienced, N_i is the number of customers impacted for each of the n interruptions experienced, and N_t is the total number of customers provided. It can be interpreted as the average time a customer can expect to experience an outage in a given period.

System Average Interruption Frequency Index (SAIFI) is a measure of the frequency of outages, measured as

$$\mathrm{SAIFI} = \frac{\sum_{i=1}^{n} N_i}{N_t}$$

where N_i is the number of customers impacted by each interruption experienced, and N_t is the total number of customers the utility provides. It can be interpreted as the average number of times a customer can expect to experience a power outage in a given period.

Natural disaster risk:

The natural disaster risk data was sourced from the Federal Emergency Management Agency (FEMA). FEMA (2025) defines a natural disaster as "environmental phenomena that have the potential to impact societies and the human environment."

We used the National Risk Index for Natural Hazards (NRI) data. The NRI is an online tool designed and built by FEMA in close collaboration with 91 entities, including state governments and institutions. It compiles natural hazards and community risk factors to develop a baseline risk measurement for each United States county and census tract.

The NRI assigns relative Risk Index percentiles and ratings based on data for expected annual loss from natural hazards, social vulnerability, and community resilience. Each of these components also has its separate percentiles and ratings. For the Risk Index and expected annual loss, scores can be viewed as an overall composite for all hazards or broken down by each of the 18 specific hazard types.

A community's score is expressed as a percentile ranking, compared to all other communities at the same level. For instance, if a Census tract has a Risk Index percentile of 79 for a particular hazard, it means its risk level is higher than 79% of all U.S. Census tracts. Additionally, qualitative ratings ranging from "Very Low" to "Very High" describe how a community compares to others at the same level for risk, expected annual loss, social vulnerability, and community resilience.

5.1.2 Financial data

The financial data is categorized into two main areas: Solar energy adoption and Battery Energy Storage Systems (BESS), to evaluate their financial feasibility Each category has different variables further explained in the next sections.

Solar energy adoption

The solar energy adoption model is a cost-benefit analysis. The cost input in the model is Installation and maintenance, while the benefits will be obtained from processing solar energy production and tax incentives. Energy utility costs are also an input in this assessment.

Solar energy production:

Solar energy production potential estimates how much energy an FQHC can generate based on site-specific factors. To generate results for all FQHCs, we used Google's Solar API, specifically the buildingInsights endpoint. Solar API which calculates the amount of energy produced by each site as influenced by factors such as the capacity of the solar installation, geographic location, solar irradiance, and system efficiency.

This tool provides detailed solar panel configuration data for residential buildings; however, our team works with a combination of residential and commercial buildings. To account for potential differences in results, we aligned the outcomes from SolarAPI as closely as possible to screenings that Collective Energy had previously processed using software from Aurora.

We received and analyzed roughly 40 pre-existing Aurora screenings from CE that served as a benchmark for us to compare against buildingInsights. Our analysis revealed that SolarAPI overpredicted annual solar generation by roughly 12% compared to Aurora screenings with the same solar array size.

Another consideration from SolarAPI is that the maximum number of panels listed by SolarAPI was considerably higher than the screenings. We trained a linear regression model on the supplied screenings to solve this issue. The model predicts the number of panels for any rooftop based on the maximum number of panels as given by SolarAPI, as well as the size of the roof. Although this model was quite simple, the resulting R^2 score was 0.905. This means the maximum panel count and roof size change can account for 90.5% of the change in the modeled panel count.

We retested SolarAPI results to the original Aurora screenings with these two adjustments. On average, SolarAPI overestimated solar potential by a margin of 10%. This was within the agreed margin of error, so we applied this process to all 12,000 sites. The data that results from this process includes roof area, modeled panel count, nameplate capacity, and annual solar production in kilowatt-hours. When running SolarAPI, all API request responses are saved for future reference. This is useful if the underlying process here is altered, preventing the need for API use and incurring more costs.

There are known issues with the location data, as SolarAPI relies on coordinates to match buildings, but the provided coordinates were based on streetfront addresses rather than rooftops.We utilized Google's Geocoding API to refactor all of these coordinates to match the appropriate rooftop. From our initial testing, this significantly improved the accuracy of SolarAPI queries, preventing solar generation estimates from generating for neighboring structures. Some sites still don't have precise addresses that align with a building in Google Maps, which means their SolarAPI results may be incorrect. We increase the accuracy of this data by adding functionality in the dashboard so that clinics can record their correct site information and run our system with the correct coordinates.

Energy utility costs:

The energy utility cost represents the cost per unit of electricity supplied by the utility company, in cents per kilowatt-hour (¢/kWh). We initially considered sourcing this data from Google API. However, there is considerable disagreement between what Google API predicts and what is noted in the screenings regarding energy utility costs.. Therefore, we consulted different sources, including utility companies, the Bureau of Labor Statistics (2025) and the U.S. Energy Information Administration (2025) and set the rate to be 20 cents per kWh for a commercial building.

Financial incentives for solar:

Tax incentives are crucial in the cost-benefit analysis as they can lower costs and help FQHCs afford solar. We identified three tax incentives available to these centers that can help offset solar installation costs at different levels: federal, state-specific and local tax incentives. Given the variability of state-specific incentives, we focused on federal and local tax incentives, which are explained as follows:

Tax incentives: According to the U.S. Department of Energy, the Investment Tax Credit (ITC) allows businesses to deduct a percentage of their solar installation costs from their federal taxes. As of 2024, the ITC provides a tax credit equal to 30% of the total installation cost for both new and existing commercial properties. The federal tax incentive is applicable to all FQHCs and was considered for CBA analysis.

Energy Communities Tax Incentive Calculation:

According to designation by the U.S. Department of Energy, Energy communities are areas that have historically relied on fossil fuel industries or have been affected by environmental challenges. These communities often have the highest concentrations of coal employment and have experienced the most substantial losses of coal mines and coal-fired power plants in recent years. As part of efforts to support their revitalization, these communities are eligible for additional tax incentives of up to 10%. To qualify for these incentives, regions must meet specific criteria, including one of the following two alternatives:

1. **Census Tract Alternative**:
    - A coal mine that closed after 1999, or
    - A coal-fired electric generating unit that was retired after 2009, or
    - A census tract directly adjacent to one of these areas.

2. **Metropolitan or Non-Metropolitan Statistical Area**:
    - The area has an unemployment rate above the national average, and
    - A significant portion of the local economy is dependent on fossil fuel extraction, processing, transportation, or storage, or
    - The area is in close proximity to closed or retired coal mines or coal-fired electric generating units (closed after 1999 or 2009, respectively).

These incentives aim to support areas transitioning away from fossil fuel dependency.

The following steps were taken to identify and analyze relevant data, we:

1. Used shapefiles from the energy communities websites to identify areas meeting the criteria for energy community designation.
2. Converted spatial components to the same coordinate reference system (CRS) as the FQHC locations we generated from Google's Geocoding API, using R.
3. Intersected the data from over 11,000 FQHC locations across the United States with the energy community regions, determining which sites qualify.

Our analysis revealed that more than 40% of FQHCs are in regions eligible for energy community tax incentives. As a result, we compiled a dataset that includes the federal energy community tax incentives for each FQHC.

Solar installation costs:

We determined solar installation costs using two approaches: (1) conducting online research to gather average installation costs from solar companies and (2) referencing the *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks, With Minimum Sustainable Price Analysis: Q1 2022* by National Renewable Energy Laboratory (NREL).

Our findings indicate that commercial solar panel installation costs typically range from $2.50 to $3.50 per watt for systems installed in 2024. The exact price varies based on factors such as system size, roof type, mounting structure (roof, ground, or carport), shading, permitting, and interconnection requirements.

According to the Solar Market Insight Report published by the Solar Energy Industries Association (SEIA) in 2025, commercial solar systems cost an average of $1.66 per watt as of 2023, significantly lower than residential installations at $3.27 per watt. Overall, commercial solar panel costs range from $2 to $3 per watt, with total system costs for businesses typically falling between $200,000 and $1,500,000 for systems ranging from 100 kW to 500 kW. We obtained data on the installation costs per state that will be applied into our calculations.

As mentioned above, another cost that will be factored into our calculations is annual maintenance. According to different commercial providers nation-wide, the annual maintenance cost ranges from $200 - $450 dollars; we will select $300 dollars/year as the annual maintenance cost for our model.

Financial incentives and ITC help offset these expenses. After accounting for incentives, final installation costs drop to $1.20–$1.75 per watt, depending on location, system size, and complexity. We also sourced state-level data to improve accuracy in determining average installation costs per kW. Our dataset, then, showcases the installation cost per watt at the state level.

Battery Energy Storage System

Hourly revenues (Patients per hour):

Battery storage systems can benefit an FQHC by allowing it to stay operational during a power outage. This benefits patients, and we capture the benefit by estimating the revenues that would have been lost had the power outage occurred. According to the *FQHC Financial & Operational Performance Analysis*, 2019-2022, published in 2024 by Capital Link and the HRSA, in 2022, the national median operating revenue for health centers was $21.9 million, with the median urban health center generating $27.0 million and the median rural center reporting $16.4 million. From 2021 to 2022, the national median revenue for health centers grew by 8%, following a 23% increase from 2020 to 2021. The revenue growth rate in 2022 was lower than that of the urban (9%) and rural (12%) medians.

The median health center's average operating revenue per visit was $311 in 2022, following a peak of $327 in 2021. In 2022, the median patient was estimated to have 3.8 visits each year.

For the CBA analysis, it's necessary to have information on a clinic's average hourly or daily revenue to assess how outages impact them financially. As for now, CE has provided us with a database containing the annual number of patients. However, this is not at the clinic level but aggregated data at the administrative level, so we don't have specific data on the hourly revenue per clinic. We estimated the hourly patient visits to be 3 patients per 1,000 square foot based on the Cost Per Visit Report: Measuring Health Center Performance by the National Association of Community Health Centers (2016). However, the clinics will be able to overwrite this standardized value on the dashboard for more accurate results.

Value of vaccines stored in refrigeration

The monetary value of stored vaccines is a metric that will allow us to build the CBA for BESS installation. Vaccines can spoil during power outages lasting over 4 hours (*Power Shut-Offs – California Vaccines for Children (VFC)*, n.d.). This criteria was selected by the client. We used information provided on the Cost Per Visit Report: Measuring Health Center Performance (2016) to determine a value of $20 per square foot. However, as this value varies within clinics, each clinic will be able to provide the monetary value through the dashboard.

Battery installation costs:

After initially considering use of data from National Renewable Energy Laboratory (NREL) on estimates for total cost of batteries and their installation, we instead proceeded with estimates that CE uses in-house for greater accuracy. Installation and permitting fees vary by location and installer, but the estimated cost for battery purchase and installation is $1232/kWh for the capacity, and \$3,610/kW for power. These estimates that CE uses include their project development fee. As with our solar calculations, annual maintenance was included in our calculations as an annual maintenance cost of \$10/kWh/year for our model

5.1.3 Social vulnerability

These components will support decision-making for the most effective and impactful allocation of resources with a focus on healthcare equity. This data will feed the prioritization model and be displayed in the CE dashboard.

Medically Underserved status:

Our analysis focused on Medically Underserved Areas (MUA) and Medically Underserved Populations (MUP), as these designations best align with our research objectives. Data for these designations were sourced from the Health Resources & Services Administration (HRSA), identifying areas and populations experiencing shortages in primary health care services.

MUAs are geographic regions—such as entire counties, groups of counties, or urban census tracts—where residents face limited access to primary care services. MUPs, on the other hand, refer to specific population groups within a defined area that encounter barriers to health care These populations include low-income individuals, Medicaid-eligible groups, Native Americans, migrant farmworkers, and homeless populations.

HRSA assigns a score to each designated MUA/P on a 0–100 scale, where 0 represents the most underserved areas, and 100 indicates the least underserved. To qualify for MUA/P designation, an area must meet specific criteria, including the number of primary care physicians per 1,000 residents, the percentage of the population living at or below 100% of the federal poverty level, the proportion of residents over 65 years old, and the area's infant mortality rate. The Index of Medical Underservice (IMU) score determines eligibility, with an IMU $\leq$ 62.0 indicating designation as an underserved area or population.

Given our focus on identifying disparities in healthcare access, we selected MUA and MUP data as the most relevant indicators for evaluating underserved populations. These designations provide a standardized framework for assessing primary care shortages at the local level. We cleaned the MUA/P master dataset provided by the HRSA, leaving only the MUA/P designation for each clinic (with clinic ID).

Health inequity

To assess health inequity and disparities, we developed a comprehensive metric that integrates data from two key sources: the Environmental Defense Fund’s Climate Vulnerability Index (CVI) and the Multidimensional Deprivation Index (MDI) from the U.S. Census Bureau. This approach allows us to capture both current health conditions and structural inequities that shape health outcomes at the county level.

The CVI provides a multi-dimensional view of health risks influenced by environmental and climate-related stressors. It includes factors such as the prevalence of chronic diseases, environmental pollution, and climate-driven health impacts like heat-related mortality.

In contrast, the MDI focuses on socioeconomic factors influencing well-being, such as income, education, housing quality, and economic security. The MDI accounts for individuals experiencing deprivation in multiple dimensions, offering a broader perspective on poverty beyond just income levels. By combining these two datasets, we created a health equity metric that accounts for present-day health conditions and the structural inequities that contribute to them over time.

The CVI is structured to capture health risks using three primary components:

- Baseline Health: includes chronic disease prevalence (e.g., diabetes, asthma, cardiovascular conditions), access to healthcare, maternal and child health, mental health, life expectancy, and preventive care measures.
- Environmental Exposures and Risks: Examines exposure to pollution sources such as air, soil, and water contaminants and broader environmental stressors from transportation and industrial activity.
- Climate Change-Related Health Impacts: Assesses how climate change contributes to health risks, including heat-related deaths, the spread of climate-sensitive infectious diseases, and disasters like hurricanes and wildfires.

While the CVI primarily operates at the census tract level, some datasets are available only at the county or state level. All census tracts within the broader geographic area are assigned the same values in these cases. The MDI is represented as a headcount ratio, meaning that an MDI value of 0.20 indicates that 20% of the population in a given county experiences multidimensional deprivation.

The MDI is calculated based on six core dimensions of deprivation: standard of living, health, education, economic security, housing quality, and neighborhood conditions.

An individual is considered multidimensionally deprived if they experience deprivation in at least two of these six dimensions. Unlike traditional poverty metrics focusing solely on income, the MDI provides a more nuanced view of well-being by identifying individuals and communities facing multiple barriers to a healthy life.

To create our health equity metric, we needed to merge the CVI and MDI datasets at the county level. Since the CVI data initially uses census tract-level data, we aggregated it to the county level by calculating the average values of key health-related variables. The MDI data was already structured at the county level, so no additional transformations were needed.

With some minimal data processing to combine data from these sources together, we were left with a unified dataset where each county had four key health-related variables: Baseline Health

(CVI), Environmental Exposure & Risks (CVI), Climate Change-Related Health Impacts (CVI), MDI Percentile (MDI).

We computed a total score by summing these four variables for each county to finalize our metric. Then, we calculated the percentile rank of each county. This step enabled us to quantify health inequity across different regions, incorporating climate-driven health risks and structural deprivation.

Rural/Urban designation:

This variable identifies whether an FQHC is located in a rural or urban area, as rural areas often face unique energy access and healthcare challenges. We aligned the definition of rural with the Department of Energy (DOE) which states that a rural community "is a city, town, or unincorporated area that has a population of not more than 10,000 inhabitants." A difficulty about finding population through the use of coordinates was that the returned census tract codes may define smaller areas than the DOE considers. DOE doesn't clearly define what they consider a city, town, or unincorporated area with regards to census tracts. For instance, sites located in the outskirts of cities such as Los Angeles are part of their jurisdiction, but have a unique census six digit identification number. So, the full six digit tracts were used to populate this data, leading to some cases where these types of locations would be considered rural.

For demographics calculations, the Census is the most reliable source, thus data from the US Census Bureau was widely used to generate these results. There are three different external files that were used in this process. The first is referred to by the census as DP-1 and is titled "Profiles of General Demographic Characteristics". This table provides the most value out of all the sources, because it has the best coverage for our sites. Next is a data table the census refers to as "City and Town Population Totals". In tandem, these two tables account for all but 582 FQHC locations we're concerned with. The process then utilizes a data set from SimpleMaps, which is used to link the names of neighborhoods with the larger city they belong to..

After using the data above, there were still 322 sites without population data. We utilized their coordinates to find which census tract they line up with using the census source American Community Survey (ACS). The ACS was accessed by our team through an integrated API in the R package "tidycensus". This final methodology covered the remaining sites, meaning that population counts were allocated for all sites in our analysis. From this, our team set the population threshold of 10,000 as noted by the Department of Energy, and classified all sites.

5.2 Dashboards

The second component of the methods is the creation of the dashboards. We compiled all of our data into two dashboards: one that individual FQHCs will utilize for financial assessments and site suitability (FQHC dashboard), the other which Collective Energy can use for facilitating the consultancy process (CE dashboard). Both dashboards were designed in RStudio using the "Shiny" and "Shinydashboard" packages.

5.2.1 FQHC dashboard

Calculations for clinics' assessment

The FQHC dashboard assesses the financial feasibility of adopting solar energy and BESS through a Cost Benefit Analysis (CBA). To assess the cost and benefits of implementing solar energy and/or BESS for each clinic, we:

1. Determined each clinic's potential for solar energy production by integrating site-specific characteristics (e.g., rooftop area) and geographic data (e.g., insolation)
2. Identified the costs associated with loss of electricity by analyzing power outage risks of each clinic and natural disaster risks (e.g., fire, flood, hurricanes).
3. Integrated upfront and long-term costs to determine net present value (NPV) and return on investment (ROI).

The CBA integrates every financial variable previously described and detailed site-risk components, leveraging the most recent data available on costs.

Energy savings from solar production are compared to the current energy costs of these centers, which can vary significantly depending on location. Solar production estimates are derived using Google's Solar API and adjusted based on a regression model to provide accurate energy generation predictions, even in commercial settings. The dashboard generates a clear picture of the expected return on investment for solar adoption by comparing these savings to the upfront and long-term costs.

The power outage data was used to assess the frequency and duration of outages that FQHCs may experience in their respective counties. By calculating metrics such as the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI), the dashboard quantifies the impact of power outages for each site, enabling FQHCs to factor in the economic implications of such disruptions. In addition, the National Risk Index is used to evaluate the risk of natural disasters in each clinic's region, contributing to a more comprehensive understanding of potential operational challenges and the need for energy resilience. The costs and benefits are distributed over 25 and 15-year lifetimes, respectively, which is the standard duration of both technologies.

Solar financial assessment

These calculations enable us to assess the net financial benefits of solar adoption for each site.

Annual Solar Savings ($/year) = Solar Energy Production (kWh) * Utility Rate (¢/kWh)

Where,

- **Annual solar savings ($/year)** represents the total annual savings of utilizing solar energy as an alternative to purchasing electricity from the utility company.
- **Solar energy production (kWh)** refers to the total amount of electrical energy generated by the solar power system in a year in kilowatt-hours (kWh). This value was sourced from Solar API.
- **Utility rate (¢/kWh):** represents the cost per unit of electricity supplied by the utility company, in cents per kilowatt-hour (¢/kWh).

The calculation of the present value lifetime savings is as follows:

$$\textbf{\textit{Present Value Lifetime Savings (2025 \$)}} = \sum_{t=1}^{25} Annual\ Solar\ Savings \ * \ \frac{1}{(1.05)^{t}}$$

Where:

- **Present value lifetime savings (2025 $)** represents the total savings over the lifespan of the system by discounting (rate of 5%) future savings to their equivalent value in 2025.
- **Annual solar savings ($/year)** refers to the annual savings derived from solar energy.
- **t:** range of years in the analysis (1, 2, 3, …, 25) which represents the expected lifespan of the solar system (25-year operational period).
- **1/(1.05)^t** is the component that calculates the present value of future benefits. With a discount rate of 5%, we adjust future savings to their present value in 2025 USD.

The formula used to calculate solar installation costs is:

Solar Install Costs ($/year) = Nameplate Capacity (kW) * Install Cost ($/kW) * (1 - Tax Incentive) * (1 + Collective Energy's Fee)

Where:

- **Nameplate capacity (kW)** represents the size of the modeled rooftop solar array (kW), which is dependent on Google's SolarAPI results.
- **Install cost ($/kW)** is the cost of installing the solar system, expressed in dollars per kilowatt ($/kW).
- **Tax incentive** is utilized to reduce the total installation cost. Every site qualifies for a 30% reduction, and sites that are located in energy communities will see a 40% reduction.

- **Collective Energy's fee** is in reference to its management fees that apply to the total installation cost *before* tax incentives. The fee is expressed as a percentage (e.g., 0.05 for a 5% fee).

The formula to calculate annual solar maintenance cost is:

Annual Solar Maintenance Cost ($/year) = Nameplate Capacity (kW) * Maintenance Cost ($/kW)

Where:

- **Nameplate capacity (kW)** once again represents the size of the modeled rooftop solar array (kW), which is dependent on Google's SolarAPI results.
- **Maintenance cost ($/kW)**: Cost of maintaining the solar system, expressed in dollars per kilowatt ($/kW) are set at $50 per kW. This cost includes regular system inspections, cleaning, and necessary repairs or adjustments to maintain system efficiency.

The calculation of the present value lifetime solar maintenance costs is as follows:

Present Value Lifetime Solar Maintenance Costs (2025 USD) =

$$\sum_{t=1}^{25} Annual\ Solar\ Maintenance\ Cost\ * \ \frac{1}{(1.05)^{t}}$$

Where:

- **Annual solar maintenance cost ($/year)** refers to the yearly maintenance cost of the solar system.
- **t:** range of years in the analysis (1, 2, 3, …, 25) which represents the expected lifespan of the solar system (25-year operational period).
- **1/(1.05)^t** is the component that calculates the present value of future benefits. With a discount rate of 5%, we adjust future savings to their present value in 2025 USD.

Finally, the formula for calculating the solar financial assessment is as follows:

Solar Financial Assessment (2025 USD) = Present Value Lifetime Savings - Solar Install Costs - Present Value Lifetime Solar Maintenance Costs

Where:

- **Present value lifetime savings**: Represents the total savings over the lifetime of the solar system, adjusted for the time value of money, and expressed in 2025 USD.
- **Solar install costs**: Total cost of installing the solar system, in dollars.
- **Present value lifetime of solar maintenance costs**: Total maintenance costs over the lifetime of the solar system, adjusted to 2025 USD using the present value calculation.

Table 2: Summary of values and assumptions for the solar energy financial assessment.

Summary of values and assumptions
1. A discount rate of 5% was used across all NPV calculations. 2. Solar energy production and nameplate capacity were sourced from the SolarAPI. 3. Site-specific utility rates were set to 20 (¢/kWh) for all sites. 4. Tax incentive varies between 0.3 and 0.4 for all sites. 5. The installation cost was set at $3/kW based on NREL data. 6. Maintenance costs were set at a rate of $50/kW based on revision of over 15 commercial solar providers. 7. CE applies its management fees to the total installation cost before incentives are considered. This is present in the dashboard tool but was not explicitly included in the calculation above.

BESS financial assessment

We performed several calculations to assess the costs and benefits of adopting a battery energy storage system. These are presented below:

The formula used to calculate annual value of preserved vaccines is:

Annual Value of Preserved Vaccines ($) = Stored Vaccines ($) * Frequency of 4+ Hour Outages

Where:

- **Stored vaccines ($)**: The estimated annual value of vaccines stored in the facility, calculated based on clinic square footage ($20/square foot) for all sites.
- **Frequency of 4+ hour outages**: The annual number of power outages lasting 4 hours or more that we expect a site to experience based on their county's power outage history..

The formula used to calculate annual value of preserved patient visits is:

Annual Value of Preserved Patient Visits ($) = Hourly Patient Visits * SAIDI / 60 minutes * Revenue per Patient ($)

Where:

- **Hourly patient visits**: Estimated based on clinic square footage. It was assumed that there are 3 patients per 1,000 square feet, given that a provider typically sees about 4 to 5 patients per hour, and a standard provider space is around 1,500 square feet.

- **SAIDI**: System Average Interruption Duration Index, which measures the total duration of power outages over the course of a year.
- **Revenue per Patient ($)**: The revenue per patient visit was standardized at $311 across all clinics, sourced from the financial performance report for FQHCs published by Capital Link in 2022.

The formula used to calculate value of annual value of battery storage is:

Annual Value of Battery Storage ($/year) = Annual Value of Preserved Vaccines ($/year) + Annual Value of Preserved Patient Visits ($/year)

Where:

- **Annual value of battery storage ($/year)** is a combination of the annual value of preserved vaccines and patient visits. This represents the total financial benefit of having battery storage for maintaining operations during power outages.

The formula used to calculate present value lifetime battery savings is:

Present Value Lifetime Battery Savings (2025 USD) =

$$\sum_{t=1}^{15} Annual\,Value\,of\,Battery\,Storage \;*\; \frac{1}{(1.05)^{t}}$$

Where:

- **Present value lifetime battery savings** is adjusted for the time value of money using a 5% interest rate. These savings are derived from the preservation of vaccines and patient visits during power outages.
- **t:** range of years in the analysis, which represents the expected lifespan of the battery energy storage system (15-year operational period).
- **1/(1.05)^t** is the component that calculates the present value of future benefits. With a discount rate of 5%, we adjust future savings to their present value in 2025 USD.

The formula used to calculate battery size for each site is:

Battery Size (kWh) = Peak Power Consumption (kW) * 8 hours

Where:

- **Peak power consumption (kW)** is estimated based on the clinic's annual electricity consumption. Based on a pool of about 50 test sites, the most accurate estimate is by dividing with a factor of 2,750.

The formula used to calculate the present value of battery installation costs is:

Battery Cost (2025 USD) = [Battery Size (kWh) * Cost of Capacity ($/kWh) + Peak Power Consumption (kW) * Cost of Power Output ($/kW)] * (1 - Tax Incentive)

Where:

- **Battery cost (2025 USD)** quantifies the total initial investment required to purchase and install the BESS.
- **Cost of capacity ($/kWh)** is set at $1,100 per kWh, based on data provided by Collective Energy.
- **Cost of power output ($/kW)** is set at $3,220 per kW, also provided by Collective Energy.
- **Tax incentive** is utilized to reduce the total installation cost. Every site qualifies for a 30% reduction, and sites that are located in energy communities will see a 40% reduction.

The formula used to calculate the present value of battery maintenance costs is:

Present Value Lifetime Battery Maintenance Costs (2025 USD) =

$$\sum_{t=1}^{15} Annual\ Battery\ Maintenance\ Cost \ * \ \frac{1}{(1.05)^t}$$

Where:

- **Present value lifetime battery maintenance costs** represents the total maintenance costs in 2025 USD over the lifetime of the battery storage system, adjusted for the time value of money at a 5% interest rate.
- **Annual battery maintenance cost ($/kW)** is set at a rate of $10 per kW, based on industry reports from HRC.
- **t:** range of years in the analysis, which represents the expected lifespan of the battery energy storage system (15-year operational period).
- **1/(1.05)^t** is the component that calculates the present value of future benefits. With a discount rate of 5%, we adjust future savings to their present value in 2025 USD.

The formula used to calculate the final assessment is:

Battery Financial Assessment (2025 USD) = Present Value Lifetime Battery Savings - Battery Cost - Present Value Lifetime Battery Maintenance Cost

Where:

- **Battery financial assessment** is the total financial evaluation of the battery storage system in 2025 USD, accounting for savings from preserved vaccines and patient visits, minus the upfront cost of the battery system and the ongoing maintenance costs.

- **Present value lifetime battery savings** is adjusted for the time value of money using a 5% interest rate. These savings are derived from the preservation of vaccines and patient visits during power outages.
- **Battery cost** quantifies the total initial investment required to purchase and install the battery energy storage system. It takes into account both the capacity of the system and its power output capabilities.
- **Present value lifetime battery maintenance cost** represents the total maintenance costs over the lifetime of the battery storage system, adjusted for the time value of money (5% interest rate). Maintenance costs are incurred annually and include expenses for upkeep, repairs, and inspections to ensure the system operates efficiently.

Table 3: Summary of values and assumptions for the CBA on BESS

Summary of values and assumptions
● An interest rate of 5% was used across all present value calculations. ● Stored vaccine values were estimated based on clinic square footage. A value of $20/sqft was assumed for all sites. ● Frequency of 4+ Hour Outages and SAIDI were sourced from the power outage data processing. ● Hourly patient visits were estimated based on clinic square footage. A value of 3 patients per 1,000 square feet was assumed for all sites. ● Revenue per patient is a standard $311 across all clinics. This value was sourced from the financial performance report for FQHCs from Capital Link (2022). ● Peak power was estimated based on screenings that Collective Energy provided. Peak power is estimated as the site's annual electricity consumption divided by a factor of 2,750. A standard battery is sized based on having a duration of 8 hours at maximum energy consumption. ● Cost of capacity is dependent on the size of the battery required. The associated cost was relayed to our team by Collective Energy and is $1,100/kWh. ● Cost of power output is dependent on the power output required by the battery system. The associated cost was relayed to our team by Collective Energy and is $3,220/kW ● Tax incentive varies between 0.3 and 0.4 for all sites. ● Annual battery maintenance costs were set at a rate of $10/kW based on a report coming from HRC. ● Collective Energy applies its management fees to the total installation cost before incentives are taken into account.

By considering all relevant calculations, the clinic dashboard allows users to evaluate the financial and operational impacts of adopting solar and battery energy storage systems. When interacting with the dashboard, users are prompted to update critical data specific to their clinic, such as their location, the monetary value of vaccines stored in refrigeration units and the number of patient visits for more accurate outputs. By updating these data points, clinics can receive tailored assessments, making it easier to determine whether solar energy and battery energy storage solutions are a viable investment to protect operations and improve resilience.

5.2.2 CE dashboard

Calculations for the prioritization framework

The CE Dashboard enables our client to prioritize FQHCs for solar energy and BESS implementation, incorporating both financial and social equity considerations. To support effective resource allocation, this dashboard:

- Incorporates a prioritization model that factors in each clinic's community role, and financial feasibility.
- Evaluates clinics based on their importance to the community, such as the size of their patient population and their role in underserved areas.
- Combines financial data with social equity metrics to help CE identify clinics that would benefit most from renewable energy investments, ensuring resources are allocated where they can have the most significant positive effect.

The collected data will support two elements of the CE dashboard: the filtering tab and the prioritization model. The filtering tab will let CE filter clinics that meet certain criteria like rural/urban designation, energy communities (tax incentives), and tribal status.

The prioritization widget will display a weighted score for all clinics that passed the filtering screen, allowing CE to adjust the weights and rank clinics accordingly. The scoring system incorporates both financial and non-monetary factors, reflecting healthcare equity and resilience.

Site prioritization framework

Financial factors

The financial assessment of each FQHC is evaluated by the net benefits of solar systems and BESS calculations explained in the previous section. The financial assessment is structured as follows:

$$\textit{Combined Financial Assessment} = W_{Solar} * F_{Solar} + W_{Battery} * F_{Battery}$$

Where:
F_{Solar} = Solar financial assessment
$F_{Battery}$ = Battery financial assessment
W_{Solar} = Weight for solar component (input by the user)
$W_{Battery}$ = Weight for battery component (input by the user)

These weights are constrained such that:

$$\boldsymbol{W_{Solar} + W_{Battery} = 1}$$

Non monetary factors:
The non-monetary component assesses each site's vulnerability and need based on multiple indicators, each of which is normalized using the same z-score transformation to ensure consistency across different metrics. The variables used in this analysis are:

- SAIDI (System Average Interruption Duration Index): Measures power outage risk based on historical electricity reliability data.
- FEMA disaster risk : Evaluates natural disaster vulnerability using FEMA risk assessments.
- Health care disparities (MDI): Captures health equity disparities and socioeconomic marginalization.
- Medically Underserved Areas/Populations (MUA/P): Indicates the level of medical service accessibility per county and the clinic's designation as MUA/P.
- Rural/Urban designation: Differentiates between rural and urban sites to reflect geographic disparities in healthcare infrastructure.

The Combined Non-Monetary Assessment is calculated as:

$$\boldsymbol{(W_{SAIDI} * Z_{SAIDI}) + (W_{FEMA} * Z_{FEMA}) + (W_{MDI} * Z_{MDI}) + (W_{MUA/P} * Z_{MUA/P}) + (W_{Rural} * Z_{Rural})}$$

Where:

Z_{SAIDI} = z-score adjusted value for the SAIDI power outage metric
Z_{FEMA} = z-score adjusted value for FEMA natural disaster risk metric
Z_{MDI} = z-score adjusted value for the Multidimensional Deprivation Index (MDI)
Z_{MUA} = z-score adjusted value for Medically Underserved Areas (MUA/P)
Z_{Rural} = z-score adjusted value for a site's rural designation
W_X = Weight for the component with the corresponding name, denoted here as "X"

Variables denoted with "Z" have undergone a transformation from their original value to z-scores. A variable like SAIDI can be valued as high as 1,000, whereas rural indication is binary (true or false). Calculating z-scores is done to ensure that all variables are evaluated on the same scale so that they can play even roles in prioritization.

Here is an example of how a value of SAIDI would get transformed by the following function:

$$z = \frac{x-\mu}{\sigma}$$

Where x is a specific observation, μ is the mean of all observations, and σ is the standard deviation of all observations.

Here is an example of how a value of SAIDI would get transformed by the z-score function:
Say an FQHC in Santa Barbara County had a SAIDI of 600 in 2023. The average SAIDI across all clinics in the United States was 250, with a standard deviation of 200. The z-score for that site would thus be (600 - 250) / 200 = 1.75

Each factor is weighted according to user-defined priorities. The system automatically scales weights to ensure they sum to 1:

$$W_1 + W_2 + \ldots + W_n = 1$$

Final Prioritization Score

To determine the final prioritization of FQHCs, the standardized financial and non-monetary assessments are combined into a single score:

$$(W_{Financial} * Z_{Financial}) + (W_{Non\text{-}Monetary} * Z_{Non\text{-}Monetary})$$

Where:

$Z_{Financial}$ = Calculated z-score resulting from the combined financial assessment above
$Z_{Non\text{-}Monetary}$ = Calculated z-score resulting from the combined non-monetary assessment above
$W_{Financial}$ = Weight for the financial assessment component of the final ranking
$W_{Non\text{-}Monetary}$ = Weight for the non-monetary assessment component of the final ranking

Both components are weighted to sum to 1:

$$W_F + W_{NM} = 1$$

Values and Assumptions:

- All z-scores are calculated assuming that the original set of values were normally distributed before this conversion.
- All weights in the dashboard are restricted to the range $[0, \infty)$. They are then proportionally scaled to sum to 1.

The dashboard dynamically updates based on user-defined criteria, displaying a ranked table of high-priority clinics and updating both the site list and the interactive map in real time.

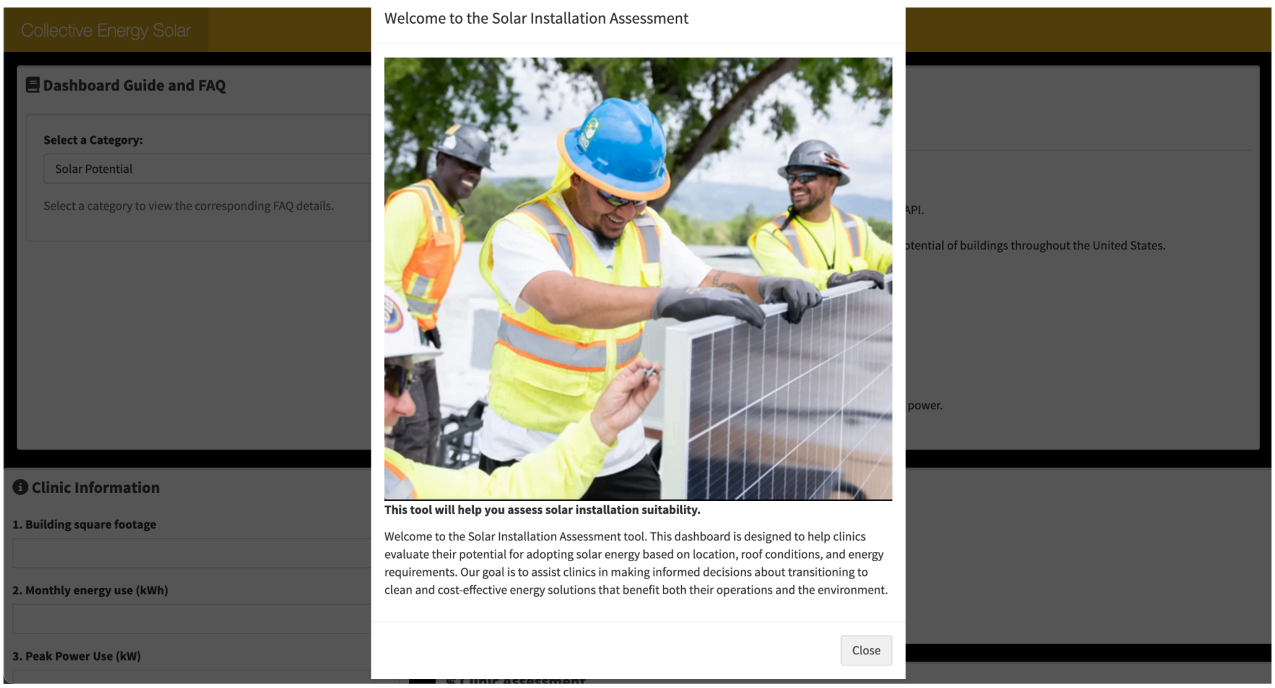
6. Results

This project has two products: the FQHC dashboard and the CE dashboard. This digital product displays the data we collected in an accessible form for the clinics, allowing users to provide additional information for increased accuracy. This provides the user with an opportunity for feedback and testing. These dashboards will live on the Collective Energy website via a server that they host.

6.1 FQHC Dashboard

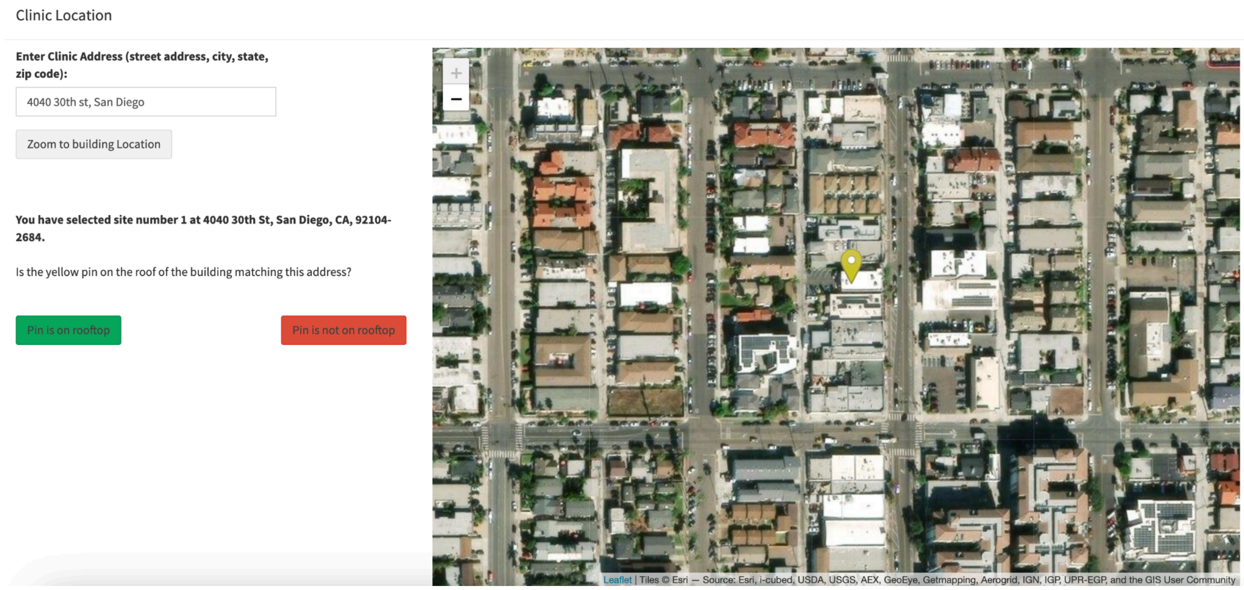
The FQHC dashboard enables hospital administrators to conduct a preliminary assessment of their facility for solar and battery backup systems. The dashboard also provides other relevant information on the site characteristics. We built the dashboard, ensuring information accessibility and clear communication. Here, we provide an overview of the tool:

Introduction page:



The dashboard user is first directed to a welcome page, briefly explaining the purpose of the tool and how it will help them. They are then directed to a page where they can input the address of their facility and confirm that the map pin is on the rooftop of their building. This enables the dashboard to draw information from that site and provide custom results to the clinic.

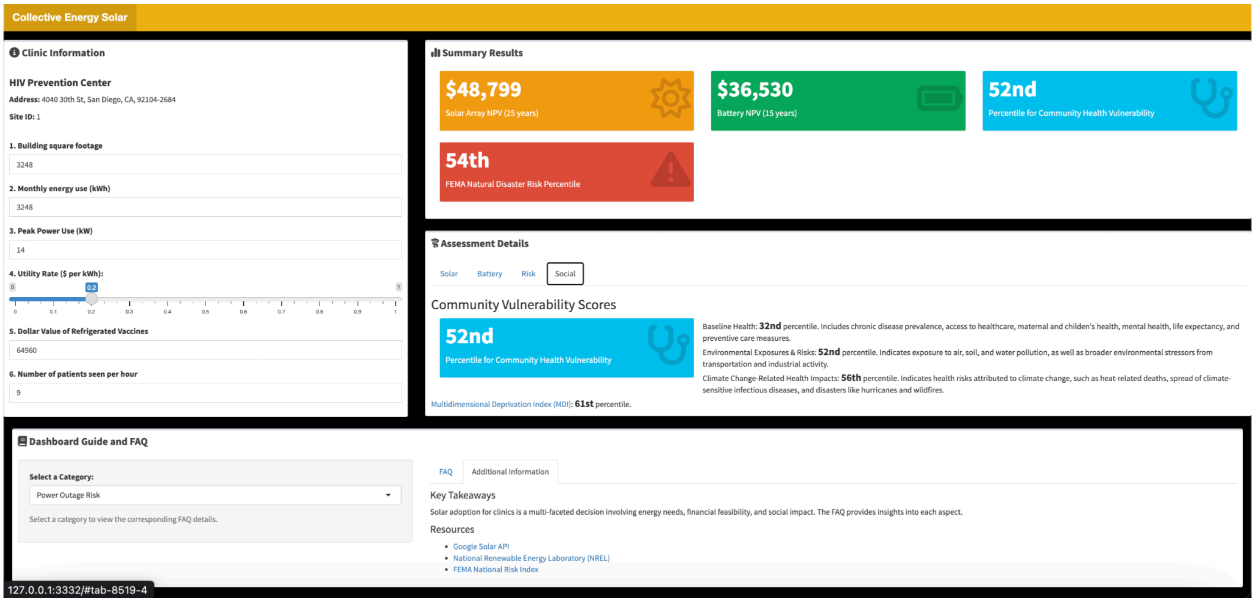
Clinic Location Page:



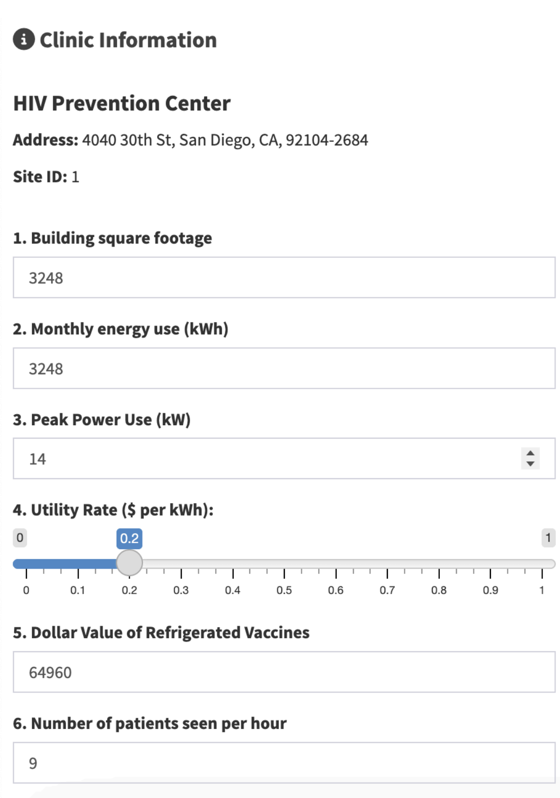
Without a correctly placed pin, the Google Solar API results do not draw information about the correct rooftop. Users who do not have a correctly placed pin confirm are redirected to a "corrective survey" page, which generates a code that can be used to correct the pin location. Users who confirm a correct address are directed to the dashboard page, now populated with information associated with their chosen address.

The dashboard displays a series of widgets to provide spaces for user input and feedback. A brief description of the dashboard materials is available to the user. There is also a summary section, which consists of an annual savings value, the installation cost of the system, where their local community places relative to others in the US in terms of social vulnerability, and their risk of facing a natural disaster which could cause a power outage.

Overview of dashboard:



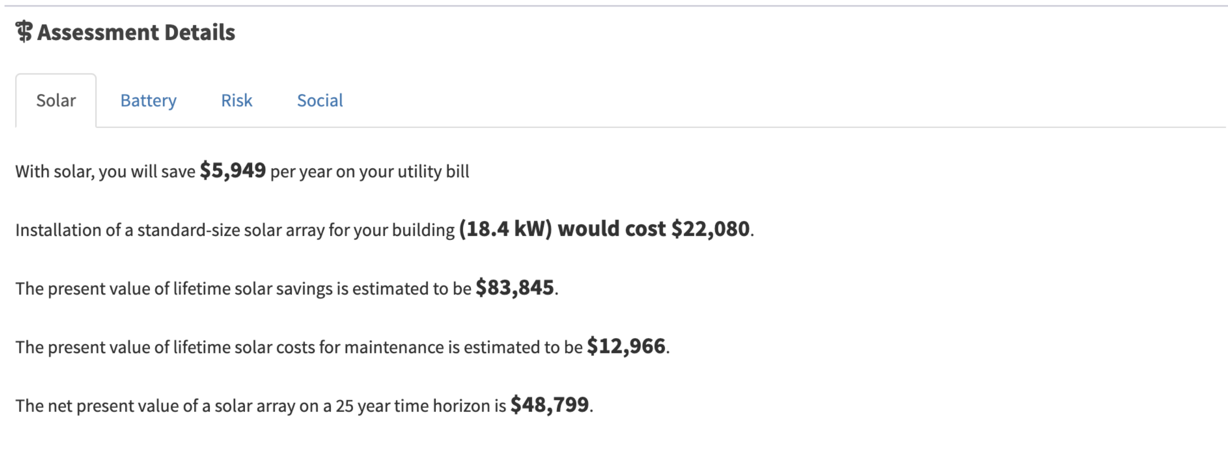
Clinic information:



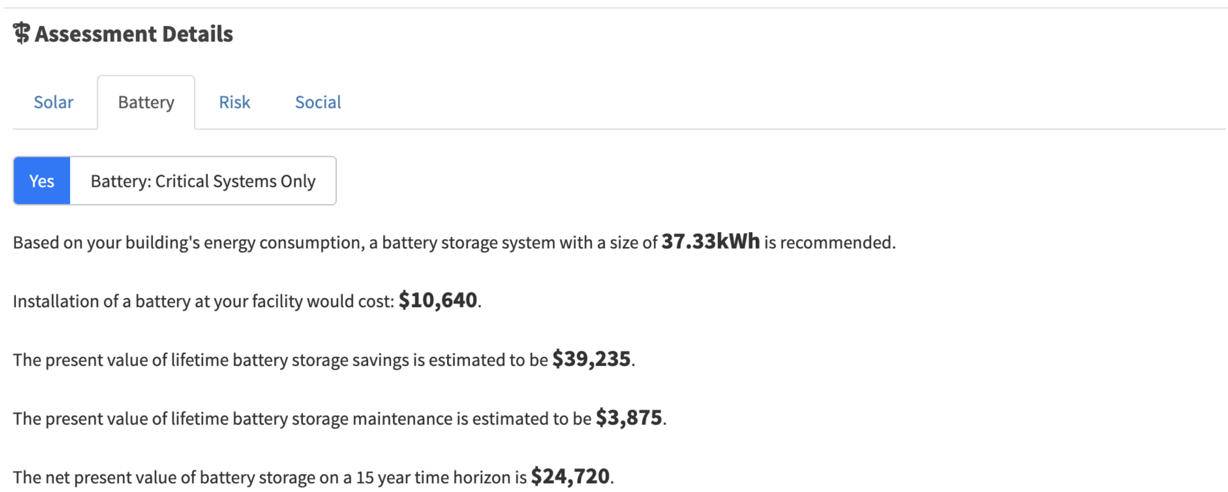
The clinic information widget contains a series of pre-populated fields that the user can adjust. We made these values adjustable because they are estimates, and enabling the user to provide more detailed information about their FQHC will generate a more custom-tailored cost-benefit analysis of rooftop solar and/or BESS installation. The fields that can be adjusted are square-foot size of the facility; monthly energy use (in kWh); peak power use (kW); utility rate ($/kWh), dollar value of refrigerated vaccines on-site; and number of patients seen per hour.

Other information is available under various tabs: “solar”, “battery”, “risk” and “social.” The information under “solar” is generated by the address entered on the dashboard (via Google Solar API information), and can be further modified by the utility rate under Clinic Information. Here, the user can find financial information regarding their investment in a solar array. We provide estimations of annual utility bill savings, system size, and installation cost of the solar array. The present value lifetime solar savings shows how much the user will save in electricity costs over the 25 years the solar array is expected to operate (in present-day value of dollars). The present value lifetime solar costs of maintenance is the total cost of maintaining the solar array over 25 years, again brought back to today's dollars. Lastly, there is the overall present value of the solar array on a 25 year time horizon. This is the "bottom-line" figure that combines both the benefits (savings) and the costs (initial installation and maintenance) into one number—how much the solar array is worth in today's dollars over 25 years.

Solar assessment output:

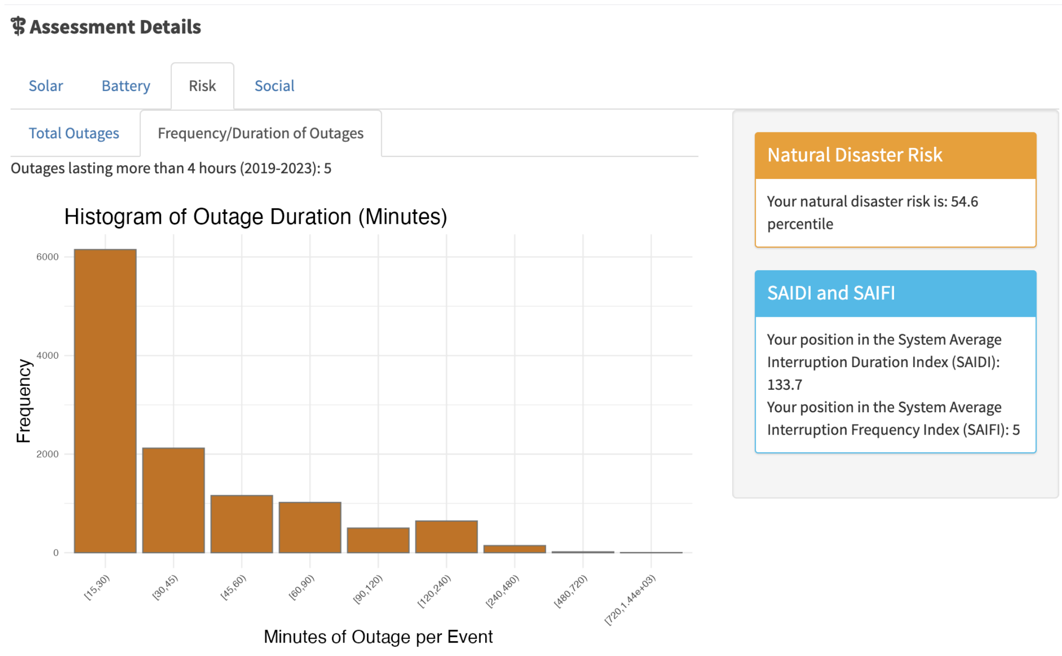


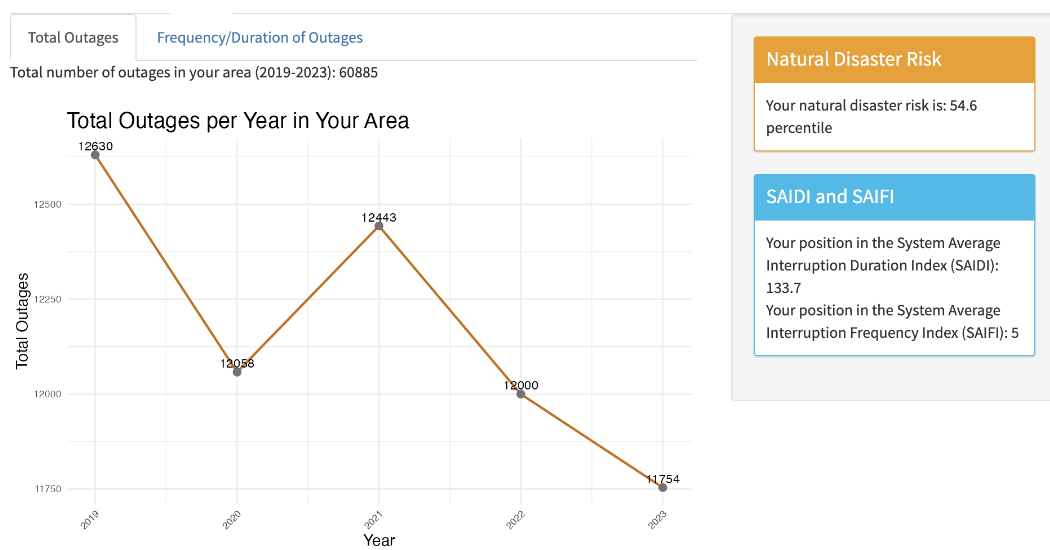
Battery assessment output:



The battery tab provides the same kind of specifications and financial information regarding investment in a battery system. Using these inputs, the user can determine what size of battery storage system their facility might need (kWh), the initial cost of the battery installation, the present value savings of the 15-year lifetime battery storage, the present value cost of the 15-year lifetime battery storage maintenance, and the "bottom-line" net present value of getting a battery energy storage system on a 15-year time horizon. We included a switch that the user can toggle to see "Battery: Critical Systems Only" information. This changes the values to represent a battery that is approximately one-third the size of a battery that provides full power to the clinic. This information can help the user decide if they want a smaller, cheaper battery to cover essential power needs, or a full-sized battery that maintains full electrical operations of their clinic.

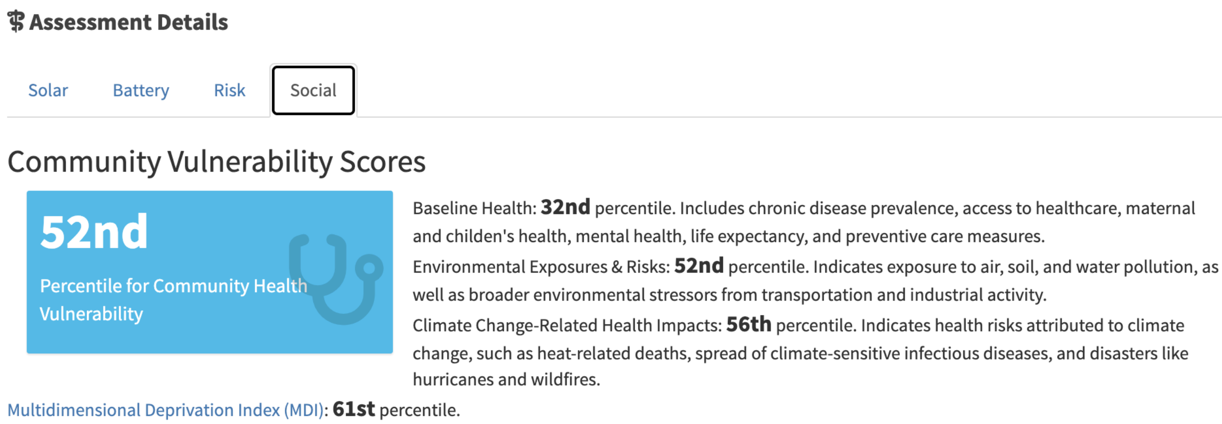
Risk output:





The user can refer to the risk tab to find a histogram of the frequency and duration of power outages, and a chart showing the number of outages their county saw from 2019 to 2023. There is at-a-glance information that shows the number of outages lasting more than four hours in this period (the general length of outages that can spoil refrigerated vaccines,) and the total number of outages in that time. Natural disaster information tells the user their county's FEMA natural disaster risk percentile. Additionally, the county's SAIDI and SAIFI information are available for the user, providing them with more related information as they are deciding to invest in a solar or battery system. The SAIDI tells them how many minutes, on average, each customer is without power in the event of a power outage. The SAIFI tells them how many times, on average, each customer's power is interrupted.

Social output:



The social tab of the location assessment provides more information about the clinic's community. Beyond the financial assessments for purchasing solar, we want the user to be aware of the demographics they are serving and the conditions of their community's health relative to other counties in the US. Making this information readily available should help users understand the significance of becoming a resiliency hub for their community. The "community health vulnerability" score is a combined average percentile score of the other vulnerability scores: baseline health, environmental exposures & risks, climate change-related health impacts, and the Multidimensional deprivation index score.

6.2 CE dashboard

The CE dashboard is an interactive decision-support tool designed to assist the client in identifying and prioritizing FQHCs for consultancy based on a combination of financial, environmental, and social equity factors. It streamlines the process of selecting high-impact investment opportunities. The dashboard allows users to apply customizable filters and weighting criteria to facilitate decision-making on resource allocation.

Dashboard components

The dashboard consists of four main components, the first two are for selecting metrics or weights preferences and the last two shows the impact of them in the ranking of FQHCs, helping users prioritize the most strategic investment locations:

1. Filtering tab: Allows users to refine their selection of FQHCs based on geographic location (state selection) and community designations such as Energy Communities, Tribal communities(if the clinic is located in a tribal designated area), and rural designations. This ensures that clients can focus on facilities serving communities with the highest need.
2. Prioritization model tab: Features an adjustable weighting system that enables users to assign varying levels of importance to key factors, including:

    a. Solar and battery energy storage feasibility
    b. Natural disaster risk
    c. Power outage vulnerability
    d. Medically underserved area/population (MUA/P) status
    e. Rural designation
    f. Health inequity

3. Map Visualization: Provides a geographic overview of FQHC locations, offering spatial insights into their distribution across different states and communities.
4. Ranked Table: Displays a detailed ranking of FQHCs based on the applied filters and weightings. Each entry includes key attributes such as site name, address, state, and community designations.

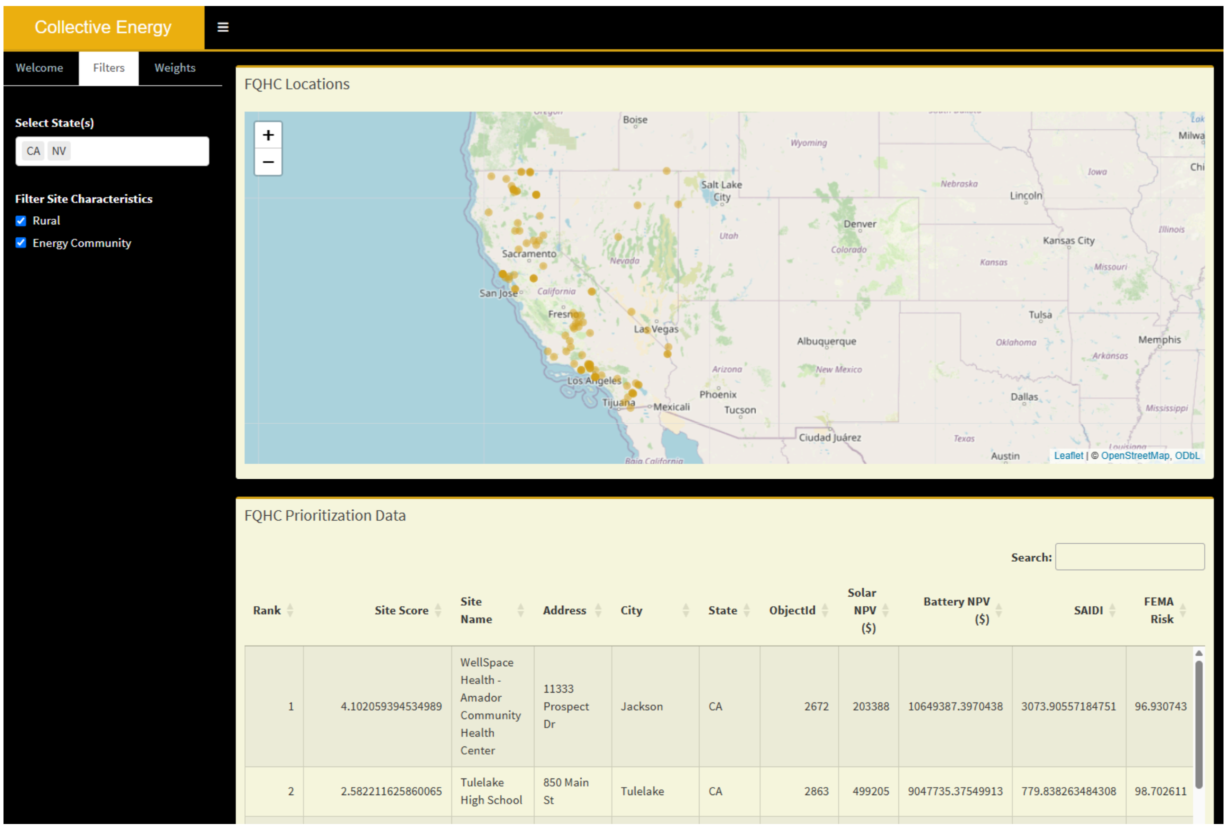
By integrating multiple data sources into a single, interactive tool, this dashboard ensures a transparent and data-driven approach to decision-making. Images of the final dashboard and its components (with the selection of California and Nevada states) is provided below:

Overview of final dashboard:

This is a user-friendly, single-page tool designed to help our client easily identify and prioritize FQHCs for consultancy. Only authorized users will have access to this dashboard, ensuring secure and exclusive use.

The layout is straightforward and intuitive, with clear sections on the left, right, and bottom of the page, each serving a distinct purpose. On the left, users will find the Filtering Tab and the Weights for Prioritization, where they can customize their selection criteria based on geographic location, community designations, and factors like solar feasibility or health inequities.

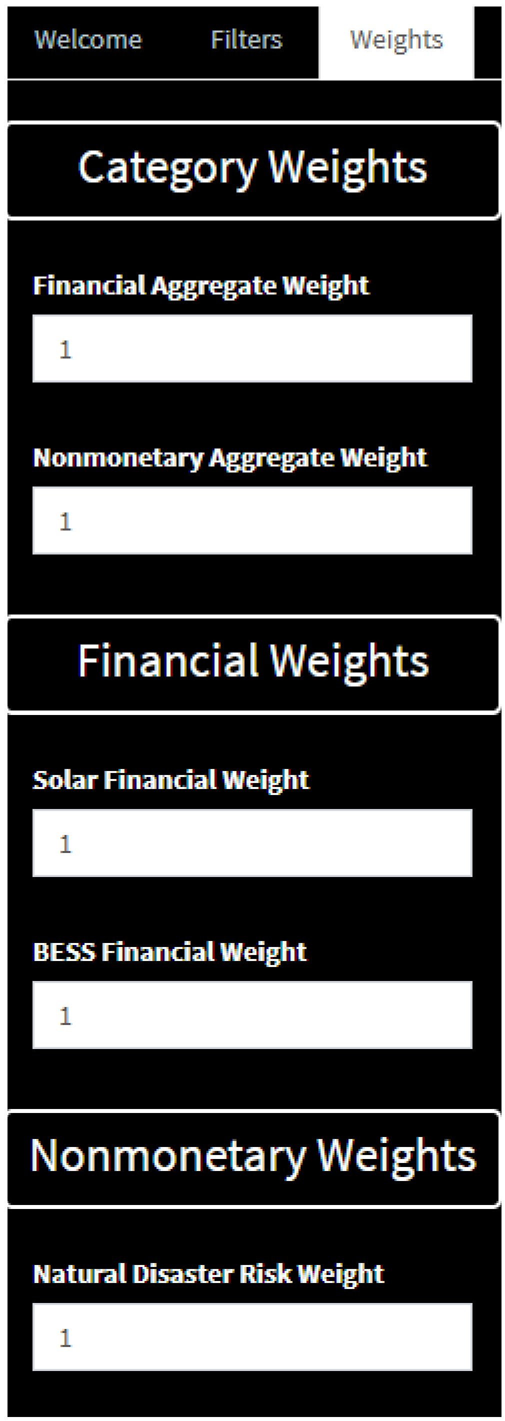
At the top right, the Interactive Map provides a geographic overview of the selected FQHCs, visually displaying their distribution across different regions. This interactive feature allows users to explore the location of each center and understand how it relates to the applied filters. At the bottom, the Prioritization Results Table ranks the FQHCs based on the selected filters and weightings, showing each clinic's key attributes, such as location, community designations, and overall ranking. This seamless design ensures that clients can efficiently navigate the dashboard to make informed, data-driven decisions on where to allocate resources.



Filtering and weighting widgets:

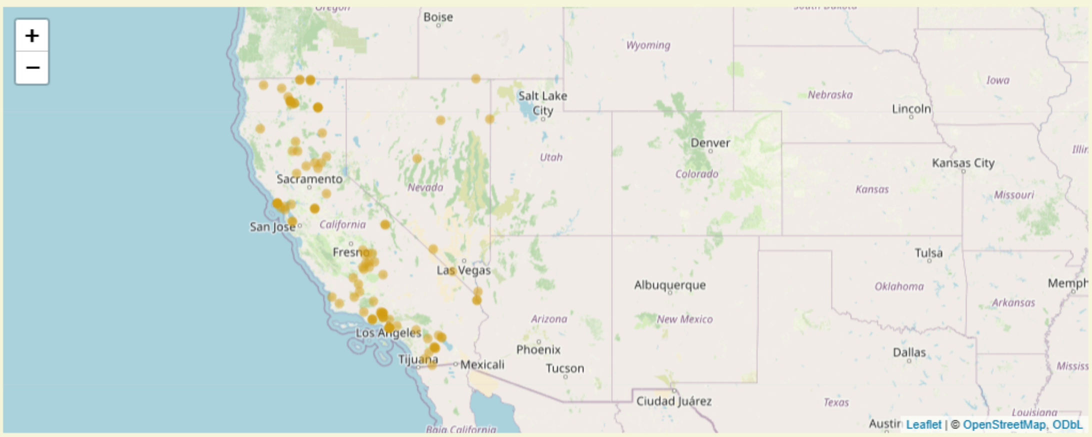
In the first step, the Filtering Tab, located in the left side of the dashboard, is designed to help our client narrow down their selection of Federally Qualified Health Centers (FQHCs) based on critical factors such as geographic location (state selection) and and areas of high need such as community designated as Energy Communities, Tribal communities and/or rural designations. This step ensures that users can focus on clinics located in communities that require the most support, thus making it easier to identify strategic investment opportunities.

Next, users move to the **Prioritization Model Tab ("Weights")**, where they can adjust the weighting system to prioritize various factors. This feature allows them to apply different levels of importance to specific criteria, such as solar and battery storage feasibility, natural disaster risk, power outage vulnerability, medically underserved area (MUA) status, rural designations, and health inequities. By adjusting these parameters, clients can tailor the tool to align with their unique goals and focus areas, ensuring that the dashboard provides insights most relevant to their needs.



Map and table outputs:

FQHC Locations



FQHC Prioritization Data

Search:

Rank	Site Score	Site Name	Address	City	State	ObjectId	Solar NPV ($)	Battery NPV ($)	SAIDI
1	4.102059394534989	WellSpace Health - Amador Community Health Center	11333 Prospect Dr	Jackson	CA	2672	203388	10649387.3970438	3073.90557184751
2	2.582211625860065	Tulelake High School	850 Main St	Tulelake	CA	2863	499205	9047735.37549913	779.838263484308
3	1.646058099094171	Sierra Family Medical	15301 Tyler Foote Rd	Nevada City	CA	2299	35770	3510006.40031693	2851.04466900155

Finally, the Map Visualization and Ranked Table provides our client a clear and concise overview of the results. The map displays the geographic distribution of selected FQHCs, while the table ranks them according to the applied filters and weightings, showcasing each clinic's key attributes such as ID, location, community designations, and ranking score. This tool is setup so that CE can easily visualize the data, export prioritization results, and make strategic decisions on where to invest resources for maximum impact.

7. Discussion

Here we discuss the main caveats and limitations of our analysis.

Solar assumptions & limitations

This is a component of the tool that our team generally feels highly confident about. There was a great set of training data supplied by our client that led to decision making oriented towards matching our analyses to the concrete data we had as reference. One piece of information that eluded the efforts of our team was the utility rate for customers in dollars per kilowatt-hour. This value varies in real time due to constantly shifting demand and is difficult to pin down across the thousands of utility providers in the US. Therefore it was assumed that a standard utility rate of 20 cents per kilowatt-hour would be the most accurate representation. This value is manipulable in the FQHC dashboard for clinics to get a better understanding of their solar savings, however the prioritization tool is locked at that rate.

Battery assumptions & limitations

Battery storage brings with it a handful more assumptions than did solar, primarily because of a lack of site-specific details provided by public datasets. Many of the important components our team identified as the financial benefits of having a battery storage system are likely highly variable across different types of FQHCs. For example, our team was not able to access databases listing site square footage. Instead, the roofing area was determined to be the closest estimate our team could leverage. Although we explored several APIs and elevation modeling, none of these efforts ended up as a solution. Building square footage was an important piece of information because it serves as a regressor in our estimates for energy consumption, peak power, vaccine storage, and patients seen per hour. This means that any location with multiple stories is likely heavily underestimated and any site that shares a roof with other businesses is likely overestimated. This initial inaccuracy would lead to all the components that rely on square footage to have similar inaccuracies.

Power outage assumptions & limitations

The data sourced to quantify power outage risk was the most comprehensive source we could find. Even with this being the best source publicly available, there were just over 2% of sites that were outside of our coverage. These sites were represented with averages across the entire country, which may introduce some inaccuracies.

Site Prioritization assumptions & limitations

As the final piece of our work, this step will be impacted by all assumptions upstream. Any inaccuracies that occur in the components contributing to this site prioritization process may skew results in ways that were unintended by our team. By setting weights in the model to zero, components can be excluded from analysis, therefore removing any biases or poor estimates from the evaluation process.

8. Conclusion

FQHCs are key to providing more equitable healthcare in the United States, and it is vital that they are able to continue operating in the event of a power outage or natural disaster. While many remain without a backup power system, Collective Energy is working to bring reliable, affordable energy to more of these clinics. Our dashboard tools assist them in their mission. The FQHC dashboard will allow healthcare clinics to receive an initial cost-benefit analysis of proceeding with solar array and battery backup installations for their facility, assisting them in their decision to purchase solar and BESS. The CE dashboard will assist Collective Energy in prioritizing FQHCs for solar energy and BESS based on financial and social equity considerations, enabling them to select high-impact investment opportunities within some of the most vulnerable communities.

Creating these two dashboards will help make some of the most vulnerable communities more resilient in the face of power outage events. Climate change will bring more severe heatwaves, tornadoes, hurricanes and other weather events that will strain the US electricity grid and disproportionately affect vulnerable groups. Clinics with solar and battery backup systems can continue to provide healthcare when the power is out, and designing CE's prioritization tool increases energy and healthcare equity in the places where it is most needed.

There are potential applications for this project beyond its current scope. The aging infrastructure of the US electrical grid poses risks of more frequent power outages in the near future, as do increasingly severe weather events from climate change (*What Does It Take to Modernize the U.S. Electric Grid?*, 2023). Accelerating the modernization of the grid through the deployment of renewables will further reduce GHG emissions by reducing demand for electricity generated through the burning of fossil fuels. Assessment tools such as ours can help guide effective investment in the modernization of the US electrical grid through the deployment of on-site renewables and BESS.

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