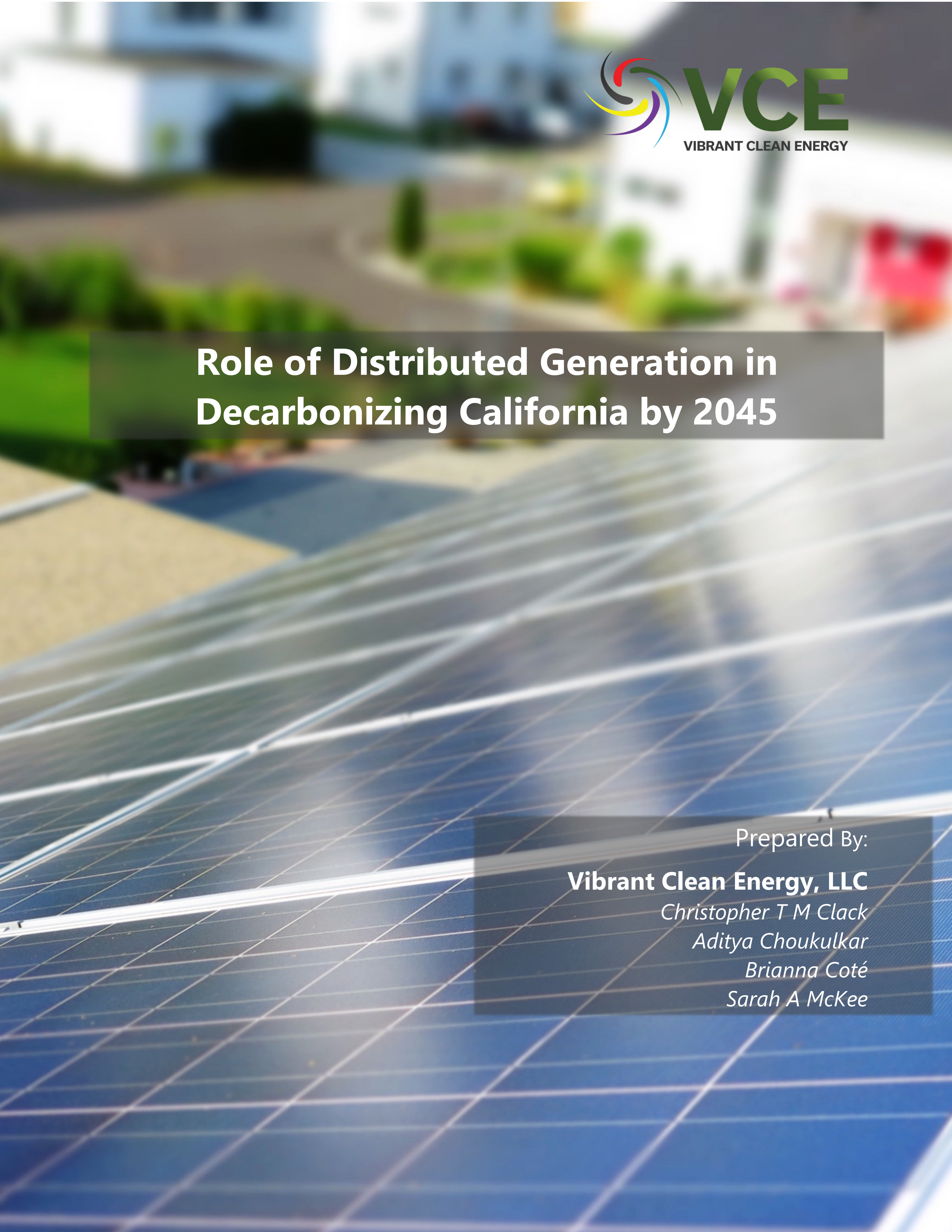

Role of Distributed Generation in Decarbonizing California by 2045

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1 Study Description

The Coalition for Community Solar Access (CCSA) and Local Solar for All commissioned Vibrant Clean Energy (VCE®) to investigate scenarios that electrify and completely decarbonize the economy for the state of California by 2045. The scenarios discussed in this report model California undergoing economy-wide electrification with decarbonization of the electricity sector while using distributed generation as part of the decarbonization strategy. The modeling was performed using the WIS:dom®-P, a state-of-the-art model capable of performing detailed capacity expansion and production cost while co-optimizing utility-scale generation, storage, transmission, and distributed energy resources (DERs). The modeled scenarios use the National Renewable Energy Laboratory (NREL) Annual Technology Baseline (ATB) 2020 "moderate" cost projections for installed capital and Operation and Maintenance (O&M) costs. For fuel costs, forecasts from the Annual Energy Outlook (AEO) 2020 High Oil and Gas supply scenario are used.[1]

The scenarios modeled in this study are:

(1) **Electrify and decarbonize CA without distribution co-optimization and no new distributed generation ("Utility-scale Only"):** In this scenario, California undergoes economy-wide electrification and decarbonization of the electricity sector without co-optimizing the distribution system with the utility-scale generation. In addition, no new distributed generation is allowed to be installed after 2020. All nuclear generation in California is assumed to be retired by 2025. This scenario serves as a counterfactual to compare changes in system costs and retail rates for customers as a result of co-optimizing the distribution system and utilizing distributed generation.

(2) **Electrify and decarbonize CA with distribution co-optimization and with increased distributed generation buildout ("Local Solar & Storage Future"):** In this scenario, WIS:dom-P co-optimizes the distribution system with utility-scale generation to decarbonize California by 100% by 2045 while undergoing economy-wide electrification. All nuclear generation in California is assumed to retire by 2025. In this scenario a minimum level of distributed solar and community solar adoption is assumed per year as shown in Fig. 1.1.

[1] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2020&region=1-0&cases=highogs&start=2018&end=2050&f=A&linechart=highogs-d112619a.3-3-AEO2020.1-0~highogs-d112619a.36-3-AEO2020.1-0~highogs-d112619a.37-3-AEO2020.1-0~highogs-d112619a.38-3-AEO2020.1-0~highogs-d112619a.39-3-AEO2020.1-0~highogs-d112619a.40-3-AEO2020.1-0&map=highogs-d112619a.4-3-AEO2020.1-0&sourcekey=0

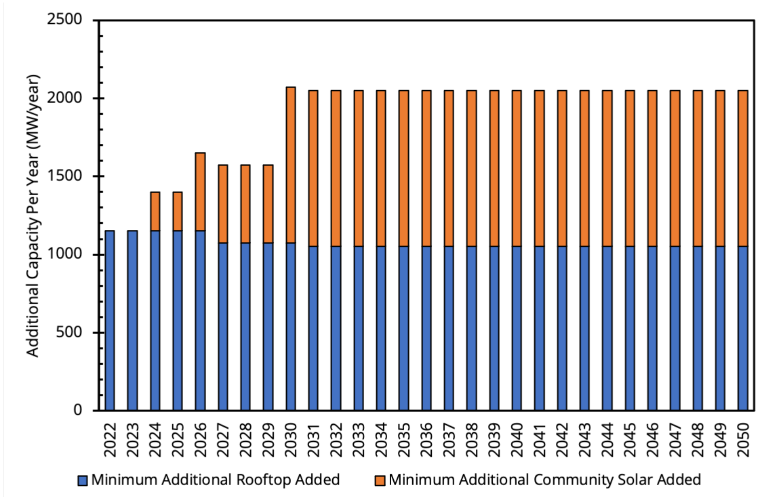

Figure 1.1: Minimum annual distributed (DPV) and community solar (CSP) installation assumed in the scenarios modeled.

The scenarios are initialized and calibrated with 2018 generator, generation, and transmission topology datasets. The scenarios then determine a pathway from 2020 through 2050 with results outputted every 5 years. As part of the optimal capacity expansion, WIS:dom-P must ensure each grid meets reliability constraints through enforcing the planning reserve margins specified by the North American Electric Reliability Corporation (NERC) and having a 7% load following reserve available at all times. Detailed technical documentation describes the mathematics and formulation of the WIS:dom-P software along with input datasets and assumptions.[2]

[2]https://vibrantcleanenergy.com/wp-content/uploads/2020/08/WISdomP-Model_Description(August2020).pdf

1.1 WIS:dom®-P Model Setup

To model the capacity expansion pathway for a 100% decarbonized California with economy-wide electrification of energy related activities, WIS:dom-P modeled California with its existing generator topology, transmission, and weather inputs obtained from National Oceanic and Atmospheric Administration (NOAA) High Resolution Rapid Refresh (HRRR) model[3] at 3-km horizontal resolution and 5-minute time resolution. The initialized generator dataset is created by aligning the Energy Information Administration Form 860 (EIA-860) dataset[4] with the 3-km HRRR model grid. The existing generator topology in California in 2018 along with existing transmission at 3-km resolution is shown in Figure 1.2.

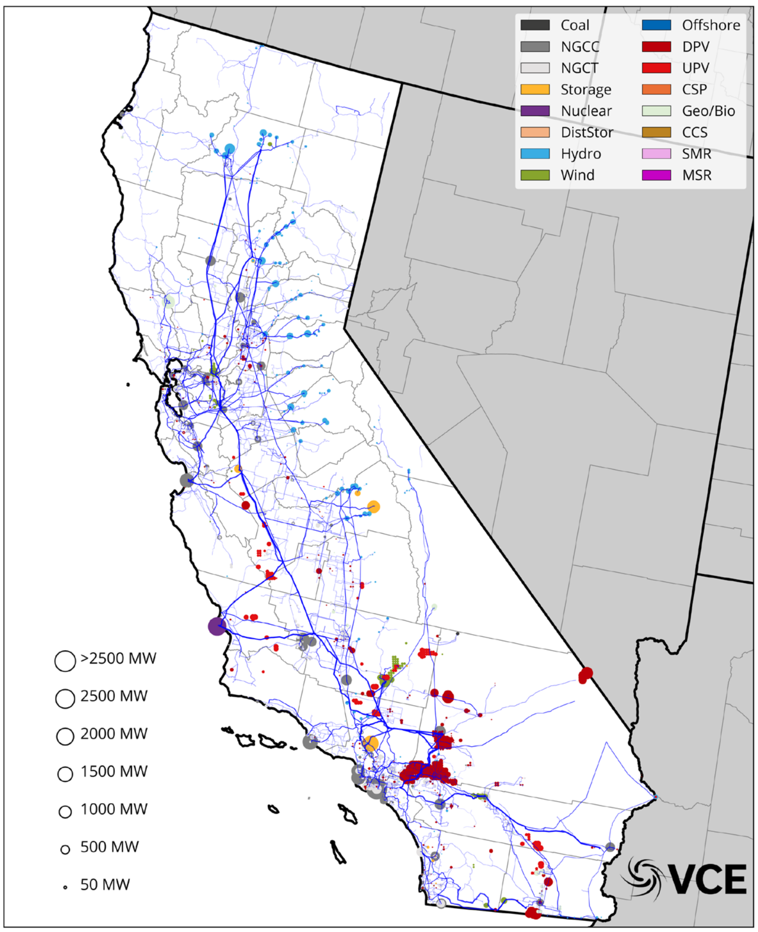

Figure 1.2: WIS:dom-P model domain and existing generators with transmission.

Existing transmission corridors between CA and neighboring states are modeled as imports and exports with energy prices provided by a background modeling scenario ("CE-DER").[5] In addition, the transmission capacities between CA and neighboring states are assumed to expand as in the "CE-DER" scenario.

[3] https://rapidrefresh.noaa.gov/hrrr/
[4] https://www.eia.gov/electricity/data/eia860/
[5] https://www.vibrantcleanenergy.com/wp-content/uploads/2020/12/WhyDERs_TR_Final.pdf

2 Modeling Results

2.1 System Costs, Retail Rates & Jobs

The evolution of the total system costs and retail rates for California in the scenarios modeled is shown in Fig. 2.1. In both scenarios, total system costs remain relatively constant between 2020 and 2030 with the "Local Solar & Storage Future" scenario being slightly cheaper than the "Utility-scale Only" scenario. During this period, the fossil fuel generation is replaced with clean variable renewable energy (VRE) generation, which keeps costs low in spite of the increasing electric load due to electrification. After 2030, load growth due to electrification accelerates resulting in significantly more generation added to the grid. As a consequence, costs in both scenarios also start to increase. The "Utility-scale Only" scenario showing larger increases in cost compared with the "Local Solar & Storage Future" scenario. The cost savings in the "Local Solar & Storage Future" scenario is driven mainly by savings in the distribution sector. The cumulative savings, from 2018 to 2050, in total system costs in the "Local Solar & Storage Future" scenario compared to "Utility-scale Only" is $120 billion.

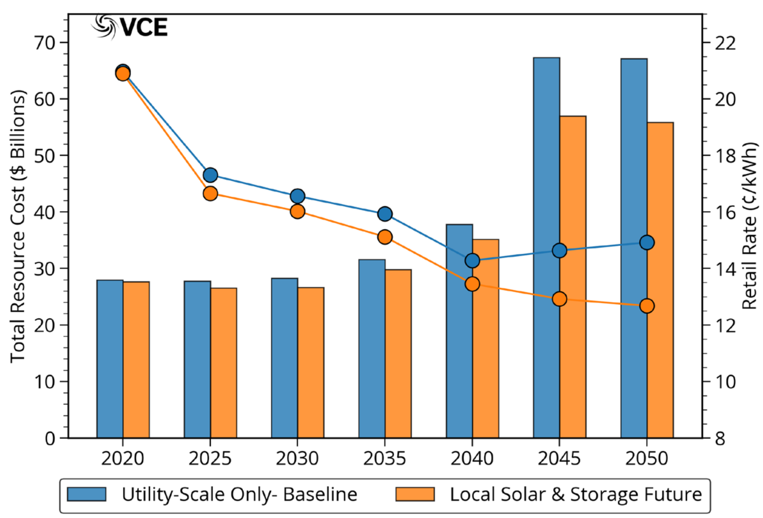

Figure 2.1: Total system cost (bars) and retail rates (solid lines) in California for the two scenarios modeled.

As the state of California undergoes economy-wide electrification, the retail rates in both scenarios reduce from 2020 levels. In the "Utility-scale Only" scenario, the retail rates reduce from 2020 to 2040, after which they start to increase as the lack of new distributed generation results in increased expenditure on utility-scale generation and transmission to connect them with the load centers. In the "Local Solar & Storage Future" scenario, the retail rates continuously decrease from 2020 to 2050 as the model optimizes the distributed generation with the utility-scale generation to ensure the lowest system cost per kilowatt-hour generated.

The increase in retail rates in the "Utility-scale Only" scenario occurs as economy-wide electrified starts to pick up after 2040, while in the "Local Solar & Storage Future" scenario, retail rates continue to decrease. This continued reduction in retail rates is crucial as it ensures customers have a financial incentive to pursue electrification, while in the "Utility-scale Only" scenario, the increase in retail rates can hinder electrification efforts leading to increased emissions.

Figure 2.2 shows annual spending on electricity purchases in California over the investment periods. The increased spending on electricity purchases after 2030 is due to the electrification of economy-wide energy related activities. The lower retail rates in the "Local Solar & Storage Future" scenario means that customers spend less on electricity purchases compared with the "Utility-scale Only" scenario throughout the modeling period. The reduced spending on electricity purchases result in cumulative savings of $29 billion from 2018 to 2050 on expenditures for energy related activities, which provides secondary economy-wide benefits for the state not captured in the modeling. This modeling assumes that spending on all distributed generation is rate-based. Private investments in distributed PV and behind-the-meter storage will provide the same benefits, while reducing the costs rate-based and should result in further reductions in retail rates.

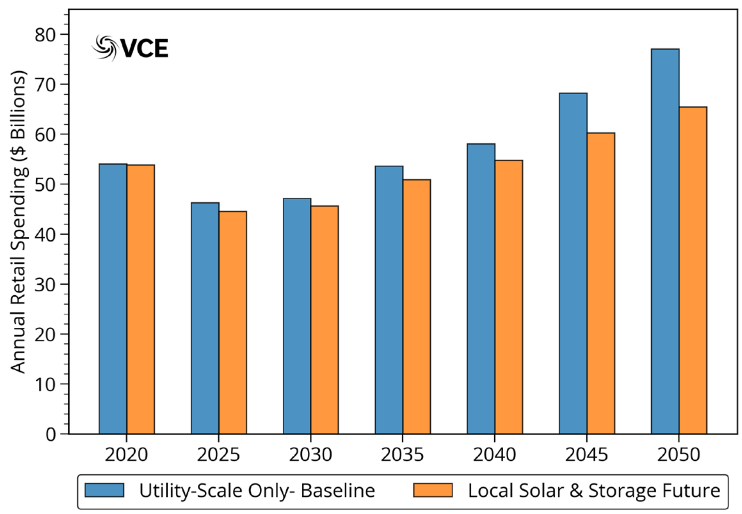

Figure 2.2: Annual retail spending in California for electricity purchases in the scenarios modeled.

The contributions to the cost per kWh of electricity delivered broken out by sectors in the "Local Solar & Storage Future" scenario is shown in Fig. 2.3. From 2020 to 2040 the cost per kWh delivered drop from 9.3 ¢/kWh to 8.44 ¢/kWh as a result of replacing fossil fuel generation with renewables and co-optimizing the distribution system with the utility scale generation. The cost contribution from the distribution system reduces from 2.51 ¢/kWh in 2020 to 1.89 ¢/kWh in 2040 as a result of the co-optimization. After 2040, California installs large amounts of utility-scale solar and storage to meet the state's decarbonization goal. As a result, the cost per kWh increases from 8.44 ¢/kWh in 2040 to 12.48 ¢/kWh in 2045. However, this increase in costs is offset in part from revenues made from exports as California becomes a net exporter of energy by 2045.

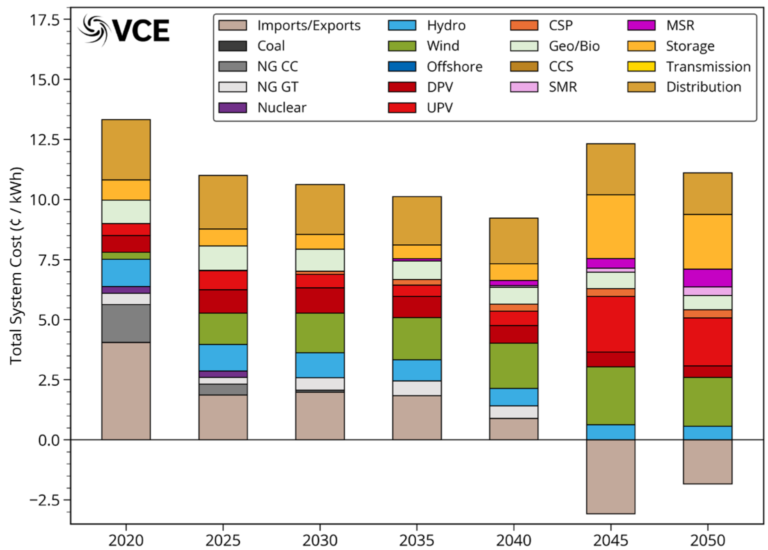

Figure 2.3: Contribution to total system cost per kWh load from each energy system sector in the "Local Solar & Storage Future" scenario.

The total full time equivalent jobs created in California in the electricity sector broken out by industry is shown in Fig. 2.4. The total jobs supported by the electricity sector increase from 221,000 in 2020 to 683,000 in 2040 driven by the renewable energy installations. Distributed solar industry is the largest contributor to the job growth followed by utility-scale solar and storage. Due to the large installations of utility-scale solar and storage by 2040 required to meet California's decarbonization goals, there is a sharp increase in jobs created in the utility-scale solar and storage industries after 2040.

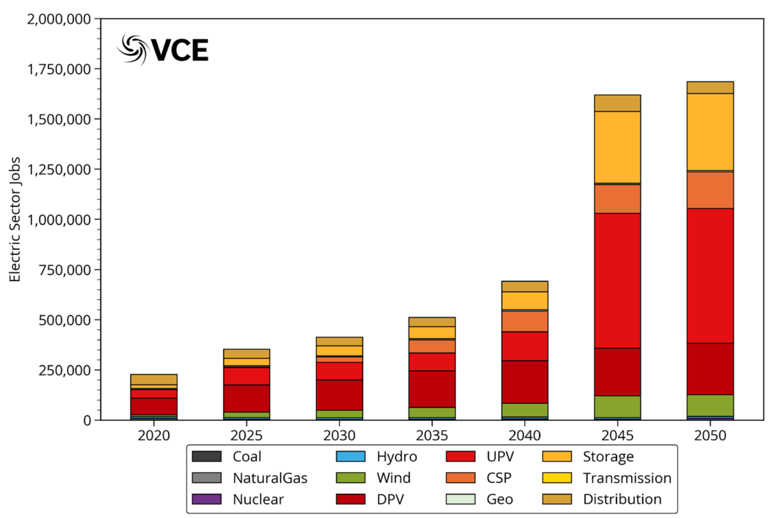

Figure 2.4: Direct full-time equivalent jobs created in the electricity sector by industry in the "Local Solar & Storage Future" scenario.

Figure 2.5 shows the percentage increase in jobs by 2050 compared with 2020 for each county in California. Every county in California shows an increase in jobs created, with some counties showing very large percentage increases due to having very few jobs in the electricity sector in 2020. This shows that economy-wide electrification and decarbonization with distributed generation co-optimization creates jobs in every part of the state ensuring improved economic outcomes throughout the state.

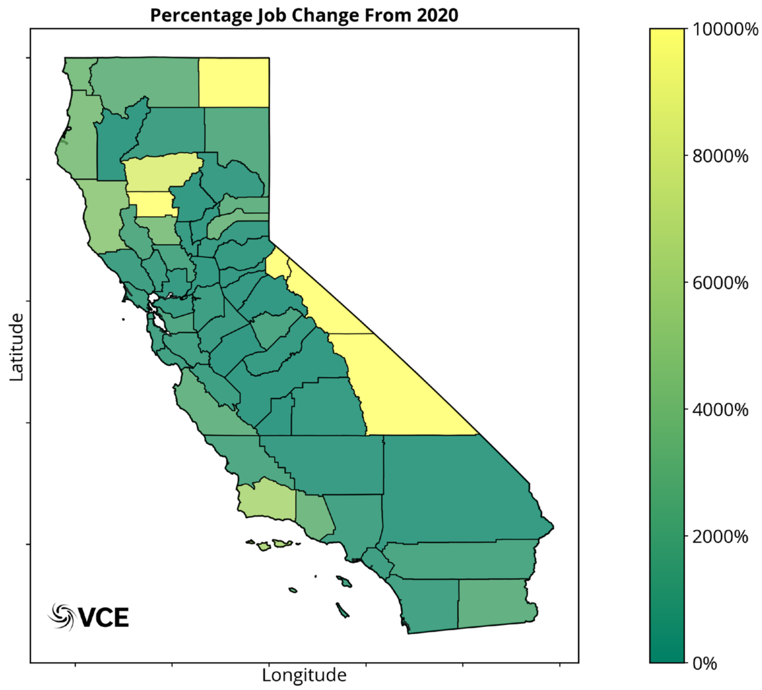

Figure 2.5: Percentage change in jobs compared with 2020 in the "Local Solar & Storage Future" scenario.

2.2 Changes to Installed Capacity & Generation

The evolution of the installed capacities and generation mix in California for the "Local Solar & Storage Future" scenario is shown in Figure 2.6 (top and bottom panels respectively). Between 2020 and 2040, California retires its natural gas combined cycle (NGCC) fleet, while adding some natural gas turbines (NG GT) generation which is dispatched very rarely and exists mainly for resource adequacy and ensuring demand is met during periods of high system strain. After 2040, the NG GT generation is also retired and storage is used to ensure reliability during periods of high system strain.

The increase in deployment of renewables reduces the cost per kWh of delivered energy as shown in Fig. 2.3. However, the larger reductions in retail rates are driven by California steadily reducing its reliance on imports and becoming a net exporter of energy by 2045 as shown in bottom panel of Fig. 2.6.

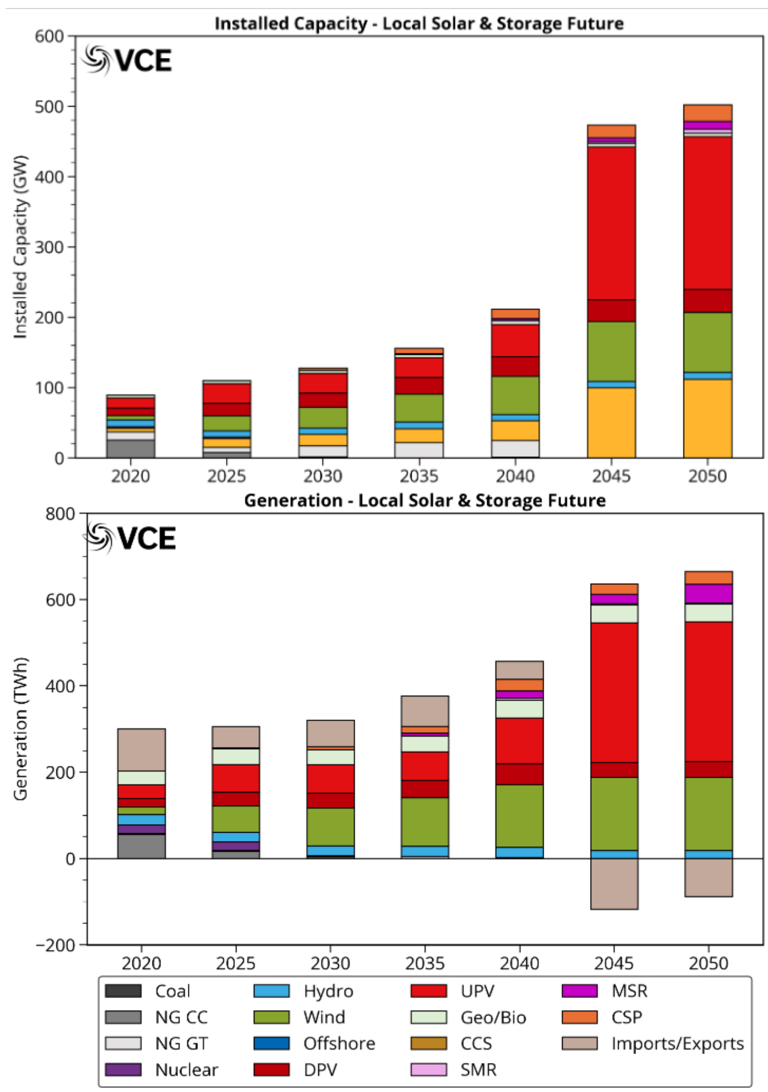

Figure 2.6: WIS:dom-P installed capacities (top) and generation (bottom) for the "Local Solar & Storage Future" scenario in California.

California installs a large amount of utility-scale solar and storage after 2040 to help meet the state's decarbonization goals. The model chooses to install utility-scale generation in 2045 over distributed generation so that the excess generation can be exported to make revenues, which subsidizes the cost of the new installed generation resulting in reduction of retail rates in spite of the large increase in total system costs.

Figure 2.7 shows the utility- and distribution-scale storage installed in California in the "Local Solar & Storage Future" scenario over the investment periods. Until 2040, the majority of new storage installed is on the distribution grid to pair with the installation of distributed PV and community PV (see Fig. 2.8). After 2040, as California installs a large amount of utility-scale PV, the model installs both utility- and distributed- storage resulting in a roughly equal mix of distributed and utility-scale storage by 2050.

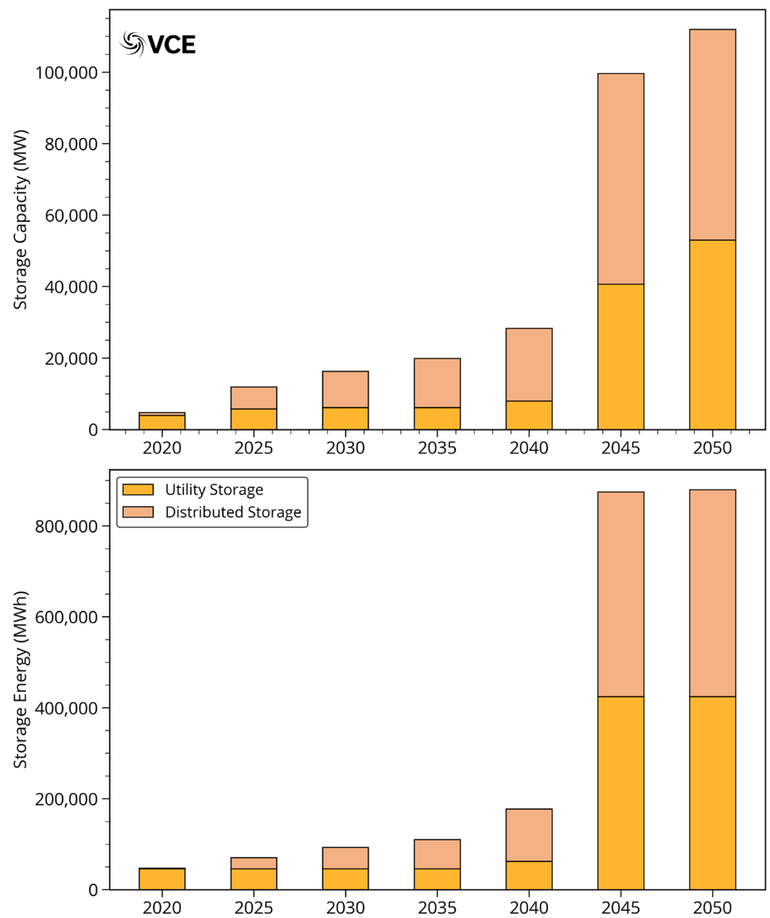

Figure 2.7: Utility storage and distributed storage installed in each investment period for the "Local Solar & Storage Future" scenario.

The reason the model chooses roughly equal amounts of utility-scale and distributed storage is that the model installs large amounts of utility-scale PV after 2040 (see Fig. 2.8) as it has the lowest cost per kWh generated. Some of the excess generation from utility-scale PV is absorbed by utility-scale storage and some of it is exported out of state to generated revenues. During the nighttime and early morning hours when demand is lower, the utility-scale storage transfers its stored energy to the distributed storage installed behind the 69-kV substations. This stored energy in the distributed storage is then dispatched during the peak load hours (late afternoon and evening in summer) ensuring that peak power moved through the utility-distribution interface is minimized and the load seen by the utility-scale generation is flatter.

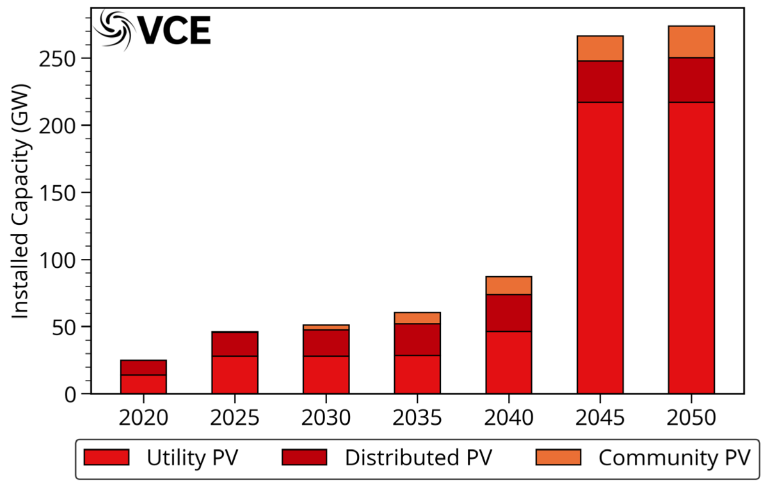

Figure 2.8: Utility PV, Distributed PV and Community PV installed over the investment periods in California in the "Local Solar & Storage Future" scenario.

2.3 CO_2 Emissions & Pollutants

The annual CO_2 emissions change with respect to 2005 levels and the cumulative electricity sector emissions in the "Local Solar & Storage Future" scenario compared with the reference case of emissions staying at the same levels as 2018 is shown in Figure 2.9. The model shows a rapid reduction in annual emissions as fossil fuel generation is either retired or used to a lesser extent and is replaced with clean VRE generation. The annual emissions decline by 97.5% by 2040 as all NGCC and coal generation is retired and replaced by renewable sources of generation. The cumulative emissions from the electricity sector almost flatten after 2025 as California eliminates over 80% of emissions from the electricity sector. As a result of the decarbonization, California saves 2,225 million metric tons (mmT) of CO_2 by 2050 compared with a reference case of continuing to emit at 2018 levels.

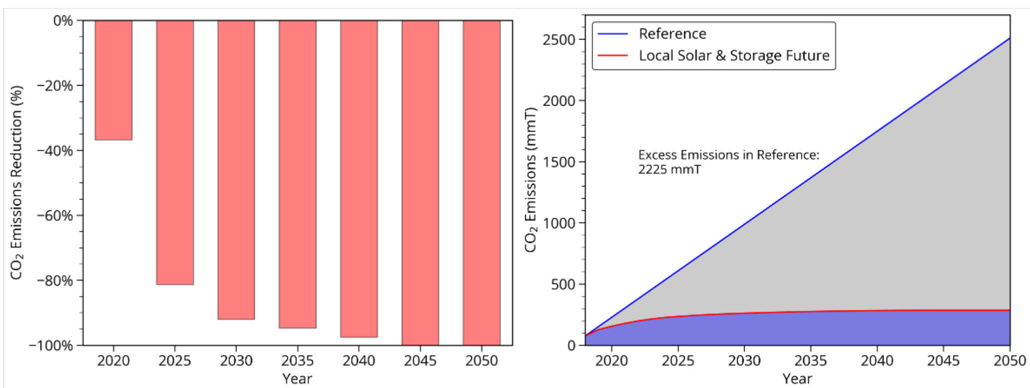

Figure 2.9: Annual emissions change with respect to 2005 (left) and cumulative carbon dioxide emission in the electric sector.

The economy-wide cumulative emissions in California in the "Local Solar & Storage Future" scenario is shown in Figure 2.10. Electrification alone is responsible for a considerable reduction in economy-wide emissions, saving a cumulative 5,083 mmT of CO_2 by 2050. The "Local Solar & Storage Future" scenario further reduces emissions by decarbonizing the electricity sector resulting in an additional savings of 2,225 mmT of carbon dioxide cumulatively by 2050. Therefore, the cumulative economy-wide emission savings from the "Local Solar & Storage Future" scenario is 7,305 mmT of carbon dioxide compared with continuing at 2018 levels without emission reductions or electrification.

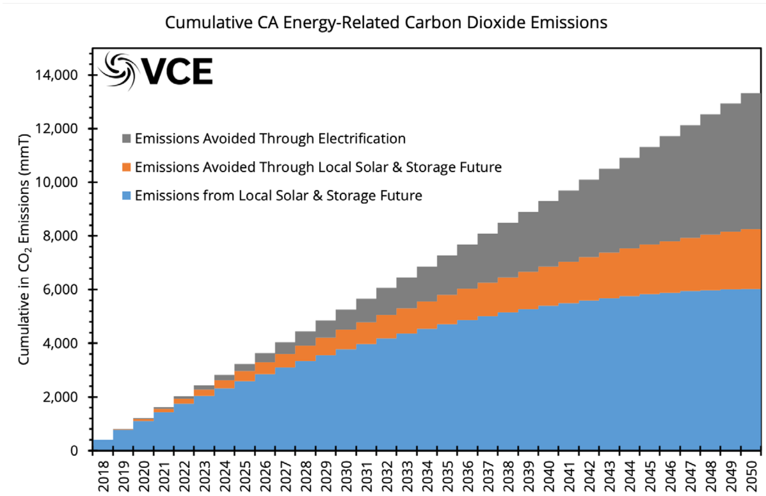

Figure 2.10: Economy-wide carbon dioxide emissions in California

In addition to eliminating carbon emissions, the "Local Solar & Storage Future" scenario also completely eliminates other criteria air pollutants from the electricity sector. Figure 2.11 shows the emissions levels for criteria air pollutants tracked by WIS:dom-P in the electricity sector. Emissions of all pollutants drop sharply between 2020 and 2030 as all fossil fuel use is eliminated. After 2030, emissions continue to decrease and are completely eliminated by 2045. Therefore, the "Local Solar & Storage Future" scenario will result in better health outcomes for the local population while increasing economic activity through creating jobs and reducing the energy burden for customers.

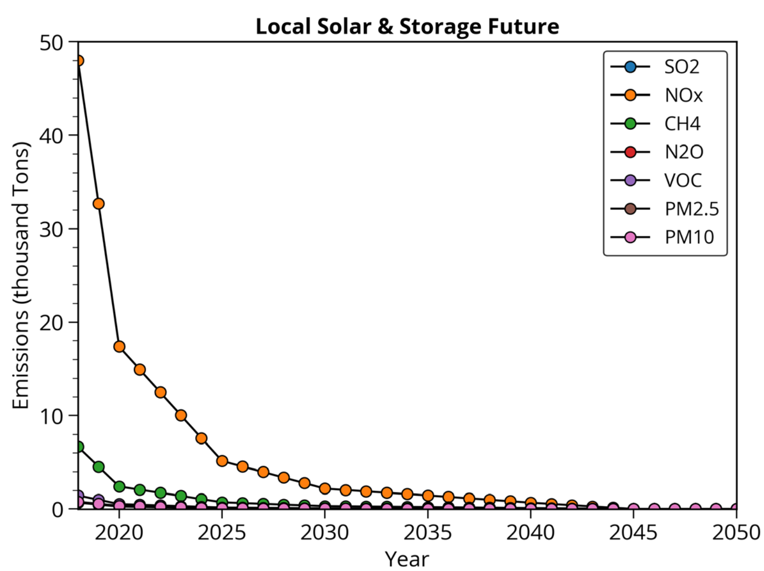

Figure 2.11: Emissions from other criteria pollutants tracked by WIS:dom-P.

Note that other non-tracked pollutants will be reduced in the transportation and industrial sectors, because they are fully electrified. Further, water use is dramatically decreased because of the transition to an electrified and decarbonized economy.

2.4 Siting of Generators (3-km)

WIS:dom-P uses weather datasets spanning multiple years at 3-km spatial resolution and 5-min temporal intervals over the contiguous United States. WIS:dom-P performs an optimal siting of generators on the 3-km HRRR model grid. The WIS:dom-P installed capacity layout at 3-km resolution along with the transmission paths above 115 kV for 2035 is shown in Figure 2.12 (left panel), while the WIS:dom-P installed capacity by 2050 is shown in Figure 2.12 (right panel). The grid is largely transformed to a VRE dominated one by 2035 and has completely emission free generation by 2050. California deploys significant solar generation at both utility- and distribution- scale along with substantial wind generation.

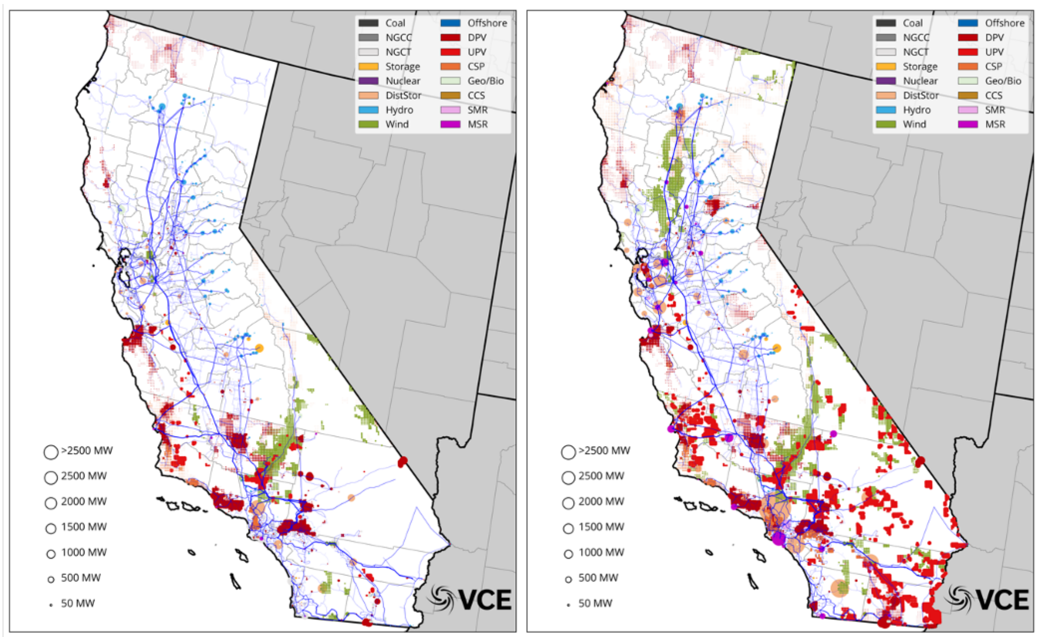

Figure 2.12: Installed generation layout in 2035 (left) and 2050 (right) at 3-km resolution along with transmission paths above 115 kV.

By 2035, large installations of distributed PV are seen at load centers such as Los Angeles and the Bay Area. Wind installation are seen to be concentrated in the Central Valley region. By 2050, significant utility-scale solar is deployed mainly over the southern part of the state including the Deserts region. Wind generation is also deployed in the Sacramento Valley region to help meet the load in the northern part of the state with clean electricity.

When making the siting decisions, the model takes into account several criteria to determine the optimal siting for generators. In addition to accounting for expected generation and distance from the load (for transmission considerations), the model ensures that generation is not sited in unsuitable locations. The model also ensures that the technical potential of each grid 3-km grid cell is not exceeded. The technical potential for the various VRE technologies in each grid cell is determined according to factors such as population, land cover, terrain slope, and others. In addition, each technology is limited by a maximum packing density to ensure that generators do not hamper performance of other generators in the grid cell, such as through wakes for wind turbines and excessive shading for solar panels.

Table A: Total jobs by county in California over the investment periods in the "Local Solar & Storage Future" scenario.

County	2020	2025	2030	2035	2040	2045	2050
Alameda	2451	3039	3540	4441	5896	18310	39151
Alpine	2	2	3	3	4	13	274
Amador	235	249	259	274	308	599	601
Butte	2411	2239	2292	2363	2612	4527	4500
Calaveras	305	323	336	353	393	744	748
Colusa	152	77	53	55	77	6247	6248
Contra Costa	2492	2555	2874	3359	4408	12802	12958
Del Norte	32	43	953	963	987	1195	1201
El Dorado	908	982	1034	1103	1269	2704	2728
Fresno	10209	9642	9976	10383	11454	19312	19210
Glenn	40	52	60	70	94	5413	6802
Humboldt	182	223	255	302	421	1455	7583
Imperial	6422	6411	6463	6549	6733	161675	161657
Inyo	111	119	2018	10419	19868	60342	60344
Kern	32935	52775	64521	74799	131244	137629	137643
Kings	1886	1929	1992	2069	2215	3347	3348
Lake	99	125	143	167	226	1753	1760
Lassen	95	107	116	128	155	397	1912
Los Angeles	26425	57906	60726	103310	180844	259408	260662
Madera	616	669	709	770	912	2136	2142
Marin	339	448	523	619	850	3010	3057
Mariposa	112	119	124	131	147	283	1561
Mendocino	118	156	1111	2978	3055	5974	5992
Merced	3274	3066	3128	3214	3514	5808	5766
Modoc	11	15	18	21	29	3109	3762
Mono	108	113	833	839	851	15178	15179
Monterey	742	751	11213	16771	17151	20385	20513
Napa	207	265	305	358	486	1593	1612
Nevada	230	270	298	335	424	1192	7673
Orange	4402	5635	6554	7749	10576	34974	35501
Placer	1035	1148	1250	1405	1758	4719	4715
Plumas	503	510	516	523	539	681	2393
Riverside	10633	11244	11965	13009	24232	149672	149648
Sacramento	2756	2673	2734	3019	3605	8027	7525
San Benito	578	601	3831	3853	3907	4370	4373
San Bernardino	78083	78609	79150	79987	81954	290328	290449

San Diego	6076	7075	8159	12683	15699	59199	59688
San Francisco	882	1274	1531	1831	2568	9105	9368
San Joaquin	1240	1440	1647	1940	2606	8184	8260
San Luis Obispo	5727	5709	8882	20890	21063	90951	90826
San Mateo	882	1684	1908	2183	2848	8692	8874
Santa Barbara	737	24035	40574	41915	42303	47333	47443
Santa Clara	2917	3536	4072	4803	6522	29379	29697
Santa Cruz	337	454	534	634	875	2979	3035
Shasta	2073	2130	2185	2258	2420	3784	16496
Sierra	16	17	18	19	22	45	402
Siskiyou	119	137	149	3123	3162	3499	3506
Solano	2137	3756	3915	4121	4518	7786	7858
Sonoma	693	901	1043	1230	1676	5562	5643
Stanislaus	1102	1236	1424	1665	2165	6193	6259
Sutter	289	233	254	302	397	1079	1090
Tehama	121	141	157	180	238	5868	10428
Trinity	147	152	156	161	173	275	276
Tulare	1760	2650	2782	2964	3385	6977	7010
Tuolumne	976	998	1013	1034	1082	1499	1506
Ventura	1579	43454	43645	43973	44755	51431	51510
Yolo	482	554	609	697	901	6571	6548
Yuba	414	444	465	493	560	1142	1150