Method for Estimating Solar Plus Storage Microgrid Installations Needed for California Public Schools

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Background

The report "Climate-Resilient California Schools: A Call to Action" was written under the leadership of Stanford University's Sean N. Parker Center for Allergy and Asthma Research, Center for Innovation in Global Health, Action Lab for Planetary Health (ALPHA), and the University of California, Berkeley's Center for Cities + Schools in collaboration with a diverse group of stakeholders and experts. PSE Healthy Energy contributed a technical appendix summarizing the potential for solar plus storage (solar+storage) at California's K-12 public schools to offset utility bills, replace grid energy with local renewable energy, and to provide increased resilience during grid outages. We summarize the results in the report, with additional technical details on methods and data offered here.

Method Summary

We calculated the environmental and economic costs and benefits of solar+storage at the more than 10,000 primary and secondary schools in California. We then modeled the additional solar+storage capacity required to meet resilience needs. For both the *economic potential* and *resilience potential* of solar+storage, we model the schools in National Renewable Energy Laboratory's REopt[1][2] modeling tool. For both economics and resilience we collected data on the location (latitude and longitude) of each school, researched additional data sources to estimate the size of each school (a key variable for estimating energy needs), and the roof space available for solar panels. For *resilience potential*, we must also select a target electricity outage duration, and energy use during the outage.

Method Details

Economic Potential

The California Department of Education (CDoE) 2018-19 data[3] on school locations lists 10,003 active schools, providing latitude, longitude, and enrollment data. We augment this data set using Open Street Maps (OSM)[4] to estimate school roof size. From OSM, we found 3,988 school campuses that matched CDoE data. We used the OSM data to estimate total roof size and roof space available for solar panels. For the sites with no OSM match, we used the average size of matched schools as a proxy. For 200 of these schools, randomly selected from the 3,988 considering both urban and rural locations, we performed map and imagery analysis to identify the average number of floors in each building. Results are summarized in Table 1,

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[1] Cutler, D., Olis, D., Elgqvist, E., Li, X., Laws, N., DiOrio, N., Walker, A., & Anderson, K. (2017). REopt: A Platform for Energy System Integration and Optimization. *Renewable Energy*, 75.

[2] *REopt Web Tool User Guides | NREL*. (n.d.). Retrieved October 21, 2022, from https://reopt.nrel.gov/user-guides.html

[3] *California Schools 2018-19*. (n.d.). Retrieved October 21, 2022, from https://gis.data.ca.gov/datasets/CDEGIS::california-schools-2018-19/data?geometry=-163.440,31.022,-74.758,43.235

[4] OpenStreetMap contributors. (2015), [data file from 3/24/2021 (geofabrik)]. Retrieved from https://planet.openstreetmap.org

which shows significant differences between urban and rural locations and between primary (elementary) and secondary (middle, high, and mixed K-12) schools.

The location, school level, and school size allows us to estimate each school's energy consumption, as energy use is largely a function of the school level, school size, and the climate that the school experiences. REopt provides energy load profiles[5] for primary schools and secondary schools, consistent with the typical school schedules, both daily and seasonally.

REopt adjusts the load profile to take into account climate zone impacts on cooling energy needs. REopt makes this adjustment based on the International Energy Conservation Code (IECC) climate regions, which breaks down geographic regions by climate zones ranging from warmest to coldest (1-8[6]) and moisture regime (moist, dry, marine) as shown in Figure 1.

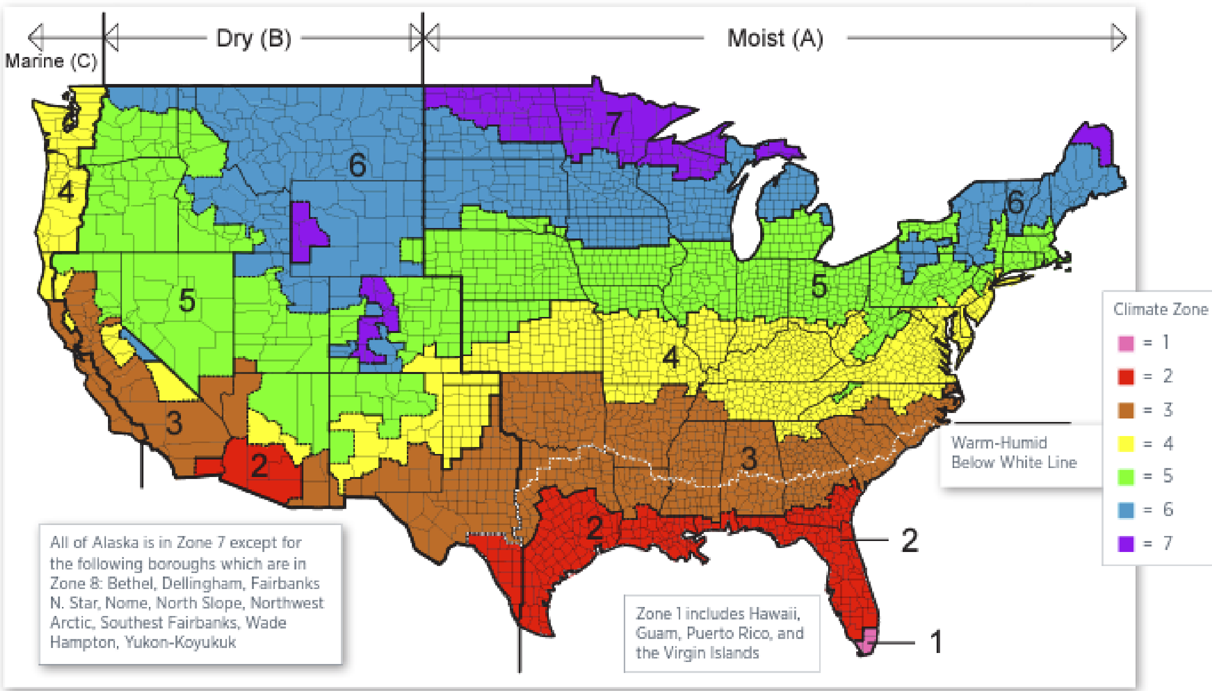

Figure 1: International Energy Conservation Code (IECC) Climate Regions[7]

[5] A load profile is the amount of energy used over a period of time. In this case, hourly usage data for each of the 8,760 hours in a year.
[6] Climate Zone 8 is in Alaska, and not shown on this map.
[7] Baechler, M. C., Gilbride, T. L., Cole, P. C., Hefty, M. G., & Ruiz, K. (2015). *Guide to Determining Climate Regions by County* (PNNL-17211 Rev. 3; BUILDING AMERICA BEST PRACTICES SERIES, p. 50). https://www.energy.gov/sites/prod/files/2015/10/f27/ba_climate_region_guide_7.3.pdf

School Level (Primary vs. Secondary)	City vs. Not City	Number of Schools in California	Number of Schools in GIS Sample	Sample as % of all Schools	Sample Average Number of Floors	Sample Average Campus Roof Area (thousand square feet)	Sample Average Campus Floor Area (thousand square feet)	Sample Total Campus Roof Area (million square feet)	Sample Total Campus Floor Area (million square feet)	Total Campus Roof Area (million square feet)	Total Campus Floor Area (million square feet)
Primary	Not City	3,544	1,780	50	1.00	52	52	93	93	184	184
Primary	City	2,436	1,781	73	1.30	52	68	93	120	127	165
Primary	**Both**	**5,980**	**3,561**	**60**	**1.15**	**52**	**60**	**185**	**213**	**311**	**358**
Secondary	Not City	2,464	971	39	1.20	128	154	124	149	315	378
Secondary	City	1,559	767	49	1.40	137	192	105	147	214	299
Secondary	**Both**	**4,023**	**1,738**	**43**	**1.29**	**132**	**170**	**229**	**295**	**531**	**684**
Total	**Both**	**10,003**	**5,299**	**53**	**1.20**	**78**	**94**	**415**	**496**	**783**	**935**

Table 1: School Statistics

California contains IECC climate zones 2 through 6, with zone 2 corresponding to the hot, dry region bordering Arizona and Mexico, and zone 6 in the Sierra Mountains. Taking the humidity regions into account, the IECC has seven unique climate regions in California, as shown in the table below. REopt has distinct load profiles for typical primary and secondary schools in each of these climate zones that take into account cooling energy needs in each region. These load profiles can be easily adjusted for larger and smaller schools, with energy use scaling linearly with floor area.

IECC Climate Zones in California	**Climate Region (Temperature)**	**Climate Region (Humidity)**	**Climate Zone Example City in California**
2B	Hot	Dry	El Centro
3B	Warm	Dry	Anaheim
3C	Warm	Marine	San Francisco
4B	Mixed	Dry	Bishop
4C	Mixed	Marine	Eureka
5B	Cool	Dry	Yreka
6B	Cold	Dry	Lee Vining

Table 2: IECC Climate Zone Descriptions

The California Energy Commission divides the state into 16 climate zones that are not completely consistent with the IECC regions. The CEC zones provide more resolution in some areas, like the Los Angeles and San Diego metropolitan areas (CEC zones 6, 7, 8, 9), and less resolution in the Sierra Mountains (CEC zone 16), as can be seen in Figure 2. To account for the effects of both classifications, we combined these two zone sets into a set of 34 distinct climate zones. For each combined zone we have calculated power and energy demands using the seven IECC climate regions used in REopt, and adjusted them based on the difference between combined IECC-CEC climate zone monthly Cooling Degree Day (CDD) data versus CDD data in the IECC example city using data from the Western Region Climate Center at the Desert Research Institute.[8]

Even with the further breakdown to 34 climate zones, the temperature and CDD variation within climate zones can be greater than the variation between climate zones. According to Huang & Gurney, (2016)[9] and this suggests a potential bias when estimating energy impacts with only a

[8] *Western U.S. Climate Historical Summaries*. (n.d.). Retrieved November 1, 2022, from https://wrcc.dri.edu/Climsum.html
[9] Huang, J., & Gurney, K. R. (2016). The variation of climate change impact on building energy consumption to building type and spatiotemporal scale. *Energy*, *111*, 137–153. https://doi.org/10.1016/j.energy.2016.05.118

small number of representative locations. PSE is working to scale temperature and CDD data to more local sources, and to improve fidelity; that work is ongoing.

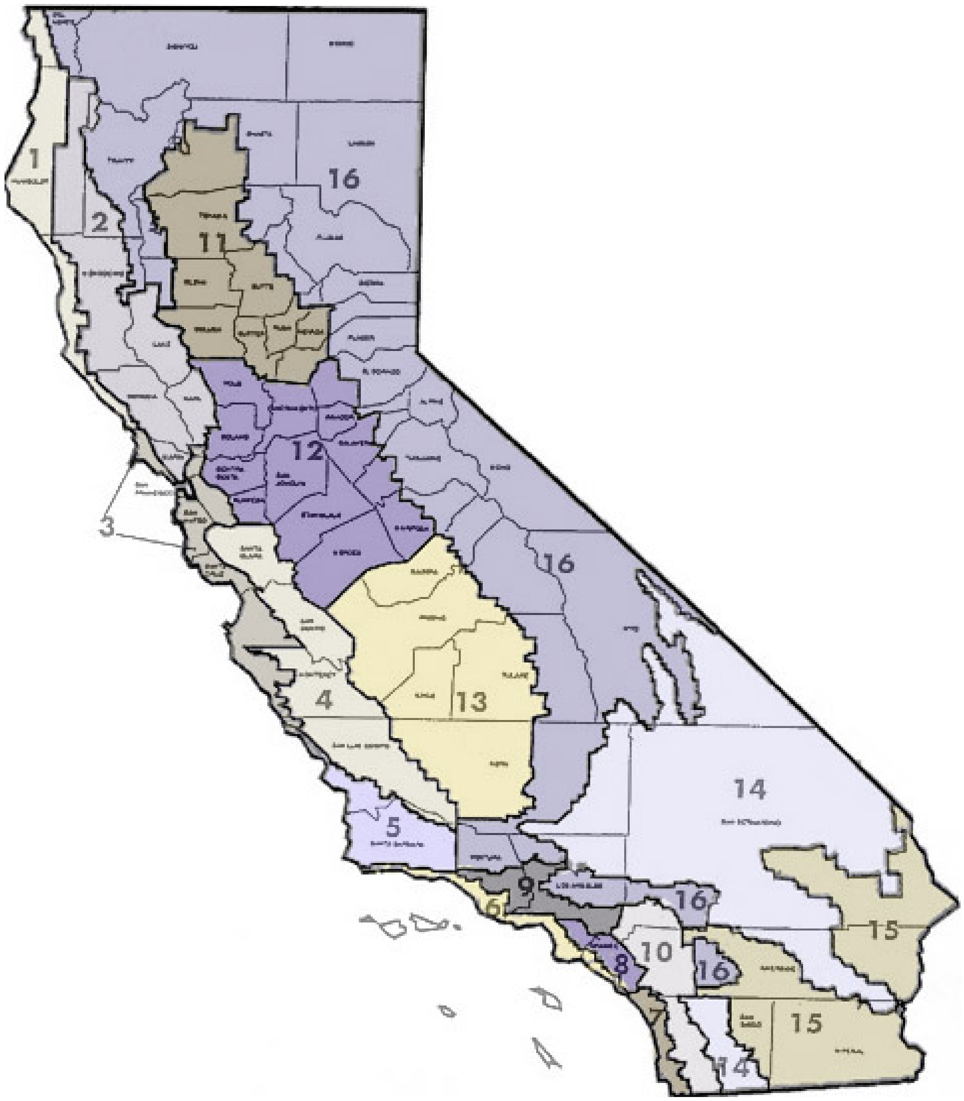

Figure 2: California Energy Commission Climate Zones[10]

The final set of data necessary for economic analysis are utility rates for each school. While there are more than 40 utilities serving California, 90 percent of all customers receive electricity from the top five largest utilities: 33 percent from Pacific Gas and Electric (PG&E); 31 percent from Southern California Edison (SCE); and 9 percent each from Los Angeles Department of Water and Power (LADWP), Sacramento Municipal Utilities Department (SMUD), and San

[10] *Guide to California Climate Zones*. (n.d.). Retrieved November 1, 2022, from https://www.pge.com/myhome/edusafety/workshopstraining/pec/toolbox/arch/climate/index.shtml

Diego Gas and Electric (SDG&E).[11] No other provider accounts for more than one percent of California customers, however, to ensure we consider the potential impacts of smaller city and rural utility companies, we considered five more utilities: City of Riverside, Imperial Irrigation District, Modesto Irrigation District, Turlock Irrigation District, and City of Anaheim Public Utilities Department. For each of the schools in the sample set, we map their location to areas served by these utilities. If a school is not in a district served by one of these ten utilities, we select the nearest possible utility from this set. Finally, based on school size, we select the appropriate utility rate from a subset of time-of-use rates available to commercial customers in these utility districts, pulling possible sets from most current rates available as of 2021 in the U.S. Utility Rate Database.[12]

Due to time limitations of running a larger sample set, we selected seven representative schools ranging in size within each of the 34 combined climate zones. Our selected sample set represents the first through 99th percentile of campus sizes in the sample, including the three middle quartiles and the upper and lower 10ths and 100ths, such that we have the following quantiles represented: (0.01, 0.10, 0.25, 0.50, 0.75, 0.90, and 0.99).

For each school, we limit the size of solar arrays to be no larger than the average roof space available for solar panels. Based on estimates used by StationA, an energy services company that synthesizes geospatial and environmental data to estimate solar potential, this is typically assumed to be 50 percent of the total roof space[13]. We therefore used 50 percent of roof space available for solar.

Resilience Potential

PSE's resilience hubs work is considering a range of outage scenarios with various durations and critical energy needs during the outage, but results are not yet available. For this estimate, we will pick an outage duration and a level of critical energy need as a single example of resilience potential.

Outage durations range from less than a second to days or even weeks long. The average outage duration in PG&E territory in 2020, for example, was 451 minutes (7.5 hours). A recent major contributor to long outages in California is Public Safety Power Shutoffs (PSPS), the longest of which lasted just under one week. Between 2013 and 2020, 95 percent of PSPS outages were less than 96 hours (four days) long, but more than 150,000 people in California have experienced PSPS events of four days or longer.[14] We will use four days as a reasonable worst-case scenario for this analysis.

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[11] *Electricity Consumption by Entity*. (n.d.). Retrieved November 1, 2022, from http://www.ecdms.energy.ca.gov/elecbyutil.aspx

[12] *Utility Rate Database | Open Energy Information*. (n.d.). Retrieved November 1, 2022, from https://openei.org/wiki/Utility_Rate_Database

[13] *Station A - How It Works*. (n.d.). Station A. Retrieved November 1, 2022, from https://stationa.com/how-it-works

[14] *Preventing Wildfires with Power Outages: The Growing Impacts of California's Public Safety Power Shutoffs | PSE | Physicians, Scientists, and Engineers for Healthy Energy*. (n.d.). Retrieved November 1, 2022, from https://www.psehealthyenergy.org/news/blog/preventing-wildfires-with-power-outages-2/

The amount of energy required during an outage will vary with the services needed during the outage. Building bottom-up critical load profiles for thousands of schools would be prohibitively time consuming. Instead, in the aforementioned resilience hub research, we consider critical load as a percentage of normal load, ranging from 10 percent of normal load to 150 percent of normal load. For this analysis, we will pick 50 percent of normal load as a test case.

Existing Installations

With data collected by Generation 180 for their Brighter Future Report[15], we determined how much of the solar potential has already been deployed, as of 2019.

Results

Solar potential at all California schools (ten thousand primary and secondary) assuming rooftop solar and storage

- For economic/normal operations
  - 5.3 GW of rooftop solar potential
  - 0.8 GW, 4.3 GWh of battery for TOU shifting
  - Producing more than 11,000 GWh of solar electricity per year (approximately net zero on average across all schools)
  - $13B initial capital cost
  - Net present value of $3.1B
  - Average simple payback of seven years under current net metering rules
  - Offsetting more than seven million tons of CO_2 each year by displacing 0.67 tons of CO_2e/MWH of gas power plant emissions.
- Add resilience, assuming all sites designed to serve 50 percent of their normal load for a 96 hour outage, add
  - 1.9 GW of PV (totalling 8.2 GW)
  - 1.4 GW, 48 GWh of battery (totalling 2.2 GW, 52 GWh)
  - producing 18,000 GWh of solar electricity per year
  - $15B additional capital (totalling $28B)
  - Net present value (NPV) of -$960M (no value of resilience calculated)
  - Simple payback cannot be calculated for negative NPV
  - offsetting more than 10 million tons of CO_2 each year by displacing 0.67 tons of CO_2e/MWH of gas power plant emissions.
- Some of this solar has already been deployed. As of 2019:[16]
  - 0.6 GW of solar (12 percent of rooftop potential, but much of this is actually off-roof)
  - 5 MW of batteries (less than one percent of economic potential), and virtually none of these are sized for resilience.

[15] Generation180. (2020). Brighter Future Report Third Edition. https://generation180.org/brighter-future-2020-download/?submissionGuid=20d9ba3b-0b1b-4c4d-b45d-f53f621da411

[16] Generation180. (2020). Brighter Future Report Third Edition. https://generation180.org/brighter-future-2020-download/?submissionGuid=20d9ba3b-0b1b-4c4d-b45d-f53f621da411