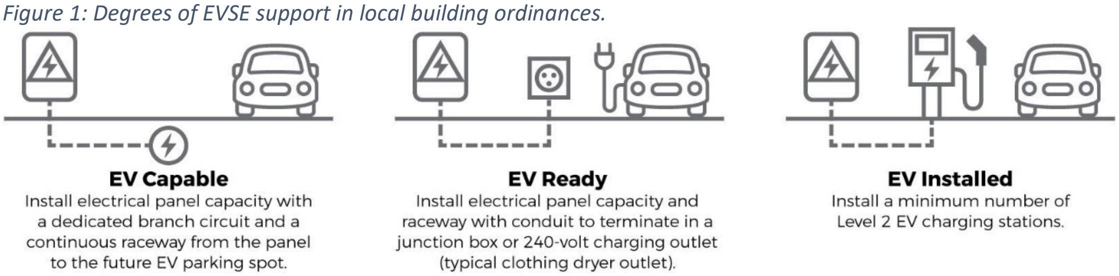
Energy Modeling to Assess Impacts of EVSE in New Developments

California Green Building Standards (CALGreen) dictate the measures that built environment must put in place to meet climate reduction goals set forth in AB32, including "facilitating future installation of electric vehicle supply equipment (EVSE)". New codes are adopted every three years, and 2019 started a new code. As in previous code cycles, it requires EV Capable parking spaces, meaning that the building has capacity in the electrical panel and spacing for wiring for a building inhabitant to install wires, circuits, and plugs for EV charging later. Figure 1 explains the different levels of EVSE support.

Figure 1: Degrees of EVSE support in local building ordinances.



Codes have mandatory compliance that all California jurisdictions must enforce, and some codes have voluntary compliance levels that jurisdictions can enforce or use as an incentive. The EVSE requirements have two voluntary levels called Tier 1 and Tier 2.

The 2019 CALGreen codes went into effect on January 1, 2020 and requires:

- Single-family residences, including townhomes and duplexes, be EV Capable
- Non-residential new construction and major alterations ($200,000 or 1,000 sq feet) to have up to 6% of parking spaces be EV Capable.
- Multifamily dwelling construction to have 10% of parking spaces be EV capable

Many jurisdictions are considering local ordinances, also called "reach codes" to require additional EVSE compliance. For additional EVSE compliance, the jurisdiction must demonstrate the reach code is "reasonably necessary because of local climatic, geological, or topographical conditions."

The Energy Code (Title 24 Part 6) of the California State Building Codes[1] requires additional energy efficiency measures and solar photovoltaics (PV) on all new construction. Some jurisdictions are also considering a reach code to require additional solar PV to offset the power used by additional charging infrastructure. This reach code, however, has a cost-effectiveness requirement.

It's important for developers and electric service providers to understand how adding electric vehicles (EVs) will impact the overall load profile on the utility, especially on the local transformers serving those developments. This is a complex issue requiring detailed utility data for specific building calculations. To provide some initial indication of potential impacts the project team completed preliminary modeling to provide initial guidance on load impacts and help municipalities understand the impacts of requiring additional solar photovoltaic (PV) to offset energy demands of car charging. Should a jurisdiction choose to apply to the Energy Commission to a local energy reach code, it is recommended that the local utility and jurisdiction conduct a more-detailed study.

[1] Effective January 1, 2020

Methodology

The existing Title 24 building energy compliance software (CBECC-Res) was used to model single and multifamily building prototypes to determine how EVs might impact the utility load shapes under various scenarios in the Sacramento, CA climate zone. The CBECC-Res software develops hourly end use data (as well as PV generation data) that was used to develop the following graphics showing the impacts. Several scenarios were explored for each building type.

For the single-family case, a 2,700 ft^2 two-story prototype home was modeled as:

1. A mixed-fuel home design meeting the 2019 Title 24 code requirements was modeled with the following gas end uses: space heating (forced air furnace), gas tankless water heating, cooking, and clothes drying. This configuration represents common construction practice currently seen in the Sacramento area. This scenario was modeled with a single EV assumed and no PV installed.
2. An all-electric home design meeting the 2019 Title 24 code was also modeled to represent future construction practices when electrification becomes more common in the Sacramento area. In this case, space heating is satisfied by a forced air heat pump and a heat pump water heater (HPWH) meets the water heating loads. All other end uses in the house were assumed to be electric. The home also has a 3.1 kilowatt direct current (kWdc) PV system, sized to satisfy the 2019 Title 24 code requirement. A second all-electric scenario was also modeled where additional PV is added to satisfy 88%[1] of the expected annual usage of the EV.

For the multifamily case, loads for a 40-unit building were determined by scaling the modeled results for the 6,960 ft^2 eight-unit apartment building prototype commonly used in Title 24 evaluations.

1. An all-electric case was assumed with the design meeting the 2019 Title 24 requirements. All-electric multifamily projects are becoming more common, so no mixed fuel case was modeled. Each apartment unit was modeled with a dedicated HPWH serving that unit.[2] The eight-unit prototype building modeled required 15.1 kWdc of PV to satisfy the 2019 requirements, which extrapolates to 75.5 kW for the 40-unit building.
2. As above, with additional PV is added to satisfy 88% of the expected usage of the EV.

Several assumptions were made about EV performance, charger efficiency, vehicle charging times, electric vehicle service equipment (EVSE) installed at parking spaces, assumed usage of home EVSE charging equipment, and the number of connected EVs.

- EV performance: An EV vehicle efficiency of 0.27 kWh/mile was assumed representative of mid-level efficiency EVs. Annual mileage based was based on a national average assumption of 13,476 miles/year[2]. 88% of EV charging was assumed to occur at home.
- EV charger efficiency: 90%.
- Charging times: For the single-family case, the assumption was that the EV charging would occur from midnight to 6am because most California utilities offer a special electric rate for EV charging during the night.[3] For the multifamily case, charging was assumed to occur uniformly

[2] This was a proxy because central HPWH for the building would be the more likely configuration. However, current modeling limitations of the CBECC-Res compliance software prevent this case from currently being run.

distributed over the 6pm to am time window to reflect diversity that would be more common in residential situations with multiple vehicles and charging stations. In the real world with widespread EV saturation, the EV charging would likely happen more equally through the night at both building types.

- Parking spaces: For single family, one EVSE with one vehicle was assumed to be charged. For multifamily, one parking space per apartment was assumed with either 10% or 20% EVSE installed. The 10% case is consistent with 2019 CALGreen requirements for EV-capable. The 20% is a reach goal for assessing Tier II "high" EV saturation scenario. Both the 10% and 20% cases assumed that two vehicles in the apartment complex would utilize each EVSE during the 13-hour charging window. Cases were analyzed where additional PV was added to offset the demands of the EVs. For the 10% EV case, this was an additional 18.1 kWdc, while for the 20% case it was 36.2 kWdc. It is important to note that siting additional PV on multifamily projects may involve ground mount installations as well as rooftop.

A summary of the electrical energy use impacts is provided in Tables 1 and 2 for each building/EV/PV scenario. Results are shown averaged over all days of the year (Annual Average), for December-February days only (Winter), for June-September days only (Summer), and for the single summer day with the peak electrical time dependent valuation (TDV) value.[3] Daily kWh consumption is disaggregated to look at time periods where PV generation will be greatest (10am to 3pm) and when peak summer electrical demand is highest (5 to 9pm). Positive values indicate new energy drawn from the grid, while negative values indicate excess PV delivery to the grid.

Table 1: Single Family Grid Energy Impacts by Time of Day for EV Scenarios (kWh/day)

Time of Year	Scenario	Full Day kWh	10am – 3pm	5pm – 9pm
Annual Average	Mixed Fuel Design (No EV, No PV)	13.7	2.4	3.6
""	Mixed Fuel Design (EV, No PV)	23.5	2.4	3.6
""	All-Electric Design (EV, Standard PV sizing)	21.5	-3.8	5.2
""	All-Electric Design (EV, Std PV+EV sizing)	15.8	-7.4	5.1
Winter	Mixed Fuel Design (No EV, No PV)	14.1	2.7	3.2
""	Mixed Fuel Design (EV, No PV)	23.8	2.7	3.2
""	All-Electric Design (EV, Standard PV sizing)	40.3	1.8	6.1
""	All-Electric Design (EV, Std PV+EV sizing)	37.1	-0.4	6.1
Summer	Mixed Fuel Design (No EV, No PV)	15.0	2.4	4.4

[3] TDV is the time varying energy caused to be used by the building to provide space conditioning and water heating and for specified buildings lighting.

Time of Year	Scenario	Full Day kWh	10am – 3pm	5pm – 9pm
“”	Mixed Fuel Design (EV, No PV)	24.7	2.4	4.4
“”	All-Electric Design (EV, Standard PV sizing)	11.8	-6.8	5.1
“”	All-Electric Design (EV, Std PV+EV sizing)	4.4	-11.2	5.0
Summer Peak Day	Mixed Fuel Design (No EV, No PV)	30.7	1.9	12.3
“”	Mixed Fuel Design (EV, No PV)	40.4	1.9	12.3
“”	All-Electric Design (EV, Standard PV sizing)	27.5	-8.3	15.3
“”	All-Electric Design (EV, Std PV+EV sizing)	20.2	-12.6	15.0

Table 2: 40-Unit Multifamily Grid Energy Impacts by Time of Day for EV Scenarios (kWh/day)

Time of Year	Scenario	Full Day kWh	10am – 3pm	5pm – 9pm
Annual Average	10% EV, No Added PV	296	-83	139
“”	20% EV, No Added PV	374	-83	157
“”	10% EV, Added PV	233	-123	139
“”	20% EV, Added PV	185	-202	155
Winter	10% EV, No Added PV	572	32	148
“”	20% EV, No Added PV	650	32	166
“”	10% EV, Added PV	536	7	148
“”	20% EV, Added PV	543	-42	166
Summer	10% EV, No Added PV	151	-148	145
“”	20% EV, No Added PV	229	-148	163
“”	10% EV, Added PV	70	-197	143
“”	20% EV, Added PV	-14	-294	158
Summer Peak Day	10% EV, No Added PV	153	-22	73
“”	20% EV, No Added PV	231	-22	91
“”	10% EV, Added PV	137	-32	73
“”	20% EV, Added PV	183	-51	90

Figures 1-8 graphically present the tabulated data above on an hourly basis. Some anomalies that appear on the peak TDV days relate to the CBECC-Res model and assignment of certain appliance loads. On a single day (such as the peak TDV day) it looks like an anomaly, but on a summer averaged seasonal basis the effect is dampened.

Figure 2: Single Family Annual Average Day Grid Impacts

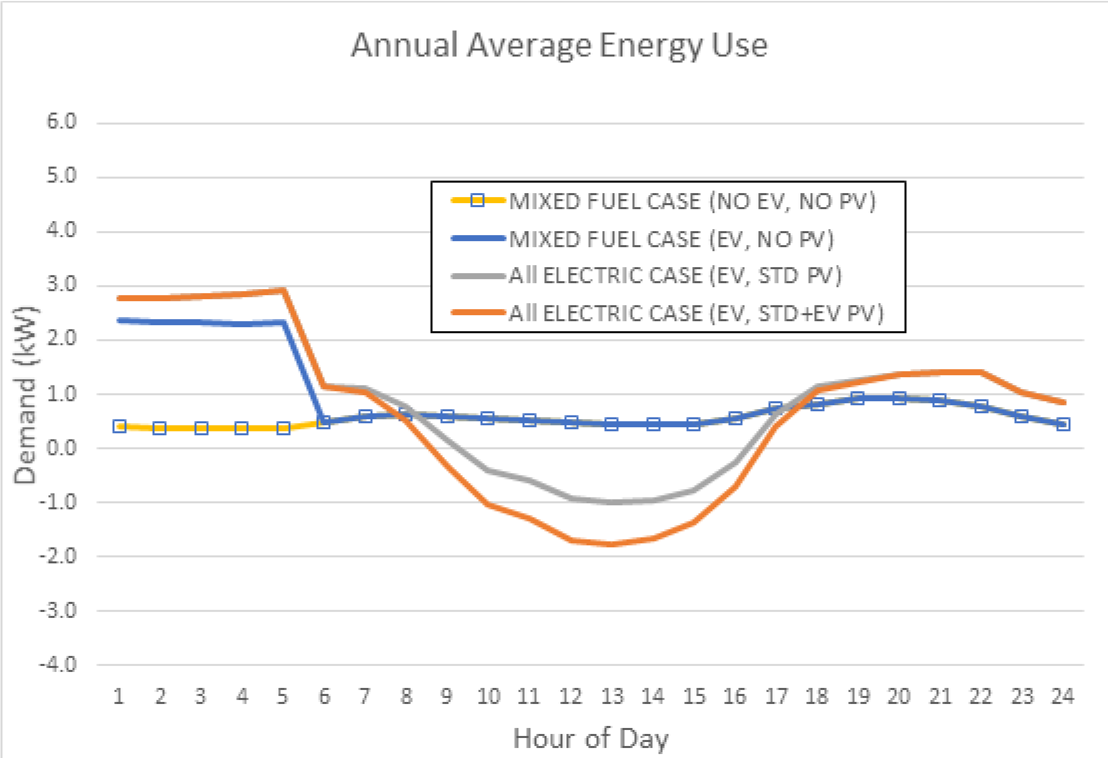


Figure 3: Single Family Typical Winter Day Grid Impacts

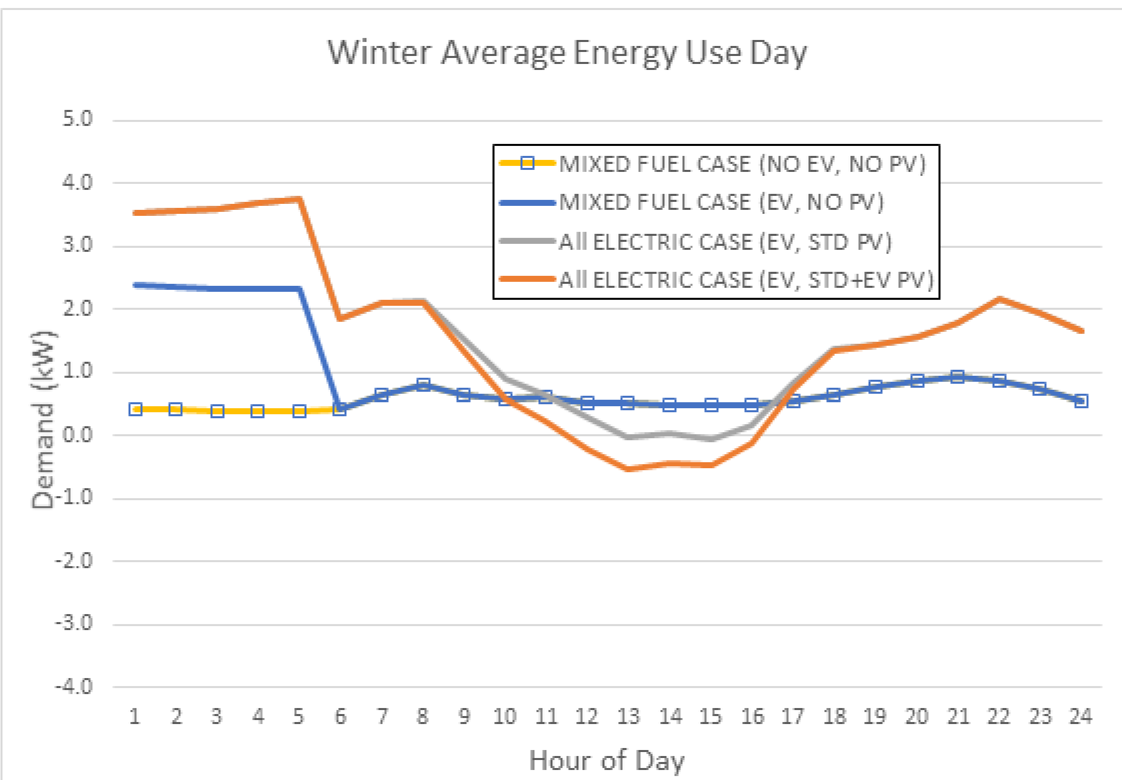


Figure 4: Single Family Typical Summer Day Grid Impacts

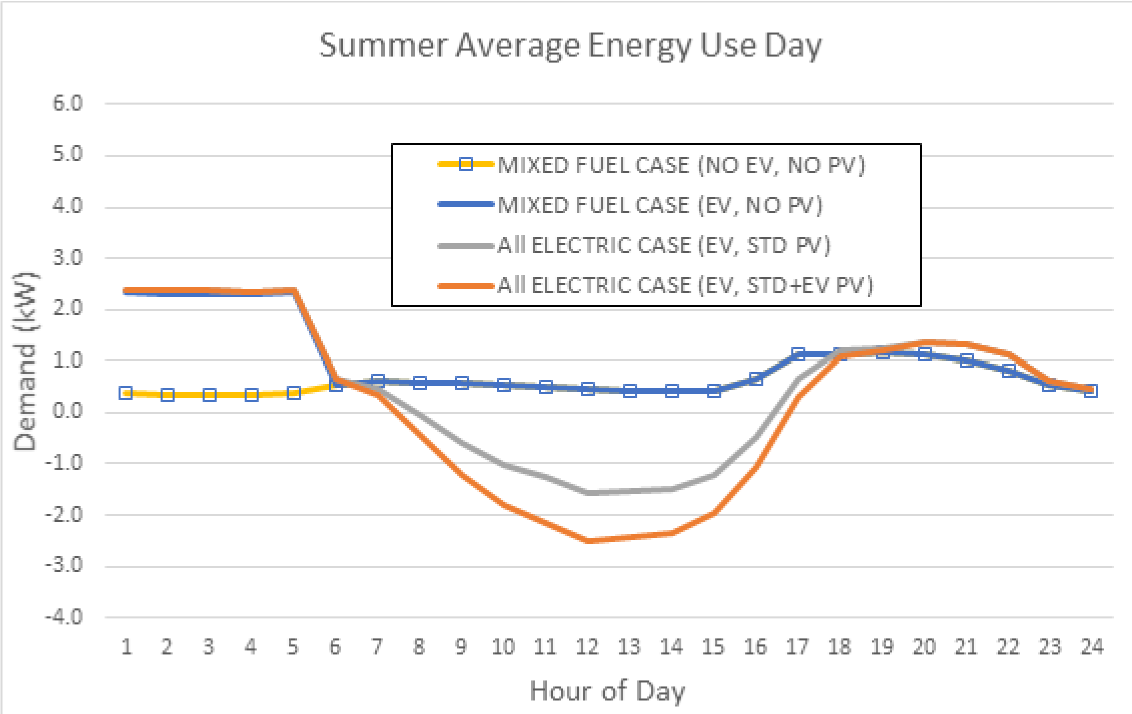


Figure 5: Single Family Peak Summer TDV Day Grid Impacts

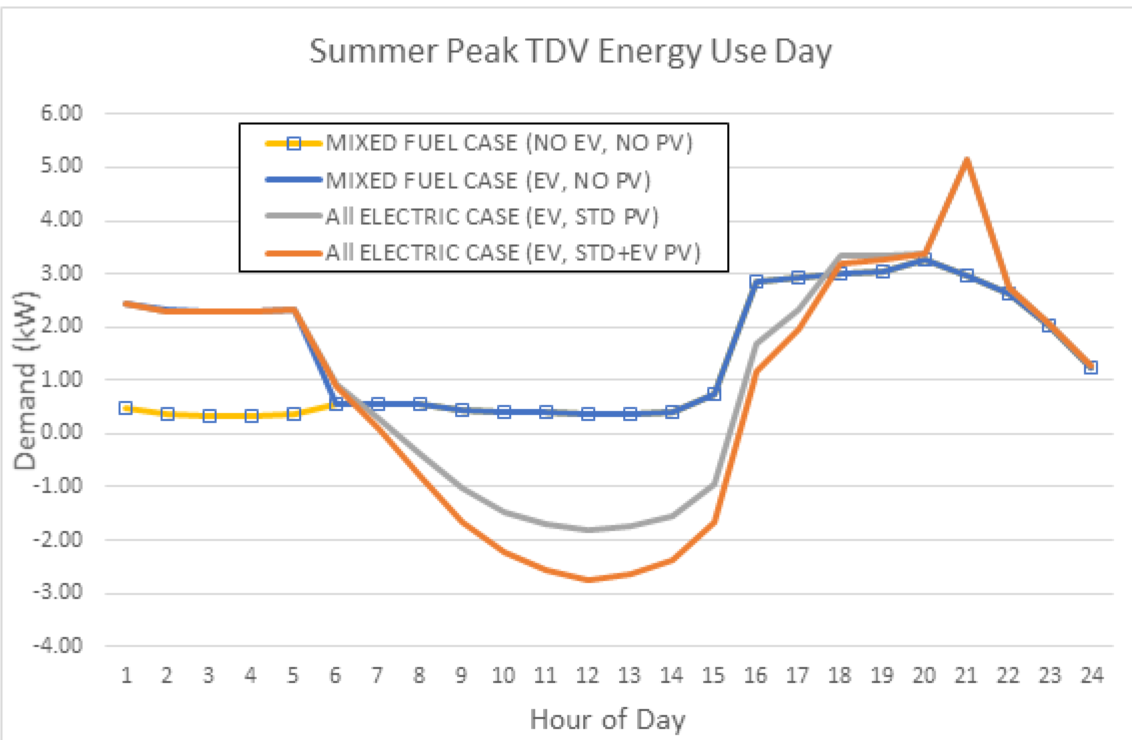


Figure 6: 40-Unit Multifamily Annual Average Day Grid Impacts

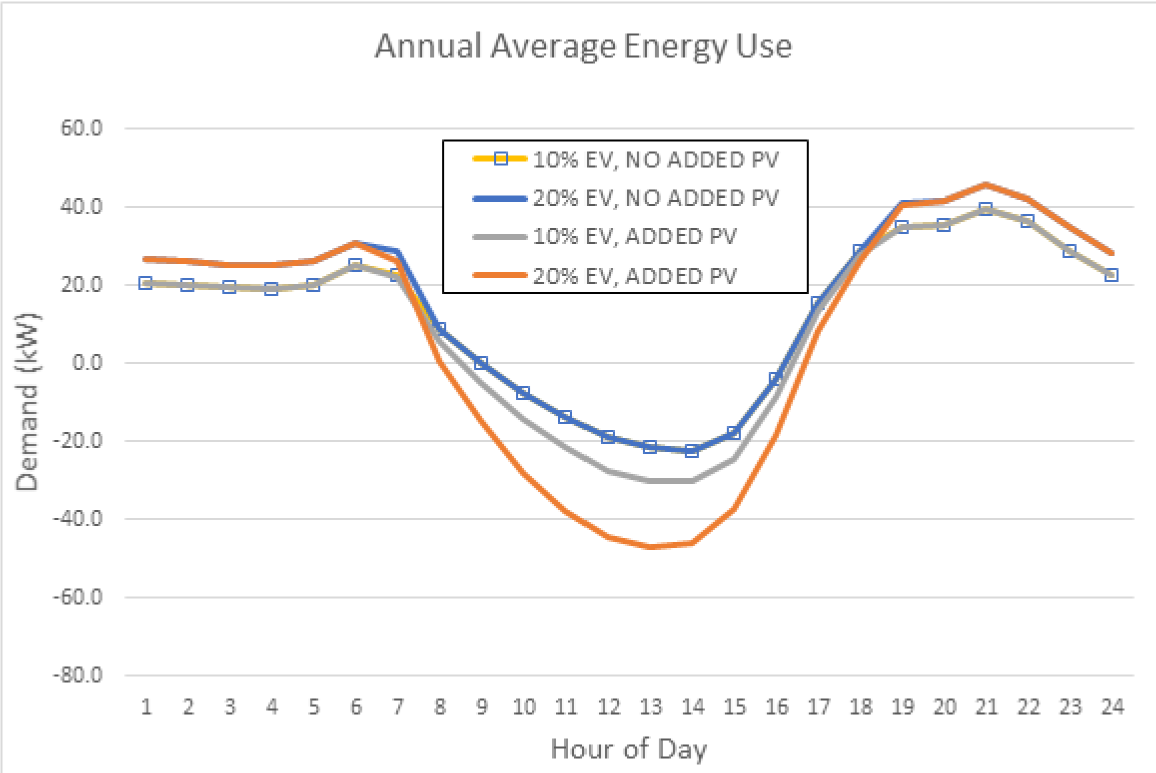


Figure 7: 40-Unit Multifamily Typical Winter Day Grid Impacts

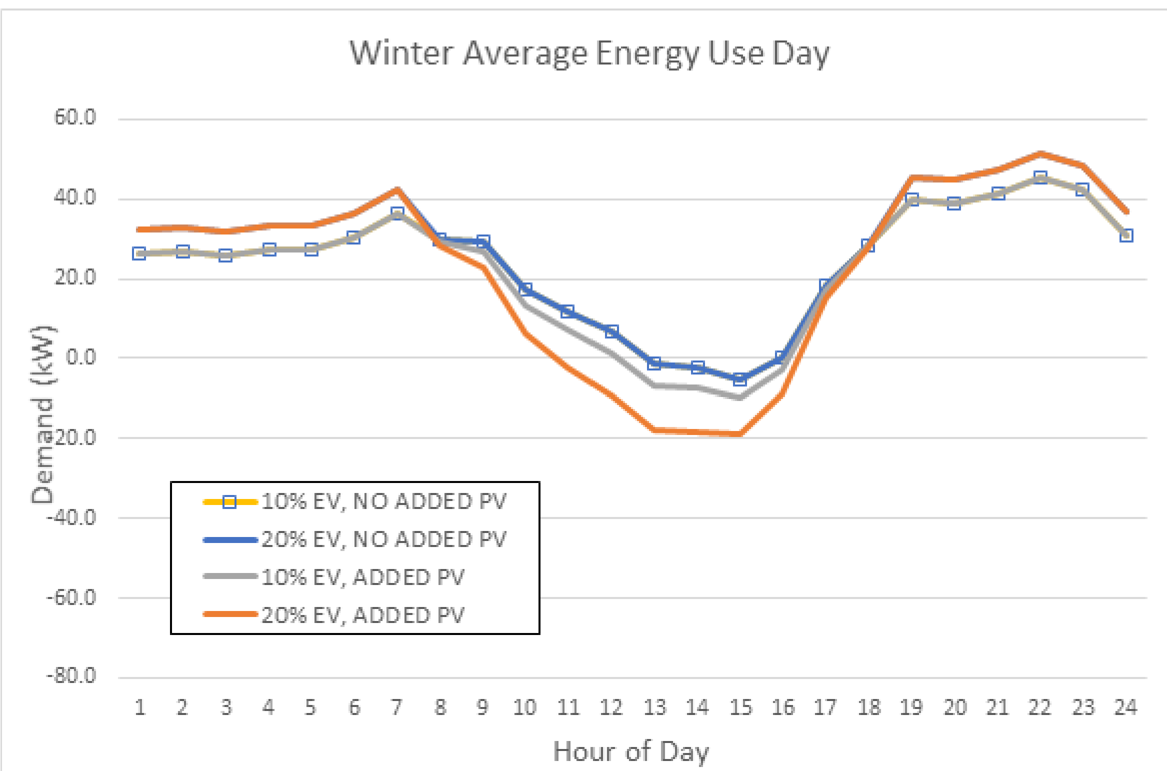


Figure 8: 40-Unit Multifamily Typical Summer Day Grid Impacts

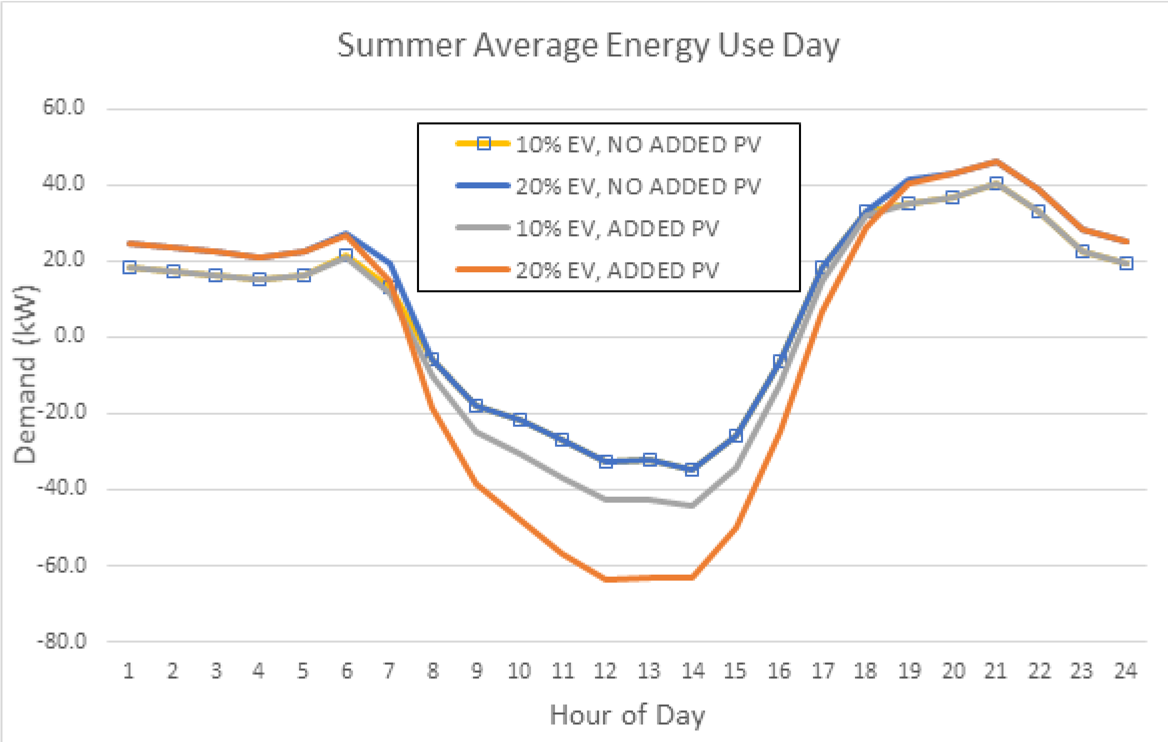
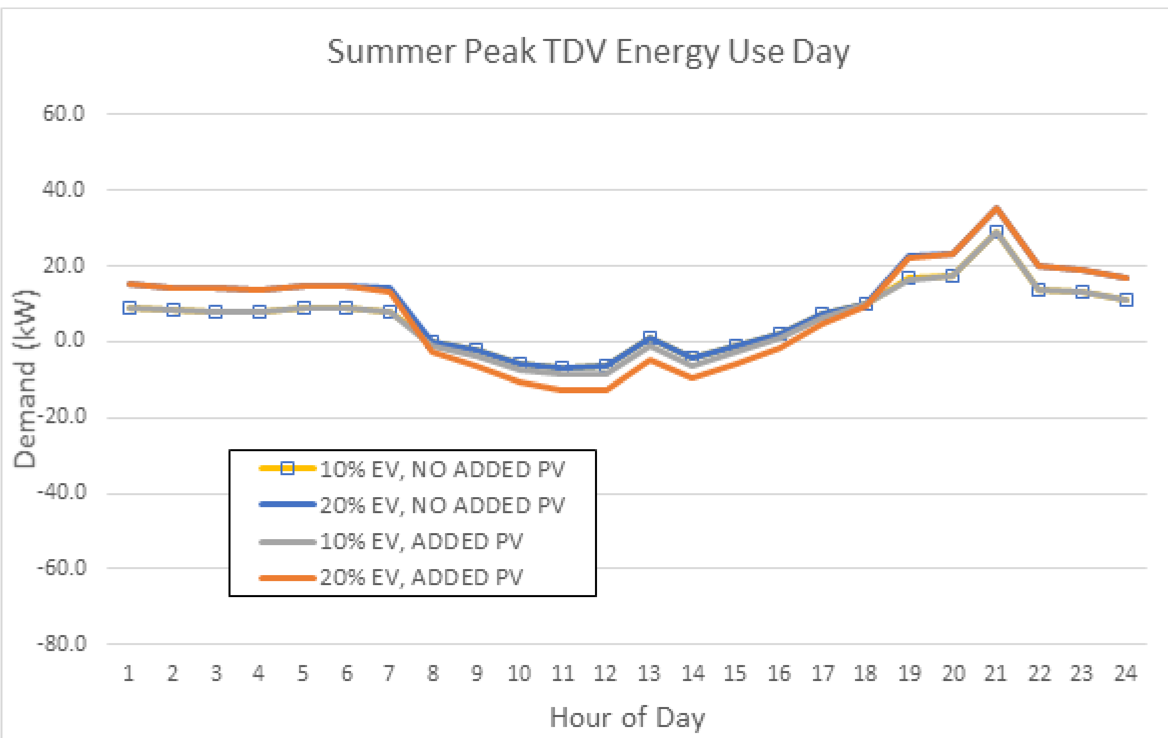


Figure 9: 40-Unit Multifamily Peak Summer TDV Day Grid Impacts



Energy Efficiency Measures and Construction Cost Impacts

The Energy Code (Title 24 Part 6) of the California State Building Codes[4] requires additional energy efficiency measures and solar PV on all new construction. Local governmental agencies can adopt and enforce standards that exceed the State code by applying to the California Energy Commission with the following materials:[5]

- The proposed energy standards
- The local jurisdiction's findings and supporting analyses on the energy savings and cost effectiveness of the proposed energy standards
- A statement or finding by the local jurisdiction that the local energy standards will require buildings to be designed to consume no more energy than permitted by Part 6
- Any findings, determinations, declarations or reports, including any negative declaration or environmental impact report, required pursuant to the California Environmental Quality Act.

Methodology

Cost increases for energy efficiency were estimated using BAE Urban Economics' report *Sacramento DSP Peer Cities Development Cost Comparison*[6] (in Figure 9) produced in August 2018 that compared the costs of two types of multifamily developments. BAE estimated that the 4-5 story building will have three levels of apartments, one parking space per unit, and 100 units. The 7-8 story building will have two levels of parking, one space per unit, and 200 units. Cost estimates are per dwelling unit.

[4] Effective January 1, 2020

[5] https://ww2.energy.ca.gov/2018publications/CEC-400-2018-020/CEC-400-2018-020-CMF.pdf/

[6] https://www.cityofsacramento.org/-/media/Corporate/Files/CDD/Planning/Downtown-Specific-Plan/News-And-Updates/SacDSP_PeerCitiesCostComparison_FINAL_8-11-2017.pdf?la=en

Figure 10: Cost per dwelling unit of multifamily buildings

Table 1: Sacramento, Residential Development Cost Summary

MULTIFAMILY 4-5 STORY WOOD FRAME OVER PODIUM

Development Costs	Range Per Unit	Range Per Leasable Sq. Ft.	Range % Total Cost
Land Cost	$8,165 - $27,148	$6 - $43	5% - 13%
Hard Construction Costs	$123,081 - $270,284	$196 - $267	59% - 74%
Permit/Fee/Inspection Costs	$12,000	$20	6%
Soft Costs	$26,761 - $63,438	$43 - $56	13% - 17%
Financing Costs	$6,810 - $33,738	$11 - $40	3% - 11%
Developer Profit	$0 $11,748	$0 $22	6% (a)
Total Development Cost (b)	**$207,548 - $364,981**	**$277 - $387**	**100% - 100%**

MULTIFAMILY 7-8 STORY + CONCRETE OR STEEL OVER STRUCTURED PARKING (c)

Development Costs	Range Per Unit	Range Per Leasable Sq. Ft.	Range % Total Cost
Land Cost	$12,500 - $40,000	$12 - $36	2% - 5%
Hard Construction Costs	$467,364 - $504,996	$424 - $470	54% - 79%
Permit/Fee/Inspection Costs	$5,000	$5	1%
Soft Costs (d)	$76,333 - $188,709	$72 - $171	12% - 22%
Financing Costs	$16,353 - $90,873	$15 - $83	3% - 10%
Developer Profit	$0 - $158,652	$0 - $168	0% - 20% (a)
Total Development Cost (b)	**$636,120 - $869,400**	**$592 - $823**	**100% - 100%**

The California Energy Commission developed the cost basis for mandatory photovoltaics using three sources of cost information:

- NREL's *2017 U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017*[7]
- Cost data from the Solar Energy Industries Association (SEIA)[8]
- Cost data from the California New Solar Homes Partnership (NSHP)[9]

The Energy Commission arrived at a conservative estimate of $3.10 per watt Direct Current (Wdc)[10] for roof-mounted PV. Many multifamily projects won't have enough roof area to accommodate all the PV panels, particularly in high-density developments. Ground-mounted PV canopies (commonly installed over parking) may be a viable option. A local PV integrator suggests that typical canopy PV installations will add about $1/Wdc to the overall cost.[11]

Estimated Costs for Meeting the 2019 Energy Code

Table 3 shows the approximate cost for meeting the mandatory measures in the 2019 Energy Code for the building in the BAE study and assumes each building is all electric and has 40 units. More or fewer

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7 https://www.nrel.gov/docs/fy17osti/68925.pdf

8 https://www.seia.org/solar-industry-research-data

9 https://www.energy.ca.gov/business_meetings/2017_packets/2017-04-27/Item_01a_NSHP/NSHP%20Guidebook%20Tenth%20Edition%20Revised.pdf

10 *https://www.energy.ca.gov/title24/2019standards/documents/Title24_2019_Standards_detailed_faq.pdf*

11 *Personal communication with John Walter, Repower Yolo on 2/4/19.*

units will change the cost per unit. (Low rise is the 4-5 tory building; high rise is the 7-8 story building).[12] In the Sacramento climate zone, the sum of all energy efficiency measures adds $250 per dwelling unit and the require PV is $4,900 or $6,800 per dwelling unit.

Table 3: Cost per dwelling unit for adding mandatory energy measures

BAE Case	Base Construction (per unit)	Energy Efficiency Measures (per unit)	PV (per unit)	Total Cost in 2020 (per unit)	Percentage Increase
Low rise with roof mounted PV	$332,000	$250	$4,900	$337,150	2.5%
High rise with roof mounted PV	$708,000	$250	$4,900	$713,150	.7%
Low rise with ground mounted PV	$332,000	$250	$6,800	$339,050	2.1%
High rise with ground mounted PV	$708,000	$250	$6,800	$715,050	1%

The 2018 LBNL Tracking the Sun report[13] provides comprehensive cost information on price trends of distributed PV systems throughout the U.S. The study distinguishes between residential, non-residential (<=500 kilowatt(kW)),[14] and non-residential (>500 kW) for systems installed during the first half of 2018. The <=500 kW non-residential costs average about 17% lower than the residential costs,[15] resulting in approximate 2020 cost estimate of ~$2.60/Wdc for a multifamily building.

Although building prototypes for commercial and office buildings were not available, construction costs and new CALGreen energy efficiency measures, including PV, are similar.

Costs of Above-Code EVSE and PV in Non-Residential New Construction

Assuming an all-electric, 40-unit multifamily prototype building Table 4 estimates the cost per unit for additional PV (above the code requirement) to offset the electricity used by charging cars at a Level 2 EVSE assuming 10% and 20% of parking spaces are equipped with a Level 2 EVSE. Several assumptions were made about EV performance, charger efficiency, vehicle charging times, Level 2 EVSE installed parking spaces and the number of connected EVs.

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[12] Using CAL-ERES for energy modeling and the default building prototype. Construction costs may be slightly more per unit for a 40-unit building instead of 100 or 200 units.

[13] https://emp.lbl.gov/sites/default/files/tracking_the_sun_2018_edition_final_0.pdf

[14] The <= 500 kW sector is comprised with a range of installed sizes with "most… smaller than 40 kW." In other words, reasonably close in size to the rough size of the installed system for the multifamily project example.

[15] see Figure 12 in LBNL report

- EV performance: An EV vehicle efficiency of 0.27 kWh/mile was assumed representative of mid-level efficiency EVs. Annual mileage based was based on a national average assumption of 13,476 miles/year[2]. 88% of EV charging was assumed to occur at home.
- EV charger efficiency: 40-amp Level 2 EVSE at 90%.
- Charging times: Charging was assumed to occur uniformly distributed over the 6 pm to 7 am time window to reflect diversity that would be more common in residential situations with multiple vehicles and charging stations. In the real world with widespread EV saturation, the EV charging would likely happen more equally through the night at both building types.
- Parking spaces: One parking space per apartment was assumed with either 10% or 20% EVSE installed. The 10% case is consistent with 2019 CALGreen Tier 1 requirements for EV Capable in multifamily construction. The 20% is a reach goal for assessing "high" EV saturation scenario (consistent with Sacramento's proposal to the Energy Commission). Both the 10% and 20% cases assumed that two vehicles in the apartment complex would utilize each EVSE during the thirteen-hour charging window.

The Energy Code (Title 24 Part 6) of the California State Building Codes[16] will require additional energy efficiency measures and solar PV on all new construction. The following calculations are to estimate additional solar to meet the energy demand of car charging.

A 10% EV case (2019 CALGreen mandatory requirement for multifamily) would require additional 18.3 kilowatts direct current (kWdc) of additional PV and a 20% case would require additional 36.25 kWdc of added PV. Table 6 projects the cost impacts of PV only under two scenarios.

1. Roof mount—all PV would be on the building roof at a cost of $2.60/Wdc
2. Ground mount—all PV would be ground mounted at a cost of $3.60/Wdc

Table 4: Estimated additional PV costs to accommodate EV readiness (40-unit multifamily building)

PV Mounting	10% EV saturation	20% EV saturation
Roof Mount	$48,000 ($1,200 per unit)	$96,000 ($2,400 per unit)
Ground Mount	$66,000 ($1,650 per unit)	$132,000 ($3,300 per unit)

Table 5 summarizes current construction per-unit costs from the BAE study (in Figure 1), added costs for 2019 Energy Code compliance (from Table 3), and costs associated with additional PV (from Table 6). To arrive at the cost per unit based on energy consumption, modeling used the following assumptions:

- Each of the buildings that BAE modeled has 40 dwelling units with one parking spot per unit
  - 10% of parking spots is four EV charging spaces
  - 20% is eight spaces
- Each space will use a 40-amp Level 2 charger
- Two cars will charge at each charger every night
- The cost for EV Capable support ($800 per EV space) is included in base construction costs; the owner or tenant will install the Level 2 charger. Costs for EVSE are not included.
- Additional PV is the amount needed to offset energy consumption from off-peak car charging
- All solar (required and additional) is 50% roof mounted and 50% ground mounted

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[16] Effective January 1, 2020

Table 5: Estimated cost per unit for additional PV to accommodate EV charging (BAE building scenarios)

BAE Case	Base Construction (per unit)	Energy Efficiency Measures and Required PV (per unit)	Additional PV (per unit)	Total Cost in 2020 (per unit)	Percentage Increase
Low rise- 10% EV	$332,000	$6,100	$1,425	$338,575	2.27%
Low rise- 20% EV	$332,000	$6,100	$2,850	$340,000	2.7%
High rise- 10% EV	$708,000	$6,100	$1,425	$714,575	1.06%
High rise- 20% EV	$708,000	$6,100	$2,850	$716,000	1.26%

Table 6 and Table 7 estimate the construction costs of exceeding CALGreen requirements and additional PV. Table 6 shows the construction costs for EV Ready spaces (at $1,100 per space) on a per dwelling unit basis and Table 7 show the cost for EV Installed (at $6,000 per space) on a per dwelling unit basis.

Table 6: Estimated cost of EV Ready and additional PV on a per-unit basis for a 40-unit building

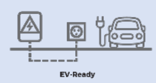
BAE Case	Base Construction (per unit)	Energy Efficiency Measures and Required PV (per unit)	Additional PV (per unit)	 EV Ready (per unit)	Total Cost in 2020 (per unit)	Percentage Increase
Low rise- 4 EV spaces	$332,000	$6,100	$1,425	$110	$339,635	2.30%
Low rise- 8 EV spaces	$332,000	$6,100	$2,850	$220	$341,170	2.76%
High rise- 4 EV spaces	$708,000	$6,100	$1,425	$110	$715,635	1.08%
High rise- 8 EV spaces	$708,000	$6,100	$2,850	$220	$717,170	1.30%

Table 7: Estimated cost of EV Installed and additional PV on a per-unit basis for a 40-unit building

BAE Case	Base Construction (per unit)	Energy Efficiency Measures and Required PV (per unit)	Additional PV (per unit)	EV Installed (per unit)	Total Cost in 2020 (per unit)	Percentage Increase
Low rise- 4 EV spaces	$332,000	$6,100	$1,425	$600	$340,125	2.45%
Low rise- 8 EV spaces	$332,000	$6,100	$2,850	$1,200	$342,150	3.06%
High rise- 4 EV spaces	$708,000	$6,100	$1,425	$600	$715,635	1.08%
High rise- 8 EV spaces	$708,000	$6,100	$2,850	$1,200	$717,170	1.30%

Although building prototypes for non-residential construction were not available, construction costs and new CALGreen energy efficiency measures, including additional PV, are similar.

Conclusion

The information from modeling indicates that a local ordinance that requires non-residential construction to install additional solar to offset the energy used during vehicle charging will not pass the cost-effectiveness requirement. The cost-effectiveness study is based on a prototype building and estimate of EVSE efficiency. Should a jurisdiction choose to apply to the Energy Commission to a local energy reach code, it is recommended that the local utility and jurisdiction conduct a more-detailed study.