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**STAFF PAPER**

# California Wind and Solar Generation During 2017 and 2018

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# ABSTRACT

The *California Wind and Solar Generation During 2017 and 2018* staff paper provides a brief overview of the status of wind and solar generation in California during 2017 and 2018. The paper provides a summary of wind and solar energy generation resources within the state and the energy delivered to the electric grid. It supports the state policy that renewable energy and zero-carbon resources supply 100 percent of retail sales of electricity to California end-use customers and 100 percent of electricity procured for state agencies by December 31, 2045. Topics include data collection, annual generation trends statewide and by region, historical generation from 2001 through 2018, flexible capacity, and generation profiles over a year, month, and day.

**Keywords**: Wind generation, solar generation, capacity factors, generation profiles

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# EXECUTIVE SUMMARY

Senate Bill 100 (De León, Chapter 312, Statutes of 2018) requires eligible renewable energy resources and zero-carbon resources supply 100 percent of retail sales of electricity to California end-use customers and 100 percent of electricity procured to serve all state agencies by December 31, 2045.

Commercial plants within state borders totaled 5,978 MW of wind and 11,896 MW of solar capacity at the end of 2018, representing 7 percent and 15 percent of in-state capacity, respectively. These plants delivered over 14,000 GWh from wind and over 27,000 GWh from solar in 2018, producing 7 percent and 14 percent of the in-state energy, respectively. Staff analyzed generation for selected days in 2017 and 2018 to find the combined generation profile from a combination with equal capacities of wind and solar plants. The analysis showed that the combination could provide a sustained output plateau from morning through afternoon in March, June, and September, with lower output in December from late morning through early afternoon. This may have implications for secondary demand peak growth resulting from SB 100 goals.

# CHAPTER 1: Background

Wind and solar power are the two leading sources of renewable electricity in California. Both resources are projected to continue to grow to meet the state's renewable portfolio standard, making up a growing proportion of the generation portfolio. Both are variable sources of electricity, meaning the output of each varies with available wind speed and solar radiation. Wind speeds are rarely zero, but there are periods of speed low enough to fall below the usability threshold. Solar radiation is zero during the night and varies during the day with sun angle, collector angle, and atmospheric conditions such as clouds, fog, and smoke. Unlike fully dispatchable generators, solar and wind resources operate at a capacity dependent on the natural solar radiation or wind flow.

Presenting accurate generation data informs an understanding of renewable energy generation and resources in the state. The data support developing policy toward increasing renewable energy and reducing greenhouse gas (GHG) emissions. This report presents the wind and solar generation for 2017 and 2018 and expands on data posted on the public website at https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data. The report also examines the combined profiles of wind and solar generators in California. This report follows previous Energy Commission reports that describe generation in California during one-to-three year periods.

## Senate Bill 100

Senate Bill 100 (SB 100) (De León, Chapter 312, Statutes of 2018) accelerates the renewables targets in California, to 60 percent of retail sales by 2030, and 100 percent of retail sales from renewable and zero-carbon resources by 2045. Benefits of the bill include displacing fossil fuel consumption, adding new renewable generating facilities, and reducing air pollution and GHG emissions, while creating a diversified and balanced electricity portfolio. This paper contributes to a better understanding of the role of solar and wind in California's portfolio.

## Data Collection Methods

Section 1304 of Title 20 of the California Code of Regulations (20 CCR section 1304) requires power plant owners to submit data and reports to the California Energy Commission (CEC) for every power plant with a nameplate capacity of at least one megawatt (MW). The required data includes power plant identification, nameplate capacity, fuel use, and energy generated. This regulation is one part of the Quarterly Fuel and Energy Reports (QFER). Data filers submit reports electronically and staff enter them into the CEC's QFER database. Energy values used in this staff paper are net of the station service, or parasitic load energy, which is energy used to operate the plant. Analysis for this report also uses data the CEC received from the California Independent System Operator (California ISO), which manages the electric grid over a large portion of California. Solar generation from behind-the-meter installations, and from plants under 1 MW, are not collected in the QFER program.

In addition to the QFER data, California regulations (20 CCR sections 1381 through 1389) require that wind project information be reported from wind projects of at least 100 kW

through the Wind Performance Reporting System (WPRS). Both QFER and WPRS regulations require wind projects to report data. The CEC has consolidated reporting by wind projects to fulfill both code sections. Project operators file wind data through the online WPRS reporting system after the end of each quarter and data revisions in later quarters. Staff in the CEC Data Integration & Policy Office (DIPO) review the data to identify inconsistencies or omissions and assist reporters with corrections. CHAPTER 2:
Generation in 2017 and 2018

## Capacity and Energy Generated

At the end of 2017, California had 112 commercial wind projects and 699 solar power plants. At the end of 2018, there were 116 in-state wind projects and 730 solar power plants. Commercial-scale, also called utility-scale, wind and solar plants are at least 1 MW in project capacity. This analysis uses plants that are available to generate but does not include those that are not operational.

The total nameplate capacity for each resource is shown in **Figure 1**. Total energy generated is shown in **Figure 2.** Capacity is the maximum power output level of a generator. Net-generation is the gross electrical energy produced minus the station service energy. From 2017 to 2018, the capacity increased for both solar photovoltaic (PV) and wind.

**Figure 1: Wind and Solar Capacity**

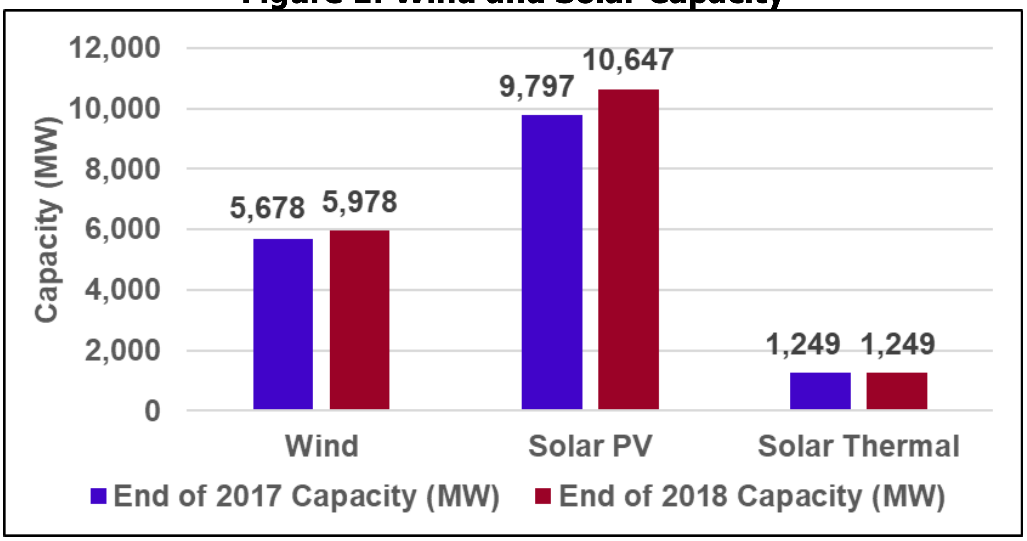
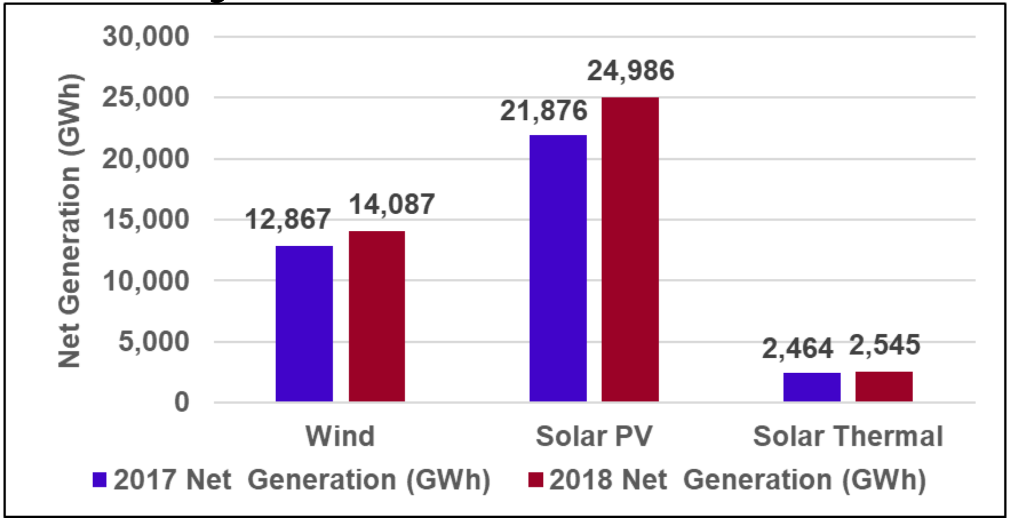


**Figure 2: Wind and Solar Net Generation**




Five companies operated 55 percent of the wind capacity at the end of 2018, shown in **Figure 3**. **Figure 4** illustrates the breakout by capacity of the top five solar companies at the end of 2018, which comprised 35 percent of solar capacity. The top five companies did not have solar thermal plants.

**Figure 3: Wind Operators with Highest Capacity**

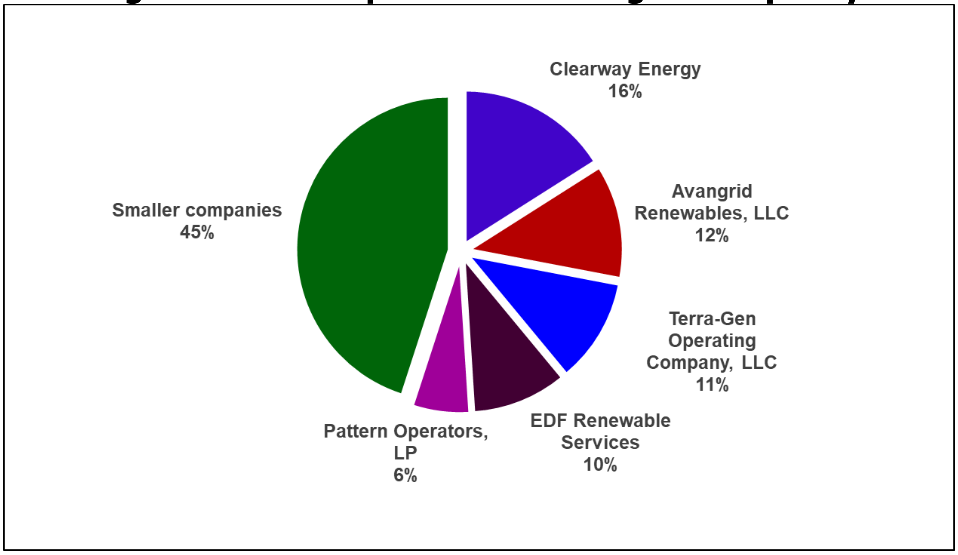
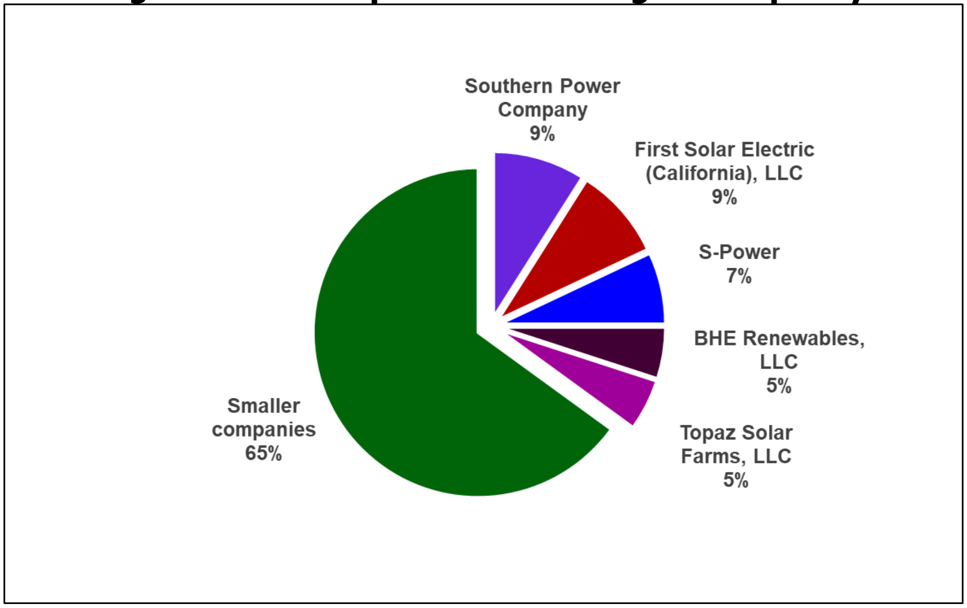


**Figure 4: Solar Operators with Highest Capacity**




The CEC tracks wind energy purchased from in-state plants through the WPRS. In 2017 and 2018, the leading purchasers of in-state wind energy, in order, were Southern California Edison, Pacific Gas & Electric, San Diego Gas & Electric, Marin Clean Energy, and the Sacramento Municipal Utility District. Most wind energy was purchased in the second quarter, followed by the third, first, and fourth quarters. The second quarter is a period of increasing sunlight in the year, which drives greater air movement and winds.

## Generation by Region

Wind and solar generator characteristics vary by region. California contains land areas ranging from minimal solar resources to excellent resources. From the foggy coastal regions to the clear deserts, there are great variations in solar radiation. Wind resources also vary, from areas of negligible resource size to areas with very high resources. Parts of the Central Valley have very low wind speeds, but locations between the coast and inland areas channel air flow, responding to daily temperature differences between land and ocean.

Staff divided the state into regions to illustrate these variations as subdivisions within the statewide generation statistics. Using the existing wind resource areas (WRAs) and creating new solar generation clusters (SGCs), **Figure 5** shows the regions where generators are concentrated.

**Figure 5: Wind Resource Areas and Solar Generation Clusters**

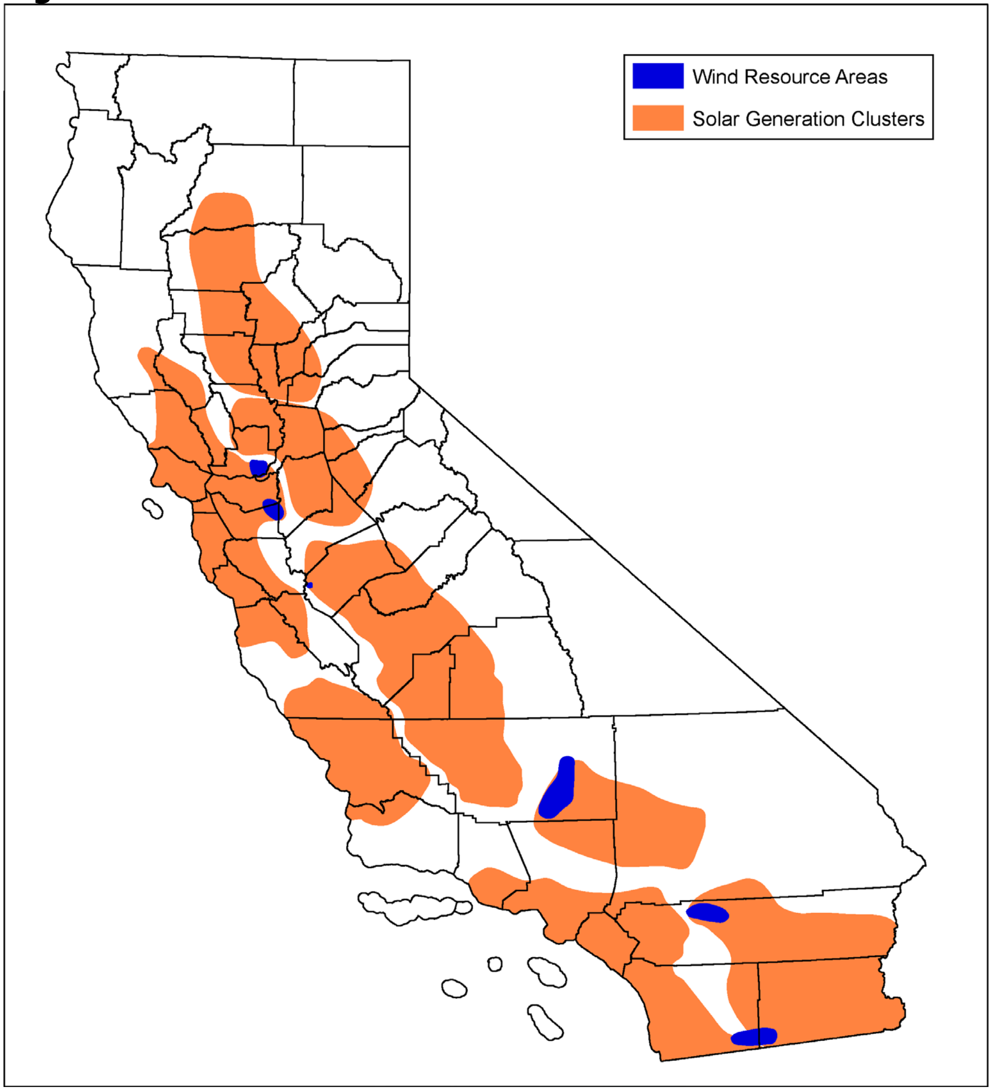



**Table 1** lists the name of the cluster, the number of solar projects, the median capacity and total capacity, capacity factor (CF), distance to the coast, elevation, global horizontal irradiance (GHI), latitude (Lat), longitude (Lon), and median project start year. GHI is the total solar radiation incident on a horizontal surface. Latitudes listed are north latitudes; longitudes are west longitudes.

**Table 1: Solar Generation Clusters**

| Name | Start Year | Percent of Projects | Median/ Total Capacity (MW) | Capacity Factor | GHI (kW/m²) | Coastal Distance (km) | Elevation (m) | Lat N (deg ) | Lon W (deg ) |
|---|---|---|---|---|---|---|---|---|---|
| North Valley | 2013 | 2 | 1.0/31 | 15% | 4.99 | 142 | 66 | 39.7 | 121.9 |
| Mid Valley | 2012 | 24 | 1.9/242 | 19% | 5.07 | 62 | 18 | 38.4 | 121.4 |
| Bay Area | 2012 | 4 | 1.1/172 | 18% | 5.00 | 10 | 28 | 37.8 | 122.1 |
| South Valley | 2014 | 16 | 4.0/2,425 | 21% | 5.32 | 125 | 100 | 36.2 | 119.6 |

| Name | Start Year | Percent of Projects | Median/ Total Capacity (MW) | Capacity Factor | GHI (kW/m²) | Coastal Distance (km) | Elevation (m) | Lat N (deg ) | Lon W (deg ) |
|---|---|---|---|---|---|---|---|---|---|
| San Luis Obispo | 2013 | 24 | 1.1/954 | 18% | 5.48 | 35 | 244 | 35.6 | 120.6 |
| Tehachapi | 2014 | 8 | 3.0/3,967 | 27% | 5.84 | 84 | 755 | 34.7 | 118.2 |
| Los Angeles Metro | 2012 | 13 | 1.5/280 | 18% | 5.37 | 37 | 256 | 34.0 | 117.5 |
| Imperial | 2014 | 9 | 16.0/2,814 | 26% | 5.84 | 156 | 120 | 33.6 | 115.7 |

Source: CEC, DIPO

Staff created the SGCs by analyzing solar generating facilities, represented by points on a map, and characterized by their distance to the coast, elevation, GHI, latitude, and longitude. The analysis developed the solar generation clusters by statistically sorting each facility into groups based upon characteristics using two algorithms. One algorithm ensures that the groups are significantly different from one another.

The second algorithm, the same process used to develop the wind resource areas, created irregular circles to encompass the points of each group. This method starts by drawing a simple polygon around a set of points, then using Bezier interpolation to smooth the polygon into an irregular circle. Bezier interpolation uses the distance and angle between polygon vertices to produce scaled curves.

Capacity factor (CF) is the ratio of the energy generated in a period to what could have been generated if the generator produced energy at maximum capacity during the same time period. CF can be expressed as either a percentage or a decimal. The SGCs include 98 percent of the total number of solar generating facilities and 92 percent of the total capacity, with the remainder residing at isolated locations that are significantly different from all other groups.

The WRAs are regions where wind generating projects have been concentrated. They do not include all regions in the state with a strong wind resource or where projects are possible. There are also single wind projects outside the WRAs that have high productivity. Those projects are in regions where additional commercial projects may become more attractive as technology and economics evolve.

Existing WRAs are shown in **Figure 5** and the characteristics are listed in **Table 2**.

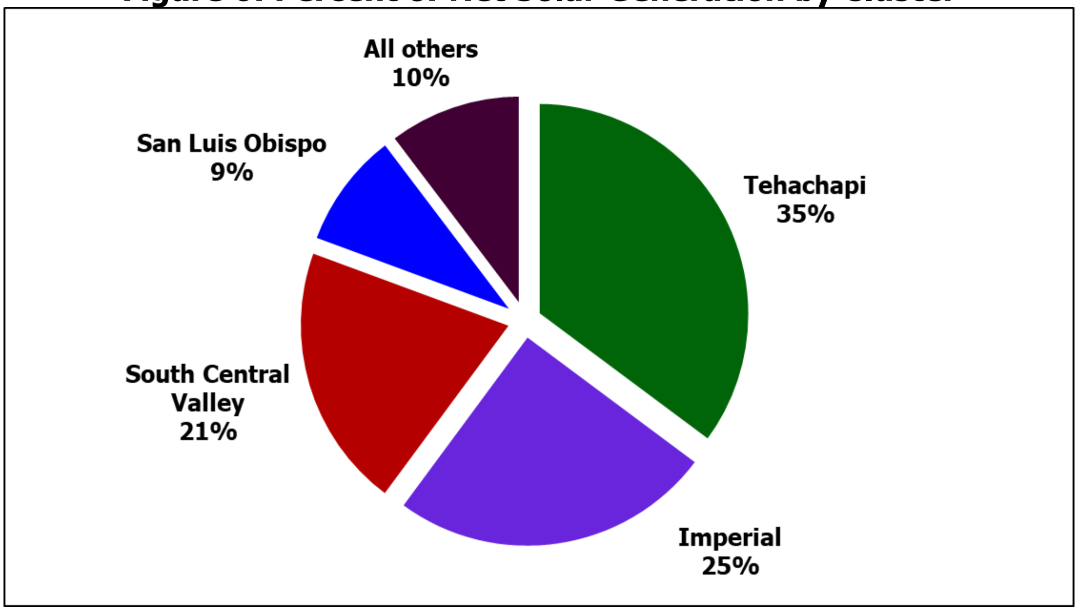
**Table 2: Wind Resource Areas**

| Name | Start Year | Percent of Projects | Median/ Total Capacity (MW) | Capacity Factor | Elevation (m) | Lat N | Lon W |
|---|---|---|---|---|---|---|---|
| Solano | 2005 | 8 | 103/1,031 | 31% | 66 | 38.1 | 121.8 |
| Altamont | 1988 | 17 | 20/268 | 28% | 304 | 37.7 | 121.7 |
| Pacheco | 1988 | 1 | 18/18 | 6% | 408 | 37.1 | 121.2 |
| Tehachapi | 1985 | 46 | 30/3,456 | 23% | 1,207 | 35.1 | 118.3 |
| San Gorgonio | 1986 | 25 | 16/634 | 27% | 306 | 33.9 | 116.6 |
| East San Diego | 2012 | 3 | 91/448 | 31% | 729 | 32.7 | 116.3 |

Source: CEC, DIPO

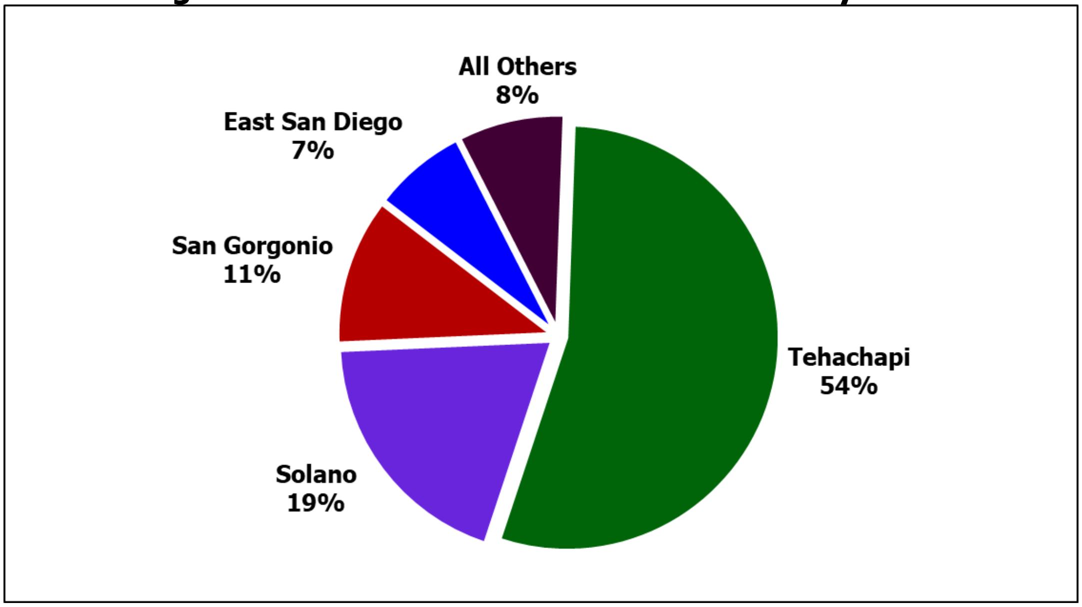
The proportion of net energy generation by region is shown in **Figure 6** and **Figure 7**.

**Figure 6: Percent of Net Solar Generation by Cluster**




Source: CEC, DIPO

**Figure 7: Percent of Net Wind Generation by Area**




Source: CEC, DIPO

In addition to commercial-scale solar, in 2018 California generated more than 13,000 GWh of energy from behind-the-meter rooftop solar PV projects located at residences and small businesses throughout the state. Behind-the-meter generators provide energy that is used on-site and are sized to contribute to the energy needs of end users. This report does not include behind-the meter generation data, but focuses on larger, commercial scale, installations operated by energy companies and other organizations.

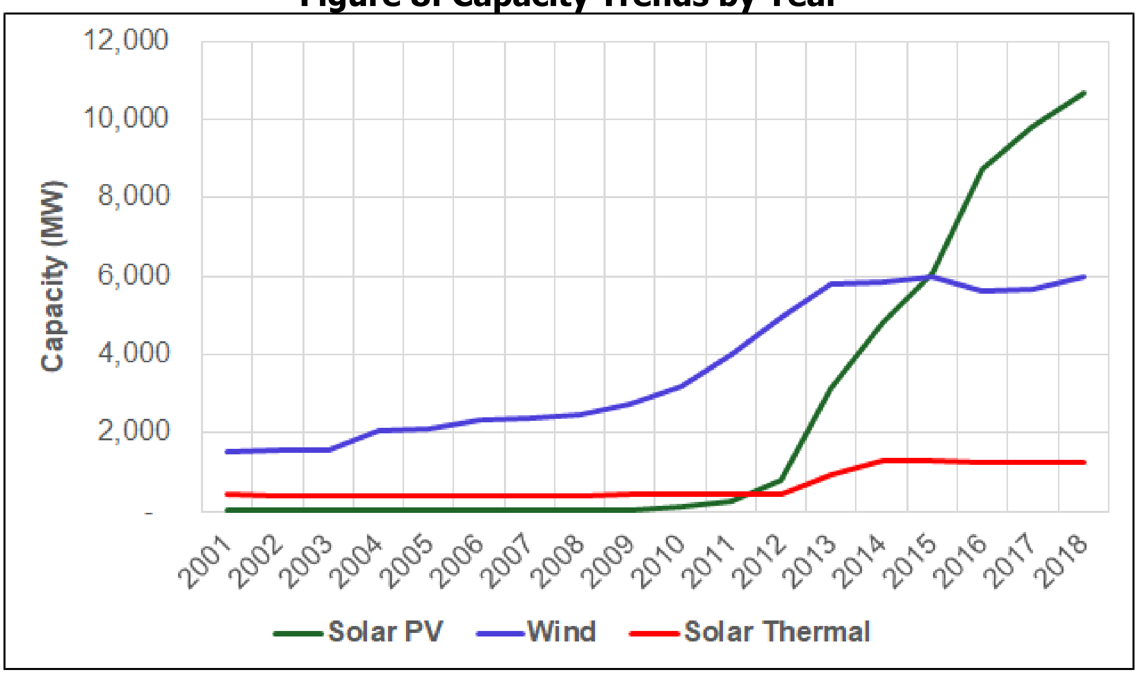
California's wind turbine fleet is evolving toward larger turbine sizes. Previously, the average operating turbine was under 1 MW. The first quarter of 2020 saw a threshold reached when the average turbine size went above 1 MW. This reflects national and global trends with larger turbines being brought to market and installed. Increasing turbine capacities can take advantage of economies of scale, from engineering and manufacturing to operation and maintenance, to lower the cost of energy produced.

# CHAPTER 3: Historical Wind and Solar Generation

Wind and solar generation over time are available from data collected in the QFER and WPRS reporting systems. QFER data is available from 2001 onward, and complete WPRS data is available from 2014, when the WPRS system supplanted the QFER for wind generation. Data from both systems are combined in this report to give a more complete picture. Using this data, wind and solar capacity and generation are shown in **Figure 8** and **Figure 9**, respectively. **Figure 10** displays the CF for each resource since 2001. Solar generation is broken into two types: PV and thermal. Solar PV generators convert sunlight directly to electricity. Solar thermal generators collect heat in a fluid and use that heat to drive a generator. The QFER system does not capture data from power plants rated under 1 MW in nameplate capacity. Accordingly, behind–the-meter residential solar PV operational data is not collected under QFER.

Capacity trends are shown in **Figure 8**. Wind capacity grew gradually through 2010 and then rose faster until 2013 when capacity returned to slower growth and then leveled off. Within this time, there was a gradual equipment modernization of the wind fleet. In recent years, operators have replaced smaller turbines with larger ones and pushed the capacity upward. Solar PV power remained low through 2012, when it began a rapid climb. Solar thermal exceeded PV until 2012. Thermal capacity climbed modestly from 2012 to 2014 and then leveled off.

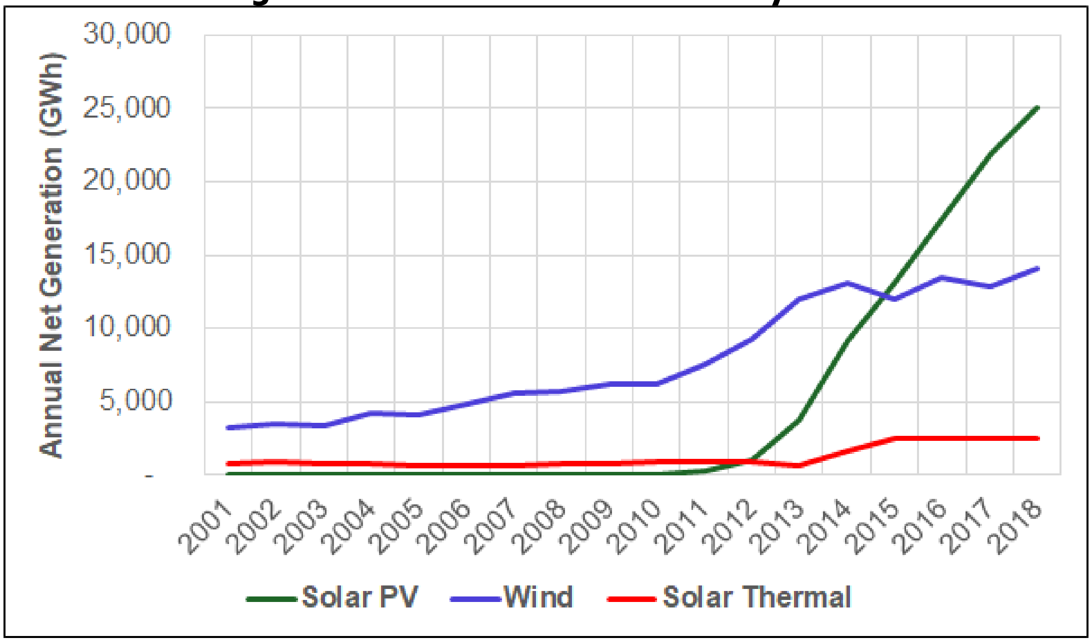
**Figure 8: Capacity Trends by Year**




Source: CEC, DIPO

Net generation followed similar trends with a temporary dip in solar thermal production in 2012 and 2013, and a dip in wind production in 2015. The 2015 dip as shown in **Figure 9**. Lower-than-average wind speeds were seen across several states.  Weather conditions in each year influence generation from wind and solar more strongly than other renewables like geothermal energy.

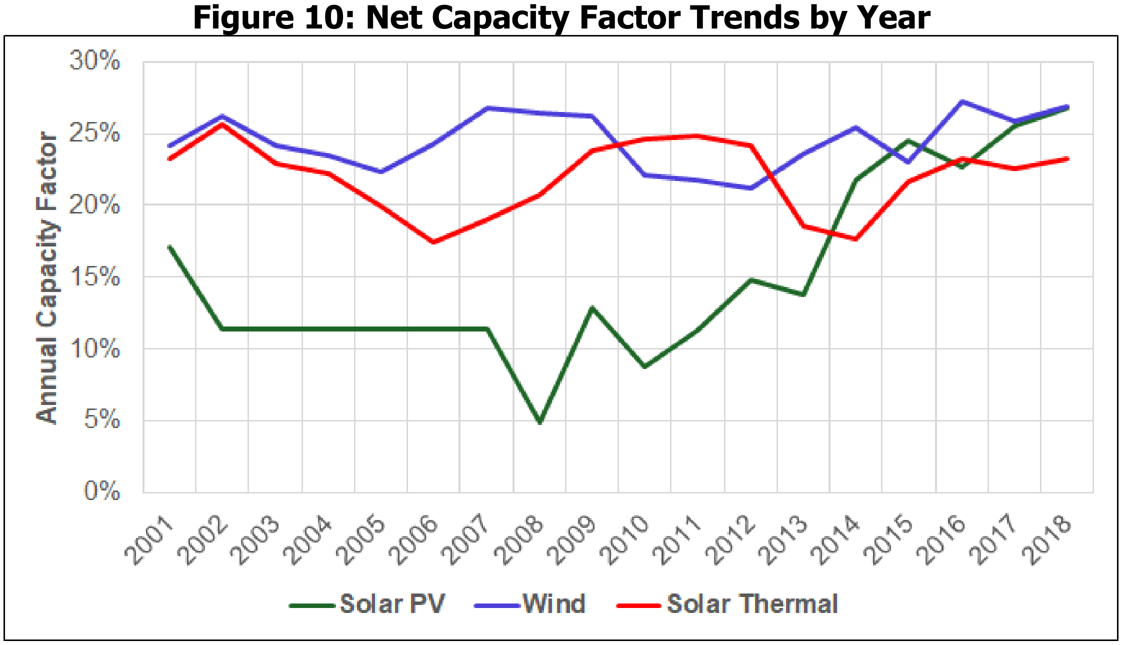
**Figure 9: Net Generation Trends by Year**




Source: CEC, DIPO

CFs for solar PV fell from 2001 to 2002, leveled off, and then increased after 2011. Wind factors have risen and fallen over the period and trended upward in recent years. Solar thermal factors rose and fell from 2001 to 2012 and then leveled off after 2015. The Ivanpah plants came online at the end of 2013 coinciding with lower solar thermal CFs in 2013 and 2014. The reduced energy output may have been due to stabilization during the first years of operation. These trends are shown in **Figure 10**.

**Figure 10: Net Capacity Factor Trends by Year**




Source: CEC, DIPO

# CHAPTER 4: Other Wind and Solar Topics

## Wind and Solar Generation and the California ISO

The California ISO manages the electric grid and wholesale electricity market for almost 80 percent of the state. Because overall electric demand is in large part driven by air conditioning, the need for electricity peaks during the hotter times of the day and the year. Typically, this occurs in the late afternoon during the late summer months. The growing portfolio of wind and solar generation, with very low variable operating cost, has displaced some thermal generation. The total demand minus wind and solar generation is the net demand that the California ISO must meet with other resources and imported energy.

The time profile of wind and solar generation has become more important when considering its effect on generation from other sources. Other sources — primarily natural gas — must be operated flexibly to adjust to the generation of wind and solar. Other renewable resources, such as ocean and some hydropower resources, can also require natural gas resources to adjust. Solar generation peaks in midday and wind peaks in the evening hours over most of the state. Most of these generators produce more in summer months than in winter. Because of these factors, the time profiles of wind and solar generation are increasingly important in managing the electric grid.

## Flexible Capacity Need

The non-renewable generation needed to adjust to wind and solar generation is supplied mostly by natural gas units. These units can ramp output up or down more quickly than power from nuclear or other fossil units. To be ready to adjust to changing renewable generation, the capacities of gas units are contracted for on a stand-by basis. This is *flexible capacity,* and it has an economic value to the grid operator and energy markets. Flexible capacity is generating capacity that can be ramped up or down to meet a changing need for power.

Flexible capacity is required primarily in the morning and late afternoon periods (California Energy Commission, 2018).[1] This control is needed mostly because of the growth of solar generation and the need for additional operational control is developing faster than anticipated. On March 4, 2018, for example, the maximum three-hour ramp was 14,777 MW. Although ramping up and down has long been part of the electrical system, growing renewable capacity with diurnal cycles increases the need, especially in the winter and spring.

Analysis by the California ISO shows that the issue of net ramping is most pronounced from November through March. Although maximum monthly ramps were fairly stable through 2014, later years show larger ramps in the non-summer months. This indicates that flexible capacity is becoming more important in winter months. Traditionally, flexible capacity was more important in the summer months.

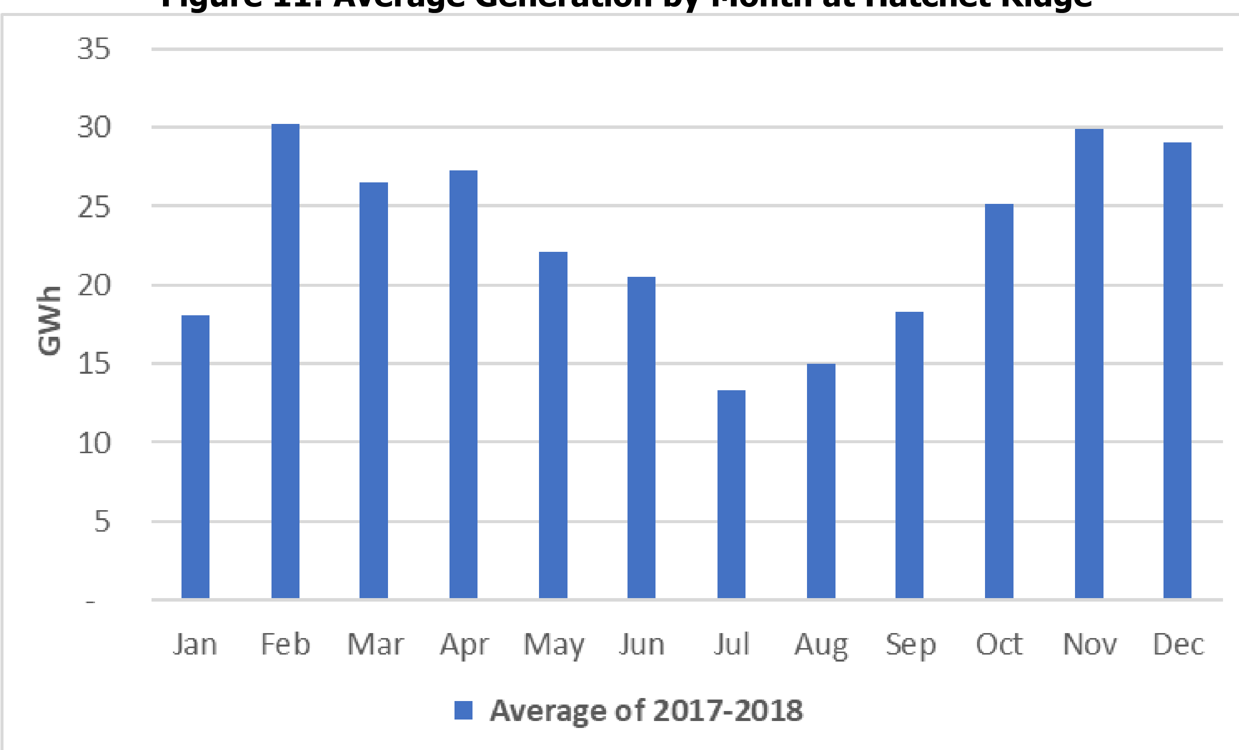
1 California Energy Commission staff. 2018. “Tracking Progress - Resource Flexibility.” October 2018. Available at https://www.energy.ca.gov/sites/default/files/2019-12/resource_flexibility_ada.pdf.

The need for more flexible capacity in winter raises the issue of when fossil-fueled generators should optimally shut down for annual maintenance. They can either avoid shutting down in winter months, to be available when needed or perform maintenance to avoid impacting availability for summer capacity.

One approach to addressing the flexible capacity issue is to expand the geographic extent of the market. Greater diversity in renewable resources can reduce the coincidence of generation. Generating resources outside the state can also help meet the need for upward ramping. A multi-state and province electricity market is developing to pool the resources of utilities in neighboring states. This includes utilities in California, Nevada, Utah, Arizona, New Mexico, Washington, Oregon, Idaho, Wyoming, and British Columbia. Pending participants are in Colorado and Montana. The Western Energy Imbalance Market is allowing utilities to trade energy across the Western region, save consumers money, and reduce GHG emissions. Additional energy imports from the Bonneville Power Administration are also being studied.

Within the state, the Hatchet project demonstrates the value of geographic diversity to the wind generation portfolio. Most wind generation projects in the state are not near the northern and southern borders, but a few newer projects are near the ends of the state. Over 2017 and 2018, the Hatchet Ridge wind project near Burney, exhibited higher output in the winter and a low point in the summer as depicted in **Figure 11**. This profile is roughly the opposite of most wind generators in the state. This contrast suggests that other wind generators in the northern part of the state could also provide capacity outside of the summer, providing diversity to the renewable generation supply portfolio.

**Figure 11: Average Generation by Month at Hatchet Ridge**



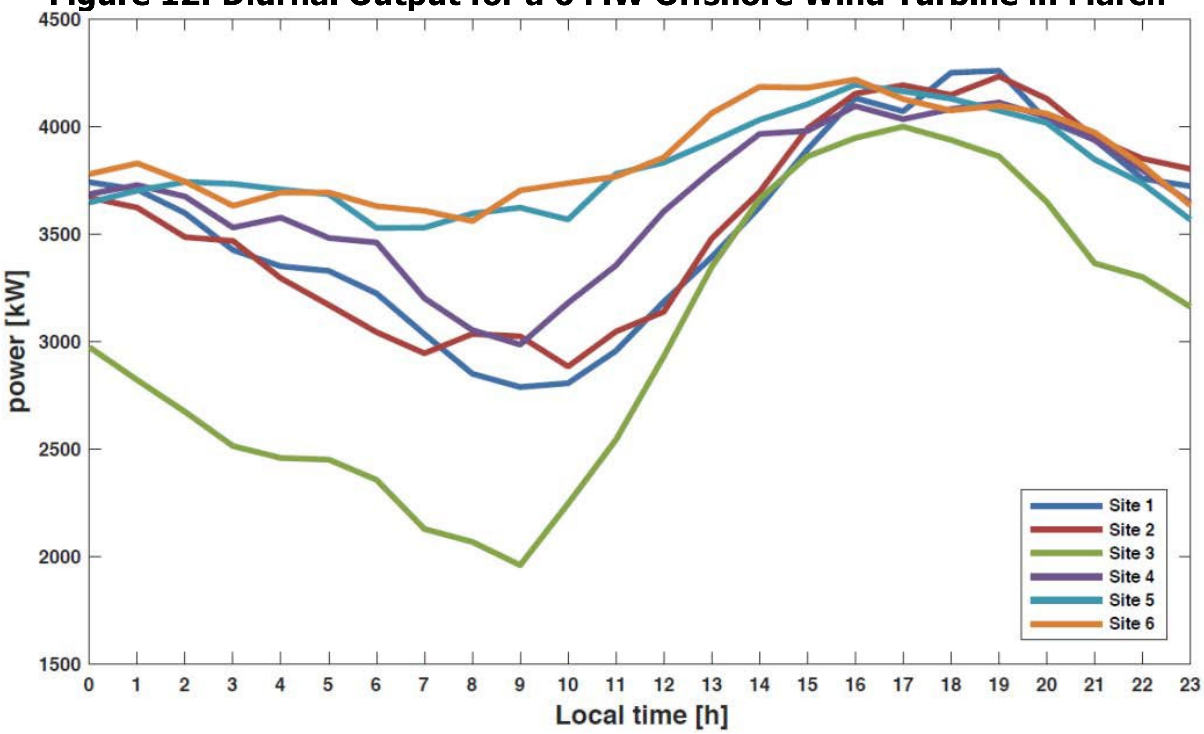

Source: CEC, DIPO

## Offshore Wind Generation

Wind plants in California are all on land, but California waters offer a larger wind resource. The CEC is working with state and federal agencies to plan for offshore wind in California. The federal government has produced studies of the potential output from offshore wind plants and typical output profiles are shown below. The United State Bureau of Ocean Energy Management is leasing public ocean areas off the coast of areas in California. A northern area is near Humboldt, and a central-coast area is near Morro Bay.

Output profiles by hours of the day for six potential California offshore generation sites are available in a 2016 report from the National Renewable Energy Laboratory (NREL).[2] In the report, the authors estimated power output for six sites off the California coast. The profiles over 24 hours in March are shown in **Figure 12**. At most of the sites studied, the peak would occur in the late afternoon or early evening.

**Figure 12: Diurnal Output for a 6 MW Offshore Wind Turbine in March**

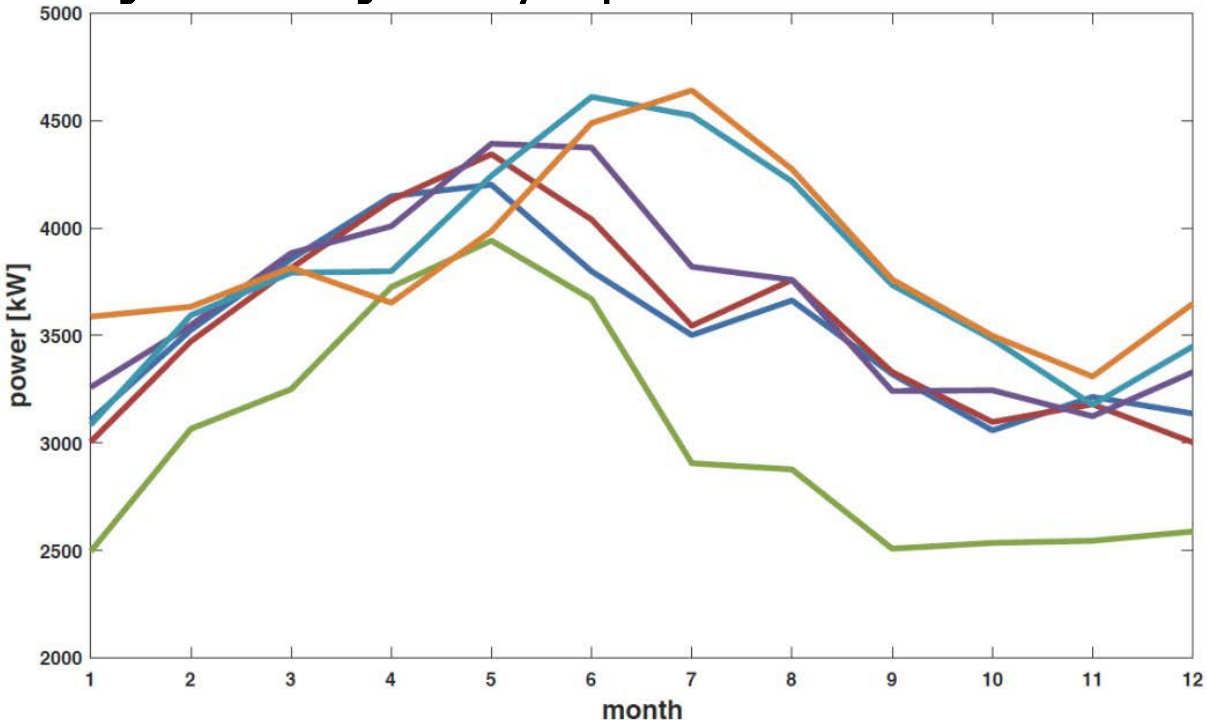



Source: National Renewable Energy Laboratory

The report also analyzed the profiles for the months of a year for the same six sites. The estimated profiles are depicted in the six colored lines in **Figure 13**. Peaks would occur between late spring and early summer, depending on the site.

2 Musial, Walter, Philipp Beiter, Suzanne Tegen, and Aaron Smith (National Renewable Energy Laboratory). 2016. Potential Offshore Wind Energy Areas in California: An Assessment of Locations, Technology, and Costs. December 2016. NREL/TP-5000-67414. Available at https://www.nrel.gov/docs/fy17osti/67414.pdf.

**Figure 13: Average Monthly Output for a 6 MW Offshore Turbine**




Source: National Renewable Energy Laboratory

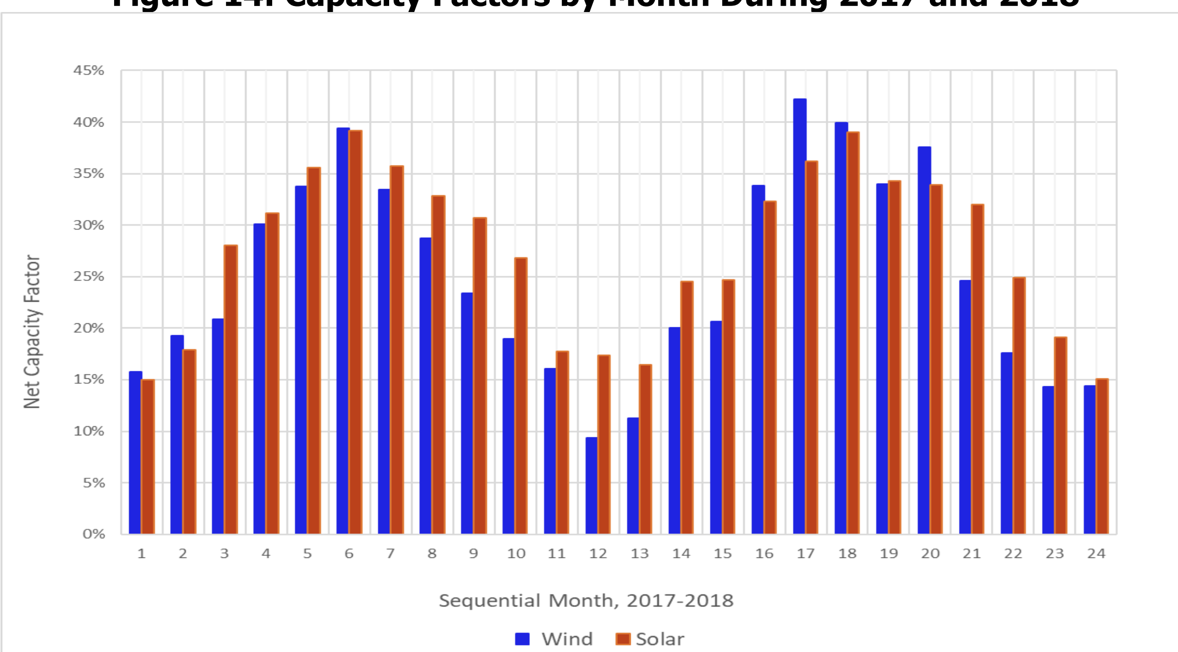
# CHAPTER 5:
# Periodic Variations

To examine the variations in wind and solar generation over time, staff used 2017–2018 data on energy generation from California ISO, supplemented by data from the QFER and WPRS data sets. California ISO energy generation data is in sub-hourly time intervals, and staff aggregated it to hourly, daily, and monthly levels. Three timeframes were examined: monthly variations, daily variations over selected months, and hourly variations over selected days. Solar PV and thermal are combined in the analyses, as solar thermal is usually a small percentage of total solar. Most in-state wind and solar capacity is interconnected with the California ISO.

## Variations Over a Year

**Figure 14** shows the CF profiles by month during 2017 and 2018 for onshore wind and solar sources within California ISO. The wind and solar profiles had approximately the same shape, with peaks in the summer and lows in the winter. May 2018 saw the highest monthly factor of the two-year period with wind at over 42 percent, while December 2017 saw the lowest with wind at 9 percent. The solar factor was highest in June 2017 at 39 percent and lowest in January 2017 at 15 percent. From 2017 to 2018, all monthly factors for the same source changed by 9 percentage points or less, showing consistency in generation from year to year.

**Figure 14: Capacity Factors by Month During 2017 and 2018**




Source: California ISO data analyzed by CEC staff

## Variations Over a Month

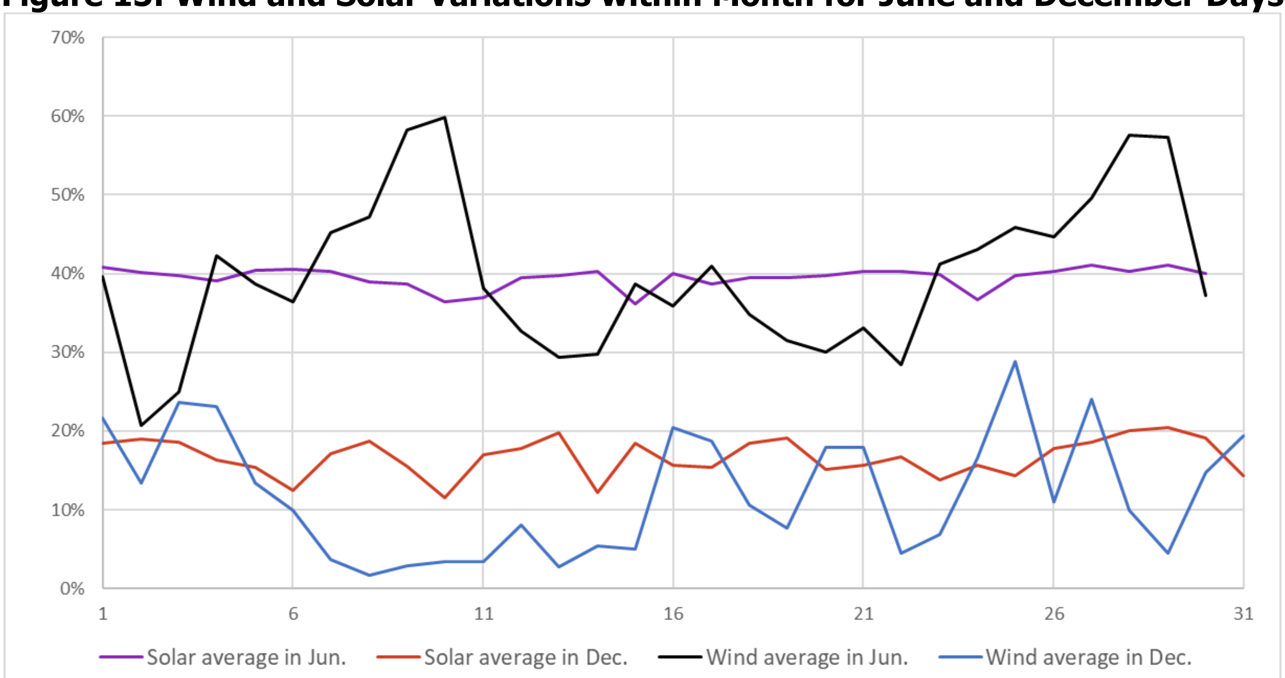
To analyze data over shorter periods, staff examined the variation using selected days, choosing four mid-month weekdays in March, June, September, and December and the peak day in each year. The four dates were selected to represent the generation situation in each season. The analysis accounts for the time change due to the shift to daylight savings time but does not adjust the hours for the difference between solar noon and clock noon during daylight savings time. The selected days were:

- In 2017: March 15, June 15, September 15, and December 15
- In 2018: March 15, June 15, September 14, and December 14

The dates when system demand peaked were September 1, 2017, and July 25, 2018. Both were weekdays, when demand is typically higher than on weekends. Peak days in most of California usually occur when weather is hottest and air conditioning demand is highest. Although California has areas where air conditioning is not essential, the large parts of the state that depend on it drive the statewide peak demand. Staff examined the daily variation during the months by averaging the capacity factors on the selected days for 2017 and 2018. **Figure 15** and **Figure 16** show the months when solar radiation is highest and lowest (June and December).

The differences in variation by day are depicted in **Figure 15**. CFs were higher in June than December throughout the month for wind and solar. The highest and the lowest factors were reached by the wind plants. The factors in June for each source were about twice those in December. The graph illustrates that wind and solar output both vary daily.

**Figure 15: Wind and Solar Variations within Month for June and December Days**

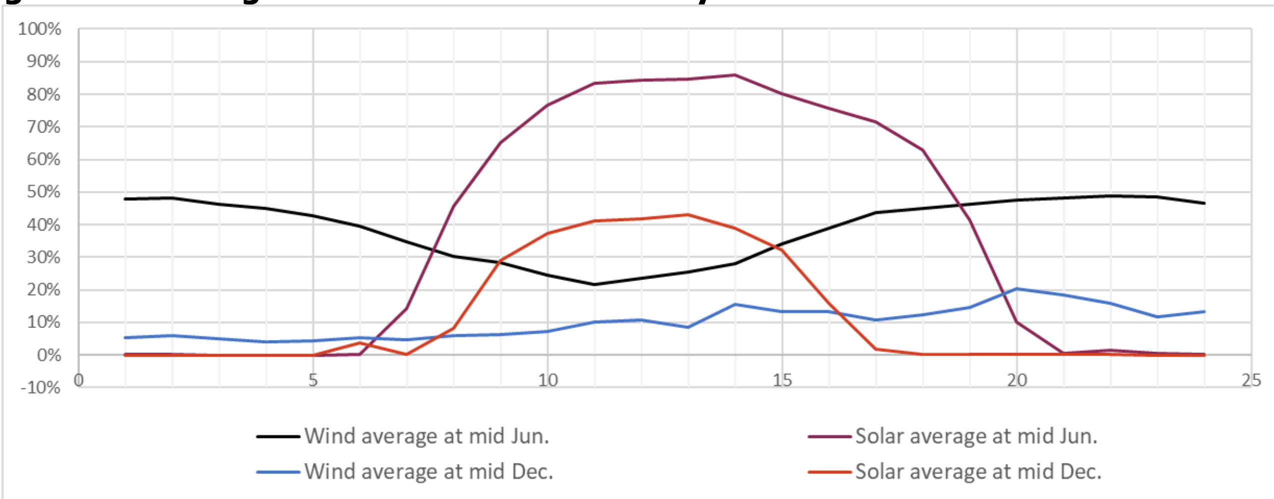



Source: CEC, DIPO

## Variations Over a Day

Daily solar generation profiles vary by hour according to received solar radiation. During periods of no solar generation at night, station load continues to consume energy from the grid, and the net solar generation becomes negative in some hours. Station load is typically a small fraction of gross generation. Wind generation varies with wind speed, and this is affected by many factors, including seasonal and daily patterns, microclimates, local topography, and land cover. Generation profiles vary by hour, as local and regional weather systems move and affect airflow at the generator site. Wind speeds can be low, but are usually not zero, and are not directly dependent on daylight. To illustrate these patterns, staff calculated the CFs for the wind and solar projects in California ISO for 2017 and 2018 and then averaged the years for each hour of the midmonth days. The factors by hour during midmonth days in June and December are shown in **Figure 16**.

**Figure 16: Average Wind and Solar Profiles by Hour in Mid-June and Mid-December**



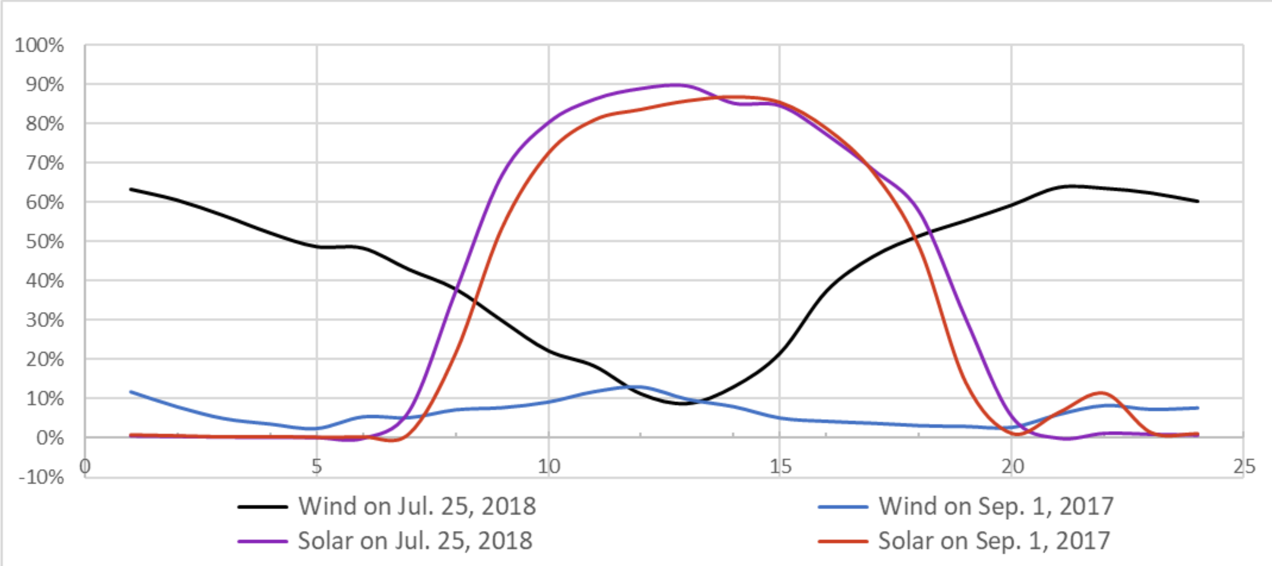

Source: CEC, DIPO

Profiles for March and September fall between the June and December profiles. In June, the average wind profile reached a daily low at midday and a daily high at night, but in December the average did not follow that trend. The average solar profile showed a peak after midday in both June and December. Both solar and wind showed higher CFs in June than in December. In December, wind factors were higher than solar until early morning and then higher from late afternoon to the end of the day. In June, solar capacity factors rose above wind capacity factors earlier in the morning and stayed higher until early evening. This reflects the dependency of the solar peak breadth on the hours of daylight.

Peak demand times require dispatching generation plants with different fuels. Wind and solar generation are part of the supply on most days, including peak days. During the peak days in these years— September 1, 2017 and July 25, 2018 — wind and solar profiles were as depicted in **Figure 17**.

Solar generation peaked near midday on both days. Wind generation showed a less pronounced peak at midday in 2017 and an inverse profile to solar in 2018. The profiles for solar between the two years were more similar than the profiles for wind in these years. The curves reinforce the fact that there can be significant variation in generation output from year to year. This is a result of many factors leading to the energy production from a renewable energy resource. Mitigation for variation includes energy storage systems and more sophisticated control technology designed into generators.

**Figure 17: Wind and Solar Profiles by Hour on Peak Days in 2017 and 2018**




Source: CEC, DIPO

## Combination of Hourly Wind and Solar Profiles

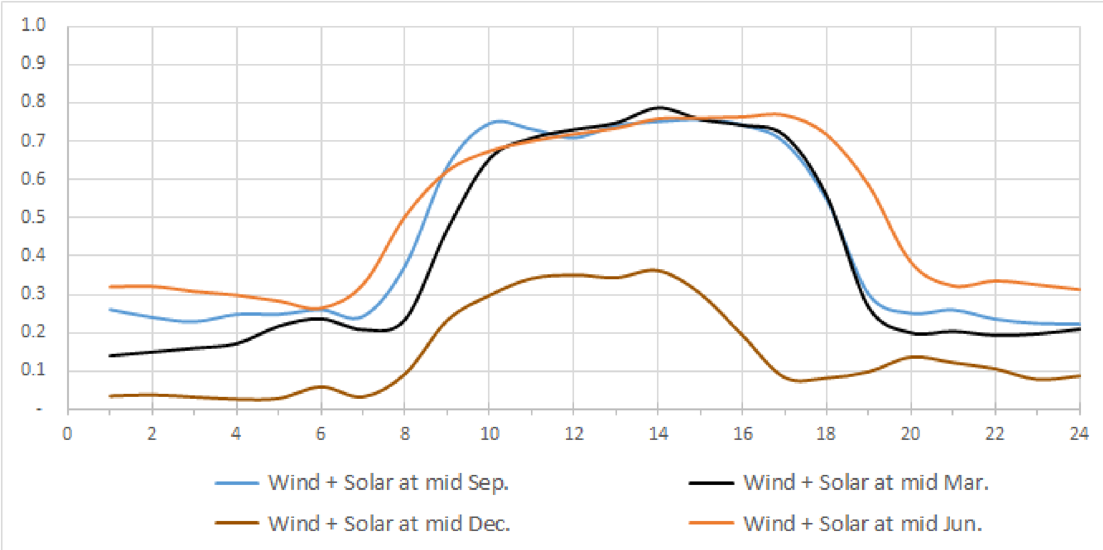
In practice, grid operators dispatch available generation resources to meet demand, accommodating must-take wind and solar energy along with other thermal resources. To illustrate the combination of wind and solar generation, first, the CFs of these two years for each of wind and solar are averaged for each midmonth day. Then the average wind and the average solar factors are added. The combined CFs are then normalized to a scale from zero to one, and the results are shown in **Figure 18**. The Y-axis is dimensionless.

Combining the two sources removes the effect of different installed capacities to focus on the time profiles on an equal-capacity basis. Over a year, a combination of wind and solar generators could theoretically produce 100 percent of the nameplate output from the wind generators and 50 percent of the nameplate from the solar generators. (Wind can generate day and night, but solar can only generate during the day.) In practice, the combination would not reach full power, full-time, because various factors limit generating hours at the plants.

The curves represent the combinations on a same-capacity basis of wind and solar generators on midmonth days in 2017 and 2018. Solar generation raises the combined profile during the daylight hours and wind generation raises it during the night hours. The plateau was centered later after noon in mid-June compared to mid-December. The time lag in June may reflect the influence of thermal inertia and more heat in the atmosphere, leading to a delay in when wind speeds peak. Winds speeds were not examined in this paper.

A combination of wind and solar generators on an equal-capacity basis would have an extended generating plateau from morning through evening in March, June, and September. The profile in December has a shorter plateau from later morning to earlier evening hours. Of the four times of the year, mid-December days provided the least combined generation. Solar radiation is low at that time of year, reducing both solar and wind generation. Lower radiation directly affects the solar generation and indirectly affects the wind generation. The combined profile in mid-September was higher than in mid-March during most hours.

**Figure 18: Combined Hourly Wind and Solar Profiles on Midmonth Days**




Source: CEC, DIPO

At the beginning and end of the day, the grid operator manages the load by ramping hydropower or non-renewable generators up or down. As solar capacity has grown in recent years, net peak has shifted to later in the day. Wind generation late in the day aids in meeting the shift to a later net peak. The graph in **Figure 18** depicts the combined generation later in the day. In each season, the combination would have maintained a minimum level during the night hours. The nighttime levels were highest at mid-June, followed by mid-September, mid-March, and then mid-December. Wind and solar generators complement one another over the course of a day.

# CHAPTER 6: Conclusions

Electricity from wind and solar generators in California contributes increasing amounts of renewable generation to the energy mix of the state. As these are variable resources, outputs vary from zero to full capacity. The average output level is usually a portion of the nameplate capacity, similar to most types of generators. SB 100 increases the renewable energy and zero-carbon targets in California through 2045. Detailed, expert analysis on the status of wind and solar power supports assessing progress toward and developing policy for meeting the targets.

Commercial plants in California totaled over 100 wind plants and over 700 solar plants at the end of 2018. Wind generating plants had a nameplate capacity of 5,978 MW, solar PV plants had 10,647 MW, and solar thermal plants 1,249 MW.

Wind plants in 2018 produced a net 14,087 GWh, PV produced 24,986 GWh, and solar thermal produced 2,545 GWh. Five companies operated 55 percent of the wind capacity. Five companies operated 35 percent of the solar capacity, though none of them had solar thermal.

Wind generating plants  are concentrated in six areas of the state. These areas were identified early in wind development as having high-quality wind resources and being close enough to load centers for economical power delivery. Earlier installations were built with many small turbines. Modern installations use larger turbines and have included single- or paired-large turbines at commercial electricity user facilities. The Tehachapi Wind Resource Area accounted for 54 percent of the net wind generation in 2018, followed by the Solano and San Gorgonio areas.

Solar generation is concentrated in eight clusters of generators across the state and reflects development in more recent years. The Tehachapi solar generation cluster had 35 percent of net solar generation for the year, followed by the Imperial and South-Central Valley clusters.

From 2001 through 2017, wind capacity grew gradually until 2010, when it climbed more steeply and leveled off in 2013. Since then, capacity has increased gradually with a shift toward larger turbines. Solar PV capacity remained stable through 2012, when it began to climb steeply. Net wind generation output rose gradually through 2010 when it climbed faster and then more slowly after 2013. PV energy production remained low until 2011, when it started climbing.

California ISO manages the grid for most of California and responds to peak demands driven by hot weather and air conditioning loads, typically in the late afternoon and late summer. As wind and solar generation grows, the net peak shifts to later in the day. Net demand is met using other renewables as well as, large hydropower and natural gas. California ISO is addressing the need to respond to changing demand profiles by seeking more flexible capacity in generation resources. Wind generators in parts of the state peak at different times of the year from the majority.

CEC is working with other state and federal agencies to plan for offshore wind power off the California coast. Because offshore generation profiles are predicted to peak late in the afternoon in most locations, this new source could complement the peak generation of solar PV occurring earlier in the day.

Staff examined the variations in solar and wind generation at different time scales from yearly to daily. The yearly profiles show both sources peaking in summer months and reaching minimums in winter months. Solar generation is directly affected by variations in solar radiation received at the generating site. Wind generation is indirectly affected, as air flows in response to temperature differences and changes in the atmosphere, over land and ocean. Both wind and solar generation CFs are about twice as high in June as in December, the high and low months of solar radiation.

The CFs for midmonth days in June and December were averaged over the two years for each hour. The profiles of variation by hour over the day show the solar generation peaking just after noon in both months. The wind CF dipped down in late morning, then rose in June. It increased throughout the day in December. Solar and wind capacity factors were about twice as high in June as December.

On the peak electric demand days of 2017 and 2018, solar profiles peaked in the early afternoon. The wind profile in 2017 peaked at noon, and the one in 2018 peaked at 9:00 p.m., with a low at 1:00 p.m. The typical late afternoon demand peak was not mirrored by either source on these days. This highlights the need for more energy storage, demand shifting, or other grid management to more closely align peak demand with renewable generation.

To examine combining wind and solar generation profiles, staff added the CFs of both sources on four, midmonth days in March, June, September, and December. The combined curves represent a combined generation resource on an equal-capacity basis. In mid-March and September, a combined generation resource could serve demand from about 9:00 a.m. to 6:00 p.m. In June, it could serve from about 8:00 a.m. to 7:00 p.m. In December, it could serve from about 9:00 a.m. to 4:00 p.m.

The analyses done in this paper show that, overall, wind and solar resources provided almost 42,000 GWh net energy to the state. This was over 20 percent of in-state generation and was a significant contribution to meeting the clean energy goals of the state.

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# Glossary

| ACRONYM | DEFINITION |
|---|---|
| California ISO | California Independent System Operator: the non-profit corporation that manages most of the electric grid in California. |
| CCR | California Code of Regulations |
| CF | Capacity factor: the ratio of the energy produced in a period to what the generator could ideally produce. |
| DIPO | Data Integration & Policy Office of the California Energy Commission |
| GWh | gigawatt-hours |
| GHI | Global horizontal irradiance: the total solar radiation incident on a horizontal surface. |
| MW | megawatt |
| PV | photovoltaic |
| SGC | Solar Generation Cluster: a region within California with a high concentration of solar generators. |
| QFER | Quarterly Fuel and Energy Report: the generation reporting system mandated by 20 CCR 1301 through 1304. |
| WPRS | Wind Performance Reporting System: the wind energy reporting system mandated by 20 CCR 1381 through 1389. |
| WRA | Wind Resource Area: a region within California with a high concentration of wind generators. |