Solar Master Plan

BERKELEY UNIFIED SCHOOL DISTRICT (BUSD)

Chapter 8

Maximizing the Value of Photovoltaic Installations on California Schools: Choosing the Best Electricity Rates

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Utility rates or tariffs are among the least understood and most complicated elements of a renewable energy system transaction. Not considering applicable and available utility rates, or making a mistake in choosing rates, when installing a PV system could diminish the benefits the school district receives from the PV system.

Every utility has a variety of tariffs for different types of customers, e.g. residential, commercial, agricultural, and industrial. Each customer within these categories also pays different tariffs based on the amount of electricity consumed and the time of day when it is consumed.

Tariffs within a school district vary; for example, different rates might apply to metered sports field lights, gymnasiums, and buildings housing classrooms. When a district sites a PV project, it is generally true that the PV should be tied into the meter that is recording the greatest electricity consumption because doing so will maximize the district's energy cost reduction.

It is important to analyze the district's historical electricity consumption and cost against the projected electricity production promised by the PV vendor. This analysis will help to ensure that the district selects the best utility tariff and that the projected savings from the PV project will be realized.

One way to achieve electricity bill savings even when PV is not contemplated is to ask your utility to analyze the district's schools electricity consumption against all relevant tariffs. It is not unusual that the tariff originally selected for the school is no longer the best tariff available. This occurs when the school is being operated in a different manner than when the tariff was set. Most utilities will run this analysis annually for a district at no cost. The utility may also provide tools that allow the district to run a "what-if" analysis. For example, see PG&E's "what if" analysis tool here: **http://www.pge.com/mybusiness/myaccount/rates/tools/**.

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Sean Ong and Paul Denholm

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
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July 2011

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NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. PVC9. 93J1

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Executive Summary

Schools in California often have a choice between multiple electricity rate options. For schools with photovoltaic (PV) installations, choosing the right rate is essential to maximize the value of PV generation. The rate option that minimizes a school's electricity expenses often does not remain the most economical choice after the school installs a PV system. The complex interaction between PV generation, building load, and rate structure makes determining the best rate a challenging task. Twenty-two rate structures across three of California's largest electric utilities—Pacific Gas and Electric Co. (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E)—were evaluated in order to identify common rate structure attributes that are favorable to PV installations. Key findings include:

- **The best electricity rate for a school depends on the amount of PV capacity installed.** The rate structure that minimizes the school's electricity expenses prior to a PV installation still remains the best rate after a PV system is installed, as long as the system is small compared to the school's electric load. Other rates become more economical than the initial rate for larger PV system sizes (see Figure ES-1).
- **When a school's PV installation is large, rates with high daytime prices are favorable.** The best rates for schools with relatively large PV systems, or high penetrations, are those with very high afternoon energy prices and little or no demand charges. However, when the PV installation is small, these expensive rates increase the school's annual electricity expenses, even with the PV system helping to offset costs.
- **The best size for a school's PV system depends on the available rate options.** When evaluating the economics of a PV system, bigger is not always better. In San Diego, the best PV system is one that is sized to meet about 10% of a school's annual electric load. For PG&E customers, maximizing the size[1] of the PV installation is best.
- **With the best rates considered, power purchase agreements (PPAs) may be a better option for schools than cash purchases.** A school purchasing a PV system up front will break even[2] at a PV cost of about $3–$5/W. This is below the average installed cost of $6/W,[3] as determined at the time of this report. Because public schools cannot take advantage of tax incentives, purchasing the system up front may not be in the school's best economic interest. The break-even PPA prices, however, are in the range of $0.16–$0.22/kWh, making the PPA option economically attractive.

[1] It is important, however, to stay within the net-metering limits. Exported PV that is not compensated at retail rates will cause the value to decrease sharply. The limit at the time of this report is 100% of net annual consumption.
[2] See Section 2.4 on the definition for break-even and how it is calculated.
[3] See Section 2.4.

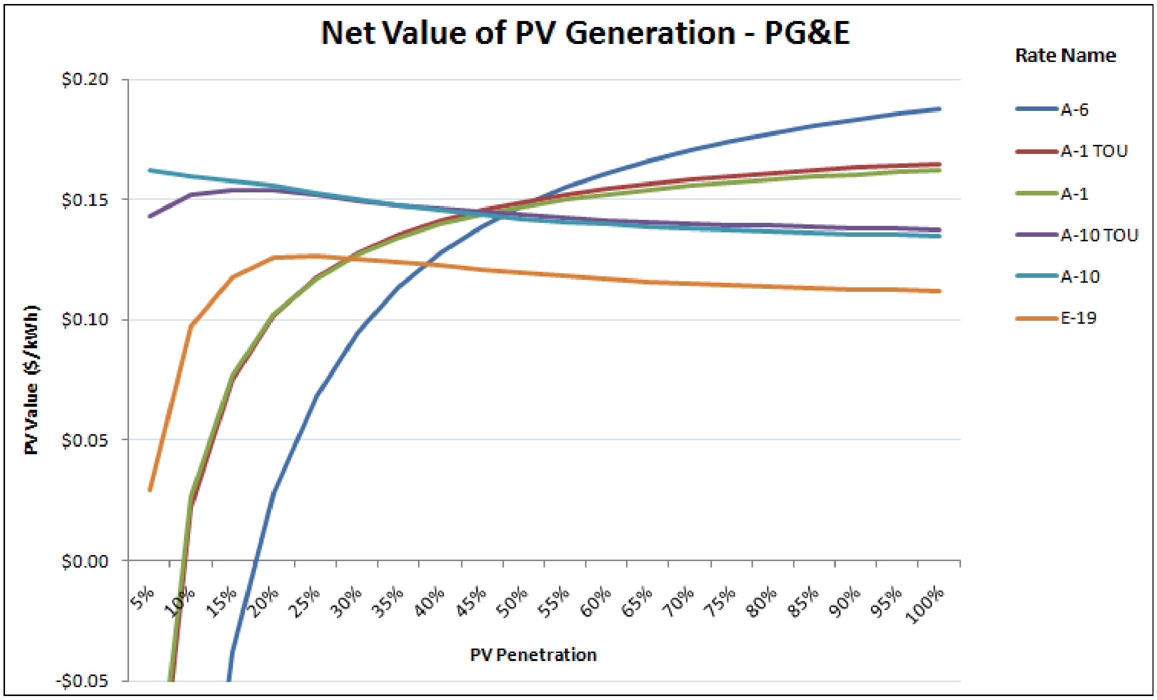

Figure ES-1. Value of PV generation under various rate structures and penetration levels for schools in the PG&E service territory

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1 Introduction

In California, schools are increasingly considering solar technologies as a way to help offset a portion of their annual energy expenditures. School buildings in the state typically have relatively large roofs that could allow for solar photovoltaic (PV) systems capable of generating a significant portion of their annual electricity needs. However, the value of this generation is highly dependent on the school's electricity rate. Schools often have a choice between multiple rate options. Understanding what rate structure optimizes savings requires an analysis of the interaction between the building load, PV generation, and rate structure. High resolution data (hourly or sub-hourly resolution) is essential when determining the impacts of time-of-use (TOU) charges and demand charges. The cost of the PV installation must also be factored into the analysis in order to determine the net effect on the school's annual expenses. These considerations may present a challenging task for schools that are trying to determine whether or not solar makes economic sense for their campus or for schools deciding whether or not to switch rates in order to maximize existing PV system value. This report identifies the rate structure elements that are beneficial to schools and the conditions under which various rate structures should be considered.

In this study, 22 rate structures from the top three electric utilities in California were evaluated. These utilities are Pacific Gas and Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E). These rate structures were used to assess PV value and annual savings for schools in each of the three utility service territories. Two case studies were also conducted for actual schools in Berkeley (Berkeley High School) and San Diego (Lewis Middle School). These case studies can be found in Appendix A and Appendix B. Rate impacts are dependent on individual school load profiles, which vary from one school to another. These results are not intended to represent all schools in California. Schools considering a solar installation should evaluate their facility's unique load profile and use this report as a guide to analyze the potential impacts of a PV system. The report results are intended to explore rate structure elements that are typically beneficial for PV installations and to help identify general trends for the impacts of rate structures on schools with solar systems.

2 Data and Methodology

2.1 Load Data

Building load data are an important component in any rate structure analysis that includes demand charges and tiered rates. Demand charges are usually based on the peak monthly power demand of a building; consequently, quantifying the demand reduction value of a PV system requires a load profile. Load profiles are also required when evaluating tiered rates, where rates vary depending on monthly energy usage. This analysis uses load profile data created in part for the U.S. Department of Energy (DOE) commercial building benchmark models (Torcellini et al. 2008), which were simulated using the EnergyPlus simulation software.[4] All loads and buildings for the benchmark models were simulated under typical meteorological year 2 (TMY2) conditions. TMY2 is a dataset of the National Solar Radiation Database (Marion and Urban 1995; Wilcox 2007). For consistency, TMY2 conditions were used when simulating PV performance. Although the benchmark models consist of a variety of different commercial building types across 16 climate zones, the data used for this analysis consist of only simulated high school buildings across two climate zones.[5] Figure 1 shows the locations of each climate zone in the United States. Table 1 summarizes the climate zones associated with each utility service territory covered in this analysis along with the schools' annual electricity usage patterns.

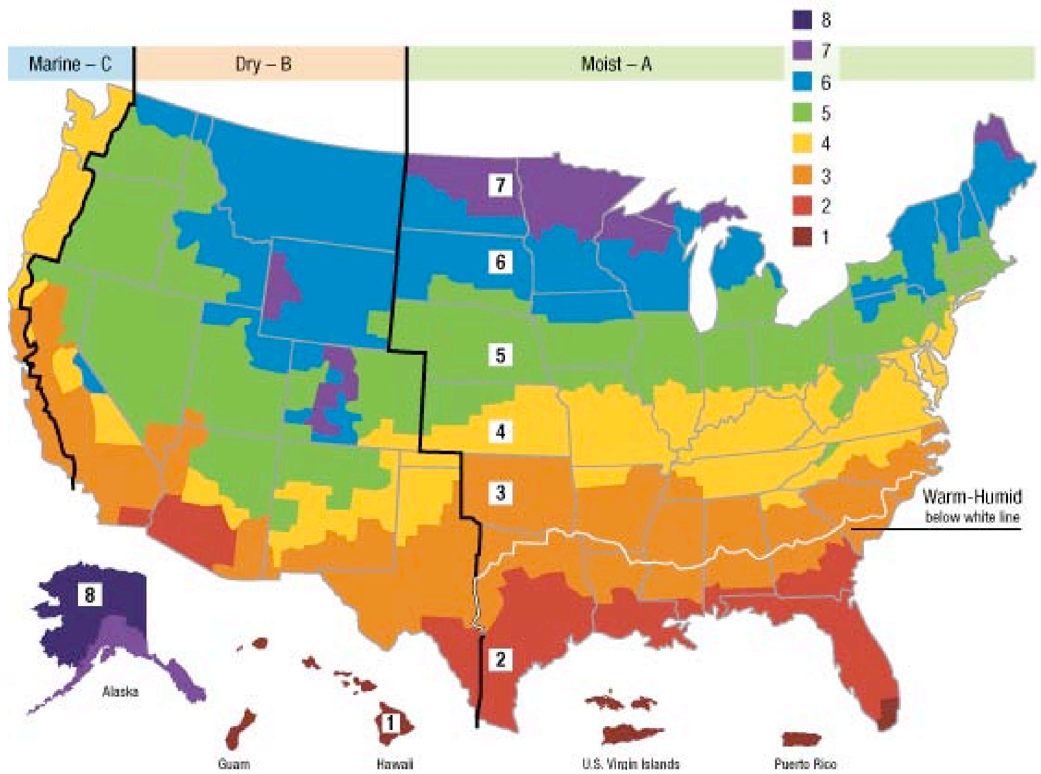

Figure 1. Climate zone map of the United States

Source: DOE 2011

[4] For more information on the EnergyPlus model, see http://apps1.eere.energy.gov/buildings/energyplus/.

[5] The climate zones used in Figure 1 are 3B-Coast and 3C. These zones are a subset of the climate zones officially recognized by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Table 1. Climate Zone and Building Characteristics Associated with Each Utility Service Territory

Utility Service Territory	ASHRAE Climate Zone	Annual Building Load (MWh)	Peak Annual Load (kW)
Pacific Gas and Electric	3C	2,682	1,150
Southern California Edison	3B-Coast	2,632	941
San Diego Gas and Electric	3B-Coast	2,632	941

The high school buildings are modeled to have three floors with a total floor area of 210,890 ft^2. The building simulation data includes aggregated hourly load profiles for all electrical loads associated with each school building and includes smaller loads such as plug loads. EnergyPlus simulated this data using the 2003 Commercial Building Energy Consumption Survey[6] (CBECS) results as guidance on the various load types within each facility. The total hourly electrical load of each building was entered into the System Advisor Model (SAM).[7] See Section 2.4 for SAM details. Figures 2 and 3 show the hourly load profile for each of the three simulated school buildings.

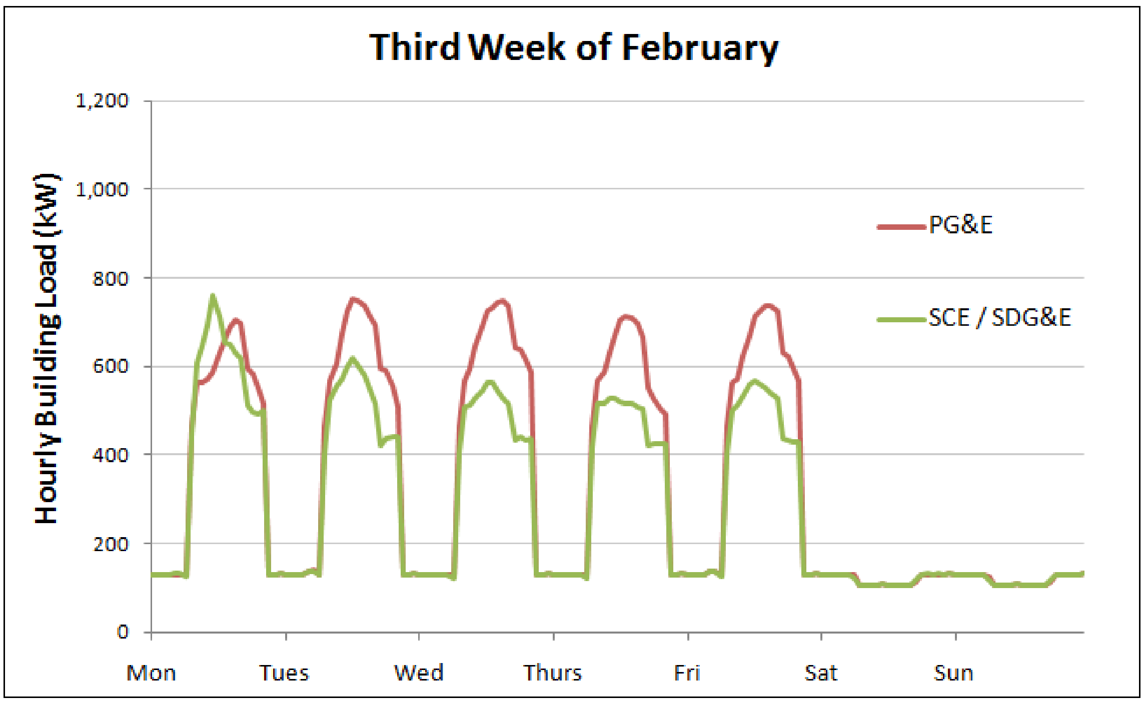

Figure 2. Hourly school load profiles during the third week of February

[6] For more information on CBECS, visit http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html.

[7] Demand charges are usually measured and billed according to 15-minute time increments. The lack of 15-minute data resolution for this analysis may present an overestimation of a PV system's ability to offset demand charges. This could occur if the hourly data masks or smoothes sub-hourly spikes and dips in demand and production. Despite a potential for overestimation, previous studies still show that rates with demand charges are poorly suited for PV systems (Ong et al. 2010).

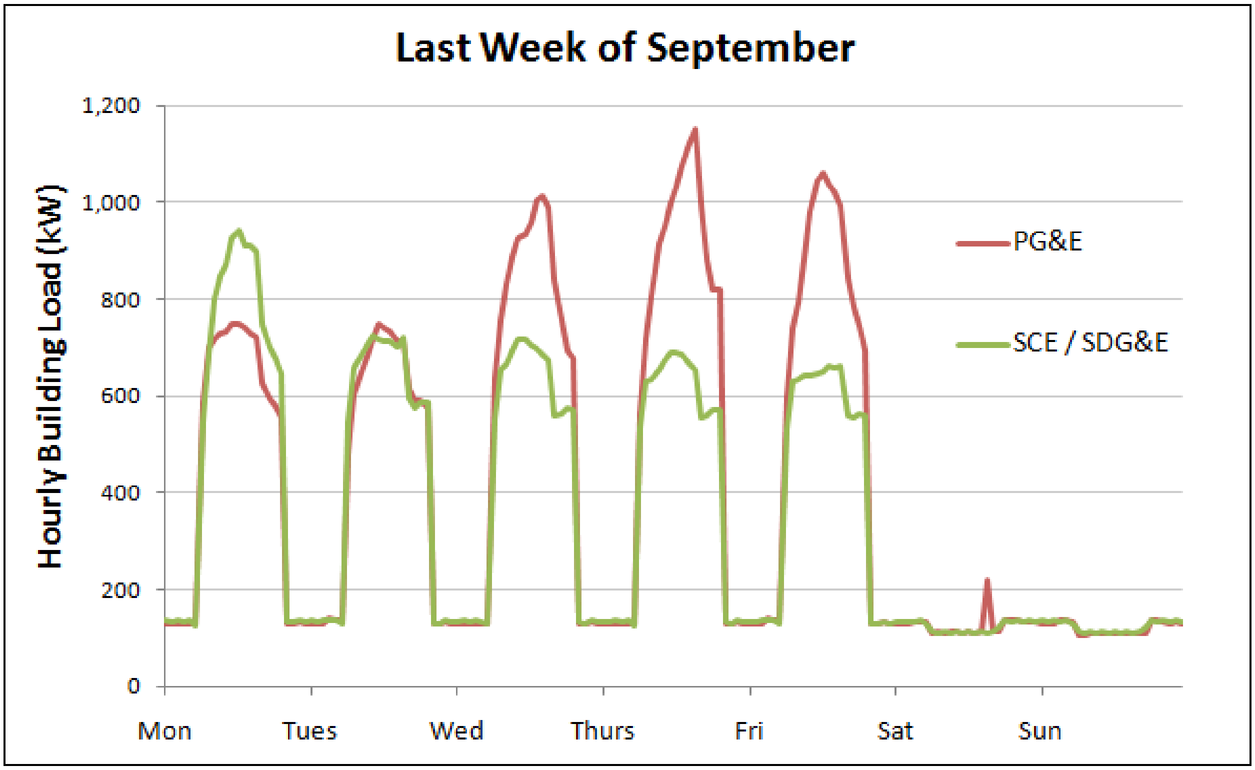

Figure 3. Hourly school load profiles for the last week of September

2.2 Rate Data

A total of 22 utility rates in the three utility service territories were evaluated. These rates were obtained from the online Utility Rate Database (URDB) on the OpenEI platform[8] and verified with the official utility tariff sheets to ensure accuracy. The utilities offer various commercial rate structures for different load sizes and types. Smaller loads typically have more rate choices than larger loads since smaller users may sometimes choose to be on rates designed and made mandatory for larger loads. In some cases, larger facilities with solar installations have the option to use rates designed for smaller facilities. In some cases, large schools may divide electricity consumption across multiple meters. Each meter is treated independently and measures only a portion of the campus's total load, thereby allowing for greater flexibility in rate choice. Figure 4 illustrates the eligibility range for each of the 22 utility rates. Note that rates A in SDG&E and rates GS-1 and GS-1-TOU in SCE are only available to customers with a maximum demand of 20 kW or less. Because this limit is very low compared to typical school campus loads (even with split meters), they were not considered in the rate and cost impact calculations, though they were still analyzed for reference purposes.

[8] Open Energy Information (OpenEI) is a knowledge-sharing online community dedicated to connecting people with the latest information and data on energy resources from around the world (http://www.OpenEI.org). OpenEI was created in partnership with the DOE and federal laboratories across the nation. OpenEI's URDB (http://en.openei.org/wiki/Gateway:Utilities) contains downloadable rate structure information from hundreds of electric utilities around the United States.

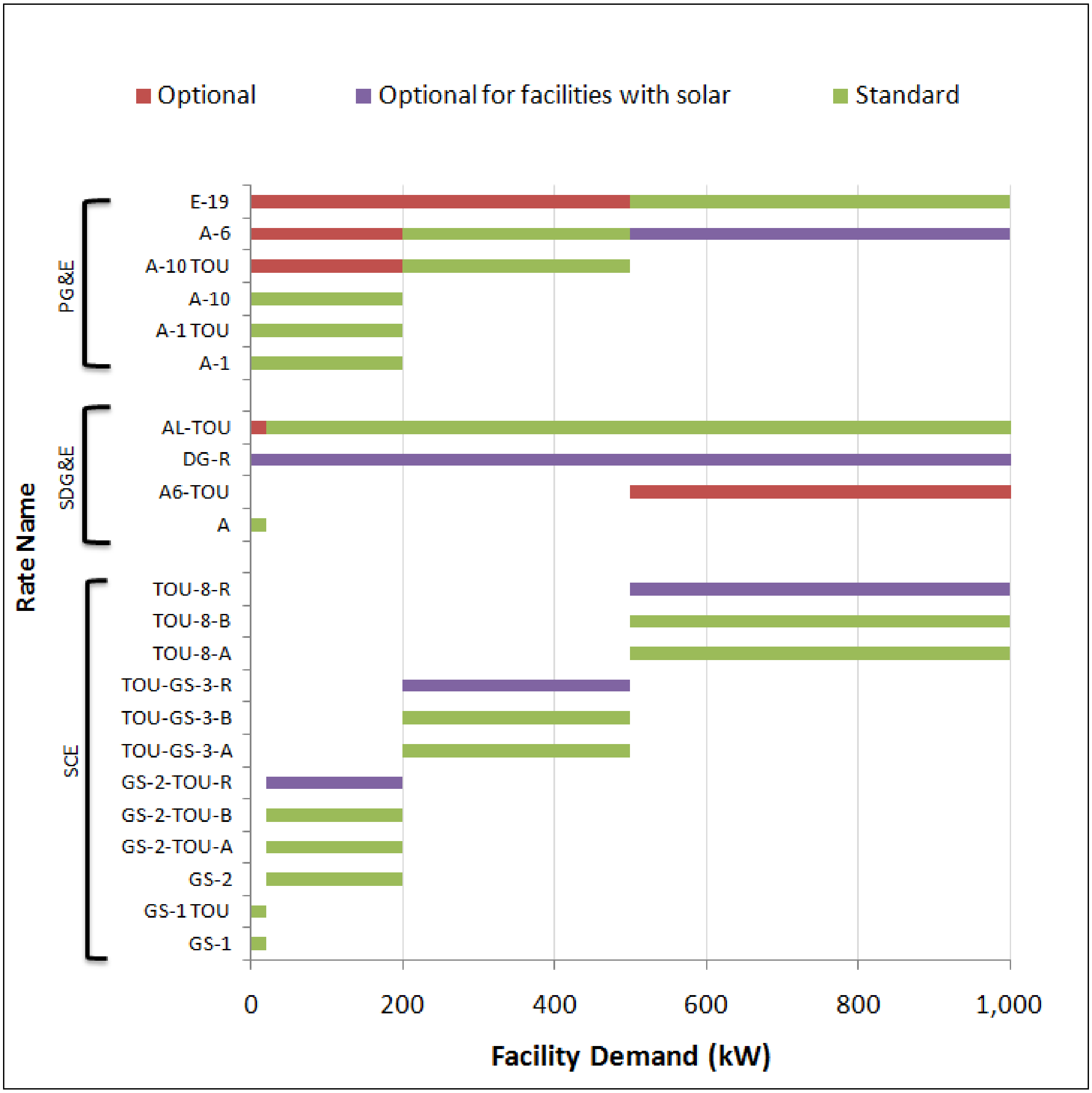

Figure 4. Applicability of electricity rates for commercial facilities in each of the three utility service territories studied

Various types of utility rates are used throughout the United States. The most common rate types (Ong et al. 2010) include the following:

- **Flat rates**. Fixed cost of energy that does not vary except for fuel cost adjustments and other fees.
- **Seasonal rates**. Rates that vary by season. A typical seasonal rate structure has a lower rate for winter months and a higher rate for summer months.

- **Time-of-use rates**. Time-of-use (TOU) or time-of-day rate structures usually vary 2–4 times a day. A typical TOU rate has a lower cost at night, a higher cost during the late afternoon, and an intermediate cost during the mornings and evenings. The term "on-peak" or "peak" is generally used to describe hours with higher prices while "off-peak" is used to describe hours with lower prices.
- **Demand charges**. Normally included with energy charges in applicable rate structures, demand charges charge customers for their peak power (kilowatts) usage. Demand charges can also be fixed or vary by season or hour.
- **Tiered or block rates**. Tiered rates typically refer to rates that increase with increasing electricity usage while block rates typically refer to rates that decrease with increasing electricity usage. These rates are most common in the form of energy charges; however, tiered demand charges are also used.

Table 2 summarizes the various categories represented by the 22 rates used for this analysis. Tiered or flat rates were not evaluated. There was a good representation of seasonal rates, TOU rates, and demand charges; 13 of the 22 rates combined all three of those categories.

Table 2. Summary of Applicable Categories and Price Levels for the Rates Evaluated

Utility	Rate Name	Flat	Seasonal	TOU	Demand	Tiered	Relative Price Level
SCE	GS-1		✓				Moderate-to-high energy prices
SCE	GS-1 TOU		✓	✓			Very high energy prices during summer afternoons
SCE	GS-2		✓		✓		Moderate energy prices; high summer demand charges.
SCE	GS-2-TOU-A		✓	✓	✓		High energy prices; moderate demand charges
SCE	GS-2-TOU-B		✓	✓	✓		Moderate energy prices; high demand charges.
SCE	GS-2-TOU-R		✓	✓	✓		Very high energy prices; low demand charges
SCE	TOU-GS-3-A		✓	✓	✓		Moderate-to-high energy prices; moderate demand charges
SCE	TOU-GS-3-B		✓	✓	✓		Low energy prices; moderate-to-high demand charges.
SCE	TOU-GS-3-R		✓	✓	✓		High energy prices; low demand charges
SCE	TOU-8-A		✓	✓	✓		High summer afternoon energy charges
SCE	TOU-8-B		✓	✓	✓		Low energy prices; high summer afternoon demand charges
SCE	TOU-8-R		✓	✓	✓		High energy prices; low demand charges
SDG&E	A		✓				Very high energy prices
SDG&E	A6-TOU		✓	✓	✓		Low energy prices; high demand charges
SDG&E	DG-R		✓	✓	✓		High energy prices; low demand

Utility	Rate Name	Flat	Seasonal	TOU	Demand	Tiered	Relative Price Level
							charges
	AL-TOU		✓	✓	✓		Intermediate energy prices; high demand charges
PG&E	A-1		✓				Moderate-to-high energy prices
PG&E	A-1 TOU			✓			High energy prices during summer afternoons; moderate prices otherwise
PG&E	A-10		✓		✓		Moderate energy prices; high demand charges
PG&E	A-10 TOU		✓	✓	✓		Low off-peak energy prices; moderate peak energy prices; high demand charges
PG&E	A-6			✓			Very high energy prices during summer afternoons; low-to-moderate prices otherwise
PG&E	E-19			✓	✓		Moderate energy prices during summer afternoons; lower energy prices otherwise; very high demand charges during summer afternoons; moderate demand charges otherwise

2.3 Solar Data

The PV production data used in this analysis were simulated using the TMY2[9] dataset of the National Solar Radiation Database (Marion and Urban 1995; Wilcox 2007). The TMY2 dataset is intended to represent a typical year's weather and solar resource patterns, though the dataset does not consist of an actual representative year. Rather, TMY2 was created by combining data from multiple years.[10] The meteorological dataset was used as an input for the SAM, which simulated hourly PV production for use in the financial calculations.

2.4 System Advisor Model and Calculations

Developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories and DOE, SAM is a performance and economic model designed to facilitate decision making and analysis for renewable energy projects (NREL 2011). The TMY2 meteorological data was provided as an input for SAM, which uses a performance model and user-defined assumptions to simulate hourly PV generation data. The following assumptions were used when generating the PV performance data:

- 15-degree tilt

[9] Although TMY3 data was available at the time of this analysis, the TMY2 data was used because the DOE benchmark buildings simulation data was also simulated using the TMY2 data. This allows for a more consistent treatment of building demand reduction and demand charge benefits.

[10] For example, the month of January may be from one year (e.g., 1989) while February may be from another year (e.g., 1994). Each TMY2 file may contain data from up to 12 different years. Data was intentionally selected to be representative of typical meteorological conditions.

- South facing (180-degree azimuth)
- A de-rate factor of 85%
- Annual degradation of 0.5%.

In addition to the meteorological data, hourly building load data and utility rate data[11] were given as inputs for SAM. A rooftop PV system was simulated for various penetration levels ranging from 0% (no PV system) to 100% (PV system generates the same amount of energy as each school's annual electrical energy consumption[12]) in increments of 5%. PV penetration is defined as the percentage of a facility's annual electrical energy consumption that is met by a PV system. The value of the PV system's generation under various penetration levels and rate structures was evaluated by comparing the schools' annual electricity costs both with and without the PV system in each scenario. Any resulting difference from the comparison was attributed to the PV system. The combination of scenarios requires hundreds of unique simulations, from which the model can determine the PV penetration and rate structures that are likely optimal.

The impacts of system costs were also considered in the analysis. Schools may choose various ways to finance a rooftop solar installation. For schools in California, typical choices include:

- **Third-party ownership/power purchase agreements**. This arrangement consists of a third party owning and maintaining the PV system installed on campus. The third party charges the school for the energy generated by the PV system, usually based on a pre-negotiated price (in cents per kilowatt-hour). The school, in turn, will realize savings from a reduced electricity bill because of the energy offset by the PV production. Since schools are non-profit entities, they cannot take advantage of tax incentives such as the 30% federal investment tax credit. However, the system owner can take advantage of the tax incentives, which may result in the solar system being economically beneficial to both the third party and the school.[13] Third-party ownership may also be in the form of a lease agreement, where the school pays a fixed monthly lease payment for the solar equipment instead of a price per generated kilowatt-hour.
- **Cash purchase**. The school district directly pays for the PV system with general funds. Schools may be less attracted to this option for large installations due to high upfront costs and ineligibility for tax incentives.
- **Publically funded/general obligation bond**. Schools paying for solar systems under a general obligation (GO) bond will have little or no upfront costs. This option is favorable to schools because they can realize the benefits of a reduced electricity bill while having little or no costs associated with the system. Public financing arrangements are not always available to schools and must first be approved by local governments or voters.

[11] SAM communicates directly with OpenEI's online URDB to obtain the latest rate information available on OpenEI. For more information about the rate data and the online rate database, see Section 2.2 and http://apps1.eere.energy.gov/buildings/energyplus/.
[12] Although the PV system generates the equivalent of 100% of the school's annual electricity consumption, there will be times that the PV system exports energy to the grid (afternoons) and times that the school imports energy (nights). Existing net-metering policies allow excess generation to be credited toward the following month's bill, effectively allowing the generation to be compensated, up to 100% of annual consumption, at retail rates.
[13] Being able to take advantage of the 30% investment tax credit allows the system owner to pass their savings on to the school (in the form of a lower PPA rate) while still making a reasonable return on their investment.

Four metrics are used to evaluate PV system economics under the three ownership models described above. For power purchase agreements (PPA) and GO bonds, the bill impacts metric is used, which quantifies the percentage increase or decrease in the schools' annual electricity expenses. The bill impact metric is calculated as follows:

$$Annual\ bill\ savings\ (\%) \ = \frac{Lowest\ cost\ bill\ without\ PV - Lowest\ cost\ bill\ with\ PV - PPA\ payments}{Lowest\ cost\ bill\ without\ PV}$$

For GO bonds, the equation above still applies but without a PPA payment cost. It is important to note that many PPA prices include an annual escalation factor (including inflation). In this analysis, it is assumed that annual electricity escalation (including inflation) is equivalent to the PPA price escalation. This simplifying assumption allows any annual escalation factors to be cancelled out of the bill impacts equation.

In the analysis, PPA prices were also evaluated on a break-even basis. The break-even PPA price is the PPA price at which the schools' annual electricity expenses neither increase nor decrease. Essentially, the break-even PPA price is the point at which the PPA price equals the net PV value. The break-even PPA prices help to determine if the schools will be saving or losing money annually. If the PPA price is above break-even, then the school will be losing money (annual expenses are increased). However, if the PPA price is below break-even, then the school will be saving money (annual expenses are decreased).

The third metric considered is the break-even PV cost, which is the point at which the lifetime costs associated with a PV system are equivalent to the lifetime benefits (Denholm et al. 2009). The break-even cost was calculated by varying the installed PV cost until the net present cost equaled the net present benefits. The following assumptions were used in the break-even cost calculations:

- Upfront cash payment
- 30-year system lifetime, 30-year analysis period
- Real discount rate of 5%
- No federal, state, or local incentives
- Annual PV degradation of 0.5%
- Inverter replacements at year 10 and year 20 ($500/kW each time).

When evaluating a cash purchase scenario, the simple payback metric is used, which roughly quantifies the number of years required to "pay back" the upfront investment using the savings from a PV system. Simple payback is calculated as follows:

$$Simple\ payback\ (years) = \frac{Initial\ upfront\ cost}{Annual\ benefit\ from\ PV\ system\ under\ best\ rate}$$

According to the California Solar Initiative database (CSI 2011), government and non-profit solar installation costs in California range from less than $3/W to well over $10/W. The weighted average cost for government/non-profit solar installations is \$6/W.[14] In this analysis, upfront purchases were evaluated using \$3/W, \$4/W, \$5/W, and \$6/W.

[14] Evaluated for systems with nameplate capacities ranging from 20 kW to 800 kW.

3 Results

3.1 Net Value of Photovoltaic Generation

In order to compare the PV value across various penetration levels, it is important to focus more on value per unit of energy than absolute PV value—in this case, dollars per kilowatt-hour. Figure 5 illustrates the value of a rooftop PV system on a school building using PG&E rates under different penetration levels. PV value under rates A-6, A-1, and A-1 TOU do not vary with penetration level, while the remaining rates decrease with increasing penetration. This is because the first three rates in question do not have any demand charge components, but the latter rates do (see Table 2 in Section 2.2). Studies have shown that PV value under rates with demand charge components tend to lose value with increasing PV penetration (Wiser et al. 2007).[15] Rate A-6 yields the greatest PV value at $0.23/kWh, far above the other rate structures. Rate A-6 is a very expensive rate, with summer afternoon rates approaching $0.45/kWh. Although this gives high value to a PV system, results show that a school switching to this rate from a less expensive rate experiences an increase in total electricity cost, rendering any PV savings useless. Evaluating a rate structure in isolation without considering net bill impacts or other rate structure options is insufficient when conducting a rate analysis.

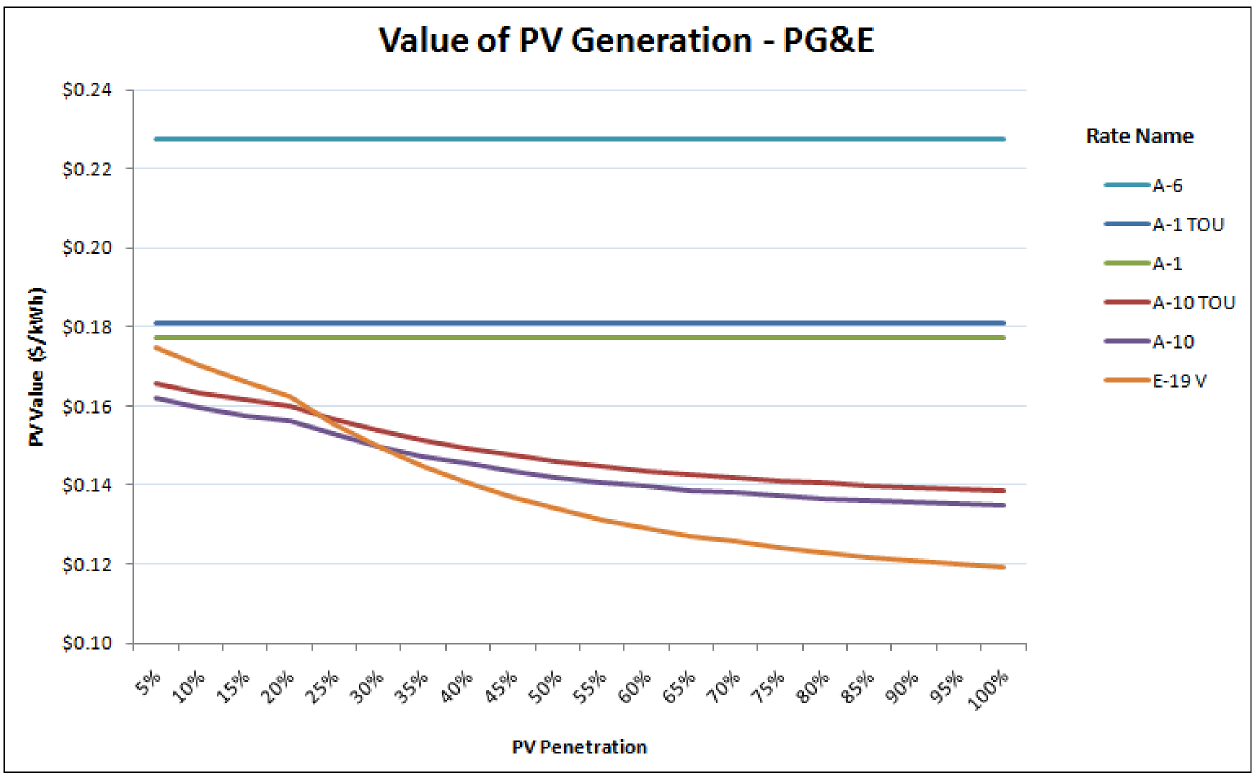

Figure 5. Value of PV generation under various rate structures and penetration levels for schools in the PG&E service territory

In order to accurately assess the value of PV under each rate structure, it is necessary to compare the schools' annual electricity costs without PV using the least cost rate. The least cost rate is the

[15] This is because PV generation is limited to the afternoon hours, and increasing PV production simply shifts the facility's peak demand to hours when the sun is not shining.

rate that minimizes annual electricity expense. This allows for the proper assessment of PV value in relation to the schools' lowest cost option prior to the PV installation. This calculation can be expressed as the following equation:

Net PV value = Energy cost with PV under rate in question – Energy cost without PV under least expensive rate

Rate A-10 turns out to be the least cost rate for the school load profile used in PG&E before installing PV. Figure 6 shows how the PV value changes once A-10 is set as the rate against which all other rates are compared. This is a significant change from the previous chart, showing that rate A-6 is no longer the most attractive rate at all penetration levels. Many rates yield a negative value when PV penetration is small. This is because switching to these rates from rate A-10 increases the school's annual energy cost, despite having a small rooftop PV system.[16] At higher solar penetrations, the increase in PV value (under rates with high energy charges and high daytime rates) is enough to offset the cost increases from switching rates, yielding a net savings. For PG&E, rate A-10 is the most economical rate until a 45% PV penetration, at which time rate A-1-TOU briefly becomes the best rate. After a 50% penetration, rate A-6 becomes and remains the most economical rate. The net PV value under various penetrations is also shown for schools in SCE and SDG&E (see Figures 7 and 8). The dotted lines denote rates that were only eligible for loads with peak demands of 20 kW or less. These rates were included in Figures 7 and 8 for comparison. Since typical school loads are much larger, these rates were not used in the bill savings and payback calculations in Section 3.2. See Section 2.2 for details on the applicable load levels for each rate.

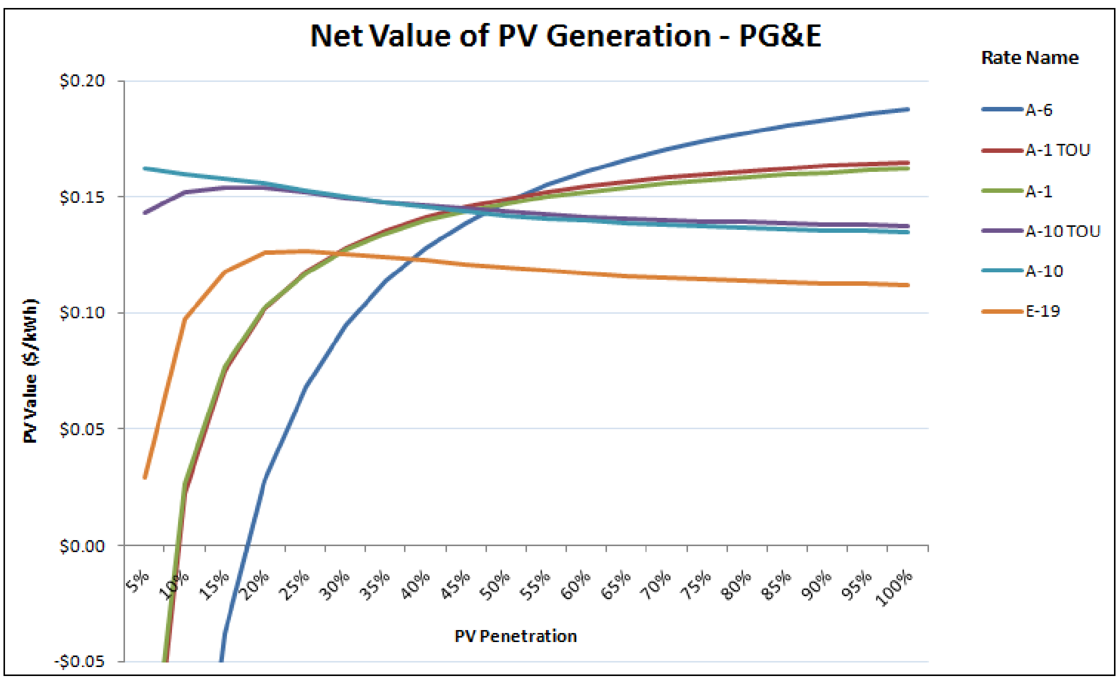

Figure 6. Net value of PV generation under various rate structures and penetration levels for schools in the PG&E service territory

[16] Though the PV system is still providing value to the school, it is not enough to overcome the increase in cost associated with switching to a more expensive rate. The result is a net annual loss to the school.

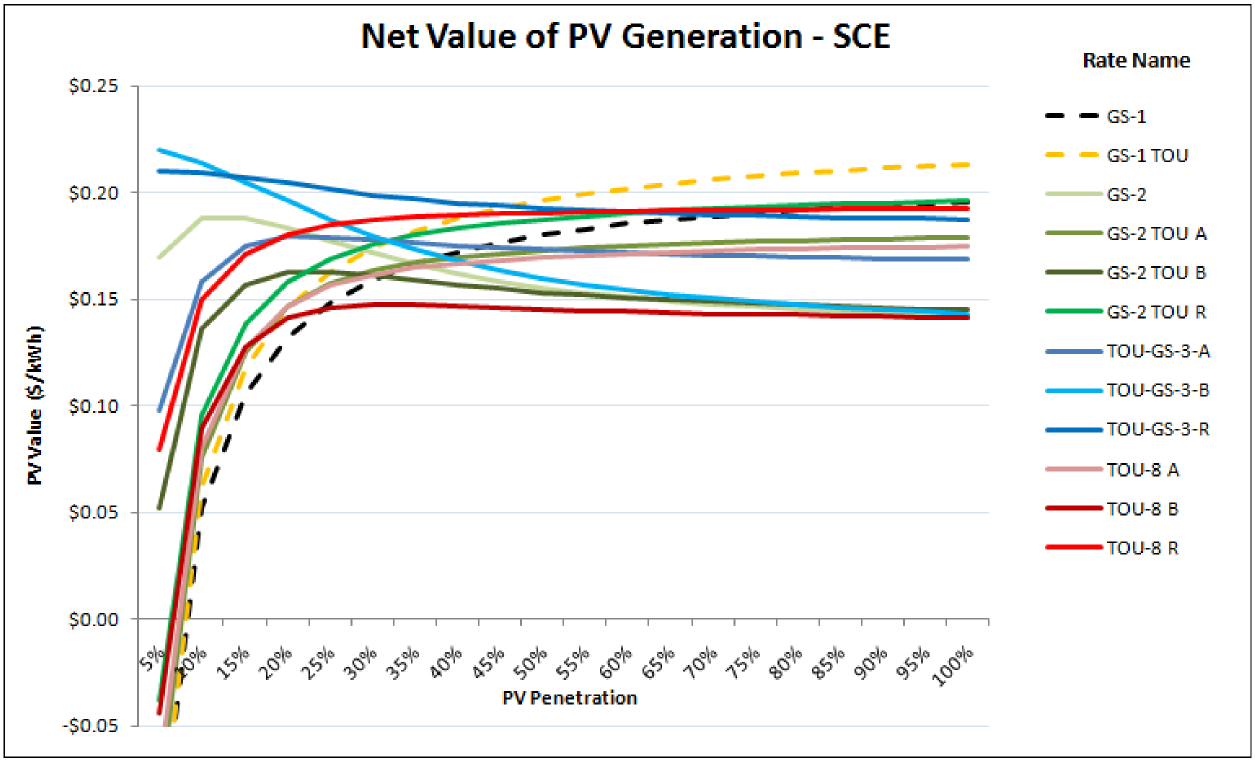

Figure 7. Net value of PV generation under various rate structures and penetration levels for schools in the SCE service territory

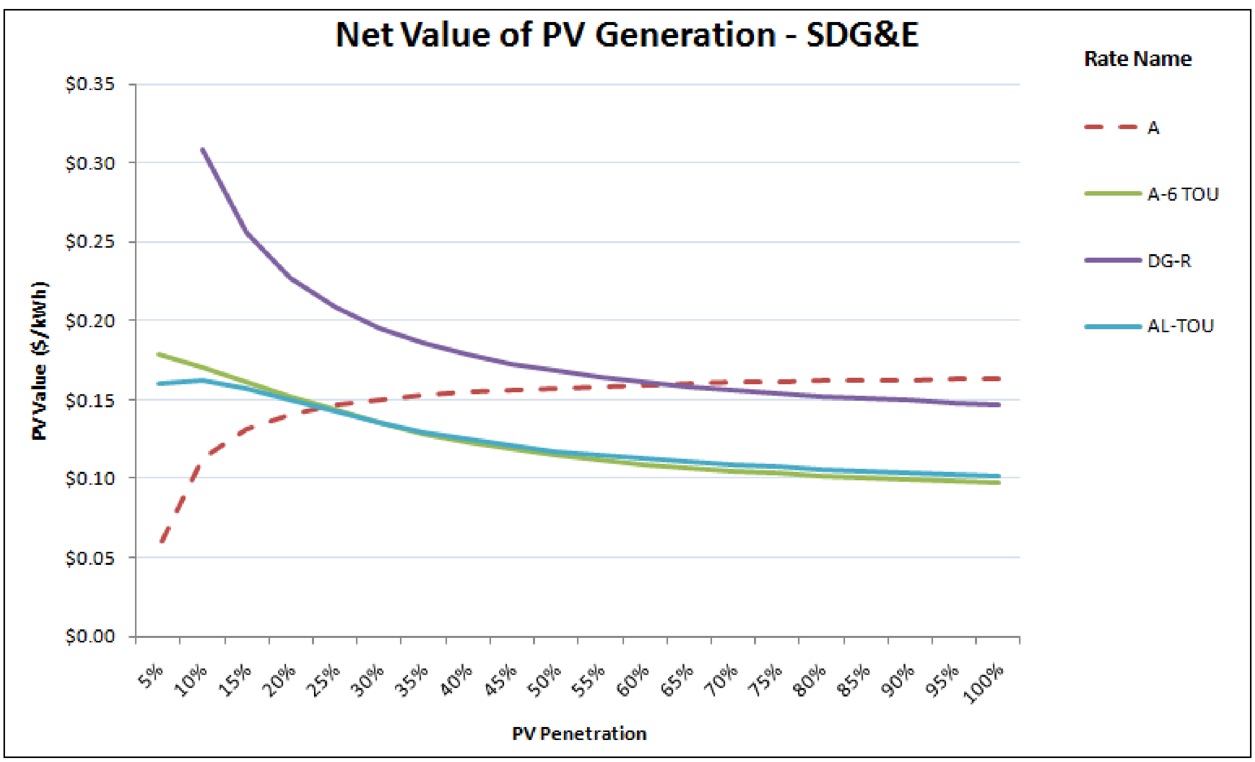

Figure 8. Net value of PV generation under various rate structures and penetration levels for schools in the SDG&E service territory

3.2 Impacts of Cost

Identifying the best rates under various PV penetration levels is important; however, in order to make a decision about installing a PV system, costs have to be factored into the analysis. Four metrics were used to evaluate PV system economics under the three ownership models described in Section 2.4:

- Simple payback
- Break-even PV cost
- Break-even PPA price
- Annual bill savings.

The simple payback period was calculated under the best rate option for each cost and PV penetration scenario. Payback periods for PG&E, SCE, and SDG&E are shown in Figures 9, 10, and 11, respectively. Payback periods at PG&E peak at a 45% PV penetration (13–27 years) and are shortest when approaching 100% penetration (10–21 years). Payback periods at SCE are shortest when PV penetration is under 30% and longest with 60% penetration. PV installations at SDG&E have a unique payback period curve due to the DG-R rate being applicable only with a 10% or greater PV penetration.[17] This causes abrupt minimum payback periods at a 10% penetration. At $6/W, the payback period for a PV system with a 5% penetration level is 21 years and quickly drops to 12 years with a 10% penetration. Payback periods continue to increase as penetration increases, with the longest periods occurring at 100% penetration.

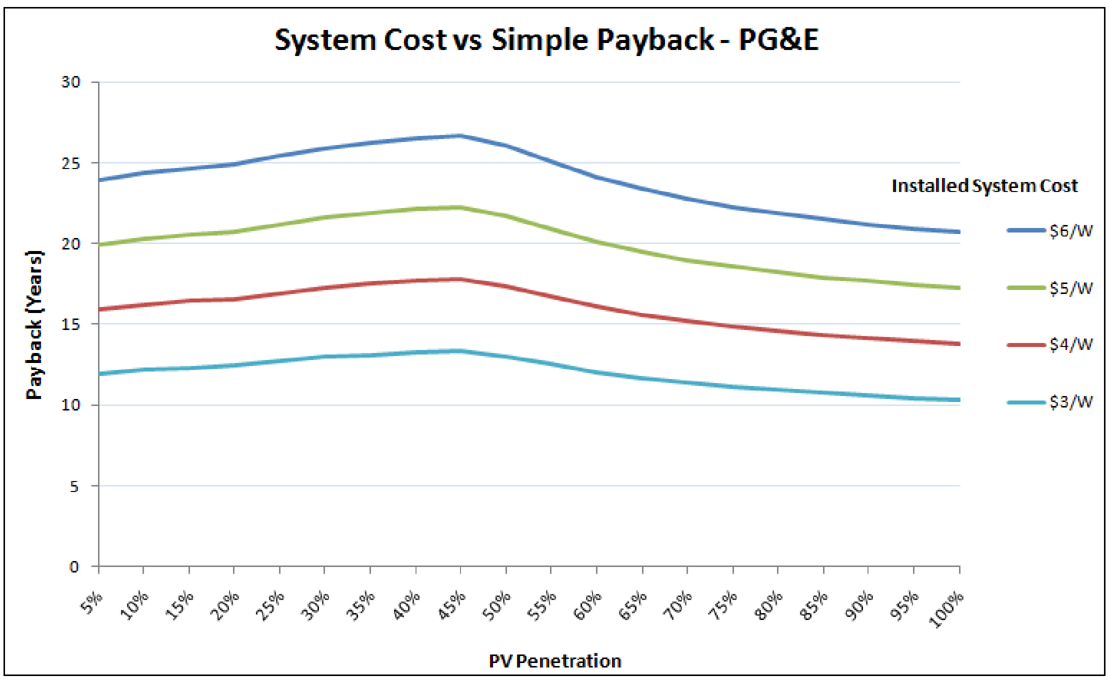

Figure 9. Simple payback for school PV system in PG&E service territory

[17] DG-R requires at least a 10% capacity penetration rather than a 10% energy penetration. It was discovered that a 7.5% energy penetration is sufficient to provide 10% of peak annual load. Because the PV penetration resolution is limited to 5% increments, DG-R was chosen to become effective at a 10% energy penetration.

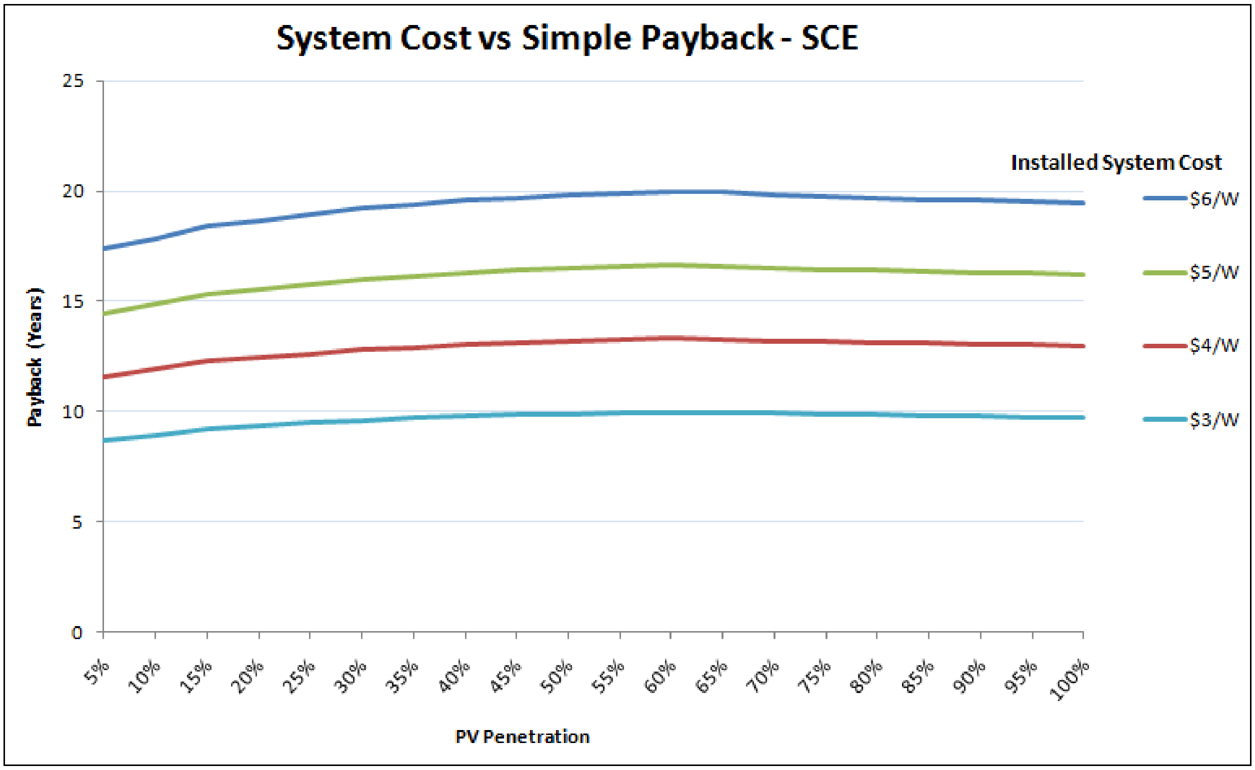

Figure 10. Simple payback for school PV system in SCE service territory

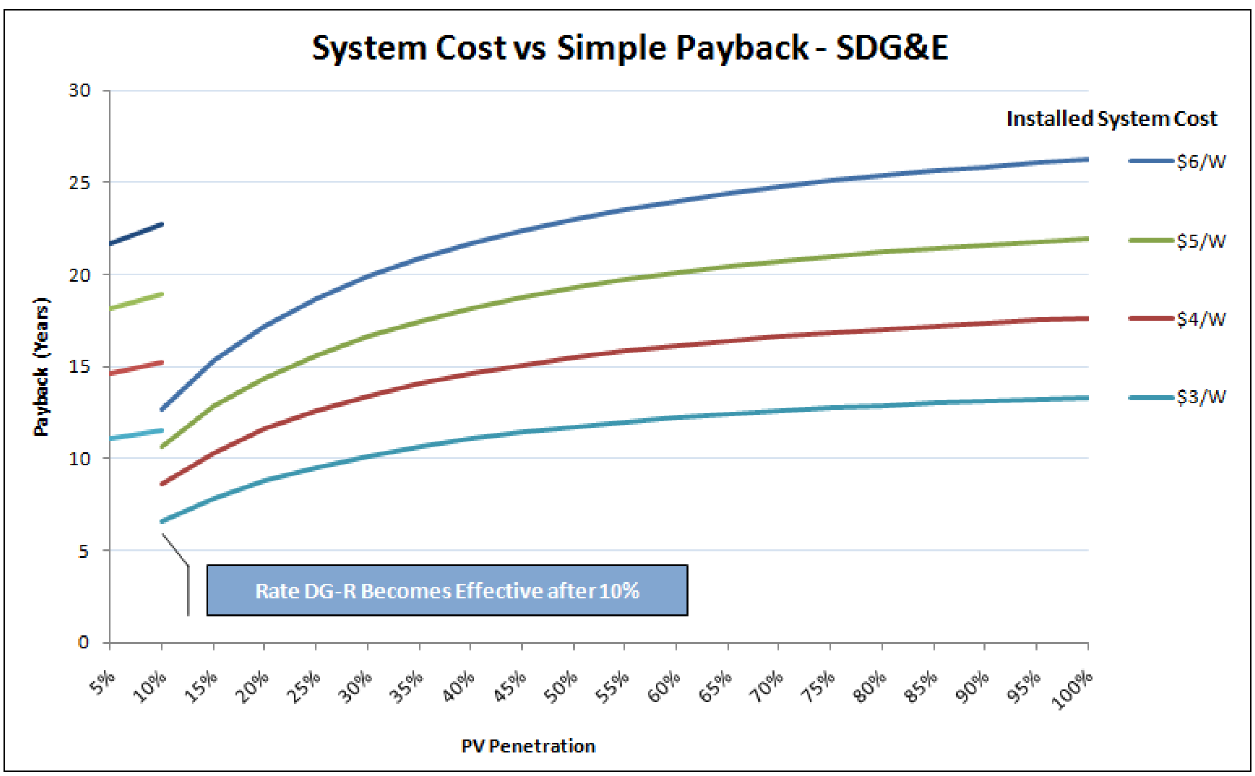

Figure 11. Simple payback for school PV system in SDG&E service territory

The simple payback metric is useful when trying to roughly determine if an investment is reasonable, but the break-even cost metric provides a more thorough economic analysis. Figure 12 shows the break-even PV costs for the three utility service territories. Break-even PV cost in PG&E ranged from $2.86/W to $3.78/W. These prices are well below the $6/W average installed cost determined at the time of this report (see Section 2.4). Break-even PV costs will be lower for schools compared to other commercial buildings in California, partly because public schools are ineligible to take advantage of the 30% federal tax credit. Break-even costs for SCE are slightly higher, ranging from $4.05/W to $4.58/W, while SDG&E has the highest break-even cost of $6.58/W at a 10% penetration.

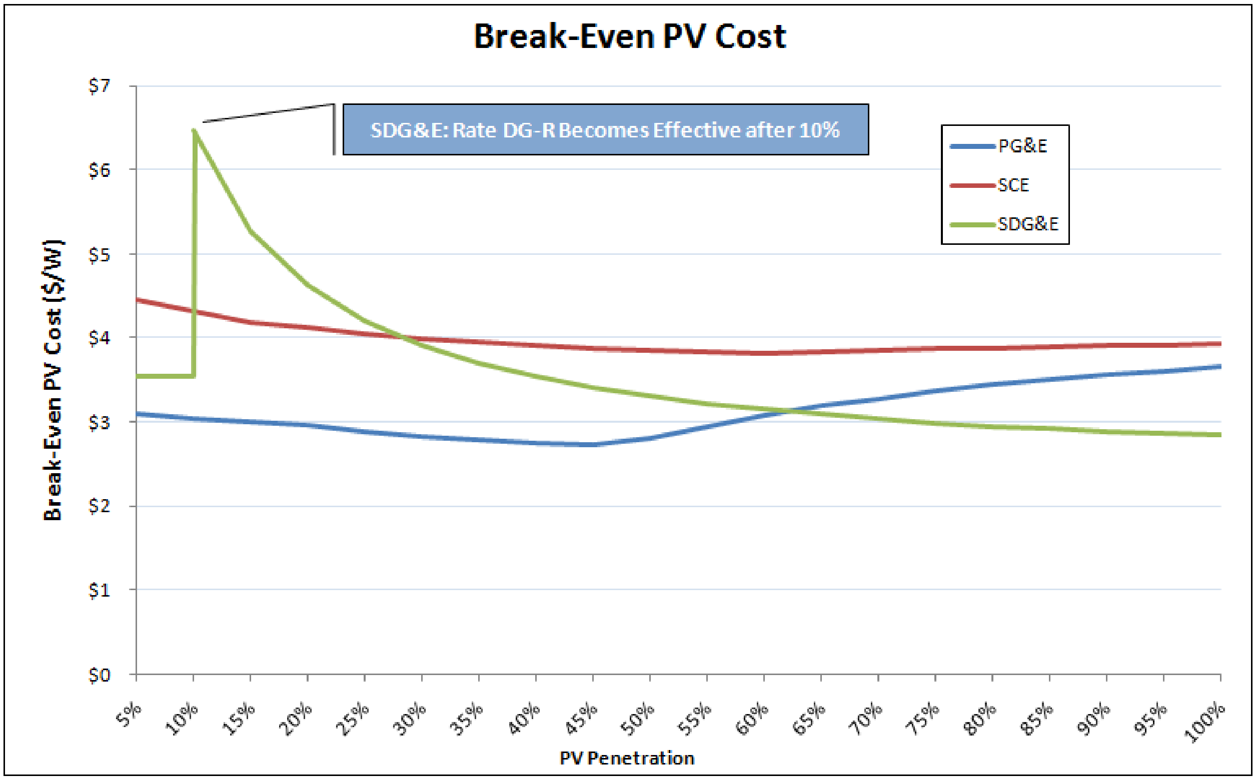

Figure 12. Break-even PV cost for each utility

When evaluating PV systems under a PPA, it is important to look at the net effect on the school's annual electricity expense. If the PV value is greater than the PPA price, then the school will realize a net savings on annual energy expenses. If the PV value is less than the PPA price, then the school will realize a net loss. The break-even PPA price (PPA price at which the school neither saves nor loses money) is shown in Figure 13. The highest break-even PPA price is seen at SDG&E, where prices exceed $0.20/kWh for PV penetrations of 10%–30%, with a peak above $0.30 at a 10% penetration. Break-even price is also above $0.20/kWh at SCE until a 30% penetration, after which prices level between $0.19 and $0.20. PG&E's minimum break-even PPA price occurs at a 45% penetration with $0.146/kWh, after increasing to nearly $0.19/kWh when approaching a 100% penetration.

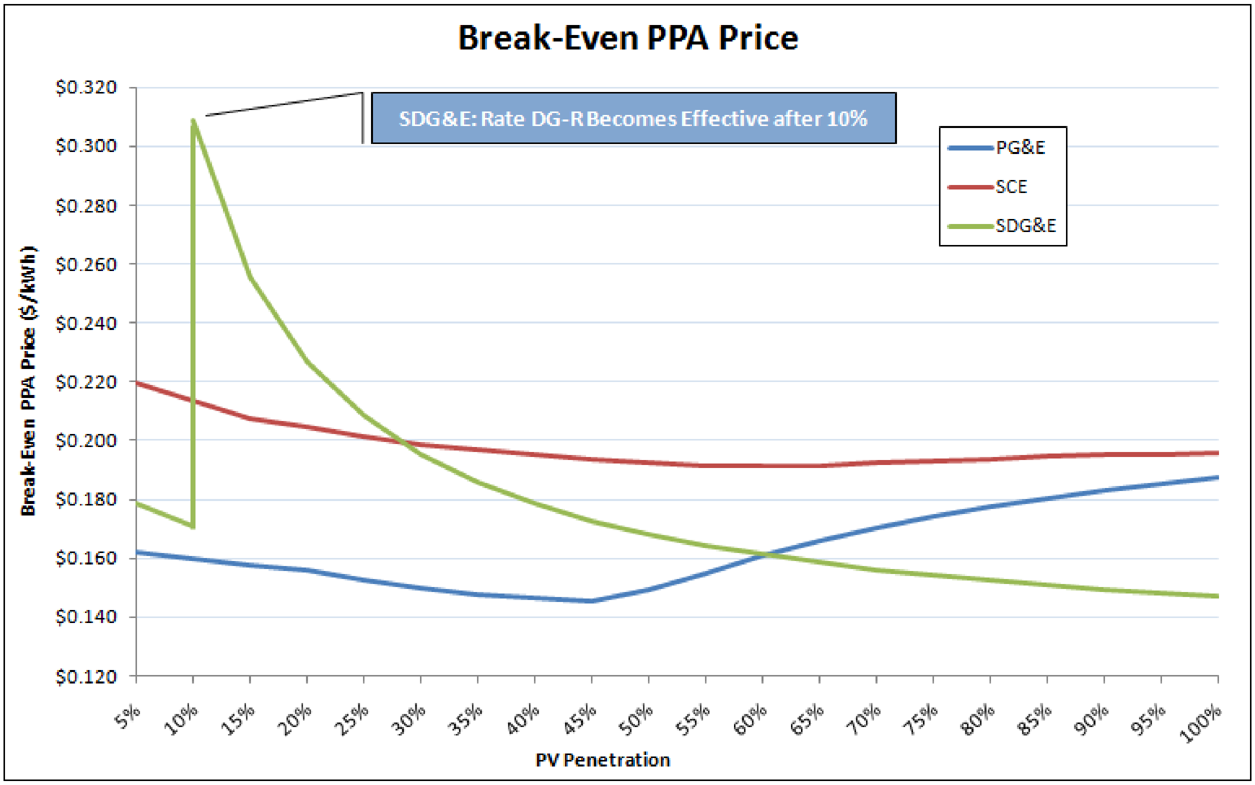

Figure 13. Break-even PPA price for each utility

In addition to the break-even PPA price, it is also useful to understand how annual electricity expenses will be impacted at various PPA price levels. Figures 14, 15, and 16 show the annual bill savings (as a percentage) under various PPA prices and penetration levels for schools in each of the three utility service territories. A change in PG&E's most economical rate, from A-10 to A-6, causes the elbow seen at the 45%–50% penetration level (see Figure 9). This chart shows that PPA prices of $0.15/kWh and below will result in a net savings to the school's annual electricity bill under most penetration levels. PPA prices of $0.20/kWh and above will always result in a net increase in the school's expenditures.

Schools in the SCE service area will always realize a net savings with PPA prices of $0.15/kWh and below. Very little change in annual electricity expenses will result under a PPA price of $0.20. Above that price, schools in the SCE service area will likely see an increase in annual electricity expenses.

Schools in the SDG&E service area can realize an annual savings under any of the evaluated PPA prices with a 10% PV penetration. This is because of the DG-R rate. Switching to this rate results in notable savings even when a PV system is not installed. However, SDG&E offers the DG-R rate only to buildings with at least 10% capacity penetration[18] from an eligible distributed generation installation. When PV penetration is small (10%), and even when the PPA price is high, switching to the DG-R rate may cover the PPA price and yield enough savings.

[18] The DG-R rate requires at least a 10% capacity penetration rather than a 10% energy penetration. This analysis found that a 7.5% energy penetration is sufficient to provide 10% of peak annual load. Because the PV penetration resolution is limited to 5% increments, DG-R was chosen to become effective at a 10% energy penetration.

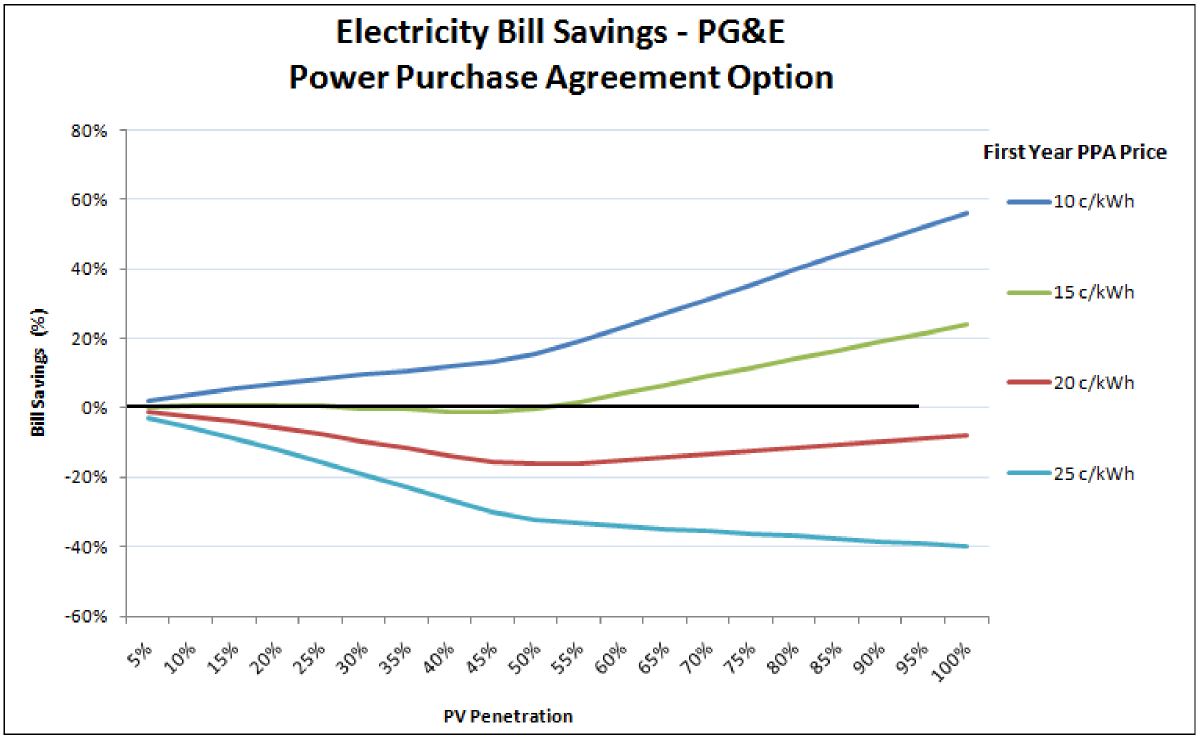

Figure 14. Annual electricity bill savings under various PPA prices and penetration levels for school in the PG&E service territory

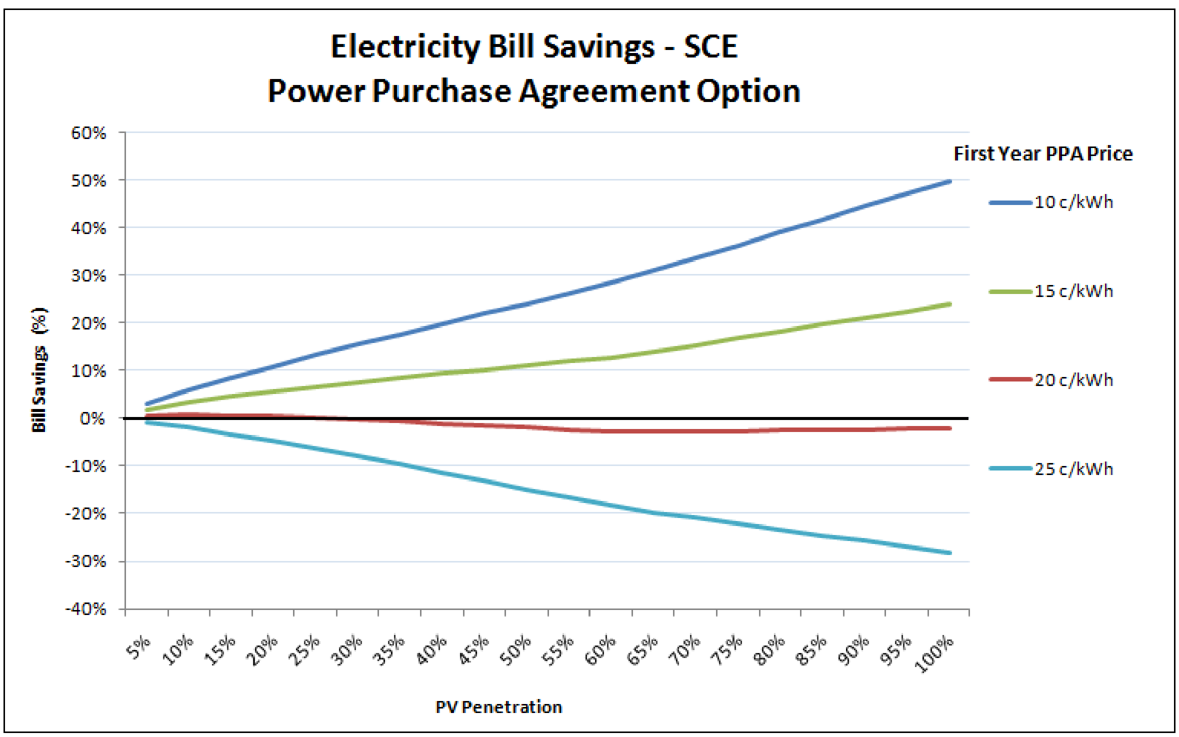

Figure 15. Annual electricity bill savings under various PPA prices and penetration levels for school in the SCE service territory

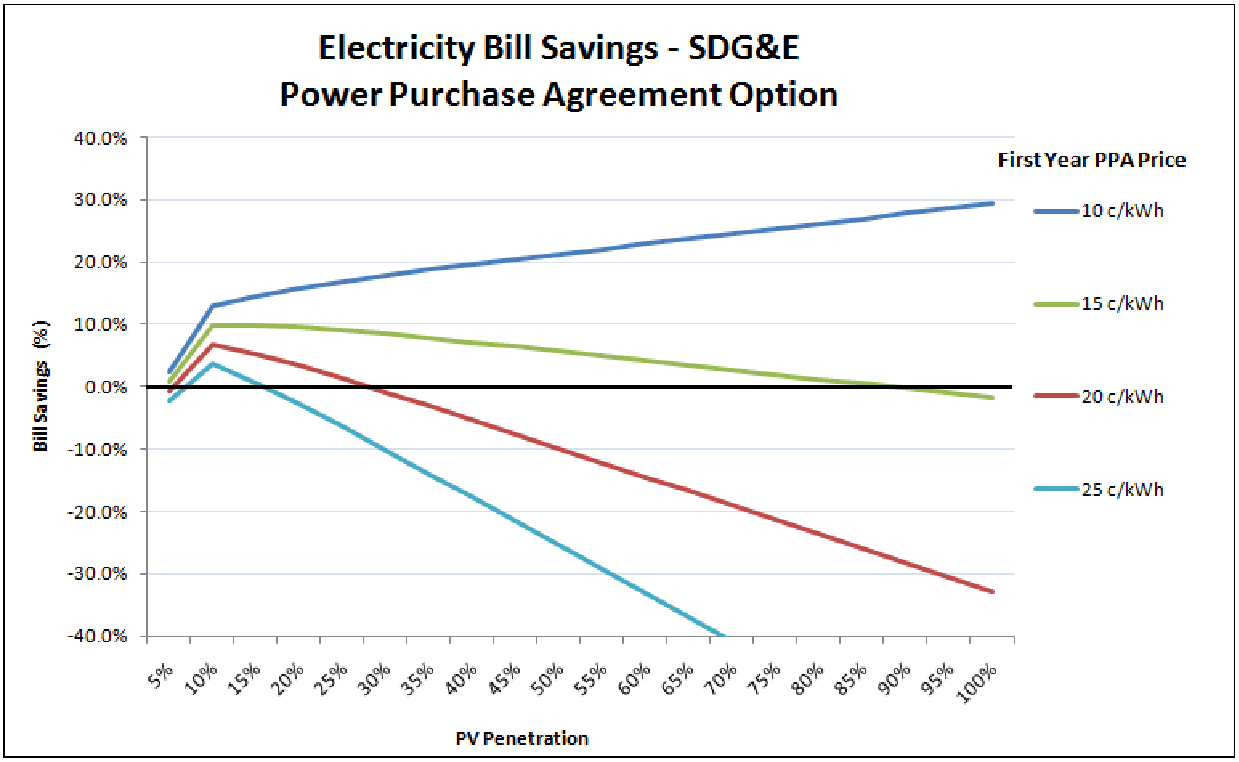

Figure 16. Annual electricity bill savings under various PPA prices and penetration levels for school in the SDG&E service territory

PV systems purchased under a GO bond require little or no upfront or recurring costs for the school. Figure 17 shows the potential annual savings that can be realized by the schools in each of the three utility service territories. Note that schools in the PG&E service area may actually realize a net revenue (even though the penetration is limited to 100%) by taking advantage of California's net-metering rules.[19]

[19] This is because the net-metering rules allow on-peak generation to be compensated at retail electricity prices even if electricity is exported during the on-peak hours as long as there are no net exports (all hours considered) at the end of each year (CPUC 2010). PG&E's A-6 rate has very high on-peak energy charges while having low-to-moderate prices during other hours, allowing for the PV system to benefit from this net-metering rule.

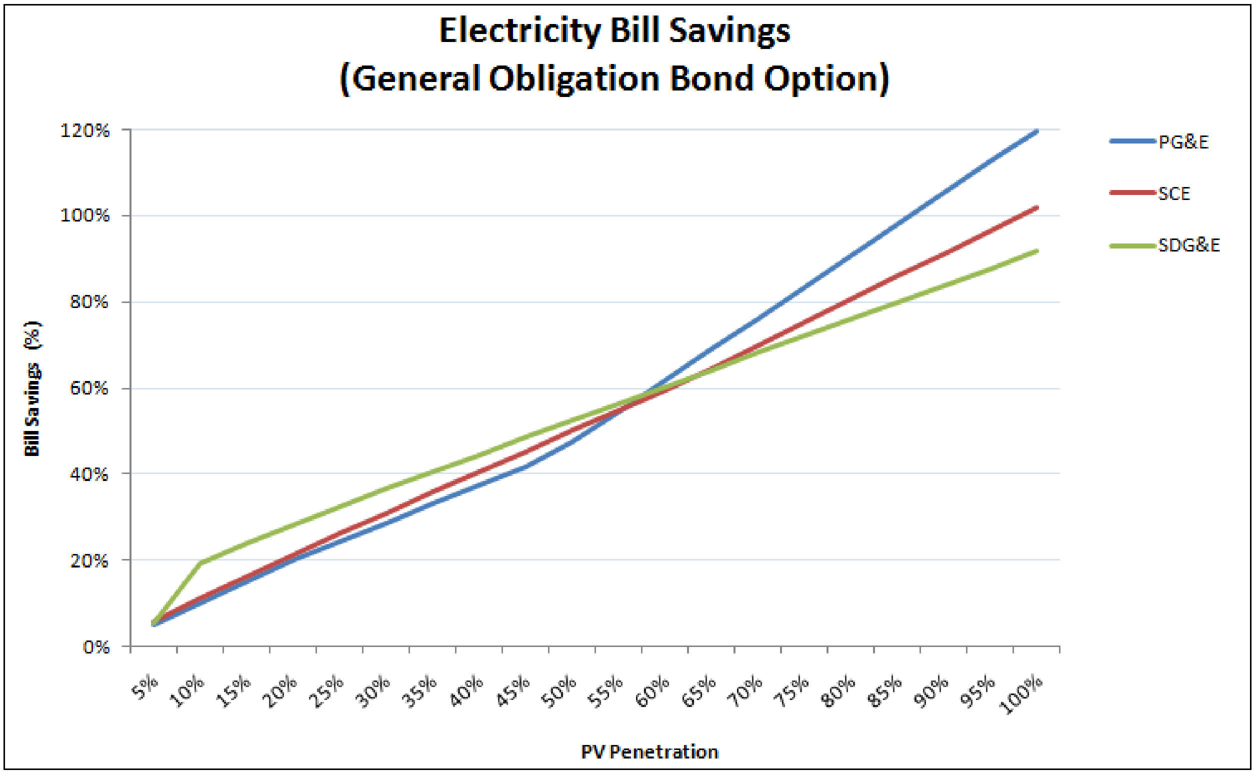

Figure 17. Annual electricity bill savings under the GO bond scenario

4 Conclusion

PV system economics are highly dependent on the host building's rate structure. System economics—under current net-metering rules—favor rates with high on-peak energy prices and low-to-moderate prices at other times. Rates with little or no demand charges are also favorable. This analysis found that there was no single best rate in any of the three utility service territories evaluated. Rather, the most economical rate depended on PV penetration. The rate that minimizes electricity expenses without PV was found to remain the rate of choice for low PV penetrations. For high PV penetration, rates with low demand charges and high on-peak energy prices became the most cost-effective option.

These results identify general relationships between rate structures and PV installations on schools. It is important to reiterate that the rate analysis applies to specific school load profiles (see Section 2.1) and is not intended to represent all schools in California. Results in case studies conducted for PG&E and SDG&E (see Appendix A and Appendix B) using actual school load profiles differ from those reached when using the simulated load profiles, showing that the results are sensitive to individual school load profiles. Recommendations for future studies include identifying the impacts of various school load variations, such as schools with summer or evening classes; assessing the impacts of critical-peak pricing; and evaluating the impacts of potential changes in net-metering rules.

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Appendix A. Case Study: Berkeley High School

Introduction and Summary of Findings

Berkeley High School (BHS) in Berkeley, California, serves approximately 3,000 students and has a large campus that consists of several buildings, some of which have been identified as favorable for rooftop PV placement (denoted as A through D in Figure A-1). These areas total approximately 47,000 ft^2—or enough to support 400 kW of PV capacity. The remaining roof space may support additional PV capacity.

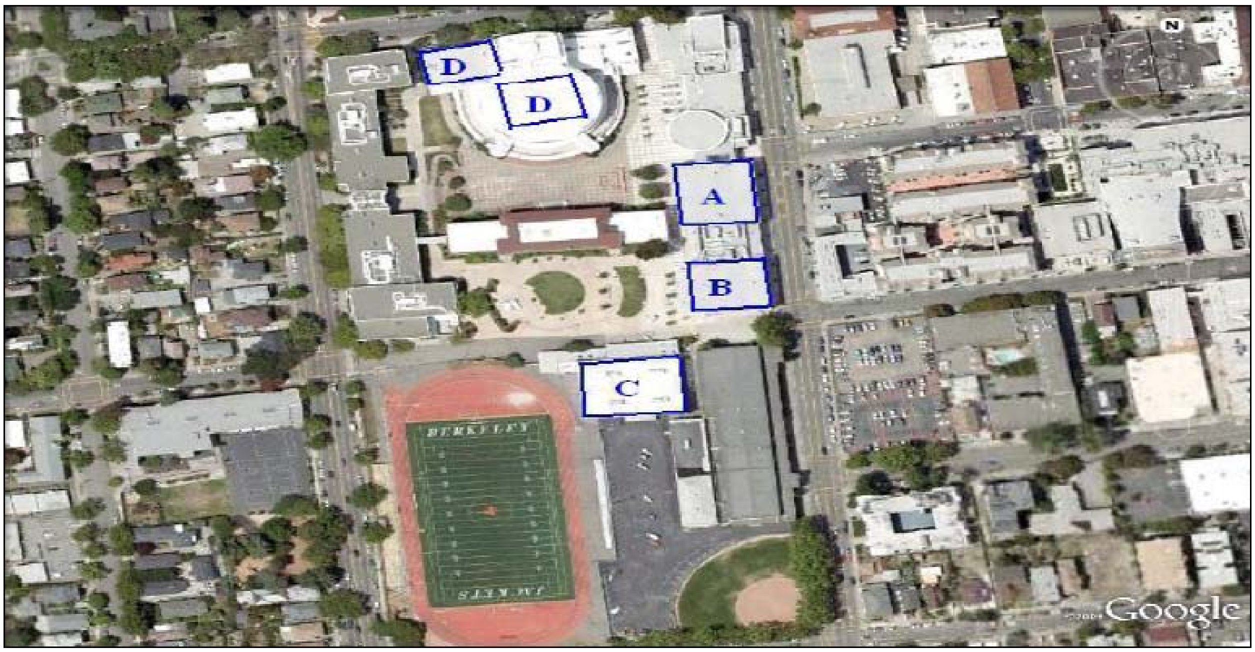

Figure A-1. Berkeley High School campus with locations favorable for rooftop PV identified (A–D)

Source: SunPower 2009

The aggregated annual electricity consumption for all BHS facilities exceeds 3 million kWh. The school qualifies for a total of six PG&E rates on the four meters that measure the school's load. These rates were evaluated to determine likely conditions for maximizing value and savings in annual energy expenses. Figure A-2 illustrates the PV value under different penetration levels and rate structures. The evaluation found that rate E-19 is the optimal option for PV penetrations up to 35%. At higher penetrations, rate A-6 becomes and remains the most economical rate option. This is because rate A-6 consists of very high daytime energy rates, which makes it too expensive under lower PV penetrations but more attractive with higher PV penetrations (see Section 3.1). Figure A-3 shows how system costs impact simple payback under optimal utility rates. Payback periods are longest at a 35% PV penetration and shortest when penetration levels approach 100%. Figure A-4 shows the impacts of various PPA prices on annual electricity expenses. System costs below \$0.20/kWh are necessary in order to realize a positive impact on the school's annual energy costs. Figure A-5 shows the annual electricity bill savings under a general obligation bond scenario. Since little or no upfront or recurring costs are required of the school and annual savings are very high and exceed 100% for penetrations above 80%. This is possible under net-metering rules that are applicable at the time of this report (see Section 3.2).

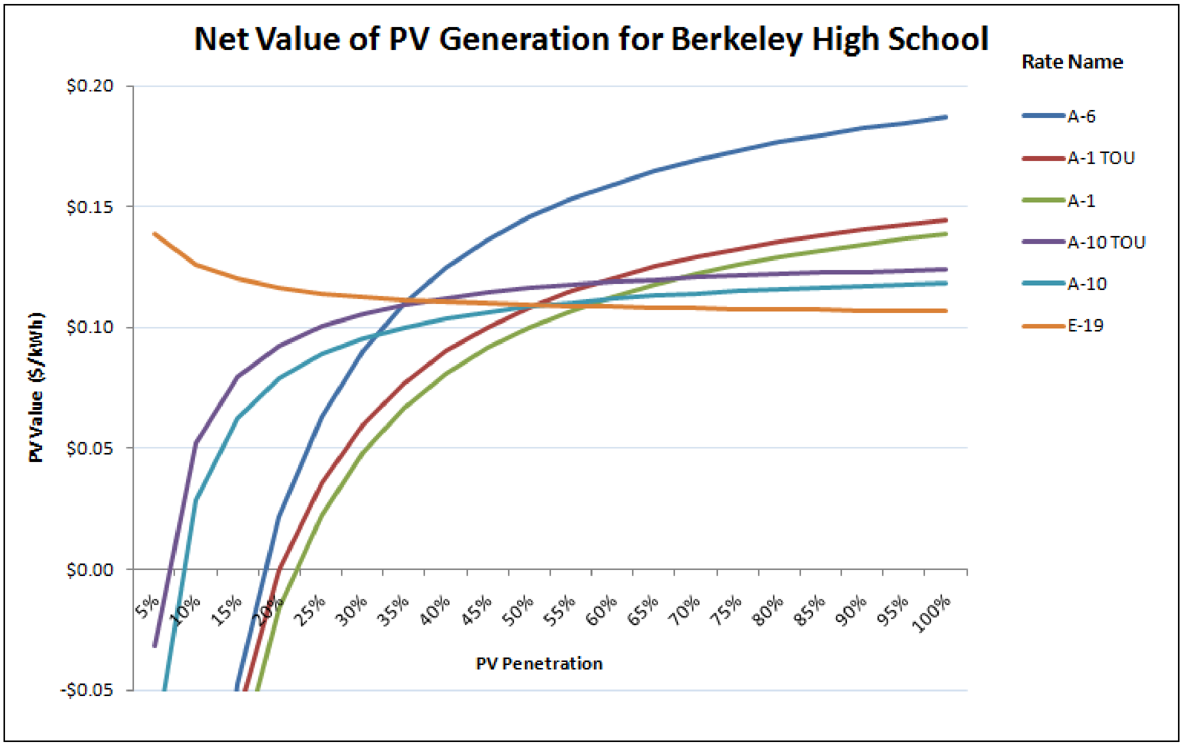

Figure A-2. Net value of PV generation under various rate structures and penetration levels

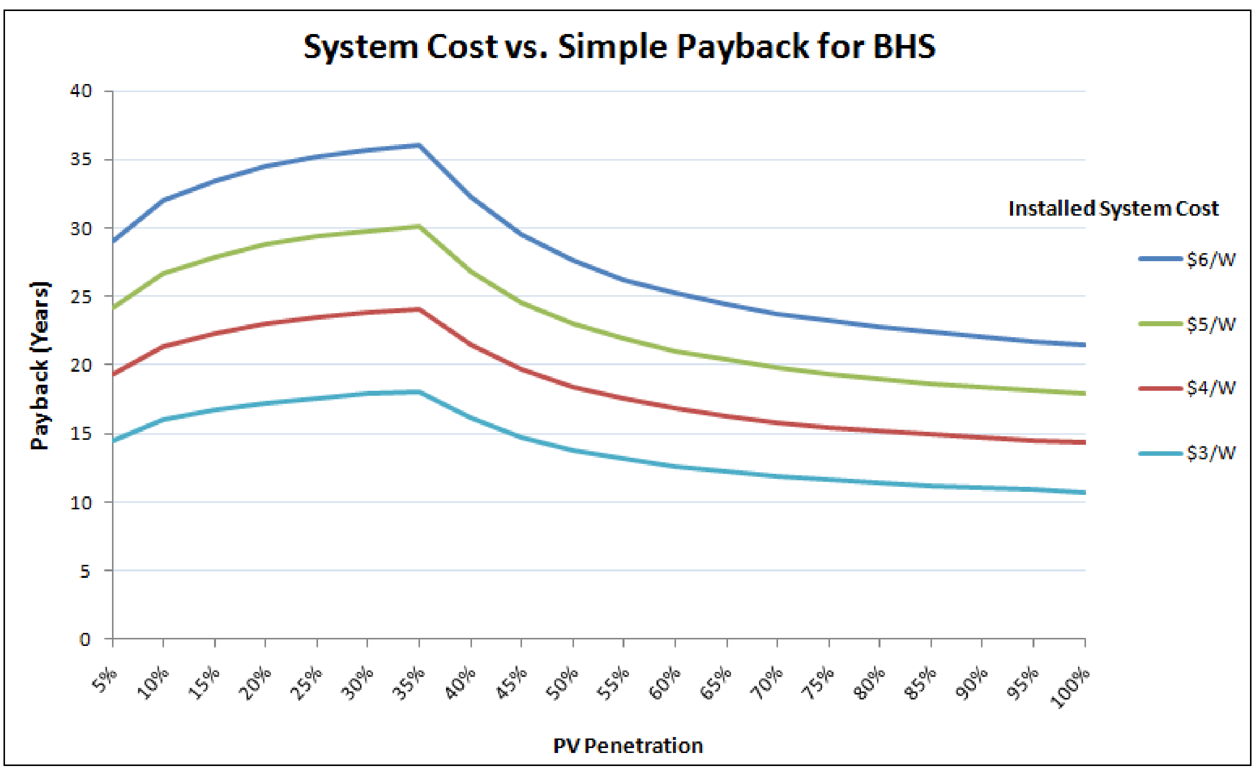

Figure A-3. Payback period for Berkeley High School under various PV system costs and penetration levels

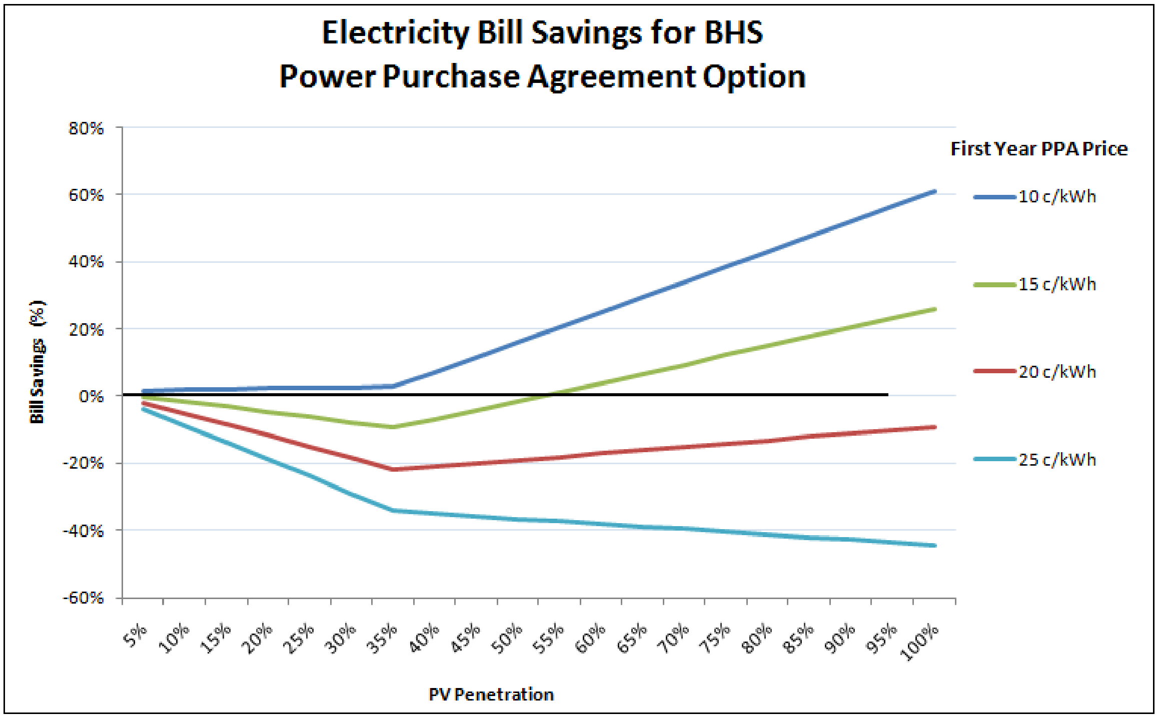

Figure A-4. Annual electricity bill savings for Berkeley High School under various PPA prices and penetration levels

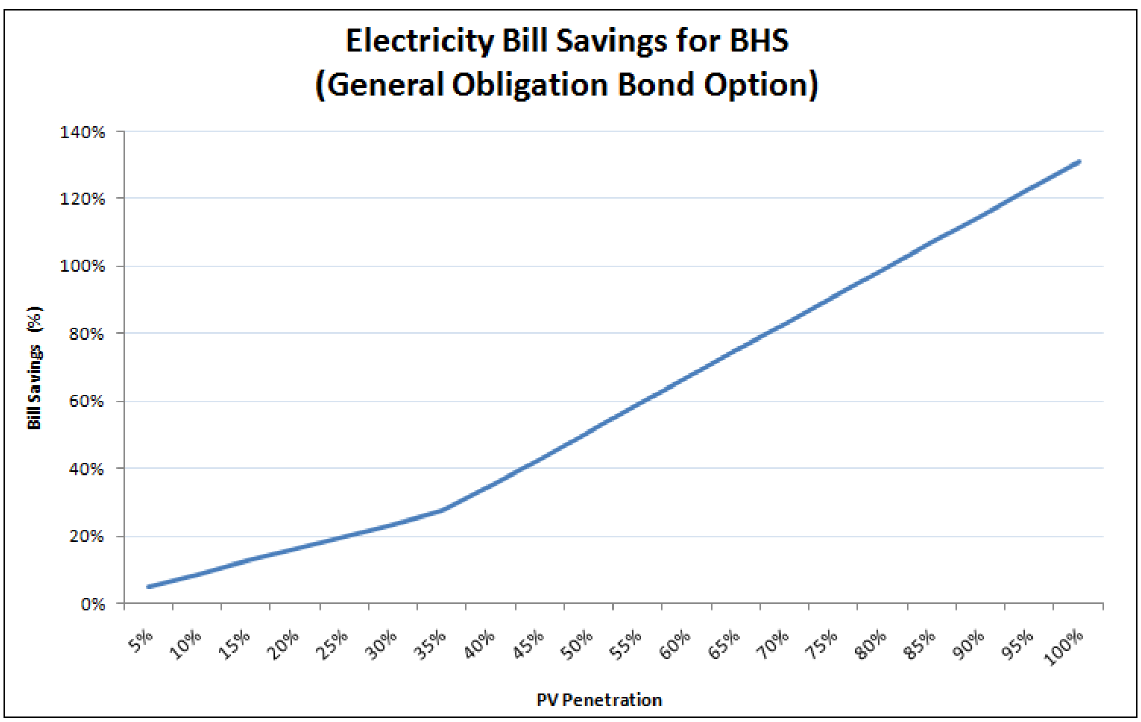

Figure A-5. Annual electricity bill savings for Berkeley High School under the GO bond option

Data and Methodology

Load Data

Due to the size of BHS and its energy use, PG&E has four separate meters that measure electricity usage from the school's various buildings and sections. Table A-1 shows the annual energy consumption of BHS during 2010, grouped by each of the four PG&E meters.

Table A-1. 2010 Energy Consumption of Berkeley High School

	2010 Energy Use (kWh)
Meter 1	788,915
Meter 2	2,074,653
Meter 3	315,200
Meter 4	44,160
Total	**3,222,928**

Monthly billing and energy data were available for each of the four meters. For detailed analyses, however, hourly or sub-hourly data are preferred.[20] Of the four meters, only meter #2 met the threshold for PG&E to make sub-hourly measurements. In order to conduct analyses, it was assumed that the sub-hourly measurements for meter #2, recorded in 30-minute intervals, reflect the hourly pattern for the entire campus. The data from meter #2 was scaled to match the annual load from all four BHS meters. Figure A-6 illustrates that, on a monthly basis, meter #2 represents the total BHS campus consumption pattern adequately. The scaled sub-hourly data (light blue) has a seasonal variation similar to that of the actual monthly measured energy data for the entire campus (dark blue).

[20] By using hourly or sub-hourly data, the impacts of TOU rates and demand charges on PV system economics can be determined. High resolution data also helps identify hours that the PV system is exporting energy to the grid, which may significantly impact system economics depending on the net-metering policy in place.

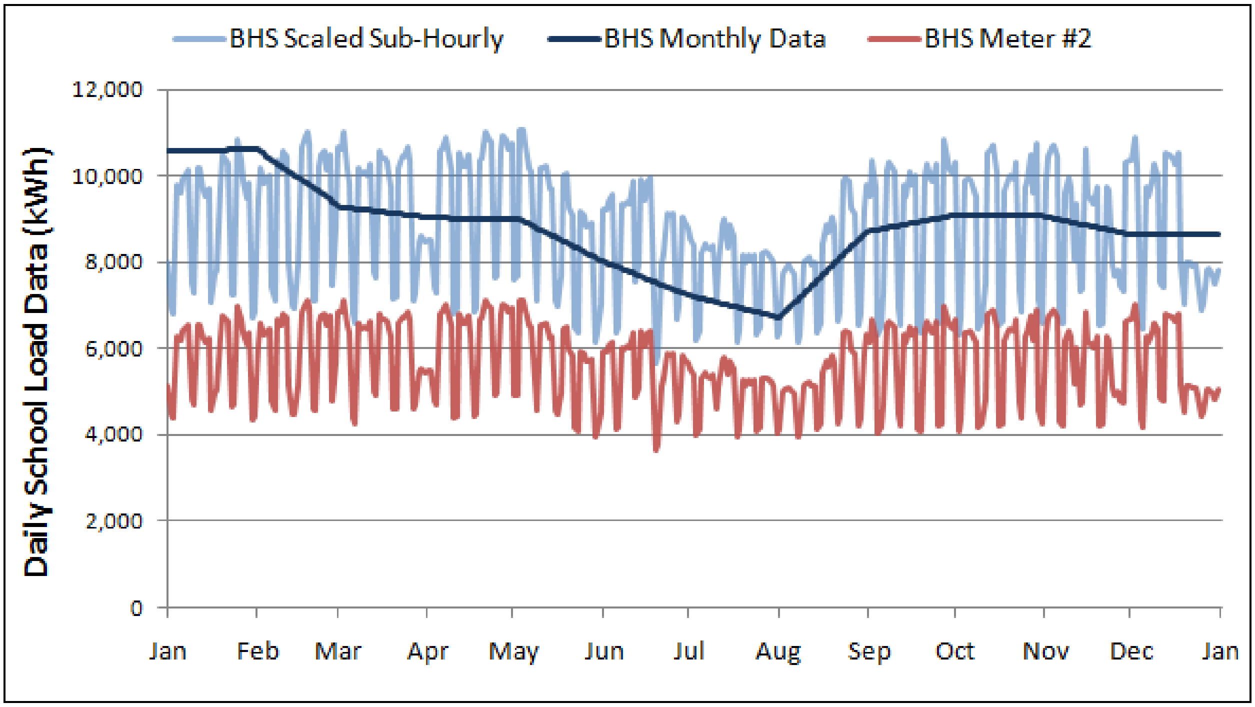

Figure A-6. Berkeley High School electricity load data during 2010—measured monthly energy data is compared with measured sub-hourly data and scaled sub-hourly data

Rate Data

BHS qualifies for a total of six PG&E utility rates. These rates were obtained from the online URDB on the OpenEI platform and verified them with the PG&E tariff sheets to ensure accuracy. PG&E offers various commercial rate structures for different load sizes and types. Smaller loads have more rate choices than larger loads since smaller users may optionally be on rates designed and made mandatory for larger loads. Larger facilities with solar installations may also be on rates designed for smaller facilities. At BHS, each of the four separate meters is treated independently and can utilize any of the eligible rate structures. Figure A-7 illustrates the eligible facility demand range for each of the six utility rates. Except for meter #2, all meters qualified for all six rates. Due to its monthly peak demand of approximately 400 kW, meter #2 qualified only for rates E-19, A-6, and A-10 TOU.

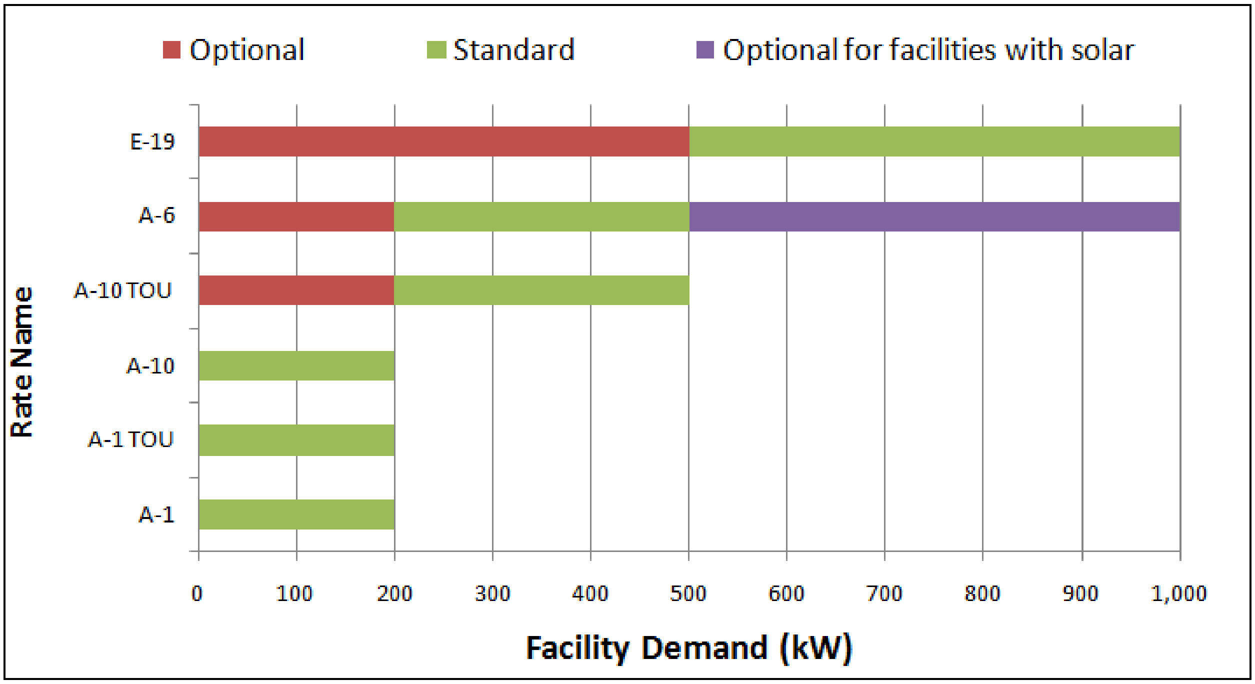

Figure A-7. Applicability of PG&E rates for commercial facilities up to 1,000 kW

Table A-2 categorizes the six PG&E rates used for this analysis. BHS did not qualify for any tiered or flat rates but did qualify for a good representation of seasonal rates, TOU rates, and demand charges. Three of the six rates fell into two or more categories.

Table A-2. Summary of Applicable Categories and Price Levels for the Rates Evaluated

Rate Name	Flat	Seasonal Flat	TOU	Demand	Tiered	Relative Price Level
A-1		✓				Moderate-to-high energy prices
A-1 TOU			✓			High energy prices during summer afternoons; moderate prices otherwise
A-10		✓		✓		Moderate energy prices; high demand charges
A-10 TOU		✓	✓	✓		Low off-peak energy prices; moderate peak energy prices; high demand charges
A-6			✓			Very high energy prices during summer afternoons; low-to-moderate prices otherwise
E-19			✓	✓		Moderate energy prices during summer afternoons; lower energy prices otherwise; very high demand charges during summer afternoons; moderate demand charges otherwise

Solar Data

The PV production data used for BHS was simulated using hourly meteorological data from the SolarAnywhere® database (Clean Power Research 2011). The SolarAnywhere dataset is similar to the National Solar Radiation Database (Wilcox 2007); however, it contains more recent data.[21] Hourly meteorological data was obtained for the year 2010 from a 10 km-by-10 km grid cell that contained the BHS campus. The meteorological dataset was used as an input for SAM, which simulated hourly PV production for use in the financial calculations.

System Advisor Model and Calculations

Using SAM, PV performance data was generated using the meteorological data obtained from SolarAnywhere and the following assumptions:

- 15-degree tilt
- South facing (180-degree azimuth)
- A de-rate factor of 85%
- An annual degradation of 0.5%.

In addition to the meteorological data, hourly building load data[22] and utility rate data were given as inputs for SAM. A rooftop PV system was simulated for BHS for various penetration levels ranging from 0% (no PV system) to 100% (PV system produces 100% of the school's annual electrical energy needs) in increments of 5%. The value of the PV system's generation under various penetration levels and rate structures was evaluated by comparing the school's annual electricity costs both with and without the PV system. Any resulting difference was attributed to the PV system. The combination of scenarios required 240 unique simulations, from which the model determined the economically optimal PV penetration and rate structure.

Conclusion for Berkeley High School Case Study

Under the conditions of this analysis, two rates maximize PV value at BHS. Rate E-19 maximizes savings for lower PV penetrations (35% and under), and rate A-6 maximizes savings for penetrations above 35%. This assessment assumes that there are no significant changes in the school's load profile. Changes in the size or shape of the school's electricity usage pattern will likely impact the results.

[21] The most recent National Solar Radiation Database update contains data through 2005. The SolarAnywhere dataset is continuously updated and contains data through the present time. Since the BHS load data is from 2010, it is important to use solar and meteorological data from the same time period to accurately capture TOU and demand charge impacts.

[22] Although sub-hourly (30-minute) resolution load data were obtained from PG&E, this data was converted to hourly resolution because SAM is currently an hourly performance model. The meteorological data obtained was also limited to hourly resolution.

Appendix B. Case Study: Lewis Middle School

Introduction and Summary of Findings

Lewis Middle School (LMS), located in San Diego, California, is a moderately sized school with an existing 200 kW PV installation. The installation provided approximately 98% of the school's electricity consumption in 2010 (98% penetration). Figure B-1 shows the LMS campus with the PV installation (dark rectangles) covering a significant portion of the available rooftop area. After obtaining detailed, 15-minute resolution data for the campus electricity consumption and PV generation, the data was scaled to evaluate a range of PV penetration scenarios. The results from this case study are intended to inform other similar schools that are exploring their options for solar generation. Since the LMS PV installation and financing is already complete, the options and recommendations given are for reference only.

LMS installed the rooftop PV system as part of a re-roofing effort, hence the high utilization of available rooftop area. The added value of combining the re-roofing and PV installation was not taken into consideration in this analysis and may significantly increase the overall economics for the school.[23]

Figure B-1. Lewis Middle School with existing rooftop PV installation

Source: Google Maps, 2011

With an aggregated annual electricity consumption exceeding 300,000 kWh, LMS qualifies for two SDG&E rates. These rates were evaluated to determine optimal conditions for maximizing

[23] LMS re-roofed its buildings using new roofing material with flexible solar panels bonded to it. The school was guaranteed maintenance-free roofs for 20 years.

value and savings in annual electricity expenses. Figure B-2 illustrates the PV value under different penetration levels and rate structures. The evaluation found that rate AL-TOU is the optimal option for PV penetrations up to 10%. At higher penetrations, rate DG-R becomes and remains the most economical rate option. Rates A and A-6 TOU, denoted by the dotted lines, are not applicable to be used at LMS and were included in the chart for comparison only. Rate DG-R is available only to buildings that have an eligible distributed generation technology with a capacity that is 10% or more of their peak annual load.[24]

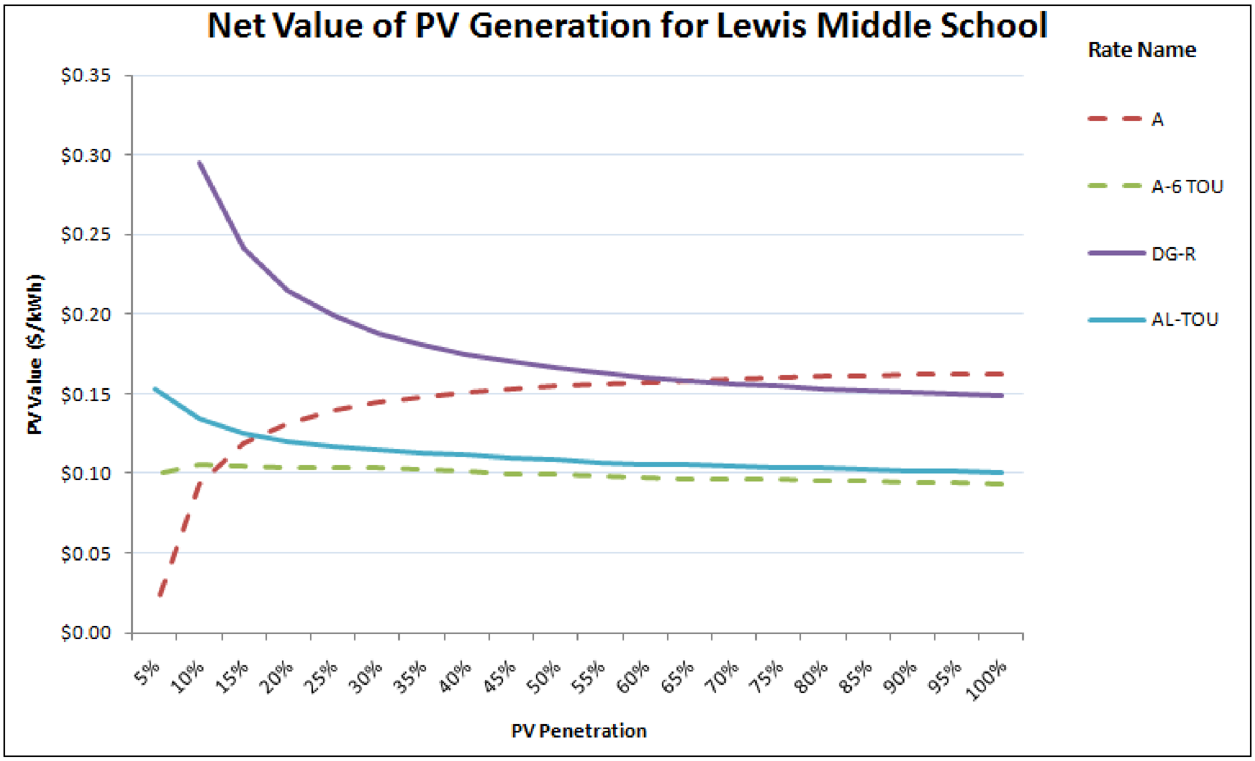

Figure B-2. Net value of PV generation under various rate structures and penetration levels

Figure B-3 shows how system costs impact simple payback under optimal utility rates. Payback periods are longest when approaching 100% PV penetration and shortest when penetration is at 10%. The abrupt dip in payback period at the 10% mark is due to the effect of rate DG-R becoming available for use after a 10% penetration.[25] Figure B-4 shows the impacts of various PPA prices on annual electricity expenses. With all PPA prices evaluated, LMS will always realize a net savings on annual electricity expenses when PV penetration is at 10% due to the DG-R rate. Below a PPA price of $0.15/kWh, LMS will always realize a net savings on annual electricity expenses, regardless of penetration level. Figure B-5 shows the annual electricity bill savings under a GO bond scenario. Since little or no upfront or recurring costs are required of the school, annual savings are very high and exceed 90% for penetrations approaching 100%.

[24] A 7.5% PV penetration is sufficient to provide 10% of the LMS peak annual load. Because the PV penetration resolution is limited to 5% increments, the DG-R rate was chosen to become effective at a 10% PV penetration.
[25] Ibid.

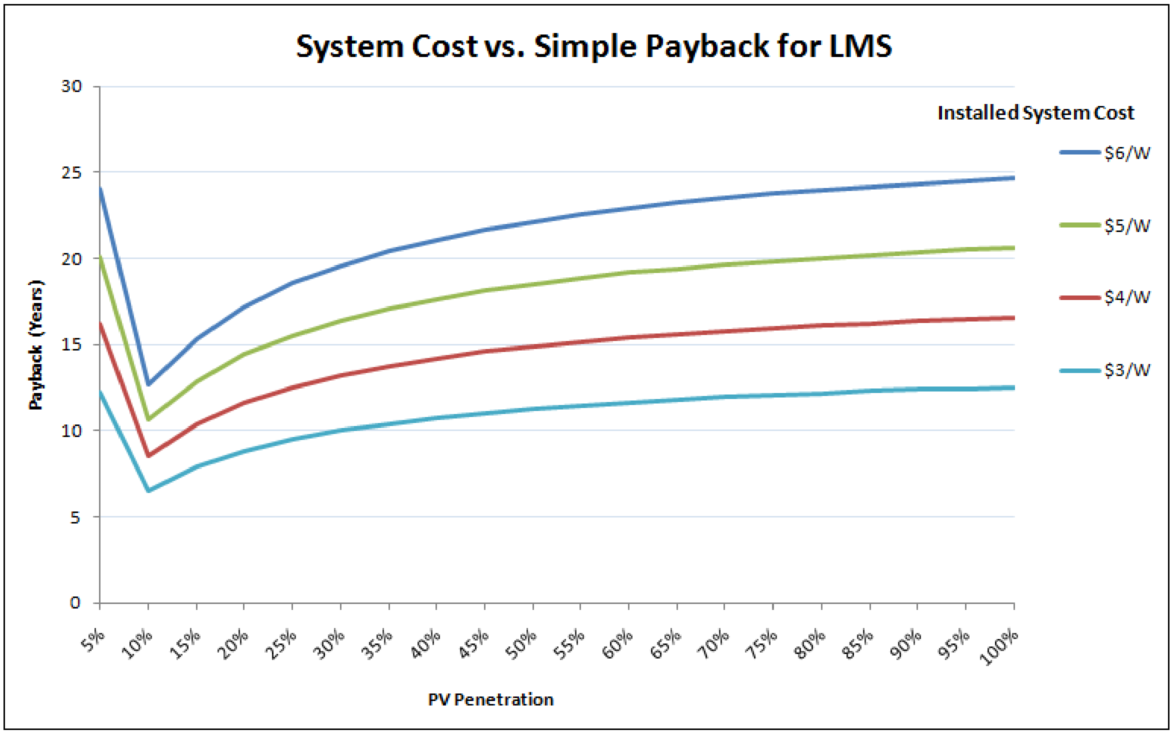

Figure B-3. Payback period for LMS under various PV system costs and penetration levels

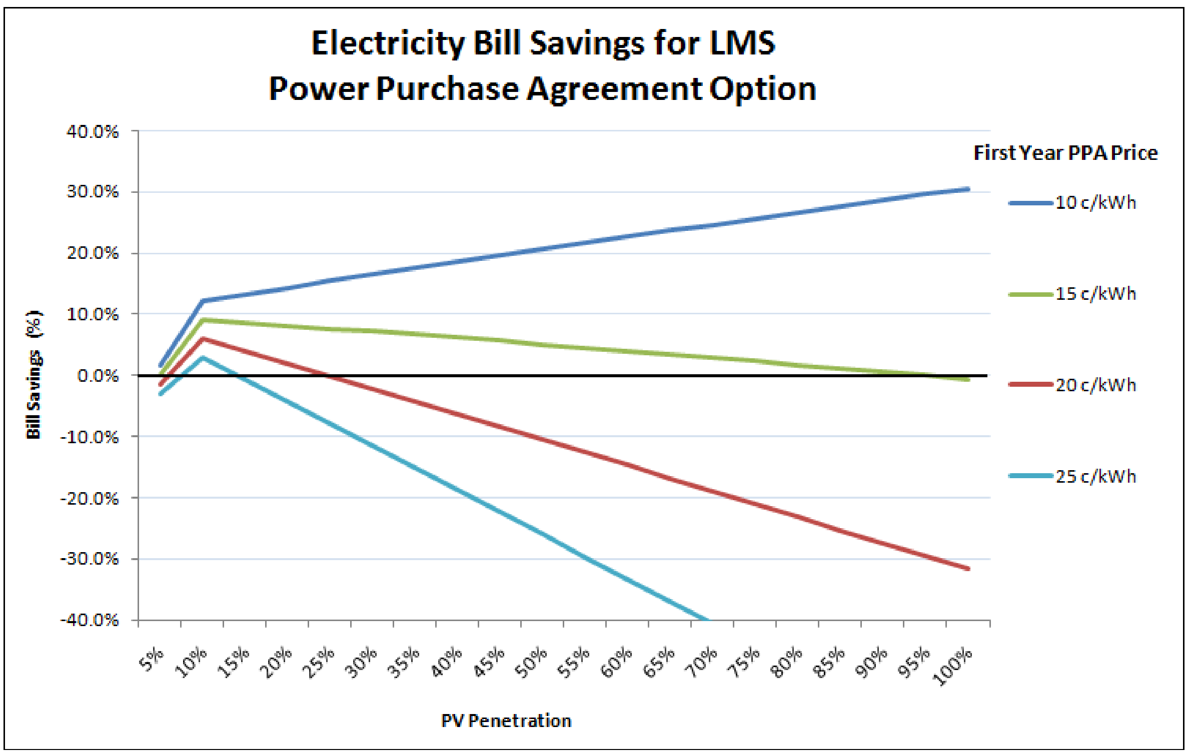

Figure B-4. Annual electricity bill savings for LMS under various PPA prices and penetration levels

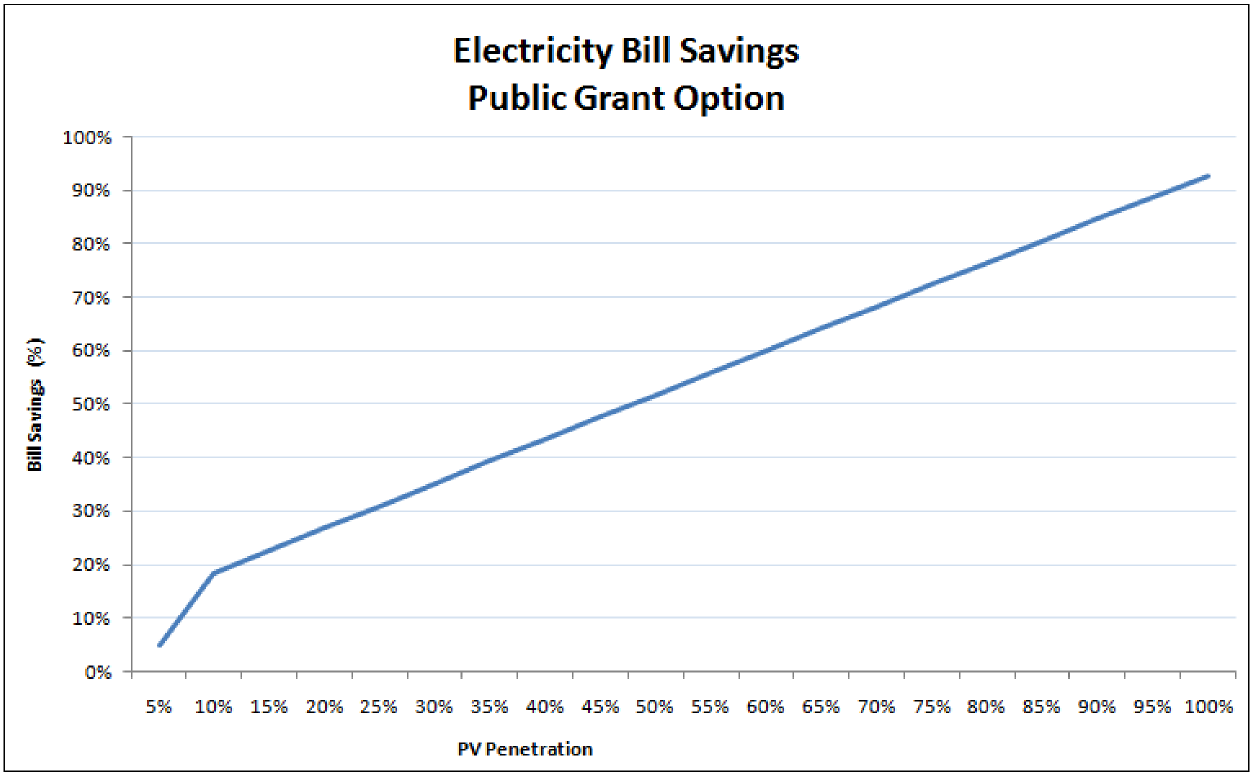

Figure B-5. Annual electricity bill savings for LMS under the GO bond option

Data and Methodology

Load and Solar Data

SDG&E measures and records LMS's energy data, including actual building energy use and PV production, in 15-minute increments. The detailed records eliminated the need to simulate data for this case study. Figure B-6 illustrates the daily school energy consumption and PV generation data for the year 2010. The PV system met approximately 98% of the LMS load in 2010. The data were entered into SAM in order to determine the impact of available rate structures on the economics of the PV system.

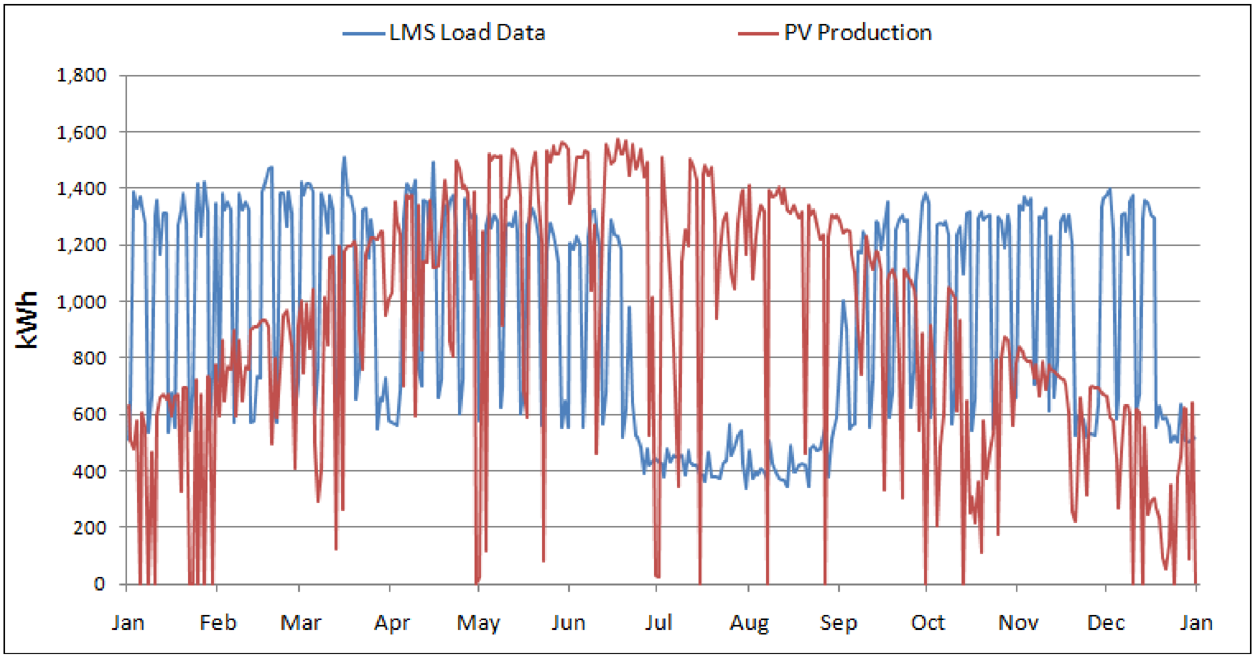

Figure B-6. 2010 daily load profile and PV generation for Lewis Middle School

Rate Data

LMS qualifies for two SDG&E utility rates. A total of four rates were evaluated for comparison, but used only the LMS-eligible rates to calculate bill savings and payback periods. All rates were obtained from the online URDB and verified with the SDG&E tariff sheets to ensure accuracy. Figure B-7 illustrates the eligibility range for each of the four utility rates. Since LMS had a peak annual load of 130 kW, the only rates applicable are AL-TOU and DG-R.

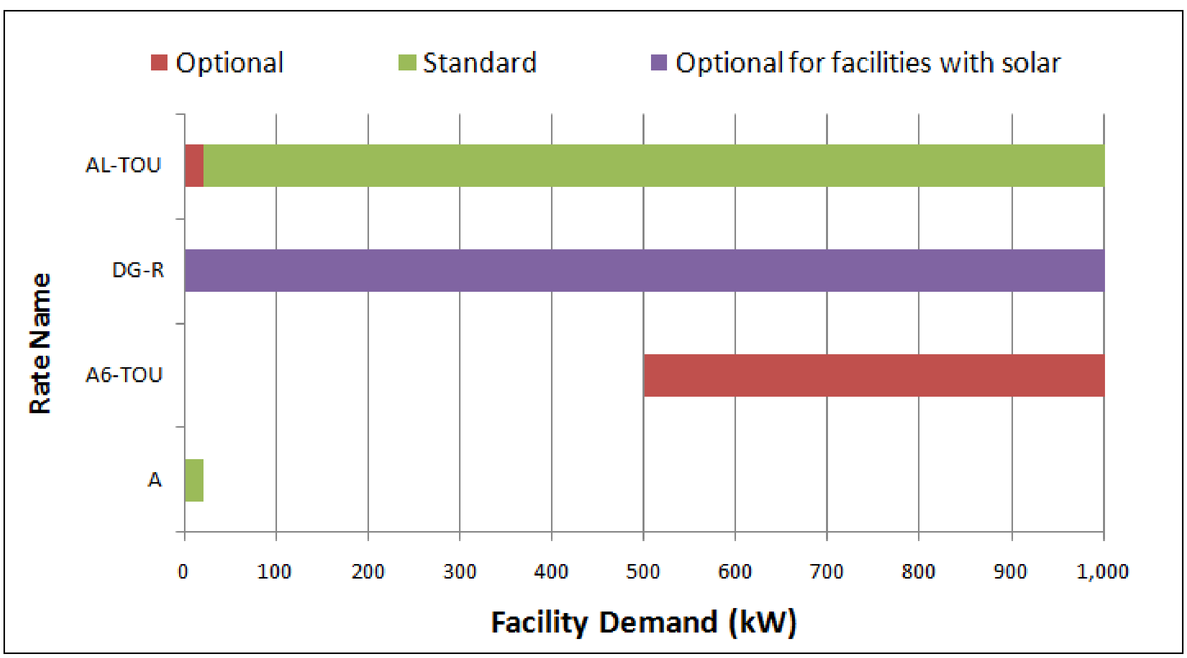

Figure B-7. Applicability of SDG&E rates for commercial facilities up to 1,000 kW

Table B-2 summarizes the various categories and features of the four SDG&E rates used for this analysis. There were no tiered or flat rates in the four SDG&E rates evaluated.

Table B-2. Summary of Applicable Categories and Price Levels for the Rates Evaluated

Rate Name	Flat	Seasonal Flat	TOU	Demand	Tiered	Relative Price Level
A		✓				Very high energy prices
A6-TOU		✓	✓	✓		Low energy prices; high demand charges
DG-R		✓	✓	✓		High energy prices; low demand charges
AL-TOU		✓	✓	✓		Intermediate energy prices; high demand charges

System Advisor Model and Calculations

Hourly PV generation data, hourly building load data,[26] and utility rate data[27] were entered into SAM. The PV generation data were analyzed for various penetration levels ranging from 0% (no PV system) to 100% (PV system produces 100% of school's annual electrical energy consumption) in increments of 5%. The value of the PV system's generation was evaluated under various penetration levels and rate structures by comparing the school's annual electricity costs both with and without the PV system. Any resulting difference was attributed to the PV system.

Conclusion for Lewis Middle School Case Study

LMS boasts a PV system that meets nearly 100% of the school's annual electricity consumption. Under a PPA, results show that large PV penetrations are ideal for PPA prices at or below $0.10/kWh, where increasing PV penetrations yield increased bill savings. For PPA prices $0.15/kWh and above, the optimal penetration level is 10%, or the lowest penetration level for rate DG-R to be used. A 10% penetration is also the point that minimizes the payback period for systems purchased up front. This case study did not look at the California Solar Initiative incentives, which were not available at the time of this report but may have been available when the PV system was installed at LMS. Including the incentives will alter these results and increase PV value. The LMS PV system was also installed as part of a re-roofing effort, which may also increase the overall economics for the school.

[26] Although sub-hourly (15-minute) resolution load data were obtained from SDG&E, the data were converted to hourly resolution because SAM is currently an hourly performance model.
[27] SAM communicates directly with OpenEI's online URDB to obtain the latest rate information available on OpenEI.