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Solar San Diego: The Impact of Binomial Rate Structures on Real PV Systems

Preprint

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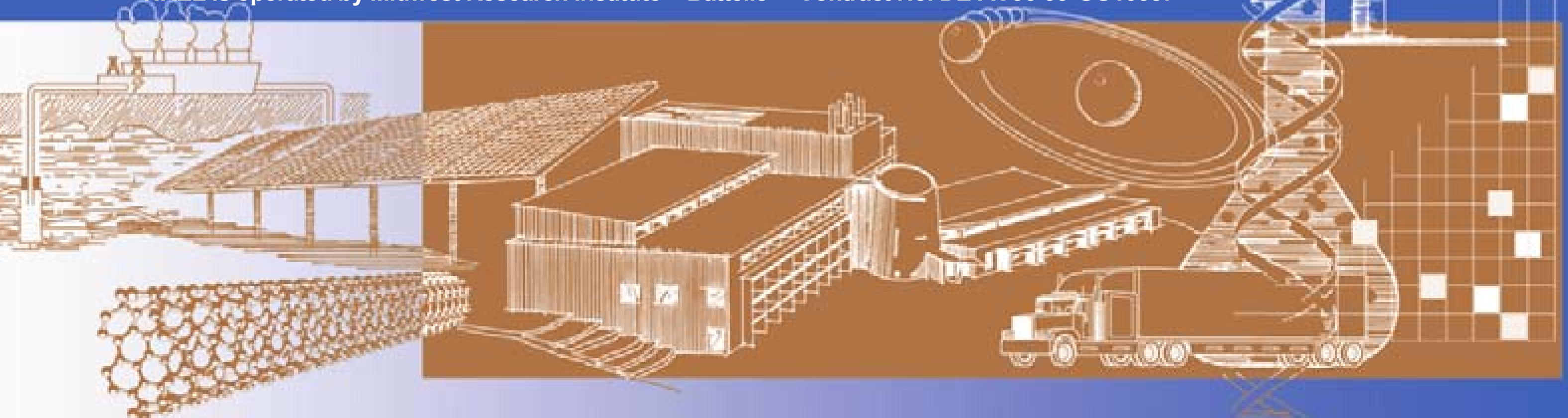

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ABSTRACT
There is confusion in the marketplace regarding the impact of solar photovoltaics (PV) on the user's actual electricity bill under California Net Energy Metering, particularly with binomial tariffs (those that include both demand and energy charges) and time-of-use (TOU) rate structures. The City of San Diego has extensive real-time electrical metering on most of its buildings and PV systems, with interval data for overall consumption and PV electrical production available for multiple years.

This paper uses 2007 PV-system data from two city facilities to illustrate the impacts of binomial rate designs. The analysis will determine the energy and demand savings that the PV systems are achieving relative to the absence of systems. A financial analysis of PV-system performance under various rates structures is presented.

The data revealed that actual demand and energy use benefits of bionomial tariffs increase in summer months, when solar resources allow for maximized electricity production. In a binomial tariff system, varying on- and semi-peak times can result in approximately $1,100 change in demand charges per month over not having a PV system in place, an approximate 30% cost savings. The PV systems are also shown to have a 30%-50% reduction in facility energy charges in 2007.

Future work will include combining demand and electricity charges and increasing the breadth of rate structures tested, including the impacts of non-coincident demand charges.

1. INTRODUCTION

Solar photovoltaic systems are touted as beneficial in certain geographic areas because of both their financial and external benefits (1). However, recent evidence in California suggests that even with all financial benefits incorporated, the high capital cost of equipment and installation is prohibitive to project completion (2). PV-system installation costs, productivity, and cost-effectiveness are highly variable based on geography, available incentives, and actual maintenance practices. Indeed, the value of externalities may be the primary economic driver for many systems, and that is determined specific to the project in the absence of carbon and other environmental consideration markets.

The City of San Diego has been a regional leader in PV implementation on its facilities, with more than 1 MW of PV installed since 2005. In San Diego, there is increasing emphasis on solar power as a an important source of in-region generation as well as for its potential to improve reliability, hedge future rate increases, decrease regional carbon emissions, and diversify the resource base. The city has invested in multiple solar PV systems and measurement equipment to measure PV-system effectiveness at both a cost and energy reliability level. Understanding the impacts of those systems on the City's cost of energy, as well as greater impacts on the grid, is important to determining the viability of future investments.

Under net energy metering, the electric customer avoids consumption from the grid with each kWh produced on-site, thus is implicitly credited with the retail value of that energy. Current literature suggests that the viability of solar electricity production depends largely on the rate structure that it is associated with (3). A detailed understanding of each rate - combined with load data from particular facilities - provides a solid basis for analysis that is tailored to enable sound energy management decision making by the customer. The wealth of data collected on the San Diego systems allows for analysis of the relative impact of different rates on the specific solar-PV systems and their associated electricity loads - vital information for City officials going forward.

This paper uses the first year of data on the systems to identify and determine how rates impact system cost-effectiveness. Note that the systems both came into use in February 2007, so the savings will be less than a full year. The analysis reflects the nature of binomial rates, and so it is divided into two portions: the peak demand charge, a charge that is applied to the peak monthly demand of the load; and the energy charge, based on consumption.

Future analyses will include analyses of the value of exported energy (momentary net over production), a broader array of rate possibilities, an incorporation of the demand and energy charges' combined impact on system cost-effectiveness and an estimation of the impacts of other charges within rates (specifically non-coincident rate charges).

2. METHODOLOGY

This analysis uses collected 15-minute interval data from two solar photovoltaic systems in San Diego to estimate the impacts of different rate structures on the system. Both systems are sloped 15 degrees and have the following characteristics (more information on the systems can be found at: http://www.sandiego.gov/environmental-services/energy/programsprojects/saving/renewable.shtml):

- System A: a 495 kW AC system atop water treatment reservoirs that provides power for the water testing lab building and pumping station. This system faces 45 degrees west of south.
- System B: a 450 kW AC system also atop water treatment reservoirs that provides power for a drinking water pumping and pressurization system. This system faces south.

The rate analysis is completed in two parts. First, the impact of different peak and off-peak timing on the demand costs of the two systems is illustrated by calculating the kilowatt peak demand in the on-peak and semi-peak time segments. Second, the real solar production data is shown under different rate structures to illustrate the impact of different rates to illustrate the impacts on energy usage costs.

Table 1 summarizes the different structures applied to real solar production. Because the systems have different load profiles for the produced electricity, the difference between the demand savings will vary. The benefit of analyzing both buildings is to show the variation and the broad impacts of rate structures.

TABLE 1: ON-PEAK AND SEMI-PEAK TIME AND DEMAND RATES USED IN ANALYSIS

Rate	Season	On-Peak (pm)	Semi-Peak
0	Summer	11 am-6 pm	6-11 am, 6-10 pm
	Winter	5-8	6 am-5 pm 8-10 pm
1	Summer	12-3	6 am-12 pm 3-10 pm
	Winter	5-8	6 am-5 pm 8-10 pm
2	Summer	12- 4	6 am-12 pm 4-10 pm
	Winter	5-8	6 am-5 pm 8-10 pm
3	Summer	1-3	6 am -1 pm 3-10 pm
	Winter	5-8	6 am-5 pm 8-10 pm
4	Summer	1-4	6 am-1pm 4-10 pm
	Winter	5-8	6 am-5 pm 9-10 pm

Notes: The rates 1-4 are based approximately on options B-E of the PAT-1 Rate Schedule available through SDG&E respectively. Rate 0 peak times are based on PAT-1-Option A (and AL-TOU) are not included in the demand section of this analysis due to lack of non-coincident charge data. Summer demand charge: $5.49/kW and Winter demand charge: $4.94/kW.

2.1 Demand Cost Impacts of Different Rates

The demand cost analysis is completed for rates 1-4 in Table 1. Rate zero is omitted for this analysis because the sample rate that it is based on has a demand cost complexity that is beyond the scope of this paper. The peak demand for each time period described is applied to the actual output data from both city PV systems to identify the peak energy import time in a billing period. The baseline scenario is calculated from the actual system tracking and utility import meter data and assumes that building load will be the same in the absence of the PV system. The demand charges are calculated by multiplying the peak demand by the actual demand charges associated with peak charges on the utility bills for the systems in 2007. Those charges are as follows:

- System A: summer $5.65/kW, winter $5.51/kW
- System B: summer $5.59/kW, winter $5.46/kW.

2.2 Rate Impacts on Energy Consumption Charges for Building with a PV System

In the second analysis, two types of energy charge rates are analyzed for their impacts on PV systems.

- Flat Rate. Based on average $/kWh for energy charges in 2007, this hypothetical rate is included to illustrate non-time-of-use rates impacts on facilities with PV systems. This value is $0.10/kWh for both systems.
- Energy Charges from Binomial Tariffs. The on- and semi peak times for these rates are described in Table 1. The energy charge rates for all these time of use options are the same:
  - On-Peak: summer $0.21/kWh, winter $0.13/kWh
  - Semi-Peak: summer $0.15/kWh, winter $0.07/kW

Analysis of the PV-system data for both facilities intends to illustrate the energy charge value of the systems over the course of activity in 2007. For each type of tariff, import, production, and export data are used to determine:

- Avoided Consumption. This calculation is estimated by subtracting the exported system energy from the overall system production.
- Avoided Costs. This is the value of the energy produced by the PV system as avoided energy costs. This calculation involves aggregating system data seasonally and according to peak and multiplying the kWh produced in each category by the appropriate charge for the rate type.

3. RESULTS AND DISCUSSION

3.1 Demand Charge Variation Impacts

Tables 2 and 3 present the monthly on-peak demand savings in 2007 by month for each of the PV systems using the actual rate structure for the systems. System A has a 7%-79% kW reduction with an average of a 35% reduction. System B has a larger range of kW reductions at 0%-95% kW and an average of 46%. For both systems, as expected, increased resource intensity in the summer months increases PV-system impact on peak-demand reduction. Despite the systems size and load differences, both systems resulted in demand reduction savings in the thousands of dollars for 2007 relative to a non-existent system.

Tables 4 and 5 illustrate the impacts of various rate structures on the demand impacts for each system including both on-peak and semi-peak charges. The rates analyzed are described in the methodology. As expected, the monthly demand savings are greatly impacted by the available resources and are larger in the summer months. Although the demand savings vary widely, the average monthly on-peak savings is about $1,100 for both systems. For System A, savings represents an approximate 30%-40% reduction in on-peak demand charges over the course of the year. For System B, that means a 2007 on-peak demand savings of approximately 30%. (Note that demand charges vary widely.) The shaded column in the graphic represents the approximation of the actual demand rate structure and indicates that the on- and semi-peak times are optimized for the peak demand of these system loads.

TABLE 2: "SYSTEM A" PV-SYSTEM ESTIMATED DEMAND SAVINGS

Billing Cycle End Date	On-Peak Demand (kW) W/O PV	On-Peak Demand (kW) W/PV	Savings (kW)	On-Peak Demand Cost Savings ($)
03/15/07	290	244	47	$258
04/15/07	267	215	52	$285
05/14/07	373	212	160	$884
06/13/07	330	155	175	$963
07/15/07	394	83	311	$1,715
08/15/07	417	310	107	$606
09/13/07	432	215	217	$1,225
10/14/07	360	271	89	$501
11/12/07	284	265	20	$111
12/13/07	264	264	0	$0
Estimated Peak Demand $ Savings:				**$6,550**

Notes: a) Billing cycles begin with 3/15 because the system came on-line in February 2007 b) Demand with PV is calculated from building meter systems, not utility bills. All values are matched to utility bill charges except billing cycles ending 4/15 and 10/14. These were billed higher than the calculated meter data, so the estimates are conservative. c) The demand charges are calculated using the on-peak demand charge of $5.51/kW for 3/15 - 7/15 and $5.65/kW for 8/15 - 12/13. This is a conservative peak charge estimate because a portion of the bill ending 7/15 was charged to the higher rate by the utility.

TABLE 3: "SYSTEM B" PV-SYSTEM ESTIMATED SAVINGS

Billing Cycle End Date	On-Peak Demand (kW) W/O PV	On-Peak Demand (kW) W/ PV	Savings (kW)	On-Peak Demand Cost Savings ($)
03/15/07	536	536	0	$0
04/15/07	436	328	108	$590
05/14/07	333	320	13	$72
06/13/07	334	76	258	$1,409
07/15/07	432	20	412	$2,250
08/15/07	333	180	153	$856
09/13/07	660	280	380	$2,124
10/14/07	434	168	266	$1,489
11/12/07	326	324	2	$9
Estimated Peak Demand Savings:				**$8,800**

Notes: a) Demand with PV is calculated from building meter systems, not utility bills. B)All values are matched to utility bill charges except billing cycles ending 7/15 c) The demand charges are calculated using the on peak demand charge of $5.46/kW for 3/15 - 7/15 and $5.59/kW for 8/15 - 11/12.

TABLE 4: "SYSTEM A" PV-SYSTEM RELATED DEMAND SAVINGS FOR VARYING PEAK AND SEMI-PEAK TIME RATE STRUCTURES (2007)

Bill End Date	Rate (See Table 1 for description) 1	2	3	4
3/15/07	592.81	592.81	780.57	592.81
4/15/07	501.60	501.60	660.81	501.60
5/14/07	1,470.55	1,439.92	1,510.94	1,510.94
6/13/07	1,290.59	1,289.61	1,477.36	1,477.36
7/15/07	1,756.49	1,751.55	2,212.37	2,106.96
8/15/07	1,046.96	1,020.28	1,132.92	1,132.92
9/13/07	1,660.83	1,380.84	1,746.48	1,380.84
10/14/07	845.06	845.06	933.98	933.98
11/12/07	378.62	378.62	626.30	378.62
12/13/07	249.96	249.96	249.96	249.96
Total 2007 PV-system Demand Savings	**9,793**	**9,450**	**11,332**	**10,266**

Note: Rate specifics can be found in Table 1. Demand Charges: On-Peak: $5.49/kW, Semi-peak $4.94/kW. Numbers differ from Table 2 because this table includes semi-peak demand savings

TABLE 5: "BUILDING B" PV-SYSTEM RELATED DEMAND SAVINGS FOR VARYING PEAK AND SEMI-PEAK TIME RATE STRUCTURES (2007)

Bill End Date	Rate 1	2	3	4
3/15/07	0.00	0.00	0.00	0.00
4/15/07	1,086.80	1,086.80	1,086.80	1,086.80
5/14/07	110.01	110.01	111.99	111.99
6/13/07	1,461.42	1,324.18	1,437.71	1,330.11
7/15/07	2,267.81	1,301.57	2,279.66	1,313.42
8/15/07	848.97	848.97	848.97	848.97
9/13/07	1,355.81	1,355.81	2,129.67	1,778.31
10/14/07	1,482.30	1,478.34	1,482.30	1,482.30
11/12/07	19.98	19.98	26.57	19.98
12/13/07	359.63	359.63	359.63	359.63
Total 2007 PV-system Demand Savings	**8,993**	**7,885**	**9,763**	**8,332**

Note: Rate specifics can be found in Table 1. Demand Charges: On-Peak:$5.49/kW, Semi-peak $4.94/kW. Numbers differ from Table 3 because this table includes semi-peak demand savings

3.2 Energy Use Consumption Charge Impacts of Rate Structures

Graphically, Figures 1 and 2 illustrate the general impact of time of use tariff systems as applied to a facility with a PV system. In the case of Figures 1 and 2, the building load and PV production data are real data taken from the 2007 dataset for System A in San Diego, California (the rate applied is Rate 3 as described in Table 1). You can see that the demand of the facility peaks at midday, as does solar production in both seasons. The winter load and production are both reduced relative to the summer months due primarily to reduced heating and cooling loads and insolation, respectively.

Both figures illustrate the benefits of time of use rates for solar production facilities in this case. Because the PV system produces the most electricity at summer peak and semi-peak times for the grid system, the electricity produced there is of high value. In the case of Rate 3, the avoided electricity costs are substantial relative to the total daily costs of energy without the system.

Tables 6 and 7 illustrate the impacts of different time-of-use energy charge rates, using the rate schedules from Table 1. These illustrate the varying impacts of different peak timing scenarios on the PV systems. The impact of the time-of-use

TABLE 6. "SYSTEM A" 2007 CONTRIBUTION TO FACILITY LOAD (KWH)

Peak Time	Summer	Winter	Total
Rate 0			
On-Peak	207,623	9,352	216,975
Semi-Peak	68,093	202,496	270,590
Off Peak	97,097	69,633	166,730
Rate 1			
On-Peak	98,276	9,352	107,628
Semi-Peak	177,441	202,496	379,937
Off Peak	97,097	69,633	166,730
Rate 2			
On-Peak	129,738	9,352	139,090
Semi-Peak	145,978	202,496	348,474
Off Peak	97,097	69,633	166,730
Rate 3			
On-Peak	65,829	9,352	75,181
Semi-Peak	209,887	202,496	412,384
Off Peak	97,097	69,633	166,730
Rate 4			
On-Peak	97,292	9,352	106,644
Semi-Peak	178,425	202,496	380,921
Off Peak	97,097	69,633	166,730
Flat Rate			
Total	372,814	281,481	654,295

TABLE 7. "SYSTEM B" 2007 CONTRIBUTION TO FACILITY LOAD (KWH)

Peak Time	Summer	Winter	Total
Rate 0			
On-Peak	133,555	4,693	138,247
Semi-Peak	54,347	96,612	150,959
Off Peak	58,551	29,610	88,161
Rate 1			
On-Peak	62,539	4,693	67,231
Semi-Peak	125,363	96,612	221,975
Off Peak	58,551	29,610	88,161
Rate 2			
On-Peak	82,423	4,693	87,116
Semi-Peak	105,479	96,612	202,090
Off Peak	58,551	29,610	88,161
Rate 3			
On-Peak	41,636	4,693	46,329
Semi-Peak	146,266	96,612	242,877
Off Peak	58,551	29,610	88,161
Rate 4			
On-Peak	61,521	4,693	66,214
Semi-Peak	126,381	96,612	222,993
Off Peak	58,551	29,610	88,161
Flat Rate			
Total	246,453	130,914	377,367

peak definitions can be very large for these actual systems. Depending on the timing, the summer peak production - the most financially valuable production - can vary from 65-207 kWh. The flat production is the total amount of electricity produced by each system in 2007.

Tables 8 and 9 illustrate the financial impacts of the different structures. The flat rate results in the least avoided energy cost, reflecting the benefit of solar under time-of-use tariffs because the production coincides with facility peaks, as is a typical touted benefit of solar PV systems. Preliminary sensitivity testing, however, illustrates that small variations in the flat rate (from 10-12 cents, for example) quickly increase the competitiveness of this schedule among the time-of-use schedules. Among the time-of-use energy charges, Rate 0 (with the 11 am to 6 pm on-peak time) proved the most beneficial to solar systems. The lease effective rates for maximizing system impact are those that have summer peaks that start after noon. Regardless of the rates, average monthly savings of approximately $5,000 for System A and $3,000 for System B reduced the actual monthly energy charges for the facilities from 30%-50% in 2007. Note that monthly charges vary widely, and the largest savings are when the PV systems are most productive in the summer months.

TABLE 8. "SYSTEM A" 2007 AVOIDED ENERGY PURCHASES ($)

Rate	Summer	Winter	Total
Rate 0			
On-Peak	44,315	1,229	45,544
Semi-Peak	10,558	14,715	25,273
Off Peak	12,652	5,030	17,681
Total			**88,499**
Rate 1			
On-Peak	20,976	1,229	22,205
Semi-Peak	27,512	14,715	42,228
Off Peak	12,652	5,030	17,681
Total			**82,114**
Rate 2			
On-Peak	27,691	1,229	28,921
Semi-Peak	22,634	14,715	37,349
Off Peak	12,652	5,030	17,681
Total			**83,951**
Rate 3			
On-Peak	14,051	1,229	15,280
Semi-Peak	32,543	14,715	47,258
Off Peak	12,652	5,030	17,681
Total			**80,220**
Rate 4			
On-Peak	20,766	1,229	21,995
Semi-Peak	27,665	14,715	42,380
Off Peak	12,652	5,030	17,681
Total			**82,057**
Flat Rate			
Total	37,281	28,148	**65,429**
Note: For all rate schedules, the Summer on peak electricity charge for electricity is $0.21/kWh and semi peak is $0.13/kWh. The winter charges are $0.15/kWh and $0.07/kWh respectively. The flat rate charge is $0.10/kWh.			

TABLE 9. "SYSTEM B" 2007 AVOIDED ENERGY PURCHASES ($)

Rate	Summer	Winter	Total
Rate 0			
On-Peak	28,506	617	29,123
Semi-Peak	8,427	7,021	15,447
Off Peak	7,629	2,139	9,768
Total			**54,338**
Rate 1			
On-Peak	13,348	617	13,965
Semi-Peak	19,438	7,021	26,458
Off Peak	7,629	2,139	9,768
Total			**50,191**
Rate 2			
On-Peak	17,592	617	18,209
Semi-Peak	16,354	7,021	23,375
Off Peak	7,629	2,139	9,768
Total			**51,352**
Rate 3			
On-Peak	8,887	617	9,504
Semi-Peak	22,678	7,021	29,699
Off Peak	7,629	2,139	9,768
Total			**48,971**
Rate 4			
On-Peak	13,131	617	13,748
Semi-Peak	19,595	7,021	26,616
Off Peak	7,629	2,139	9,768
Total			**50,132**
Flat Rate			
Total	24,654	13,091	**37,737**
Note: For all rate schedules, the Summer on peak electricity charge for electricity is $0.21/kWh and semi peak is $0.13/kWh. The winter charges are $0.15/kWh and $0.07/kWh respectively. The flat rate charge is $0.10/kWh.			

4 SUMMARY AND NEXT STEPS

The analysis completed in this report uses actual 2007 PV-system data from two facilities in San Diego California to illustrate the impacts of different rate structures. The data show that the demand savings for the 10 month period for which data was collected (from the February date that the systems came online through the end of 2007) could range from about $9,800-11,300 for System A and about $8,300-9,800 for System B, depending on the rate structure.

In addition to demand charges, avoided energy costs present a larger area of impact on the economics of a solar PV system. For System A, the savings amounted to between $65,000 and $88,000 in 2007; and for System B, the range was between $37,000 and $55,000 for the year. Both systems came online in February 2007, so the savings is over 10 months. Without the PV systems in place, the energy charges would have been 30%-50% higher than those in the 2007 actual bills.

In summary, this analysis shows that rate structures, particularly those with time-of-use energy charges, have an impact on the overall economics of a PV system, and that the impact may be large. Demand charges can also vary widely depending on when the peak time is set.

This analysis is a first step in a multi-analyses process that will estimate the financial impacts of many different tariff types on actual systems. Next steps in the analysis include combining the impacts of the demand charge and energy charges, the impact of exported energy from the PV-system on economics, as well as expanding the variety and increasing the complexity of tariffs, such as those with non-coincident demand charges applied.

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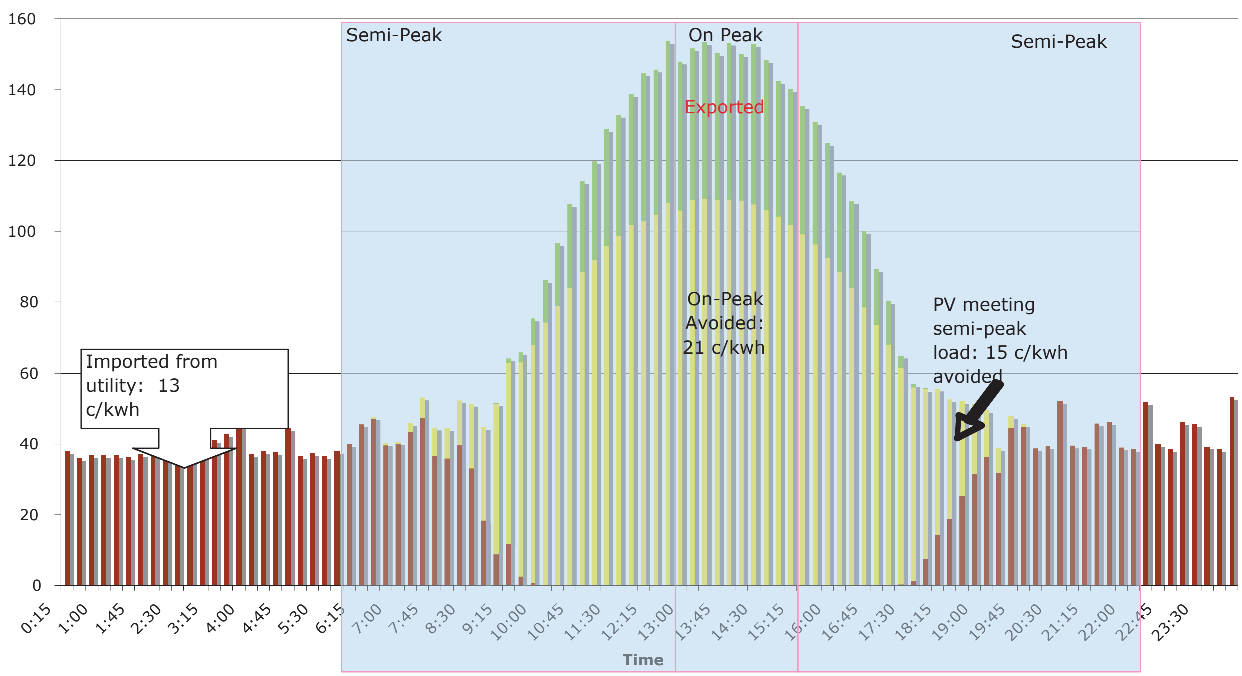

Figure 1: Sample Summer Weekday Profile with Rate 3 Overlay

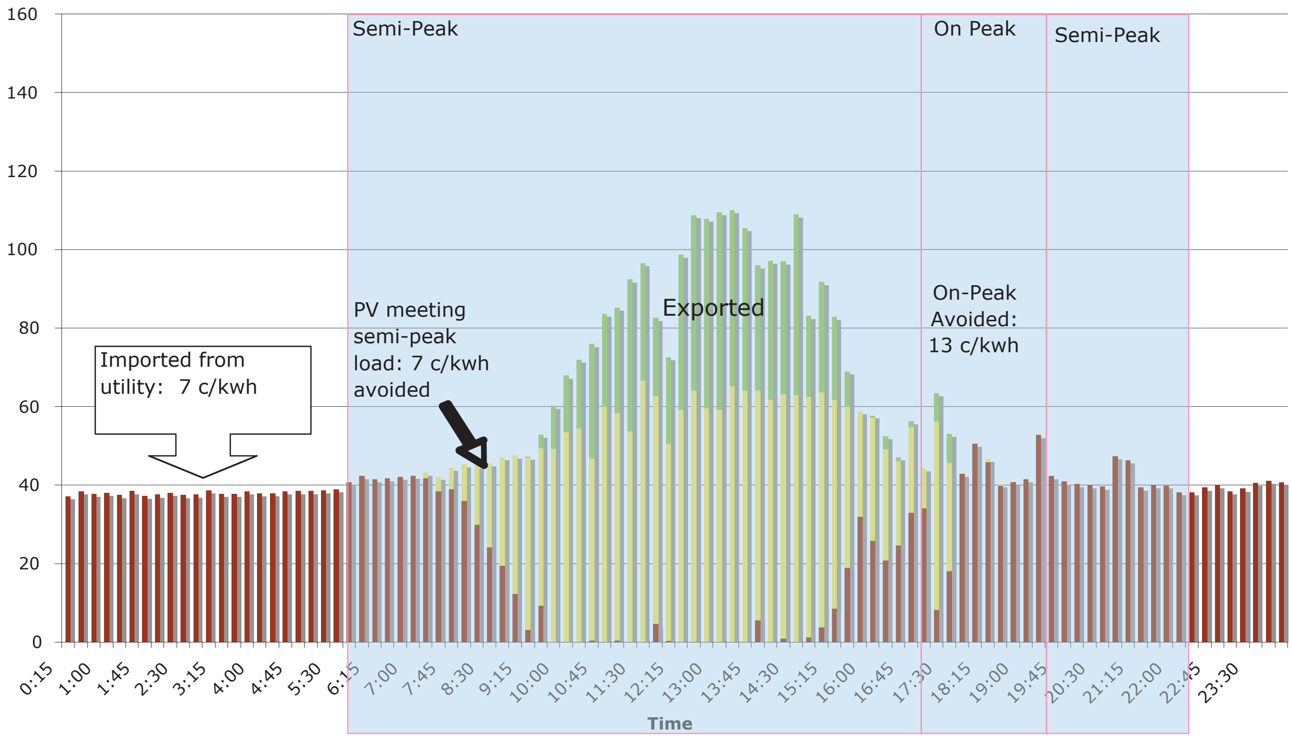

Figure 2: Sample Winter Weekday Profile with Rate 3 Overlay

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13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

There is confusion in the marketplace regarding the impact of solar photovoltaics (PV) on the user’s actual electricity bill under California Net Energy Metering, particularly with binomial tariffs (those that include both demand and energy charges) and time-of-use (TOU) rate structures. The City of San Diego has extensive real-time electrical metering on most of its buildings and PV systems, with interval data for overall consumption and PV electrical production available for multiple years. This paper uses 2007 PV-system data from two city facilities to illustrate the impacts of binomial rate designs. The analysis will determine the energy and demand savings that the PV systems are achieving relative to the absence of systems. A financial analysis of PV-system performance under various rate structures is presented. The data revealed that actual demand and energy use benefits of binomial tariffs increase in summer months, when solar resources allow for maximized electricity production. In a binomial tariff system, varying on- and semi-peak times can result in approximately $1,100 change in demand charges per month over not having a PV system in place, an approximate 30% cost savings. The PV systems are also shown to have a 30%-50% reduction in facility energy charges in 2007.

15. SUBJECT TERMS

NREL; California; Elizabeth Brown; Otto Van Geet; solar photovoltaics; PV; electricity; binomial rate structure; San Diego; PV system; binomial tariffs; energy savings

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