The Brattle Group

# The Potential Impact of Solar PV on Electricity Markets in Texas

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This report was prepared for the Solar Energy Industries Association and the Energy Foundation.

Jurgen Weiss and Judy Chang are Principals, and Onur Aydin is an Associate of *The Brattle Group*. All results and any errors are the responsibility of the authors and do not represent the opinion of *The Brattle Group*.

**ACKNOWLEDGEMENTS**

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# I. EXECUTIVE SUMMARY

The Solar Energy Industries Association ("SEIA") and the Energy Foundation asked *the Brattle Group* to evaluate the potential effects of adding solar photovoltaic (PV) generation in the Texas wholesale energy market. To evaluate such effects, we used a hypothetical situation, where a range of incremental solar PV generation was added to the supply mix of the Texas market (ERCOT) in summer 2011.

In this report, we present the findings of this analysis, which demonstrate that adding solar PV could have significantly reduced energy prices for electric customers in the summer of 2011. Specifically, we estimate that adding 1,000 megawatts (MW) of solar PV could have reduced average wholesale energy prices by approximately $0.6 per megawatt-hour (MWh); 2,500 MW of solar PV by $1.5/MWh; and 5,000 MW by $2.9/MWh. This would have lowered total wholesale energy payments by $155-$281 for each MWh of solar PV generation.

In addition, our analysis shows that adding incremental solar PV generation could also significantly reduce total electricity production costs and greenhouse gas emissions as it displaces generation from conventional, fossil-fuel plants, and these effects last through the lifetime of the solar PV assets. Including a relatively modest assumption about the value of avoided greenhouse gas emissions of $15/ton, the combined total value of avoided emissions and production costs and reduced wholesale power costs due to price effects could have been $216-$343/MWh of solar PV generation during the summer of 2011.

It is important to note that these figures represent the magnitude of the benefits accruing to all consumers in lowered underlying electric energy prices in the wholesale market. Ultimately, these savings, which correspond to the value incremental solar PV would have had in the summer of 2011, provide a basis for comparison against "all-in" costs of incremental solar PV generation; however, that is beyond the scope of this analysis[1].

Instead, our study examines the impact of incremental solar PV on the "average" ratepayer and consequently does not distinguish between benefits to system owners and other customers. Therefore, our results may differ from those of some prior studies, which focus on the savings (and costs) of solar PV to individual system owners. In reality, due to a number of factors, including the structure of retail electricity rates, benefits to system owners may differ significantly from average customer benefits.[2]

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1 A direct comparison would have to take into consideration that (1) summer benefits are likely to be higher than winter benefits, and (2) short-term benefits related to lower wholesale prices are likely to be higher than long-term benefits as discussed below.

2 While the savings associated with wholesale price reductions may be only temporary, they nevertheless represent a real impact of incremental solar PV generation. Whether these customer savings are also in the long-run interest of utilities and ratepayers depends on a number of factors. These factors include whether (and when) new fossil generation is needed in a given market, and whether analysts include all relevant externalities associated with traditional generation sources when evaluating the market.

To analyze the effect of incremental PV generation in Texas, we chose two approaches: a "statistical" approach and a "model-based" approach.

- In the statistical approach, we used historical data to construct a relationship between demand levels and energy prices, and then analyzed the price effects of solar PV by assuming that it would have reduced the net load that needs to be served by generators with higher incremental costs whenever the PV resources were generating power.

- In the model-based approach, we used publicly available data to construct electricity supply curves based on the estimated variable costs of generation sources, ordered from least to most expensive. We then estimated marginal energy prices by finding the most expensive marginal generator needed to meet demand in each hour. To estimate the impact of solar PV, we compared the results for a system with current levels of solar PV to the results for a system with incremental amounts of solar PV added.

Table 1 summarizes our estimates of the hypothetical impact on energy prices of adding various amounts of solar PV generation in Texas during summer 2011. As Table 1 shows, we estimate that adding solar PV could have reduced average energy prices in Texas by $0.6-$2.9/MWh, depending on the amount of solar PV added.

**Table 1**
**Summary of Estimated Energy Price Effects of Additional Solar PV Generation**
(for the period of June 2011 through August 2011)

| | Statistical Approach | | | Model-Based Approach | | |
|---|---|---|---|---|---|---|
| | Daytime *($/MWh)* | Nighttime *($/MWh)* | **ALL HOURS** ***($/MWh)*** | Daytime *($/MWh)* | Nighttime *($/MWh)* | **ALL HOURS** ***($/MWh)*** |
| ERCOT Region | | | | | | |
| 1000 MW | $1.2 | $0.0 | **$0.6** | $1.9 | $0.0 | **$1.0** |
| 2500 MW | $3.0 | $0.0 | **$1.5** | $3.9 | $0.0 | **$2.0** |
| 5000 MW | $5.8 | $0.0 | **$2.9** | $5.6 | $0.0 | **$2.8** |

In addition to estimating the price reduction caused by incremental solar PV, our "model-based" approach also allowed us to estimate production cost savings, and, by adding those to savings based on price reduction, total load payment savings. As Table 2 shows, we found that the solar PV-related energy price reduction could have saved customers an average of $155-$281/MWh. We also estimate that avoiding the fuel and operations and maintenance (O&M) costs associated with fossil-fuel plants could have saved customers an additional $52/MWh.

**Table 2**
**Estimated Energy Market Benefits Related to Solar PV Generation**
(for the period of June 2011 through August 2011)

| | Load Payment Savings Due to Energy Price Reduction (million dollars) | Load Payment Savings Due to Energy Price Reduction (\$/MWh of solar) | + | Production Cost Savings Due to Avoided Fuel and O&M Costs (million dollars) | Production Cost Savings Due to Avoided Fuel and O&M Costs (\$/MWh of solar) | = | **Total Customer Benefits from Add'l Solar PV** ***(million dollars)*** | **Total Customer Benefits from Add'l Solar PV** ***(\$/MWh of solar)*** |
|---|---|---|---|---|---|---|---|---|
| ERCOT Region | | | | | | | | |
| 1000 MW | **\$141.9** | *\$281* | | **\$26.0** | *\$52* | | **\$167.9** | *\$333* |
| 2500 MW | **\$283.0** | *\$225* | | **\$65.4** | *\$52* | | **\$348.4** | *\$276* |
| 5000 MW | **\$390.5** | *\$155* | | **\$129.8** | *\$51* | | **\$520.3** | *\$206* |

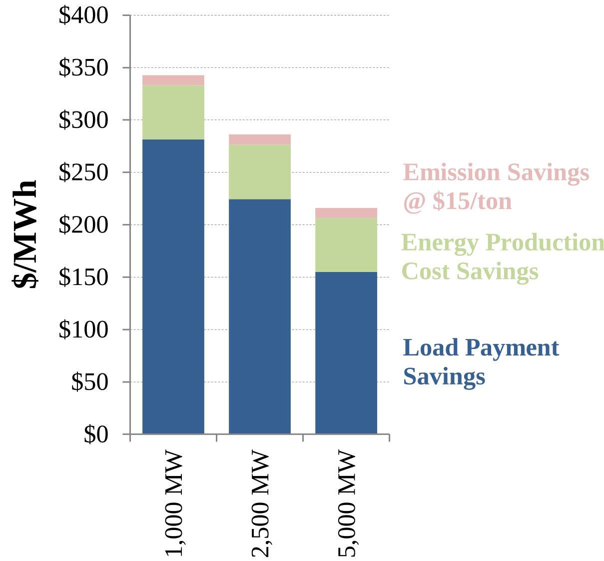
In addition to saving the costs of fuel and O&M, we estimated the corresponding amount of carbon dioxide ($CO_2$) reductions associated with decreasing the use of fossil plants. As Table 3 shows, we found that $CO_2$ emissions could have been reduced by approximately 0.64 tons for each MWh of solar PV generation (roughly equal to the emission rate of a gas-fired combustion turbine). These emissions savings would have a corresponding economic value of an incremental \$10/MWh of solar PV generation relative to a modest $CO_2$ price of \$15/ton, and \$19/MWh at a $CO_2$ price of \$30/ton.

**Table 3**
**Estimated $CO_2$ Emissions Savings Related to Solar PV Generation**
(for the period of June 2011 through August 2011)

| | Avoided Power-Sector $CO_2$ Emissions *(thousand tons)* | Avoided Power-Sector $CO_2$ Emissions *(tons/MWh of solar)* | Economic Value @ \$15/ton of $CO_2$ Price *(million dollars)* | Economic Value @ \$15/ton of $CO_2$ Price *(\$/MWh of solar)* | Economic Value @ \$30/ton of $CO_2$ Price *(million dollars)* | Economic Value @ \$30/ton of $CO_2$ Price *(\$/MWh of solar)* |
|---|---|---|---|---|---|---|
| ERCOT Region | | | | | | |
| 1000 MW | **323** | *0.64* | **\$4.9** | *\$10* | **\$9.7** | *\$19* |
| 2500 MW | **811** | *0.64* | **\$12.2** | *\$10* | **\$24.3** | *\$19* |
| 5000 MW | **1,612** | *0.64* | **\$24.2** | *\$10* | **\$48.4** | *\$19* |

Combined with load payment savings due to price effects and electricity production cost savings from avoided fuel and O&M costs[3], customers' total benefits could have been \$216-\$343/MWh. Figure 1 plots combined value of energy market benefits and avoided emissions at a $CO_2$ price of \$15/ton.[4]

**Figure 1**
**Combined Value of Energy Market Benefits and Avoided Emissions**
(for the period of June 2011 through August 2011)




Our analysis focuses on the benefits of incremental solar PV generation that may come from wholesale energy markets. Incremental solar PV generation would likely have other benefits. The potential incremental benefits of avoided $CO_2$ emissions illustrated in Table 3 are one example, but other environmental and economic benefits may also exist.

Our analysis excludes potential capacity benefits associated with solar PV resources. In Texas there is no explicit capacity market. In its absence, generators must recover their

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3 There are two sources of lowered consumer payments for electricity: First, incremental solar PV generation reduces the need to buy power from other sources proportionally. These savings are equal to the market price of power multiplied by the quantity of incremental solar PV generation, which we assume to be equal to avoided fuel and O&M expenses. The other source of lowered cost for consumers is due to the lower wholesale price of power that results from adding solar PV to the system. As we discuss, this is not a benefit to society, but rather a transfer from producers to consumers and may be temporary. Figure 4 below illustrates both effects graphically.

4 $CO_2$ price of \$15/ton is consistent with assumptions used by NYSERDA in its "New York Solar Study," published in January 2012. Higher or lower $CO_2$ prices would result in proportionally higher or lower values of emission savings.

capital costs mostly through energy prices. By excluding the highest-priced hours in Texas from our analysis, we deliberately set aside capacity considerations. Any attempt to analyze the impact of incremental solar PV on the number of high-priced hours in Texas and the level of prices during such hours is beyond the scope of this report.

## II. INTRODUCTION

The Solar Energy Industries Association (SEIA) and the Energy Foundation asked *the Brattle Group* to analyze the hypothetical impact of additional solar PV generation on wholesale energy market prices in Texas (ERCOT) during the summer of 2011. At that time, Texas experienced a summer with very hot weather, resulting in high wholesale energy prices in many parts of the state. Since solar PV can be deployed in a highly decentralized manner (as compared to utility-scale generation), requires little lead time, and generally does not face siting or other substantial regulatory hurdles, solar PV can be effective in offsetting the potential effects of extremely high prices. While high prices, in theory, attract new entry, in many cases, there are significant barriers to entry such as difficulty in permitting and siting and lack of cost-effective local infrastructure. Thus, solar PV may be effective in reducing the effects of sustained high prices in areas with limited transmission access and where siting larger energy facilities is a challenge.

In this report, we present the findings of an illustrative analysis of the power market in Texas. In particular, we use two different methodologies to estimate the impact that a certain amount of solar PV generation might have had on wholesale energy prices in specific areas in Texas in the summer of 2011. This analysis creates a hypothetical counterfactual situation that did not actually exist in summer 2011; therefore, the results should be interpreted as indicative of the impacts additional solar PV generation might have in the future under conditions similar to those in the summer of 2011.

Our analysis shows that additional solar PV generation could have had a significant effect on wholesale energy prices. This may not be surprising; the addition of any generation resource with relatively low operating costs—all else equal—tends to reduce energy prices, at least in the short term. Whether or not this is beneficial to ratepayers, however, depends on the cost of the additional generation when compared to its effect on prices over time. It also depends on the feasibility of other alternatives that would meet Texas's energy goals at similar or lower costs, and whether alternatives have similar non-market benefits (such as reducing greenhouse gas emissions or other pollutants) as solar PV. Alternatives may not be feasible for several reasons. For example, the minimum efficient scale of a power plant may exceed the amount of additional capacity that may be cost-effective. Also, other factors such as siting difficulties may prevent the entry of new generation even if such entry would be cost-effective. Finally, current power markets do not fully incorporate various environmental externalities that, were they incorporated in market prices, would make apparently less-costly alternatives to solar PV significantly more expensive.

While currently more expensive than at least some other more conventional power generation options, solar PV's costs are rapidly decreasing and solar PV does not seem to produce many of the environmental externalities of fossil-fired generation, and also does not face many of the same siting barriers. Unlike some conventional generation technologies, solar PV can also be continuously scaled. As a result, solar PV may provide a feasible path to reducing high energy prices in areas where more conventional power generation options are not available. In the remainder of this report, we explain the approach we used to analyze the potential impact of solar PV on market prices in Texas, the estimated impacts, and some caveats about estimated price effects.

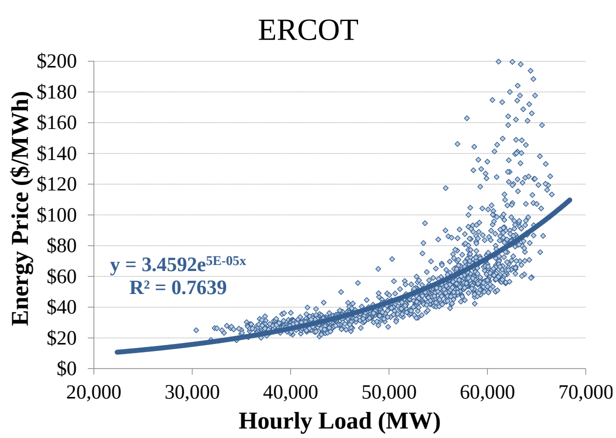
## III. OUR METHODOLOGY

We have chosen two alternative approaches to examining the potential impact of solar PV on power prices—a statistical and a model-based approach.

### A. Statistical Approach

In the statistical approach, we gathered historical data on hourly wholesale energy market prices in the summer of 2011. We then examined how the wholesale energy market prices related to the market's demand for electricity. In very basic economic theory, supply curves are upward-sloping; that is, market prices increase (or decrease) with increases (or decreases) in demand. We expected and found this to be the case for power markets in general, and for Texas in particular. Figure 2 illustrates this relationship during summer 2011.

**Figure 2**
**Relationship between Hourly Day-Ahead Energy Prices and Regional Demand**
(for the period of June 2011 through August 2011)




**Source:** Calculated based on the hourly data compiled by Ventyx, the Velocity Suite.

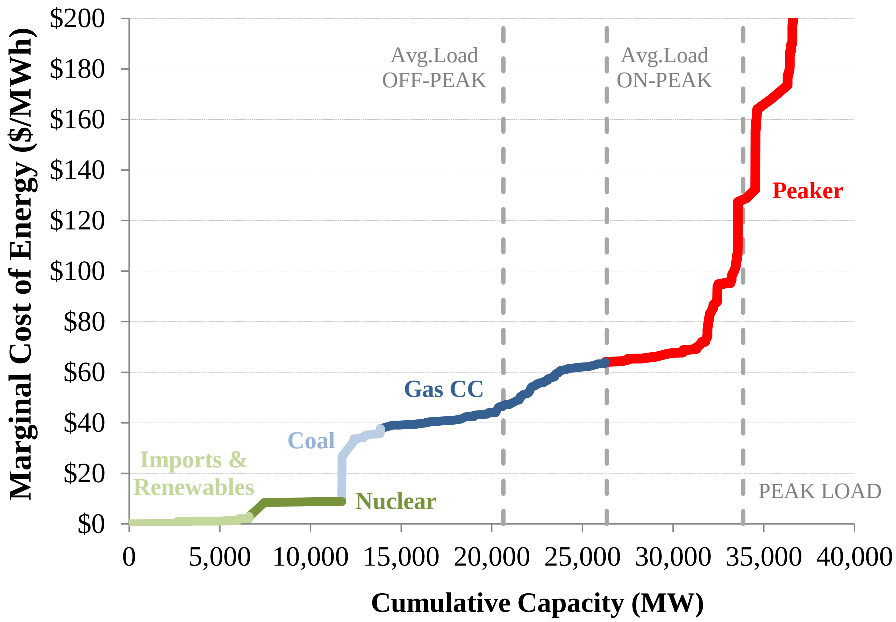
We used the hourly generation profiles from the National Renewable Energy Laboratory (NREL)'s Solar Advisor Model to determine the amount of energy that a hypothetical solar PV facility would produce during the daytime in each of the sub-regions we analyzed. From the grid perspective, the energy produced by a solar PV facility effectively reduces the "net" demand that needs to be satisfied by other system resources, such as conventional generators. Thus, reducing the demand by the amount produced by solar PV allows us to estimate the price effects of such demand reduction.

While there is typically a strong relationship between wholesale energy prices and electricity demand, other factors such as fuel price changes, plant outages, transmission constraints, imports from and exports into neighboring regions can also significantly affect the energy markets, with resulting market prices that differ across hours with similar levels of demand.[5] However, for the purpose of this evaluation, we did not analyze the specific impact of these other factors on market prices. We also did not include certain "scarcity" hours in Texas, during which energy prices are allowed to rise up to $3,000/MWh to provide appropriate price signals to attract investments in new generation when required, and to effectively replace the fixed capacity payments in regions with long-term capacity markets. Although it is likely that installing solar PV capacity would reduce some of these very high energy prices over a specific time frame compared to a system without solar PV, such price reductions may not be long-lasting since very high prices indicate a tight supply-demand balance.

### B. Model-Based Approach

Under the model-based approach, we used publicly-available data to construct energy supply curves for the Texas wholesale energy market based on the estimated variable costs of all available generation sources, ordered from least expensive to most expensive. Given the demand in each hour, we then estimated energy prices by finding the most expensive generator needed to meet that demand in that hour. Figure 3 shows the relationship between system demand, marginal generator, and the resulting energy prices.

**Figure 3**
**Illustration of Supply Curve Used to Estimate Energy Prices**



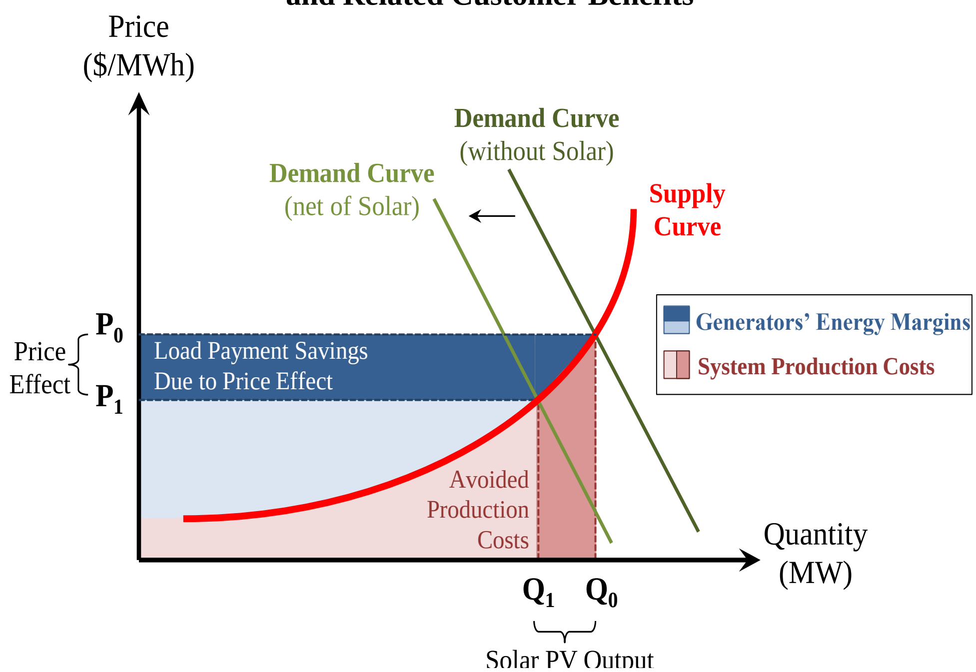

To assess the impact of solar PV in this methodology, we developed a hypothetical hourly generation profile of a solar PV facility based on NREL's Solar Advisor Model, and then reduced the hourly demand by the amount of assumed PV generation to estimate the "net" energy that needs to be produced by other generators. We then determined the impact of solar PV by comparing the results for a system without solar PV ("Base Case") to the results for a system with

5 Note that ERCOT's grid is not synchronized with the rest of the country, which limits its import and export capabilities to the capabilities of its DC linkages.

solar PV ("Alternative Case"). Key model outputs include energy prices, as well as power-sector $CO_2$ emissions, system production costs, and total payments by electricity consumers.

Figure 4 illustrates how adding solar PV could reduce energy prices, and also shows how some of the customer benefits are calculated. When incremental solar PV capacity is installed, it effectively displaces the conventional, fossil-fuel plants at the margin, and creates an economic value equal to the avoided production costs from these plants (dark shaded vertical strip). Energy prices decrease as less expensive generators set the market prices. This results in further savings for customers, as their payments for all remaining purchases of electricity decrease (dark shaded horizontal strip). It is important to note that, while the savings related to the price effects of solar PV provide an additional benefit from utility customers' perspectives, they are effectively transfer payments from generators to customers. The savings to utility customers are thus a combination of avoided electricity purchases from fossil sources, due to the electricity generated by solar PV, and a lower cost of purchasing the power not generated from the incremental solar PV due to the wholesale price-reducing effect of additional solar PV.

**Figure 4**
**Illustration of Energy Price Effects due to Solar PV and Related Customer Benefits**




This model-based approach requires a number of simplifying assumptions. First, we assumed that each generator's availability is unchanged across all hours. This means that forced outages are spread evenly throughout the year, and maintenance outages are scheduled outside of the summer period. Second, we did not analyze the transmission flows across each market and the likely congestion costs associated with transmission constraints. Third, the model assumes that the amount of electric imports and exports in and out of each market and the fuel prices associated with each generator do not change in any given month. While such a modeling effort does not capture the full effects of random forced outages, congestion-related price separation, or daily fluctuations in natural gas prices, these simplifying assumptions are reasonable for assessing the system effects of solar PV in the summer months, given that our analysis is meant to be illustrative and average outage rates and natural gas prices are relatively stable in the summer months.

In addition, our modeling approach assumes that wholesale energy market prices are equal to the marginal costs of generation. While this is generally a reasonable assumption for some power markets, in particular those with a separate capacity market, in markets without a separate capacity market, such as Texas, actual market prices may exceed the marginal production costs in hours with high demand as generators ask for more than their operating costs.

For instance, since Texas has an “energy-only” market that currently allows energy prices to rise up to $3,000/MWh during scarcity conditions (to provide appropriate price signals to attract investments in new generation when required) unlike regions with long-term capacity markets where resources collect fixed capacity payments each year, the actual energy market prices do not always reflect the marginal cost of generation. For example, in August 2011, the day-ahead energy prices in Texas exceeded $500/MWh in 52 hours, $1,000/MWh in 32 hours, and $2,000/MWh in 12 hours (hub average for ERCOT).

These prices do not reflect marginal costs of generation and therefore are not captured by our model. As mentioned above, it is likely that installing solar PV capacity would reduce some of these very high energy prices, at least in the short run, but that such price reductions may not be long-lasting since high prices may be needed to attract new resources to maintain resource adequacy and reliability.

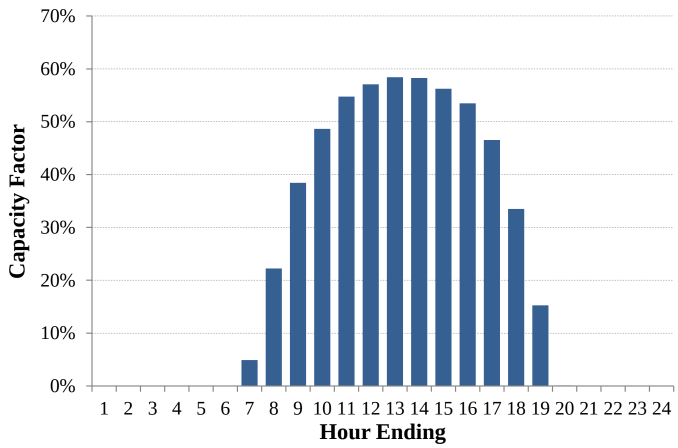
## IV. THE POTENTIAL IMPACT OF SOLAR PV ON TEXAS MARKET

For our analysis, we developed solar PV generation profiles based on hourly PV generation data from the NREL Solar Advisor model for a 1-axis, flat-plate residential PV system with sun-tracking capability (axis oriented south, tilted at 30°) located in San Antonio.[6]

[6] Calculated savings would differ somewhat depending on the assumptions regarding exact location of the PV as well as the tilt angle or the array.

**Figure 5** below shows the hourly profile of solar PV energy production on a typical summer day in Texas. The average capacity factor is 23% for June-August period, and approximately 45% for hours between 7am and 7pm.

**Figure 5**
**Average Hourly Solar PV Generation Profile**
**(Texas, June-August period)**




**Source:** Calculated based on 8,760 hourly generation data from NREL's Solar Advisor Model (SAM) version 2011.6.30.

### A. Results from Statistical Approach

As Figure 6 shows, we used an exponential function to reflect the relationship between hourly energy prices and regional demand in Texas for the summer of 2011, in hours when there is solar PV generation (*i.e.*, between 7am and 7pm). Based on this relationship, we found that ERCOT energy prices increase approximately 0.08 cents for every MW of increase in net load when the load is around 30,000 MW, gradually increasing to approximately 0.47 cents per MW when the load is 65,000 MW. Note that this does not include scarcity hours in which the prices exceed $200/MWh (107 hours for the period of June 2011 through August 2011).

**Figure 6**
**Relationship between Day-Ahead Energy Prices and Regional Demand in ERCOT**
(for the period of June 2011 through August 2011)

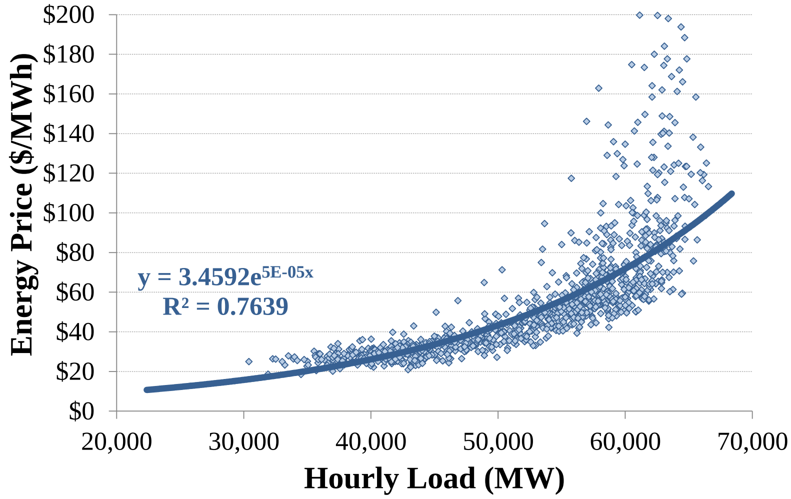



Table 4 summarizes the likely price impact of adding significant amounts of solar PV generation in ERCOT. We estimate that 1,000 MW of solar PV could have reduced the average energy prices by approximately $1.2/MWh for the hours between 7am and 7pm, resulting in an average price decrease of $0.6/MWh across all hours (including the nighttime hours). The price effect increases somewhat proportionally with higher MWs of solar PV additions; *i.e.*, 2,500 MW of solar PV reduces the average prices by $1.5/MWh, and 5,000 MW of solar PV by $2.9/MWh.

**Table 4**
**Estimated Energy Price Effect of Additional Solar PV Generation in ERCOT**
(for the period of June 2011 through August 2011)

| | **Solar PV Penetration** | | |
|---|---|---|---|
| | 1000 MW *($/MWh)* | 2500 MW *($/MWh)* | 5000 MW *($/MWh)* |
| Daytime | $1.2 | $3.0 | $5.8 |
| Nighttime | $0.0 | $0.0 | $0.0 |
| **ALL HOURS** | **$0.6** | **$1.5** | **$2.9** |

## B. Results from Model-Based Approach

Table 5 summarizes the energy price effect of various levels of solar PV penetration in the ERCOT region. Based on our model results, we estimated that solar PV, depending on the level of installed capacity added, could have reduced the all-hours average energy prices by $1.0-$2.8/MWh for the summer of 2011. As mentioned before, our model assumes that the market prices are set by the marginal cost of generation, and we have not simulated the scarcity hours in which the prices increased to $500/MW or more. However, our results are valid for all hours in which there are no such scarcity prices.

**Table 5**
**Estimated Energy Price Effects in ERCOT based on Supply Model**
(for the period of June 2011 through August 2011)

| | Average Capacity Factor for Solar PV | Estimated Base Case Energy Prices w/o Add'l Solar PV | Estimated Energy Prices for Alternative Cases w/ Add'l Solar PV Capacity | | |
|---|---|---|---|---|---|
| | | | 1000 MW | 2500 MW | 5000 MW |
| | *(%)* | *($/MWh)* | *($/MWh)* | *($/MWh)* | *($/MWh)* |
| June 2011 - daytime | 43.0% | $50.2 | $49.7 | $49.0 | $48.0 |
| July 2011 - daytime | 47.1% | $51.1 | $50.6 | $49.8 | $48.6 |
| August 2011 - daytime | 45.6% | $60.0 | $55.1 | $50.6 | $48.0 |
| Nightime | 0% | $40.9 | $40.9 | $40.9 | $40.9 |
| **Daytime Hours** | **45.2%** | **$53.7** | **$51.8** | **$49.8** | **$48.2** |
| **ALL HOURS** | **22.6%** | **$47.3** | **$46.3** | **$45.4** | **$44.5** |
| *Average Price Change from Base Case →* | | | *-$1.0* | *-$2.0* | *-$2.8* |

Table 6 summarizes our model results for changes in system electricity production costs and lowered customer load payments (due to lower wholesale energy prices and corresponding lower generator energy margins) resulting from incremental PV capacity in ERCOT for the June-August 2011 period relative to a "Base Case" without addition of incremental PV capacity. We found that adding solar PV capacity could have reduced the production costs by $52/MWh of solar PV generation (through avoided fuel and O&M costs from fossil-fuel plants). From the customers' perspective, the total savings in load payments would have been about $206-$333/MWh of solar PV generation (includes both price effects and production cost reductions).

**Table 6**
**Impact of Solar PV on Production Costs and Load Payments in ERCOT**
(for the period of June 2011 through August 2011)

| | Base Case w/o Add'l Solar PV | Alternative Cases w/ Add'l Solar PV Capacity | | |
|---|---|---|---|---|
| | | 1000 MW | 2500 MW | 5000 MW |
| **Generators' Energy Margins** | | | | |
| Total Margins *(million dollars)* | $3,005 | $2,863 | $2,722 | $2,615 |
| Reduction from Base Case *(million dollars)* | | -$142 | -$283 | -$390 |
| Unit Impact *($/MWh of solar PV)* | | -$281 | -$225 | -$155 |
| **System Production Costs** | | | | |
| Total Costs *(million dollars)* | $2,432 | $2,406 | $2,367 | $2,303 |
| Change Relative to Base Case *(million dollars)* | | -$26 | -$65 | -$130 |
| Unit Impact *($/MWh of solar PV)* | | -$52 | -$52 | -$51 |
| **TOTAL LOAD PAYMENTS** | | | | |
| Total Payments *(million dollars)* | $5,438 | $5,270 | $5,089 | $4,917 |
| Change Relative to Base Case *(million dollars)* | | -$168 | -$348 | -$520 |
| Unit Impact *($/MWh of solar PV)* | | -$333 | -$276 | -$206 |

Table 7 summarizes our estimates of power-sector $CO_2$ emissions savings related to solar PV generation. We found that $CO_2$ emissions could have been reduced by approximately 0.64 tons in Texas (roughly equal to the emission rate of a gas-fired combustion turbine). These emission savings would have an economic value of an incremental $10/MWh of solar PV generation assuming a $CO_2$ price of $15/ton, and $19/MWh at a $CO_2$ price of $30/ton.

**Table 7**
**Estimated $CO_2$ Emissions Savings Related to Solar PV Generation**
(for the period of June 2011 through August 2011)

| | Avoided Power-Sector $CO_2$ Emissions | | Economic Value @ $15/ton of $CO_2$ Price | | Economic Value @ $30/ton of $CO_2$ Price | |
|---|---|---|---|---|---|---|
| | *(thousand tons)* | *(tons/MWh of solar)* | *(million dollars)* | *($/MWh of solar)* | *(million dollars)* | *($/MWh of solar)* |
| ERCOT Region | | | | | | |
| 1000 MW | **323** | *0.64* | **$4.9** | *$10* | **$9.7** | *$19* |
| 2500 MW | **811** | *0.64* | **$12.2** | *$10* | **$24.3** | *$19* |
| 5000 MW | **1,612** | *0.64* | **$24.2** | *$10* | **$48.4** | *$19* |

As Figure 7 shows, the combined savings from lowered load payments, avoided fuel and O&M costs, and emission reductions could be as high as $216-$343/MWh of solar PV generation (assuming a $CO_2$ price of $15/ton).

**Figure 7**
**Combined Value of Energy Market Benefits and Avoided Emissions**
(for the period of June 2011 through August 2011)

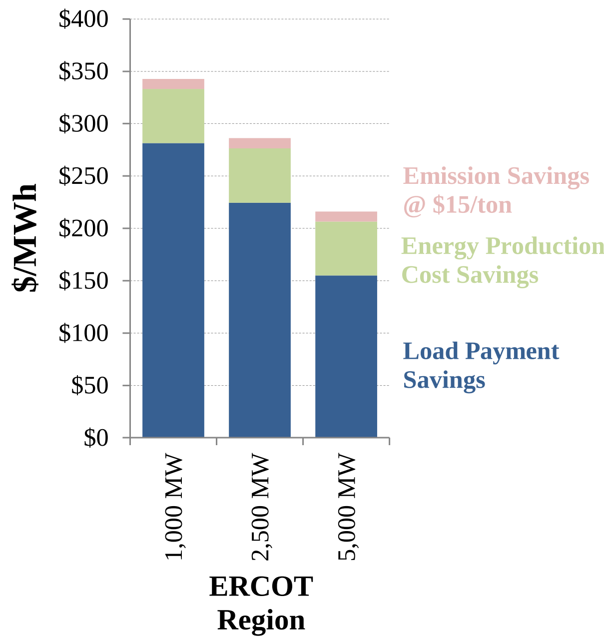
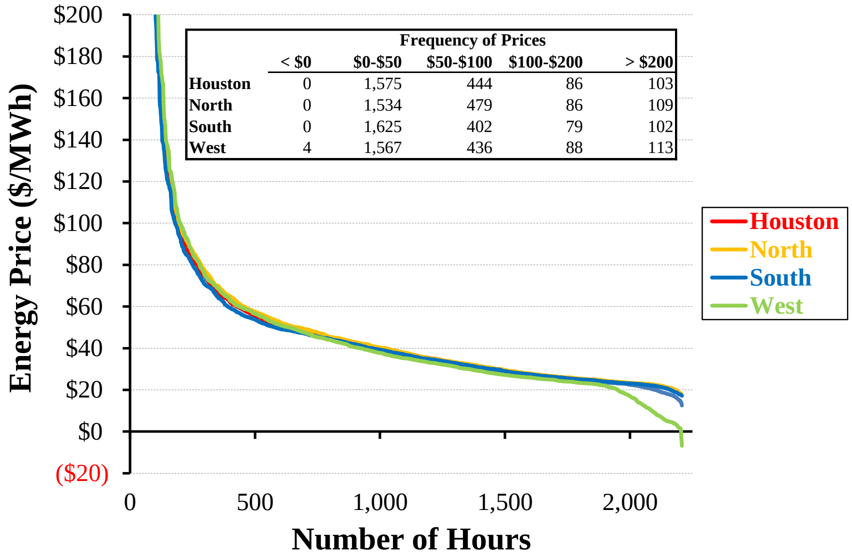


Figure 8 below plots the price duration curves for each sub-zone in ERCOT for summer 2011. It shows that the hourly average day-ahead prices in the Houston, North, South, and West sub-zones were very similar, except for the lowest 10% of the hours. This suggests that there was very little transmission congestion during the on-peak hours, during which a solar PV facility would produce energy. As a result, we did not separately analyze the price effects of solar PV for any of the sub-zones in Texas.

**Figure 8**
**Energy Price Duration Curves for Houston, North, South, and West Zones**
(for the period of June 2011 through August 2011)




**Source:** Calculated based on the hourly data compiled by Ventyx, the Velocity Suite.

## V. SOME FURTHER COMMENTS ON PRICE EFFECTS

In this section, we briefly put into a broader context the results of our analysis related to wholesale price reductions caused by incremental PV.

As a practical matter, under similar conditions as those that form the basis of our analyses, the addition of solar PV capacity in the Texas wholesale energy market would be very likely to lead to the kinds of price reductions we estimate in the short run. Whether such effects would persist, however, and the extent to which the price reductions represent a real benefit—in the sense of improving the efficiency of the overall market, as opposed to simply shifting revenues from power suppliers to customers—depends on a number of factors including whether or not the market, as it exists, is perfectly competitive and whether it incorporates all relevant externalities.

Most importantly, as long as it is expected that incremental new generation will eventually need to be attracted on the basis of market revenues alone, market prices need to be high enough in expectation for new entry to occur when it is needed. This means that over time the price-reducing effect of incremental solar PV generation could dissipate if the cost of new entrants does not decline due to changes in expected fuel prices, capital costs, power plant technological advances, etc. For example, a recent NYSERDA study analyzing the impact of solar generation in New York found that the "price suppression" benefits would dissipate in approximately 10 years.[7] Ultimately, the duration of solar PV-related price reduction will depend on how much and when such incremental new capacity will be needed.

Another important consideration is whether society should be indifferent about the source of reduced wholesale energy prices, which could be caused by incremental renewable generation from solar PV or from any other generation resource. Here, it is important to point out that in all likelihood, current electricity markets do not fully reflect the negative (mostly environmental) externalities associated with existing power generation from fossil-fuel plants.

Fully incorporating such externalities would likely lead to higher end-use prices and lower margins for generators than is currently the case since these negative externalities are not fully reflected in wholesale market prices. The addition of solar PV would likely directionally lead to the same or a similar outcome than reflecting negative externalities directly in wholesale prices: even though wholesale prices would be lower, average customer bills likely would increase as long as subsidies are still needed to support the entry of solar PV, and as the margins of existing fossil-fuel generators shrink due to lower wholesale energy prices. It is possible, therefore, that even though an ideal outcome would be for electricity prices to explicitly reflect various environmental (and other) externalities, adding incremental solar PV (especially where its value is high even in the absence of wholesale price-lowering effects) might simply shift the electricity mix in the direction it would take were all the relevant externalities reflected.

## VI. CONCLUSIONS

Summer 2011 was characterized by relatively high prices in Texas. Our statistical and model-based analysis suggests that solar PV could have been an attractive technology to address these high prices.

The analysis shows that, particularly when incorporating relatively modest assumptions about the value of avoided greenhouse gas emissions, the combined value of avoided emissions and lowered payments by customers (as a result of avoided production costs from conventional, fossil-fuel plants at the margin, and reduced energy prices) could be approximately \$216-\$343/MWh in Texas. This suggests that, at least during the summer months when solar PV production and energy prices are highest, the short-term benefits of increased solar PV production approach or exceed the likely cost of incremental solar PV generation.[8]

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7 New York Solar Study: An Analysis of the Benefits and Costs of Increasing Generation from Photovoltaic Devices in New York, NYSERDA, January 2012.

8 The cost of solar PV generation depends on a number of factors, including, in particular, the system size and location. NREL estimates the Levelized Cost of Energy ("LCOE") for PV to be between \$90/MWh and \$270/MWh including 30% Investment Tax Credit ("ITC") and 5-year accelerated depreciation. Without the ITC, this would correspond to levelized costs between \$130/MWh (utility) and \$390/MWh (residential); National Renewable Energy Laboratory, 2010 Solar Technologies Market Report, November 2011, p.52. In Germany, where more than 7,000 MW of new solar PV capacity was installed in

The total value of new solar PV systems is likely to be lower when calculated over the entire year and the short-term price reductions resulting from new solar PV likely are not a permanent benefit.  Nonetheless, especially in areas where it may be difficult to install new conventional power generation, solar PV, due to the fact that it can be installed in highly modular fashion, may provide an attractive option to address local capacity shortfalls leading to relatively high energy prices.  It is likely that this attractiveness will only increase going forward as solar PV technology continues to progress

2011, the current feed-in tariff for solar PV is between $230/MWh and $310/MWh, suggesting that the cost of new solar PV systems may have already reached a level below $300/MWh.