LETTING THE SUN SHINE ON SOLAR COSTS: AN EMPIRICAL INVESTIGATION OF PHOTOVOLTAIC COST TRENDS IN CALIFORNIA

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ABSTRACT

This paper summarizes a detailed statistical analysis of the cost of customer-sited, grid-connected solar photovoltaic (PV) installations in the largest solar market in the United States: California. We find that: (1) solar costs have declined substantially over time; (2) policy incentives have impacted pre-rebate installed costs, and some cost inflation is apparent; (3) economies of scale have driven down costs for larger systems; (4) systems installed in new home developments and in affordable housing projects have experienced much lower costs than the general retrofit market; and (5) installer experience and type, module type, and system location have all affected costs, but the effects differ by program. Results hold important implications for solar suppliers and customers, and for policymakers designing incentive programs.

1. INTRODUCTION

The promise of electricity generated from photovoltaics (PV) is alluring: PV is renewable, clean, distributed, and fuel-free. As a result, markets for customer-sited, grid-connected PV systems are expanding rapidly, albeit from a small base. Government incentives aimed at encouraging reductions in the cost of PV over time are the principal drivers for this growth, and substantial cost reductions will be needed if PV is to become more than a niche technology.

This article, which is based on a longer report from Berkeley Lab (Wiser et al. 2006), summarizes an in-depth statistical analysis of PV system costs in California. Through mid-November 2005, a total of 130 MW_{AC} of grid-connected PV capacity was installed throughout California, making that state the dominant market for PV in the U.S., though still far behind Germany and Japan on a worldwide basis.

California's market is poised for dramatic new growth, as the California Public Utilities Commission (CPUC) announced in January 2006 that the CPUC and the California Energy Commission (CEC) would dedicate roughly $3.2 billion over 11-years for customer-sited solar installations. This California Solar Initiative has the stated goal of increasing the amount of rooftop solar units to 3,000 MW by 2017, making it the most ambitious publicly-funded PV deployment program in the country.

The results presented here are based on an analysis of 18,942 grid-connected PV systems totaling 254 MW_{AC},[1] either installed, approved for installation, or waitlisted (approved but awaiting program funding) under what are currently the two largest PV programs in the state. The data used for this analysis represent what is likely the most comprehensive source of actual PV installed cost information available worldwide.

[1] Data on PV capacity and costs are expressed throughout this article in W_{AC}, which we convert (where necessary) from $W_{DC\text{-}STC}$ (DC Watts at standard test conditions) using a de-rate factor of 0.84. Many other solar programs use $W_{DC\text{-}STC}$, making comparisons of California data with those in other states and countries more difficult.

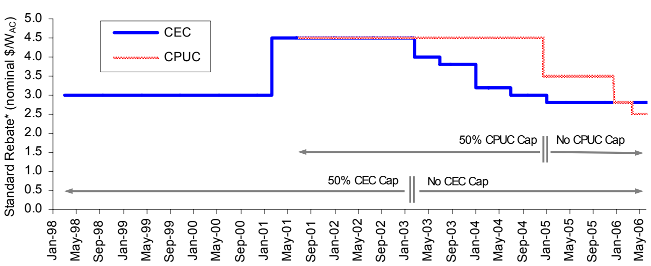
Analysis of these data provides insights on California's PV market by exploring historical cost trends, and by untangling the various factors that affect the cost of PV systems. Results also have important policy ramifications, both for California's new solar programs and for those programs offered elsewhere.

2. CALIFORNIA'S SOLAR PROGRAMS

California's PV market is driven by a mixture of state and local incentives. Most prominent are capital cost rebates offered to PV system installers or owners to "buy down" the installed cost of solar installations. The two most significant current rebate programs are overseen by the CEC and the CPUC, and it is on these two programs that our analysis is based.

The CEC has administered a PV rebate program since March 1998, focusing more recently on grid-connected systems under 30 kW in size. The CPUC's program began accepting applications in July 2001, and provides rebates to PV systems of at least 30 kW in size (rebates can apply to systems up to 1 MW in size, recently changed to 5 MW, though larger systems are eligible). Both programs primarily target customers served by the state's investor-owned utilities.

Over time, both programs have altered the size and structure of their incentives for PV installations, as shown in Figure 1. The CEC initiated five gradual reductions in incentive levels beginning in 2003 (at which time it also discarded a cap that had previously limited the rebate to 50% of eligible costs), while the CPUC imposed a single large reduction in late 2004 (when it also eliminated its 50% cap), followed by two more recent reductions in late 2005 and early 2006.



* Within the CEC's program, systems installed on affordable housing and schools have, at times, received higher incentives; owner-installed systems have, at times, received lower incentives; systems >30 kW_{AC} were eligible for rebates from program inception to February 2003; and systems >10 kW_{AC} received \$2.5/W_{AC} (capped at 40%) from March 1999 to February 2001.

Fig. 1: Standard Rebates for the CEC and CPUC Programs

In aggregate, the two programs have already paid roughly \$400 million in rebates to currently operating PV projects in the state. And, as already noted, on January 12, 2006, the CPUC ordered a dramatic expansion of these programs with a \$3.2 billion, 11-year program of declining (and potentially performance-based, or \$/MWh) incentives.

3. METHODS

The CEC dataset used for our analysis was updated through April 2005, and contains 17,889 PV systems (72.8 MW_{AC}), including 12,856 completed systems (48.5 MW_{AC}) and 5,033 systems that had been approved for a rebate, but that were awaiting completion at the time we received the dataset (24.3 MW_{AC}). The CPUC program generally covers systems of at least 30 kW, and our dataset includes 1,053 PV systems (180.8 MW_{AC}), including 327 completed systems (35.7 MW_{AC}), 464 approved systems (73.4 MW_{AC}), and 262 waitlisted systems (71.7 MW_{AC}). Analysis of each dataset was conducted using multivariate regression techniques; the dependent variable was the pre-rebate installed cost of PV systems, in real 2004 \$/W_{AC}.

4. SOLAR COSTS HAVE DECLINED SUBSTANTIALLY

In real dollar terms, average pre-rebate total installed costs under the CEC's program have declined substantially, from more than \$12/W_{AC} (2004 \$) in 1998 to less then \$9/W_{AC} for 2004-05 (see Figure 2, where time is expressed in quarter-year intervals). Regression results show annual average cost reductions among the CEC-funded systems of approximately \$0.70/W_{AC}, representing a 7.3% annual decline.

Larger systems (e.g., 10-30 kW) funded by the CEC are found to have experienced more modest cost reductions than have smaller systems. We also find that cost reductions in the CEC dataset have been caused by both an overall shift in the market towards lower-cost systems, and by a significant reduction in the number of high-cost outliers, suggesting that price competition has become more robust in California's maturing PV market.

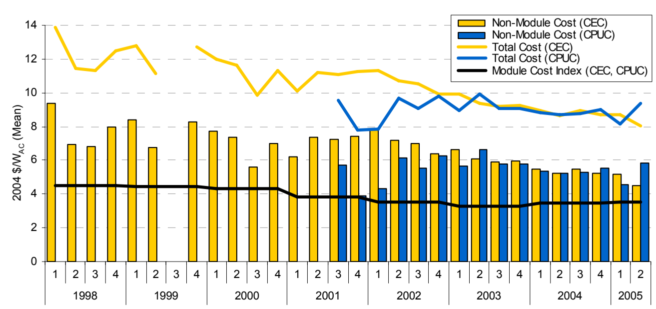


Fig. 2: Costs Trends Over Time (CEC and CPUC)

Some of the overall cost reductions within the CEC program are due to decreases in worldwide module costs (notwithstanding the recent increase in those costs). Regression results confirm that changes in worldwide module costs have largely been passed through directly to

PV system purchasers on a one-for-one basis.[2] Much of the overall cost reduction, however, has come from improvements in *non-module* costs – e.g., installation and balance of system costs.

This reduction in non-module costs for CEC-funded systems is encouraging. Unlike module costs, which are set in a worldwide market and are therefore heavily influenced by factors outside of the control of an individual PV program (e.g., demand for PV in Japan and Germany), non-module costs are potentially subject to the influence of local PV programs. Reducing non-module costs may therefore be the most appropriate goal for local PV programs. Though we are unable to prove that non-module cost reductions in California have been *caused* by the state's incentive programs, our results do show that non-module cost reductions have been significant.

In contrast to the longer-running CEC program, which exhibits clear downward cost trends over time, costs under the CPUC's program have declined more moderately (though Figure 2 does show a more substantial decline – in lock-step with the CEC program – since 2003). Compared to the \$0.70/W_{AC} (7.3%) annual average cost reduction in the CEC dataset, regression results show that systems funded by the CPUC have seen annual average reductions of \$0.36/W_{AC} (4.1%).[3]

The more-aggressive CEC cost reductions may be due to the larger proportional labor and installation costs associated with smaller (< 30 kW) systems and the greater opportunities in that market segment for distribution and installation efficiency gains. Alternatively, it could be a result of policy design – whereas the CEC has (since 2003) gradually lowered its rebate over time, the CPUC has been slower to follow suit (see Figure 1). The quality of our data does not allow us to definitively explain the difference in cost reductions between the two programs.

5. <u>POLICY INCENTIVES AND REBATE LEVELS HAVE IMPACTED PRE-REBATE INSTALLED COSTS</u>

Analysis results also suggest, however, that heavy subsidies can and have dampened, to some degree, the motivation of installers to provide, and/or customers to seek, lower installed costs in California. Figure 3, for example, shows a tight relationship between rebate levels and average pre-rebate installed costs among the CEC-funded systems since mid-2000, a relationship that is confirmed through regression analysis.

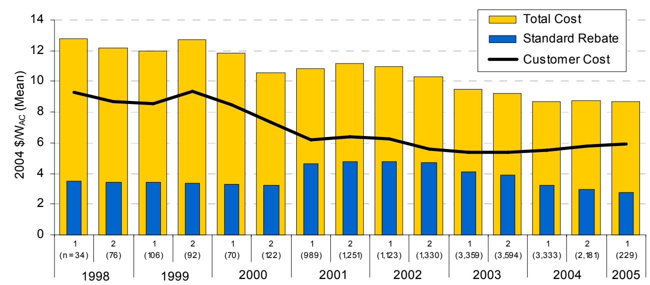


Fig. 3: Impact of Standard Rebate Level on Average Installed Costs (CEC)

In particular, we find that each \$1/W_{AC} change in the rebate level has, on average, yielded a \$0.55-0.80/W_{AC} change in pre-rebate installed costs (with the range representing results from different regression models). In other words, when the CEC increased its rebate level by \$1.5/W_{AC} in early 2001, system purchasers may have only realized \$0.3-\$0.7/W_{AC} of that increase on average, with the remaining \$0.8-\$1.2/W_{AC} being "captured" by system retailers or installers through correspondingly higher prices.

We also find some evidence that the existence of the 50% rebate cap prior to 2003 may have increased pre-rebate system costs somewhat under the CEC program. This result is consistent with widespread speculation that this cap – which limited the size of the rebate to 50% of total eligible costs in an attempt to ensure that the program did not over-subsidize lower-cost eligible technologies (such as small wind) – has, perversely, encouraged artificial cost *inflation* as a way to maximize the dollar amount of the rebate. As an example, under a binding 50% cap, every \$1 in cost reduction will reduce the incentive payment by \$0.5, meaning that the customer captures only 50% of the cost savings. Likewise, the customer will pay only 50% of any cost increase. As a result, the specific mechanics of the percentage cap *do not* provide a strong incentive for cost reductions, and – even more vexing – *do* provide opportunities for gaming of the program.[4]

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[2] The CEC database contains disaggregated information on module, inverter, and labor costs, but this information is sparsely reported (and the CPUC database does not provide such information). We have therefore used an external index of worldwide module costs from Strategies Unlimited to proxy module costs for each California system.

[3] Though Figure 2 does not provide a clear visual trend of declining system costs over the entire duration of the CPUC program, the regression results are more reliable than the visual evidence provided in the figure.

[4] Gaming opportunities range from the relatively straightforward "gold-plating" of systems with expensive features, knowing that the rebate program will pick up half of the incremental cost, to much more nefarious schemes. As an example of the latter, there have been anecdotal reports of installers of commercial systems artificially pricing systems (that, for example, actually cost \$8/W) at \$9/W in order to maximize the dollar amount of the rebate (\$4.5/W, capped at 50% of eligible costs), and then sharing the ill-

Our analysis is also supportive of the oft-heard claim in California that the CPUC's richer incentives in recent years ($4.5/$W_{AC}$ until December 2004, with a 50% cap) have not motivated system cost reductions to the same extent as under the CEC's program (the CEC's program also offered $4.5/$W_{AC}$, but reduced that incentive earlier and more rapidly than did the CPUC). As illustrated by Figure 4, and as regression results confirm, among similar sized systems (20-40 kW) approved or installed over similar time periods , those funded by the CPUC's program have had pre-rebate installed costs that are on average at least $0.60/$W_{AC}$ higher than those funded by the CEC.

Finally, some of the systems in the CPUC dataset received sizable local incentives (of more than $2/$W_{AC}$), *in addition* to those offered under the CPUC's program. These systems recorded higher average costs of roughly $0.60/$W_{AC}$. As with the CEC dataset, we also find evidence that the existence of the percentage rebate cap under the CPUC's program (which was eliminated in December 2004) increased pre-rebate system costs.

6. ECONOMIES OF SCALE DRIVE DOWN COSTS AS SYSTEM SIZE INCREASES

Focusing on the period in which both the CPUC and CEC programs were operating simultaneously, Figure 4 shows that average system costs fall substantially for larger systems in both datasets, though both datasets also show a leveling off of those economies among larger system sizes. Regression results confirm these trends. The largest systems in the CEC dataset are roughly $2.5/$W_{AC}$ cheaper than 1 kW installations. Meanwhile, the largest CPUC-funded systems are roughly $1.5/$W_{AC}$ less expensive than the smaller systems funded by that program.

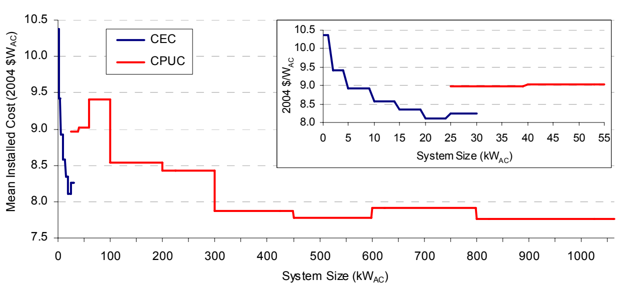

Fig. 4. Installed Cost, by System Size (CEC and CPUC)

7. SYSTEMS INSTALLED IN LARGE NEW HOME DEVELOPMENTS AND IN AFFORDABLE HOUSING PROJECTS EXPERIENCE MUCH LOWER COSTS

Regression results show that the nearly 2,000 systems installed (or planned for installation) under the CEC's program in large new residential developments have lower costs of approximately $1.2/$W_{AC}$, on average, compared to the general retrofit market (see Table 1). Similarly, the 340 systems used in affordable housing applications, which often involve new construction and presumably enable bulk system installation, exhibit costs that are $1.9/$W_{AC}$ lower than the general retrofit market.

Systems installed in single new homes (or small clusters of new homes) – which number 770 – exhibit modestly *higher* costs, perhaps due to the custom-designed nature of many of these systems, as well as a lack of the economies of scale possible in larger new home developments. The 60 systems installed at schools (most are retrofits) do not have statistically significant differences in cost compared to the general retrofit market.

8. INSTALLER EXPERIENCE AND TYPE, MODULE TYPE, AND SYSTEM LOCATION ALL AFFECT COSTS

As also shown in Table 1, the average impact of installer and retailer experience varies between those systems funded by the CEC and CPUC programs. Meanwhile, owner-installed systems in the CEC program are found to have considerably lower reported costs than contractor-installed systems. Similarly, the sixteen CPUC-funded systems installed at fairgrounds by the California Construction Authority (CCA) have come in at a substantially lower cost than other systems, with a cost differential of roughly $4/$W_{AC}$, on average.[5]

In the CEC dataset, projects using thin film PV technology are found to have had systematically lower costs than those relying on traditional crystalline silicon. Though only bordering on statistical significance, projects using thin film technology in the CPUC dataset are found to have had slightly higher costs on average over the course of that program. The reason for this discrepancy between the two programs is unclear.

The population density of the location of installation also appears to have some effect on system costs in the CEC dataset, with more densely populated areas experiencing higher average costs. This finding is consistent with the

gotten incremental rebate with the system purchaser, to the financial benefit of both purchaser and installer.

[5] The CCA provides financing, design, inspection and construction management services for fairgrounds throughout California. The low cost of the CCA systems is perhaps partially attributable to bulk equipment purchases for multiple fairground projects. Some have also speculated that the CCA is able to install systems at apparently lower costs than the PV industry at large due to the fact that it has no marketing, sales, or overhead costs, and/or that certain internal costs are not reported.

idea that population density may be a proxy for the cost of living, and therefore labor costs. We also find differences in average installed costs across different utility service territories, but further analysis would be required to understand these differences, and why these effects vary between the CEC- and CPUC-funded systems (outside of PG&E's service territory – where the majority of systems have been installed – systems funded by the CEC have had lower average costs, while systems funded by the CPUC have had higher average costs).

TABLE 1. IMPACT OF OTHER VARIABLES ON AVERAGE INSTALLED COSTS

Application Type	**CEC**	**CPUC**
Large new residential developments	↓ $1.2/W$_{AC}$	n/a
Single new homes or small clusters	↑ $0.18/W$_{AC}$	n/a
Affordable housing projects	↓ $1.9/W$_{AC}$	n/a
Schools	No Impact	n/a
Experienced Installers	↑ $0.29/WAC	↓ $0.70/W$_{AC}$
Experienced Retailers	↑ $0.17/WAC	n/a
Owner-Installers	↓ $1.8/WAC	↓ $4.0/W$_{AC}$ [CCA]
Thin-Film Modules	↓ $0.70/WAC	↑ $0.20/W$_{AC}$
Utility Service Territory	↓ costs outside of PG&E	↑ costs outside of PG&E
Population Density	↑ costs in densely populated areas	n/a

9. CONCLUSIONS AND RECOMMENDATIONS

Results presented here reveal a number of expected, and some unexpected, trends. Perhaps of most importance, we find substantial reductions in PV system costs over time, especially among systems funded by the CEC's program. Although our analysis cannot, without comparison to a control group, definitively conclude that the CEC and CPUC programs *caused* these cost reductions, it is clear that – despite the lack of continuity and stability experienced by both programs to date – pre-rebate installed costs have come down.

Several policy recommendations derive from our analysis:

- ***Reducing non-module costs should be a primary goal of local PV programs.*** Unlike module costs, which are set in a worldwide market and are therefore heavily influenced by factors outside of the control of an individual PV program, non-module costs are subject to the influence of local programs. Policymakers may wish to undertake programmatic activities aimed specifically at reducing non-module costs. This could include: (1) targeted approaches to building local supply infrastructure (e.g., providing business development funding to installers, supporting standardized PV products, or offering installer training and certification); (2) focusing some activities to the new construction market where non-module costs are generally lower than in retrofit applications; and (3) making PV system cost data more publicly accessible to further encourage supply competition.

- ***Sustained, long-term programs may enable more significant cost reductions.*** Sustained, sizable, and stable markets for PV may be the most direct way of reducing non-module costs because such markets will presumably attract suppliers and encourage those suppliers to create an efficient delivery infrastructure. Though PV cost reductions in California are significant, at least among CEC-funded systems, experience from Japan – which, for the last decade, has had a much more stable and sizable market than California – suggests that deeper cost reductions are possible with a more sustained policy effort. In 2004, for example, the average cost of a residential PV system in Japan was reportedly $1.4/W$_{AC}$ lower than in California, while annual average cost declines from 1999 through 2004 were greater in Japan (8.9%) than in California (5.2%) for similar-sized residential systems.

- ***The structure and size of PV incentives should encourage cost reduction.*** We find some troubling evidence that policy design has adversely impacted the cost of PV systems in California, at least at times. For example, the 50% cap on the size of the rebate employed by both programs at one time or another appears to have, at best, impeded cost reductions. The decision by both programs to abandon such percentage caps is a positive development; we encourage other PV programs to do the same. Furthermore, the total pre-rebate cost of PV installations in California has tracked, to some degree, the size of the rebate itself. Whether this link is merely representative of the "teething problems" that are typical of new programs,[6] or should instead be of long-term concern is somewhat unclear. As rebates are reduced over time, however, we expect that the link between incentive levels and pre-rebate installed costs will be severed, as lower rebates require contractors to price systems at cost in order to ensure a sale. Hence, while rich incentives may be required initially to jump-start the market, over time the incentives should decline to a level that can support a functional market infrastructure without providing room for potential price manipulation.

- ***Targeted incentives may be appropriate.*** Though there is a significant spread in the data, we find clear evidence of sizable economies of scale in PV installations. We also find that systems installed in large new home developments are, on average, far more economical than retrofitted systems. These results suggest that a further targeting of incentives to account for the relative economics of different system sizes and application types may be appropriate.

10. ACKNOWLEDGMENTS

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[6] Such "teething problems" might include initial over-subsidization intended to spur the market, coupled with insufficient supply infrastructure to handle the resulting increase in demand, leading to lackluster competition and artificial price increases until new supply infrastructure enters the market.