

Value of solar to New Jersey and Pennsylvania utilities

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Executive Summary

This report presents an analysis of value provided by large-scale, grid-connected, distributed PV in Pennsylvania and New Jersey. The analysis does not provide policy recommendations except to suggest that each benefit must be understood from the perspective of the beneficiary. Policies designed for utility compensation of PV production should be tied only to utility-related benefits (e.g., wholesale energy savings). On the other hand, taxpayer-funded (or ratepayer-funded) incentive programs may be designed with the objective of capturing societal benefits (e.g., environmental value).

Four different fleet configurations were evaluated at seven locations, representing a diversity of geography and economic assumptions in six utility service territories. The analysis represented a moderate assumption of penetration: PV was to provide 15% of peak electric load for each study location. PV was modeled using SolarAnywhere, a solar resource data set that provides time- and location-correlated PV output with loads. Load data and market pricing was taken from PJM for the six zones, and utility economic inputs were derived from FERC submittals. Additional input data was taken from the EIA and the Bureau of Labor Statistics (producer price indices).

Results for Newark are shown below. Detailed results for all scenarios are included in Appendix 2.

Table ES- 1. Technical results, Newark.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1640	1640	1640	1640
Annual Energy Production (MWh)	2,677,626	2,303,173	2,118,149	3,350,313
Capacity Factor (%)	19%	16%	15%	23%
Generation Capacity (% of Fleet Capacity)	45%	47%	51%	54%
T&D Capacity (% of Fleet Capacity)	56%	57%	57%	57%

Table ES- 2. Levelized Value of Solar (\$/MWh), Newark.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	39	39	39	39
O&M Cost Savings	19	19	19	19
Total Energy Value	58	58	58	58
Nonenergy				
Fuel Price Hedge	44	44	44	44
Generation Capacity Value	26	31	37	25
T&D Capacity Value	8	10	10	7
Market Price Reduction	51	61	66	43
Environmental Value	22	23	23	22
Economic Development Value	44	44	44	44
(Solar Penetration Cost)	-22	-22	-22	-22
Total	173	190	202	163
Other				
Security Enhancement Value	22	22	22	22
Long Term Societal Value	28	28	28	28
Total	50	50	50	50
Total				
All Components	280	298	310	270

Figure ES- 1. Value (\$/kW), Newark.

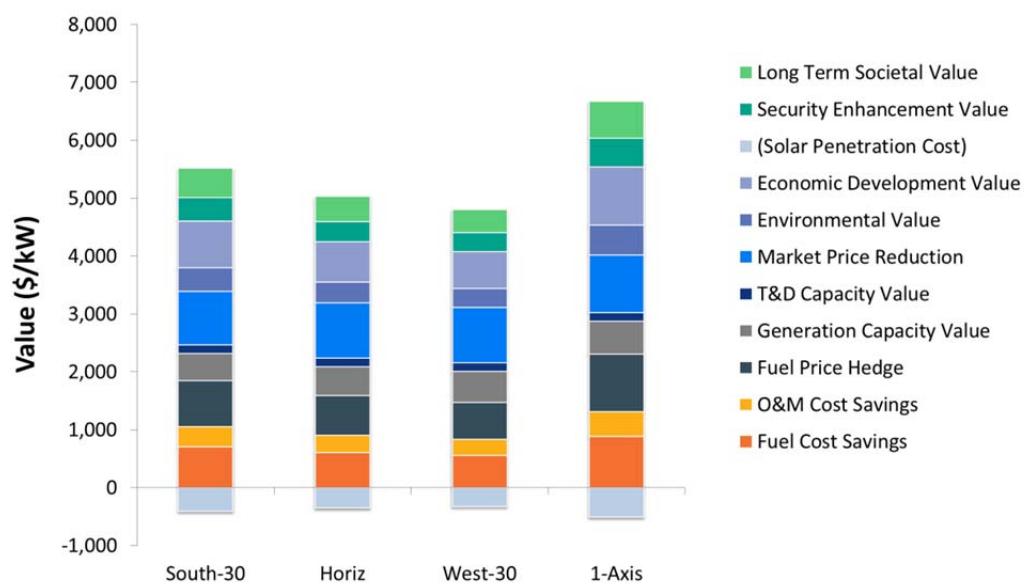
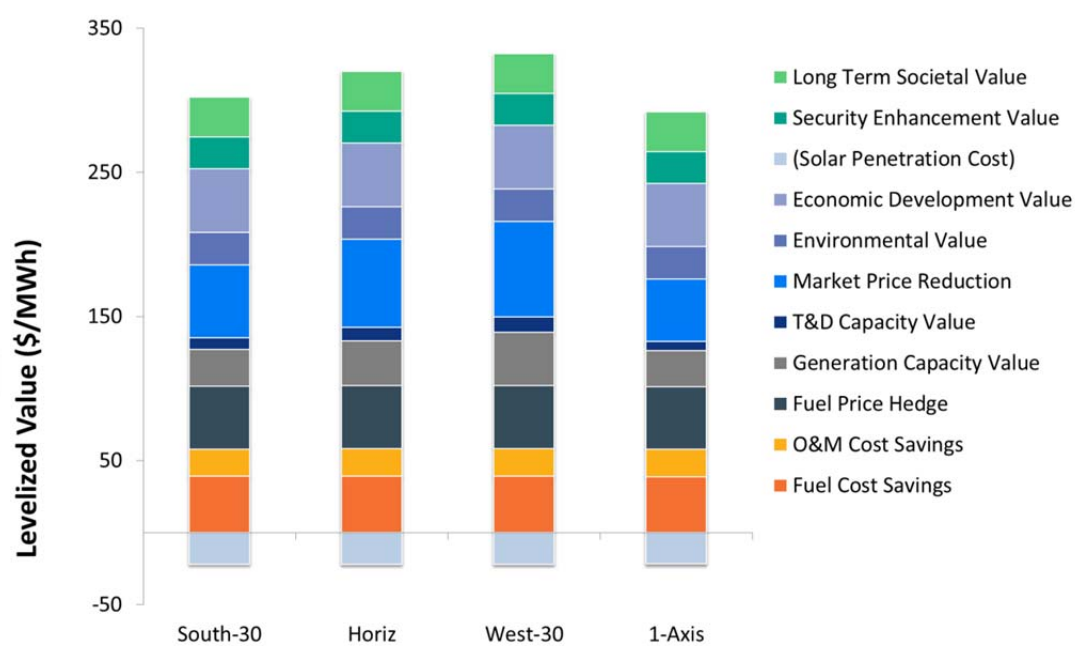


Figure ES- 2. Levelized Value (\$/MWh), Newark.



The value of solar is shown to range from \$4,486 to \$6,170 per kW in Newark (levelized \$270 to \$310 per MWh), depending upon orientation. Tracking systems offer more value than fixed systems, and value is generally related to the energy production. The match between PV output and load is not strong (as indicated in Table ES- 1 by the generation capacity and T&D capacity results), and this results in small values for generation capacity and T&D capacity value. However environmental, economic development, and fuel cost savings are all large value components.

Table ES- 3 compares results across all study locations for a south-facing 30°-tilt orientation. Levelized value ranges from \$256 to \$318 per MWh.

Table ES- 3. Comparison of value by location (levelized \$/MWh), South-30.

	Pittsburgh	Scranton	Harrisburg	Philadelphia	Jamesburg	Newark	Atlantic City
Fuel Cost Savings	41	41	41	38	42	39	41
O&M Cost Savings	20	20	20	18	21	19	20
Fuel Price Hedge	31	42	42	47	24	44	25
Generation Capacity Value	22	17	16	22	19	26	18
T&D Capacity Value	6	1	1	3	1	8	2
Market Price Reduction	35	69	67	54	52	51	54
Environmental Value	54	55	55	52	23	22	23
Economic Development Value	44	45	45	42	45	44	45
Security Enhancement Value	23	23	23	22	23	22	22
Long Term Societal Value	28	29	29	27	28	28	28
(Solar Penetration Cost)	-23	-23	-23	-22	-23	-22	-22
Total	282	318	315	304	257	280	256

Introduction

This report attempts to quantify the value of distributed solar electricity in Pennsylvania and New Jersey. It uses methodologies and analytical tools that have been developed over many years. The framework supposes that PV is located in the distribution system. PV that is located close to the loads provides the highest value per unit of energy to the utility because line losses are avoided and capital transmission and distribution costs are potentially deferred.

Perspective (“Who receives the benefits?”)

The value of solar accrues either to the electric utility or to society, depending upon component. For example, PV reduces the amount of wholesale energy needed to serve load, resulting in savings to the utility. These utility purchases are passed on to customers through rates, making the utility whole and indifferent to the source of energy. Similarly, utilities should be indifferent to compensating PV production in the amount of wholesale energy savings.

In contrast to this utility benefit, some benefits described in this report accrue to society. The environmental benefits covered in this analysis, for example, represent future savings for mitigating environmental damage (erosion, etc.). These costs are understood to be the future responsibility of society, paid through tax levies. PV provides a value to society by reducing its future expenditures on such environmental remediation.

Approach

Scenarios

A value scenario is defined for any given fleet of PV systems corresponding to a physical configuration (e.g., south-facing, 30-degree tilt) at a single location. Four PV system configurations were included:

- South-30 (south-facing, 30-degree tilt, fixed)
- Horizontal (fixed)
- West-30 (west facing, 30-degree tilt, fixed)
- 1-Axis (tracking at 30-degree tilt)

Seven locations were selected to provide broad geographical and utility coverage in the two states of interest (see Figure 1). Four locations were selected in Pennsylvania representing three utilities¹ and three locations were selected in New Jersey, each served by a separate utility.

Figure 1. Relief map of study locations (Map created using Google Earth).



¹ Scranton and Harrisburg are both served by PPL Utilities.

Table 1 summarizes some of the study location data. 2011 peak loads for each utility are shown, obtained by downloading 2011 hourly load data² from PJM for each of the respective zones.

Table 1. Study location summary.

		Location	Utility	2011 Peak (MW)
PA	1	Pittsburgh	Duquesne Light Co.	3,164
	2	Scranton	PPL Utilities Corp.	7,527
	3	Harrisburg	PPL Utilities Corp.	7,527
	4	Philadelphia	PECO Energy Co.	8,984
NJ	5	Jamesburg	Jersey Central P&L	6,604
	6	Newark	PSE&G	10,933
	7	Atlantic City	Atlantic City Electric	2,956

Selected PV study fleets were modeled for each of the four configurations at each of the seven locations as described in Table 2 for a total of 28 scenarios.³ Fleet capacity was based on an assumed penetration level of 15% of peak load for each utility zone. For example, one fleet was taken as a 475 MW, South-30 configuration, centered at and distributed around Pittsburgh.

² <http://www.pjm.com>.

³ $4 \times 7 = 28$.

Table 2. PV study fleet sizes and locations.

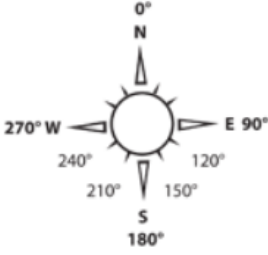
	Location	PV Fleet Capacity, 15% of Peak Load (MW-AC)	Latitude	Longitude
1	Pittsburgh	475	40.44	-80.00
2	Scranton	1,129	41.41	-75.67
3	Harrisburg	1,129	40.28	-76.89
4	Philadelphia	1,348	39.95	-75.16
5	Jamesburg	991	40.35	-74.44
6	Newark	1,640	40.73	-74.17
7	Atlantic City	443	39.37	-74.43

Fleets were described by latitude and longitude, and are rated under the convention suggested by the input fleet editor⁴ (see Figure 1 for the South-30 fleet in Pittsburgh)., AC fleet rating in this convention is defined in the study as described above and DC rating is calculated from a module derate factor (90%), inverter efficiency (95%) and other loss factor (90%). These factors were consistent across all scenarios.

⁴ <https://cprlabs.cleanpower.com>.

Figure 2. Generic fleet editor screen (CPR Labs).

PV System Specification

System Rating (kW AC)		System Rating (kW DC_{STC})		Module Derate		Inverter Efficiency		Loss Factor
<input type="text" value="475000.0"/>	=	<input type="text" value="617283.9506"/>	x	<input type="text" value="90.0"/>	%	x	<input type="text" value="95.0"/>	%
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>Tracking: <input checked="" type="radio"/> Fixed <input type="radio"/> Single-Axis Tracker <input type="radio"/> Dual-Axis Tracker</p> <p>Azimuth: <input type="text" value="180"/> ° (180° = South)</p> <p>Tilt: <input type="text" value="30"/> ° (0° = Horizontal)</p> </div> <div style="width: 45%; text-align: center;">  </div> </div>								

The CPR Labs fleet modeling tool was used to obtain hourly fleet power output for all hours in 2011. This tool uses SolarAnywhere® satellite-derived irradiance data and simulation model⁵ with a 10 km x 10 km pixel resolution. Thus, the fleet output for each of the scenarios is location- and time-correlated with hourly PJM zonal loads.

Value Components

Each value component presented in Table 3 is calculated separately for each scenario and summed to give the total potential value of PV. The methods used to calculate value are described in detail in the Appendices.

Under this study, a method was developed to calculate the market savings accruing to all ratepayers associated with reduced wholesale demand. Less power is required from the market with “out-of-market” solar generation and this effect results in a small reduction in the clearing prices. The “market price reduction value” methodology is described in Appendix 1.

⁵ <http://www.solaranywhere.com>.

Table 3. Value components.

Value Component	Basis
Fuel Cost Savings	Cost of natural gas fuel that would have to be purchased for a gas turbine (CCGT) plant operating on the margin to meet electric loads and T&D losses.
O&M Cost Savings	Operations and maintenance costs for the CCGT plant.
Fuel Price Hedge Value	Cost to eliminate natural gas fuel price uncertainty.
Generation Capacity Value	Cost to build CCGT generation capacity.
T&D Capacity Value	Financial savings resulting from deferring T&D capacity additions.
Market Price Reduction	Wholesale market costs incurred by all ratepayers associated with a shift in demand.
Environmental Value	Future cost of mitigating environmental impacts of coal, natural gas, nuclear, and other generation.
Economic Development Value	Enhanced tax revenues associated with net job creation for solar versus conventional power generation.
Security Enhancement Value	Avoided economic impacts of outages associated due to grid reliability of distributed generation.
Long Term Societal Value	Potential value (defined by all other components) if the life of PV is 40 years instead of the assumed 30 years.
(Solar Penetration Cost)	Additional cost incurred to accept variable solar generation onto the grid.

Input Assumptions

Input assumptions that are common across all of the scenarios are shown in Table 4.

Table 4. Input assumptions and units common to all scenarios.

INPUT ASSUMPTIONS		
PV Characteristics		
PV Degradation	0.50%	per year
PV System Life	30	years
Generation Factors		
Gen Capacity Cost	\$1,045	per kW
Gen Heat Rate (First Year)	7050	BTU/kWh
Gen Plant Degradation	0.00%	per year
Gen O&M Cost (First Year)	\$12.44	per MWh
Gen O&M Cost Escalation	3.38%	per year
Garver Percentage	5.00%	Pct of Ann Peak
NG Wholesale Market Factors		
End of Term NG Futures Price Escalation	2.33%	per year

PV degradation is assumed to be 0.50% per year indicating that the output of the system will degrade over time. This is a conservative assumption (PV degradation is likely to be less than 0.5% per year). Studies often ignore degradation altogether because the effect is small, but it is included here for completeness.

The system life of 30 years is a common assumption for PV. PV module manufacturers warrant systems for the majority of this time (20 to 25 years).

PV is assumed to displace power generated from peaking plants fueled by natural gas. Gas turbine capital, O&M, heat rate, and escalation values are taken from the EIA.⁶ Plant degradation is assumed to be zero.

Costs for generation O&M are assumed to escalate at 3.38%, calculated from the change in Producer Price Index (PPI) for the “Turbine and power transmission equipment manufacturing” industry⁷ over the period 2004 to 2011.

Natural gas prices used in the fuel price savings value calculation are obtained from the NYMEX futures prices. These prices, however, are only available for the first 12 years. Ideally, one would have 30 years of futures prices. As a proxy for this value, it is assumed that escalation after year 12 is constant based on historically long term prices to cover the entire 30 years of the PV service life (years 13 to 30). The EIA published natural gas wellhead prices from 1922 to the present.⁸ It is assumed that the price of the NG futures escalates at the same rate as the wellhead prices.⁹ A 30-year time horizon is selected with 1981 gas prices at \$1.98 per thousand cubic feet and 2011 prices at \$3.95. This results in a natural gas escalation rate of 2.33%.

⁶ Updated Capital Cost Estimates for Electricity Generation Plants, U.S. Energy Information Administration, November 2010, available at http://www.eia.gov/oiaf/beck_plantcosts/pdf/updatedplantcosts.pdf. Taken from Table 1, page 7. Costs are escalated to 2012 dollars.

⁷ PPI data is downloadable from the Bureau industry index selected was taken as the most representative of power generation O&M. BLS does publish an index for “Electric power generation” but this is assumed

⁸ US Natural Gas Prices (Annual), EIA, release date 2/29/2012, available at http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm.

⁹ The exact number could be determined by conduction obtaining over-the-counter NG forward prices.

Study Results

Utility results are shown in Table 5. Utility discount rate, utility system data, utility distribution data were all obtained from FERC filings and PJM hourly data using methods developed previously for NYSERDA.¹⁰ The “other data” assumptions are described in Appendix 1.

A summary of the Newark fleet technical performance results is presented in Table 6 (detailed results for all other locations are included in Appendix 2). Annual energy production is the modeled output for 2011. Capacity factor is the annual energy production relative to a baseload plant operating at 100% availability with the same rated output. Generation capacity is Effective Load Carrying Capability (ELCC) expressed as a percentage of rated capacity. T&D Capacity is a measure of the direct annual peak-load reduction provided by the PV system expressed as a percentage of rated capacity.

Table 7 and Table 8 present the value results in dollars per rated kW and levelized \$ per MWh generated, respectively. This data is also presented graphically in Figure 3 and Figure 4.

¹⁰ Norris and Hoff, “PV Valuation Tool,” Final Report (DRAFT), NYSERDA, May 2012.

Table 5. Utility analysis results.

		Pittsburgh	Scranton	Harrisburg	Philadelphia	Jamesburg	Newark	Atlantic City
Utility		Duquesne Light Co.	PPL Utilities Corp.	PPL Utilities Corp.	PECO Energy Co.	Jersey Central P&L	PSE&G	Atlantic City Electric
UtilityID		DUQ	PPL	PPL	PECO	JCPL	PSEG	AECO
UTILITY DATA								
Economic Factors								
Discount Rate	percent per year	6.63%	8.08%	8.08%	9.00%	5.68%	8.46%	5.88%
Utility System								
Load Loss Condition	MW	1,757	4,786	4,786	4,958	2,893	5,435	1,369
Avg. Losses (at Condition)	percent	5.84%	6.55%	6.55%	4.23%	6.35%	4.86%	5.61%
Distribution								
Distribution Expansion Cost	\$ PW	\$485,009,880	\$423,994,174	\$423,994,174	\$722,046,118	\$446,914,440	\$573,820,751	\$288,330,547
Distribution Expansion Cost Escalation	percent per year	3.89%	3.89%	3.89%	3.89%	3.89%	3.89%	3.89%
Distribution Load Growth Rate	MW per year	30.9	98.3	98.3	110.7	93.4	91.4	39.5
Load Loss Condition	MW	1,757	4,786	4,786	4,958	2,893	5,435	1,369
Avg. Losses (at Condition)	percent	5.84%	6.55%	6.55%	4.23%	6.35%	4.86%	5.61%

Table 6. Technical results, Newark.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1640	1640	1640	1640
Annual Energy Production (MWh)	2,677,626	2,303,173	2,118,149	3,350,313
Capacity Factor (%)	19%	16%	15%	23%
Generation Capacity (% of Fleet Capacity)	45%	47%	51%	54%
T&D Capacity (% of Fleet Capacity)	56%	57%	57%	57%

Table 7. Value (\$/kW), Newark.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	709	612	564	885
O&M Cost Savings	345	298	275	431
Total Energy Value	1,054	911	839	1,317
Nonenergy				
Fuel Price Hedge	798	689	635	996
Generation Capacity Value	470	489	534	568
T&D Capacity Value	147	151	151	151
Market Price Reduction	927	959	958	989
Environmental Value	411	355	327	513
Economic Development Value	806	696	641	1,007
(Solar Penetration Cost)	-403	-348	-321	-503
Total Nonenergy Value	3,156	2,991	2,926	3,721
Other				
Security Enhancement Value	403	348	321	503
Long Term Societal Value	504	435	401	629
Total Other Value	907	783	721	1,132
Total				
All Components	5,117	4,685	4,486	6,170

Table 8. Value (Levelized \$/MWh), Newark.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	39	39	39	39
O&M Cost Savings	19	19	19	19
Total Energy Value	58	58	58	58
Nonenergy				
Fuel Price Hedge	44	44	44	44
Generation Capacity Value	26	31	37	25
T&D Capacity Value	8	10	10	7
Market Price Reduction	51	61	66	43
Environmental Value	22	23	23	22
Economic Development Value	44	44	44	44
(Solar Penetration Cost)	-22	-22	-22	-22
Total	173	190	202	163
Other				
Security Enhancement Value	22	22	22	22
Long Term Societal Value	28	28	28	28
Total	50	50	50	50
Total				
All Components	280	298	310	270

Figure 3. Value (\$/kW), Newark.

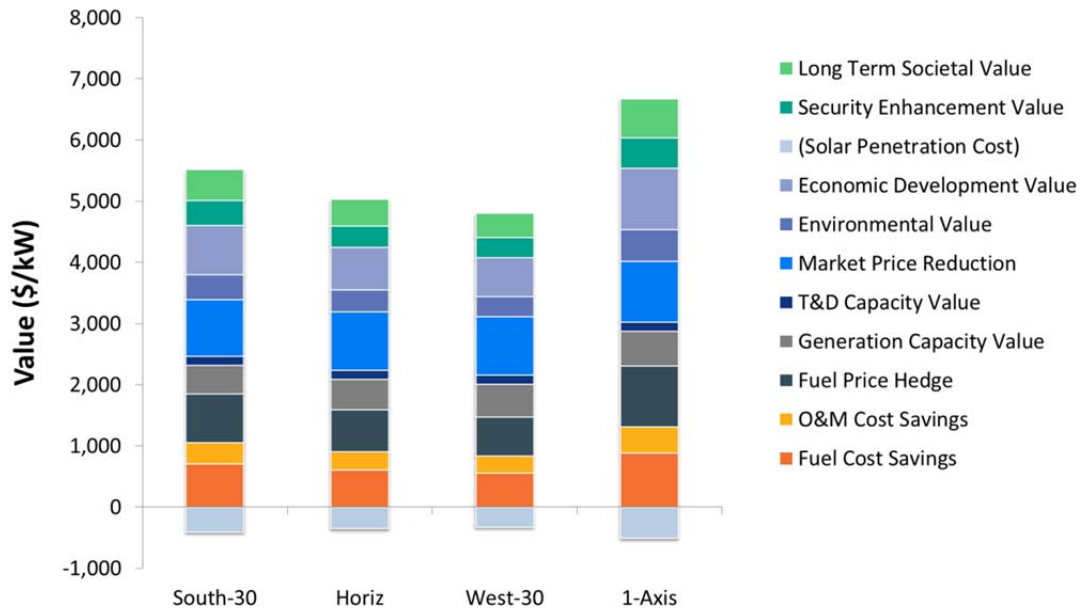
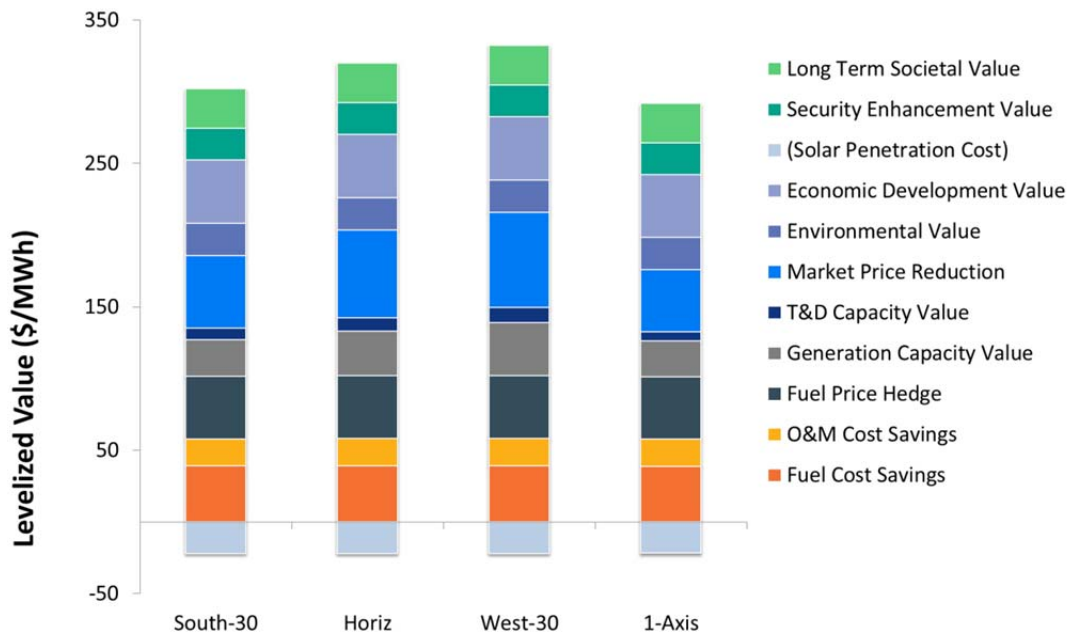


Figure 4. Levelized Value (\$/MWh), Newark.



Results by location

Table 9 summarizes technical results (described above) for the South-30 configuration by location. Table 10 presents levelized value by location.

Table 9. Summary of technical results, by location (South-30).

	Pittsburgh	Scranton	Harrisburg	Philadelphia	Jamesburg	Newark	Atlantic City
Fleet Capacity (MWac)	475	1129	1129	1348	991	1640	443
Annual Energy Production (MWh)	716,621	1,698,897	1,809,443	2,339,424	1,675,189	2,677,626	827,924
Capacity Factor (%)	17%	17%	18%	20%	19%	19%	21%
Generation Capacity (% of Fleet Capacity)	41%	28%	28%	38%	45%	45%	46%
T&D Capacity (% of Fleet Capacity)	31%	14%	14%	21%	29%	56%	36%

Table 10. Summary of levelized value (\$/MWh), by location (South-30).

	Pittsburgh	Scranton	Harrisburg	Philadelphia	Jamesburg	Newark	Atlantic City
Fuel Cost Savings	41	41	41	38	42	39	41
O&M Cost Savings	20	20	20	18	21	19	20
Fuel Price Hedge	31	42	42	47	24	44	25
Generation Capacity Value	22	17	16	22	19	26	18
T&D Capacity Value	6	1	1	3	1	8	2
Market Price Reduction	35	69	67	54	52	51	54
Environmental Value	54	55	55	52	23	22	23
Economic Development Value	44	45	45	42	45	44	45
Security Enhancement Value	23	23	23	22	23	22	22
Long Term Societal Value	28	29	29	27	28	28	28
(Solar Penetration Cost)	-23	-23	-23	-22	-23	-22	-22
Total	282	318	315	304	257	280	256

Analysis and Conclusions

Value and Annual Energy

The total value for Newark (\$/kW) in Table 7 suggests that the highest value is provided by the 1-Axis tracking fleet, followed by the South-30, the Horizontal, and finally the West-30. The same ranking is observed in the capacity factor (an annual energy). This is not surprising because the tracking system is most closely aligned with the solar vector, followed by the South-30, etc. On the other hand, the rankings in Table 8 are in reverse order: the 1-Axis tracking system has the lowest per unit value and the West-30 system has the highest per unit value.

This may be explained by the fact that much of the value is dependent upon the amount of energy produced and noting that the West-30 array produces less energy overall (hence generates less energy value) but each energy unit is more valuable as it is more synchronized with the load.

This is illustrated in Figure 5 where the variation in value is shown to be relatively independent of configuration.

Generation Capacity Value

The generation capacity shows a moderate match between PV output and PJM system load. The four Newark fleets range from 41% to 48% (relative to rated output). The generation capacity value ranges from only \$432 to \$505 per kW, smaller than the potential value \$1,045 per kW for a fully dispatchable unit (Table 4). This is not a significant variation and the results suggest that, during the hours of greatest system load, the advantage of tracking or tilted output is not critical from a generation capacity perspective.

T&D Capacity Value

The T&D capacity values are low, with the highest value of \$151 per kW. These are explained by the low value of T&D savings for a perfect resource and the low match between PV output and loads (the best matches of PV output relative to load are only 57%). Also, the value does not vary greatly by configuration. In this case, facing systems to the west do not result in an improved T&D capacity value.

Market Price Reduction

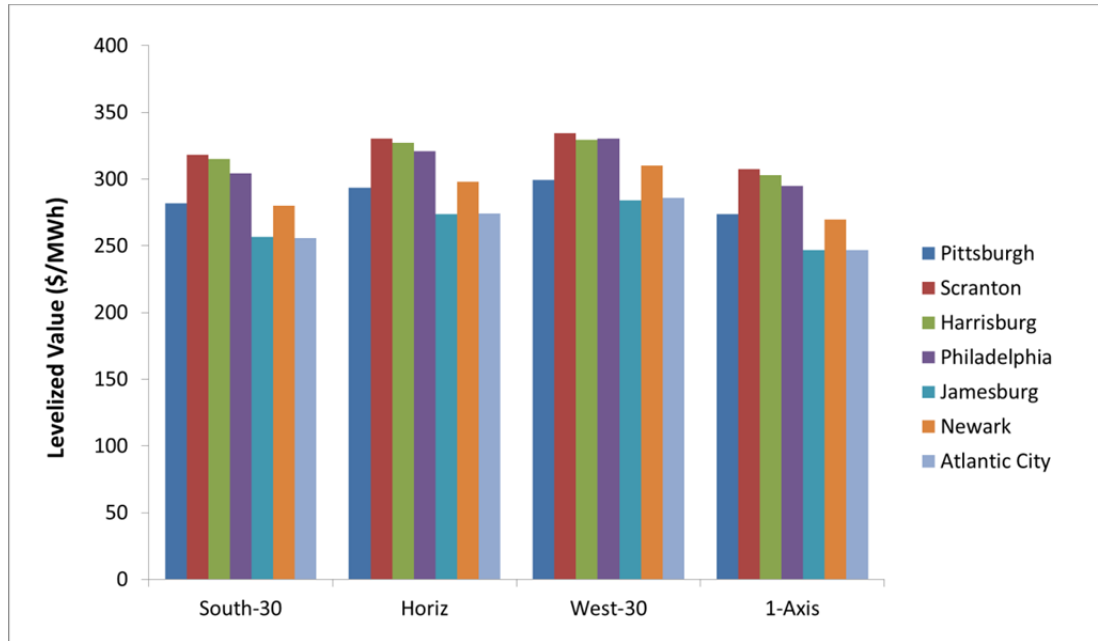
Market price reduction is shown to be the highest value. For the Newark South-30 scenario, market price reduction is \$927 per kW, or 18% of the total value. The magnitude of the benefit suggests that further investigation of the methods may be warranted. Felder [32] has covered the topic in depth, and two of his arguments should be acknowledged as they have bearing on the methodology employed here. First, while the methodology predicts the price reduction associated with out-of-market PV production, it does not treat the associated increase in demand that may be expected. Such an increase in demand would have a counteracting effect of raising prices, and this increase is ignored. Second, the methodology covers only short-run effects, ignoring the impact on capacity markets. In the long run, it is possible that capacity would adjust, also increasing prices. This feedback effect would be damped by the fact that PV provides nearly 50% of the capacity reserve that would be curtailed. This capacity-related effect is not included in the methodology. Consequently, the results here should only be considered a preliminary estimate, subject to further refinement.

Location Ranking

Figure 5 shows a consistent ranking of value by location, irrespective of configuration. The high ranking locations (Scranton, Harrisburg, and Philadelphia) include both high environmental benefits (common to Pennsylvania) and high fuel price hedge value as shown in Table 10. Pittsburgh includes the high environmental value, but not the high fuel price hedge. This is explainable by noting (Table 5) that Duquesne Light Co. has the lowest discount rate of the four Pennsylvania utilities.

Similarly, Jamesburg and Atlantic City consistently have the lowest value. These may also be explained by low hedge value, traceable again to low discount rates.

Figure 5. Total levelized value, by location and configuration.



Future Work

The market price reduction estimated as part of the present study will have to be ascertained as PV develops and penetrates the NJ and PA grids. In particular, the impact of PV-induced price reduction on load growth, hence feedback secondary load-growth induced market price increase as suggested by Felder [32] should be quantified. In addition, the feedback of market price reduction on capacity markets will have to be investigated.

In this study 15% PV capacity penetration was assumed-- amounting to a total PV capacity of 7GW across the seven considered utility hubs. Since both integration cost increases and capacity value diminishes with penetration, it will be worthwhile to investigate the value fetched by PV beyond the considered 15% horizon. In particular, it will be pertinent to establish the cost of displacing (nuclear) baseload generation with solar generation¹¹ since this question is often brought to the forefront by environmentally-concerned constituents in densely populated areas of NJ and PA.

The T&D values derived for the present analysis are based on utility-wide average loads. Because this value is dependent upon the considered distribution system's characteristics – in particular load growth, customer mix and equipment age – the T&D value may vary considerably from one distribution feeder to another. It would therefore be advisable to take this study one step further and systematically identify the highest value areas. This will require the collaboration of the servicing utilities to provide relevant subsystem data.

¹¹ Considering integration solutions including storage, wind/PV synergy and gas generation backup.

Appendix 1: Methodologies

Overview

The methodologies used in the present project drew upon studies performed by CPR for other states and utilities. In these studies, the key value components provided by PV were determined by CPR, using utility-provided data and other economic data.

The ability to determine value on a site-specific basis is essential to these studies. For example, the T&D Capacity Value component depends upon the ability of PV to reduce peak loads on the circuits. An analysis of this value, then, requires:

Hour by hour loads on distribution circuits of interest.

- Hourly expected PV outputs corresponding to the location of these circuits and expected PV system designs.
- Local distribution expansion plan costs and load growth projections.

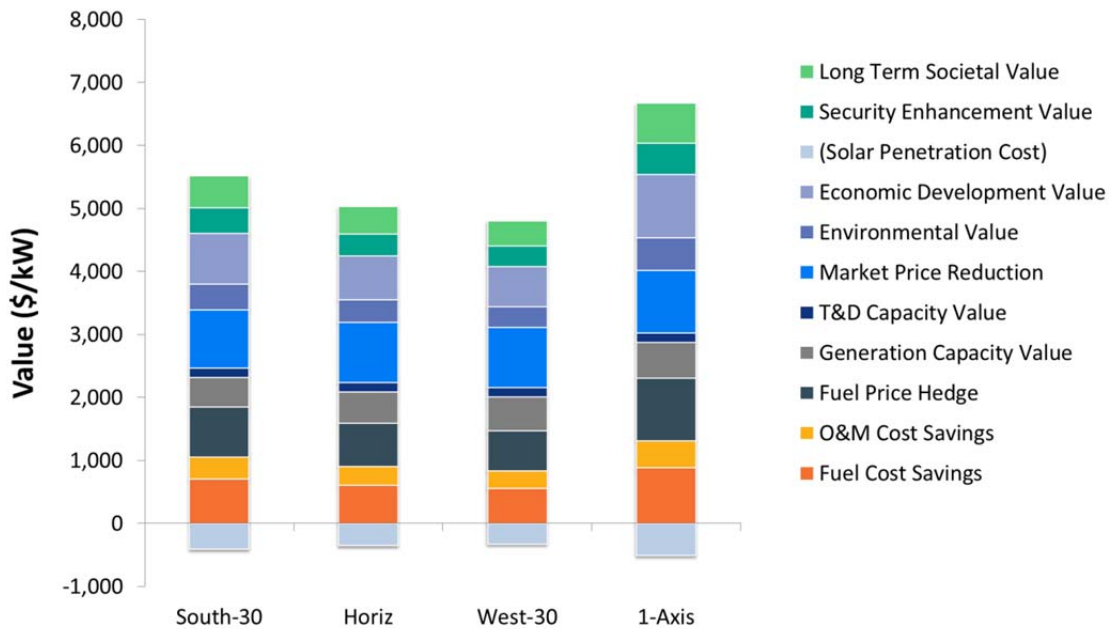
Units of Results

The discounting convention assumed throughout the report is that energy-related values occur at the end of each year and that capacity-related values occur immediately (i.e., no discounting is required).¹²

The Present Value results are converted to per unit value (Present Value \$/kW) by dividing by the size of the PV system (kW). An example of this conversion is illustrated in Figure 6 for results from a previous study. The y-axis presents the per unit value and the x-axis presents seven different PV system configurations. The figure illustrates how value components can be significantly affected by PV system configuration. For example, the tracking systems, by virtue of their enhanced energy production capability, provide greater generation benefits.

¹² The effect of this will be most apparent in that the summations of cash flows start with the year equal to 1 rather than 0.

Figure 6. Sample results.



The present value results per unit of capacity (\$/kW) are converted to levelized value results per unit of energy (\$/kWh) by dividing present value results by the total annual energy produced by the PV system and then multiplying by an economic factor.

PV Production and Loss Savings

PV System Output

An accurate PV value analysis begins with a detailed estimate of PV system output. Some of the energy-based value components may only require the total amount of energy produced per year. Other value components, however, such as the energy loss savings and the capacity-based value components, require hourly PV system output in order to determine the technical match between PV system output and the load. As a result, the PV value analysis requires time-, location-, and configuration-specific PV system output data.

For example, suppose that a utility wants to determine the value of a 1 MW fixed PV system oriented at a 30° tilt facing in the southwest direction located at distribution feeder “A”. Detailed PV output data

that is time- and location-specific is required over some historical period, such as from Jan. 1, 2001 to Dec. 31, 2010.

Methodology

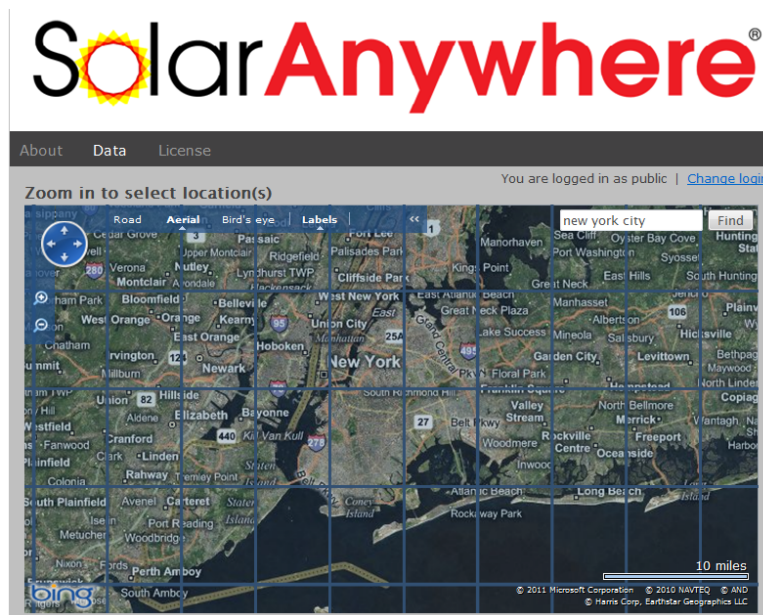
It would be tempting to use a representative year data source such as NREL's Typical Meteorological Year (TMY) data for purposes of performing a PV value analysis. While these data may be representative of long-term conditions, they are, by definition, not time-correlated with actual distribution line loading on an hourly basis and are therefore not usable in hourly side-by-side comparisons of PV and load. Peak substation loads measured, say, during a mid-August five-day heat wave must be analyzed alongside PV data that reflect the same five-day conditions. Consequently, a technical analysis based on anything other than time- and location-correlated solar data may give incorrect results.

CPR's SolarAnywhere® and PVSimulator™ software services will be employed under this project to create time-correlated PV output data. SolarAnywhere is a solar resource database containing almost 14 years of time- and location-specific, hourly insolation data throughout the continental U.S. and Hawaii. PVSimulator, available in the SolarAnywhere Toolkit, is a PV system modeling service that uses this hourly resource data and user-defined physical system attributes in order to simulate configuration-specific PV system output.

The SolarAnywhere data grid web interface is available at www.SolarAnywhere.com (Figure 7). The structure of the data allows the user to perform a detailed technical assessment of the match between PV system output and load data (even down to a specific feeder). Together, these two tools enable the evaluation of the technical match between PV system output and loads for any PV system size and orientation.

Previous PV value analyses were generally limited to a small number of possible PV system configurations due to the difficulty in obtaining time- and location-specific solar resource data. This new value analysis software service, however, will integrate seamlessly with SolarAnywhere and PVSimulator. This will allow users to readily select any PV system configuration. This will allow for the evaluation of a comprehensive set of scenarios with essentially no additional study cost.

Figure 7. SolarAnywhere data selection map.



Loss Savings

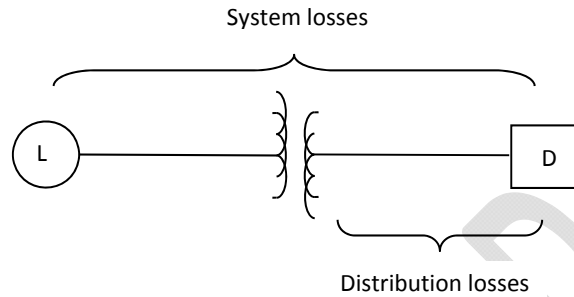
Introduction

Distributed resources reduce system losses because they produce power in the same location that the power is consumed, bypassing the T&D system and avoiding the associated losses.

Loss savings are not treated as a stand-alone benefit under the convention used in this methodology. Rather, the effect of loss savings is included separately for each value component. For example, in the section that covers the calculation of Energy Value, the quantity of energy saved by the utility includes both the energy produced by PV and the amount that would have been lost due to heating in the wires if the load were served from a remote source. The total energy that would have been procured by the utility equals the PV energy plus avoided line losses. Loss savings can be considered a sort of “adder” for each benefit component.

This section describes the methodology for calculating loss savings for each hour. The results of these calculations are then used in subsequent sections. As illustrated in Figure 8, it will be important to note that, while the methodology describes the calculation of an hourly loss result, there are actually two different loss calculations that must be performed: “system” losses, representing the losses incurred on both the transmission and distribution systems (between generation load, L, and end-use demand, D), and “distribution” losses, representing losses specific to distribution system alone.

Figure 8. System losses versus distribution losses.



The two losses are calculated using the same equation, but they are each applicable in different situations. For example, “Energy Value” represents a benefit originating at the point of central generation, so that the total system losses should be included. On the other hand, “T&D Capacity Value” represents a benefit as measured at a distribution substation. Therefore, only the losses saved on the distribution system should be considered.

The selection of “system” versus “distribution” losses is discussed separately for each subsequent benefit section.

Methodology

One approach analysts have used to incorporate losses is to adjust energy- and capacity-related benefits based on the *average* system losses. This approach has been shown to be deficient because it fails to capture the true reduction in losses on a marginal basis. In particular, the approach underestimates the reduction in losses due to a peaking resource like PV. Results from earlier studies demonstrated that loss savings calculations may be off by more than a factor of two if not performed correctly [1].

For this reason, the present methodology will incorporate a calculation of loss savings on a marginal basis, taking into account the status of the utility grid when the losses occur. CPR has previously developed methodologies based on the assumption that the distributed PV resource is small relative to the load (e.g., [2], [3]). CPR has recently completed new research that expands this methodology so that loss savings can now be determined for any level of PV penetration.

Energy Value (Fuel and O&M Savings)

Introduction

Energy Value is the benefit that utility participants derive from using distributed PV generation to offset wholesale energy purchases or reduce generation costs. Each kWh generated by PV results in one less unit of energy that the utility needs to purchase or generate. In addition, distributed PV reduces system losses so that the cost of the wholesale generation that would have been lost must also be considered. The capacity value of generation is treated in a separate section.

Methodology

Energy Value can be calculated by multiplying PV system output times the cost of the generation on the margin for each hour, summing for all hours over the year, and then discounting the results for each year over the life of the PV system.

There are two approaches to obtaining the marginal cost data. One approach is to obtain the marginal costs based on historical or projected market prices. The second approach is to obtain the marginal costs based on the cost of operating a representative generator that is on the margin.

Initially, it may be appealing to take the approach of using market prices. There are, however, several difficulties with this approach. One difficulty is that these tend to be hourly prices and thus require hourly PV system output data in order to calculate the economic value. This difficulty can be addressed by using historical prices and historical PV system output to evaluate what results would have been in the past and then escalating the results for future projections. A more serious difficulty is that, while hourly market prices could be projected for a few years into the future, the analysis needs to be performed over a much longer time period (typically 30 years). It is difficult to accurately project hourly market prices 30 years into the future.

A more robust approach is to explicitly specify the marginal generator and then to calculate the cost of the generation from this unit. It is typically assumed that the marginal generator offset by PV is a Combined Cycle Gas Turbine (CCGT) powered using natural gas. This approach includes the assumption that PV output always displaces energy from the same marginal unit. Given the uncertainties and complications in market price projections, the second approach is taken.

The Energy Value equals the sum of the discounted fuel cost savings and the discounted O&M cost savings.

Generation Capacity Value

Introduction

Generation Capacity Value is the benefit from added capacity provided to the generation system by distributed PV. Two different approaches can be taken to evaluating the Generation Capacity Value component. One approach is to obtain the marginal costs based on market prices. The second approach is to estimate the marginal costs based on the cost of operating a representative generator that is on the margin, typically a Combined Cycle Gas Turbine (CCGT) powered by natural gas.

Methodology

The second approach is taken here for purposes of simplicity. Future version of the software service may add a market price option.

Once the cost data for the fully-dispatchable CCGT are obtained, the match between PV system output and utility loads needs to be determined in order to determine the effective value of the non-dispatchable PV resource. CPR developed a methodology to calculate the effective capacity of a PV system to the utility generation system (see [10] and [11]) and Perez advanced this method and called it the Effective Load Carrying Capability (ELCC) [12]. The ELCC method has been identified by the utility industry as one of the preferable methods to evaluate PV capacity [13] and has been applied to a variety of places, including New York City [14].

The ELCC is a statistical measure of effective capacity. The ELCC of a generating unit in a utility grid is defined as the load increase (MW) that the system can carry while maintaining the designated reliability criteria (e.g., constant loss of load probability). The ELCC is obtained by analyzing a statistically significant time series of the unit's output and of the utility's power requirements.

Generation Capacity Value equals the capital cost (\$/MW) of the displaced generation unit times the effective capacity provided by the PV.

Environmental Value

Introduction

It is well established that the environmental impact of PV is considerably smaller than that of fossil-based generation since PV is able to displace pollution associated with drilling/mining, and power plant emissions [15].

Methodology

There are two general approaches to quantifying the Environmental Value of PV: a regulatory cost-based approach and an environmental/health cost-based approach.

The regulatory cost-based approach values the Environmental Value of PV based on the price of Renewable Energy Credits (RECs) or Solar Renewable Energy Credits (SRECs) that would otherwise have to be purchased to satisfy state Renewable Portfolio Standards (RPS). These costs are a preliminary legislative attempt to quantify external costs. They represent actual business costs faced by utilities in certain states.

An environmental/health cost-based approach quantifies the societal costs resulting from fossil generation. Each solar kWh displaces an otherwise dirty kWh and commensurately mitigates several of the following factors: greenhouse gases, SO_x/NO_x emissions, mining degradations, ground water contamination, toxic releases and wastes, etc., that are all present or postponed costs to society. Several exhaustive studies have estimated the environmental/health cost of energy generated by fossil-based generation [16], [17]. The results from environmental/health cost-based approach often vary widely and can be controversial.

The environmental/health cost-based approach was used for this study.

The environmental footprint of solar generation is considerably smaller than that of the fossil fuel technologies generating most of our electricity (e.g., [19]). Utilities have to account for this environmental impact to some degree today, but this is still only largely a potential cost to them. Rate-based Solar Renewable Energy Credits (SRECs) markets in New Jersey and Pennsylvania as a means to meet Renewable Portfolio Standards (RPS) are a preliminary embodiment of including external costs, but they are largely driven more by politically-negotiated processes than by a reflection of inherent physical realities. The intrinsic physical value of displacing pollution is real and quantifiable however:

depending on the current generation mix, each solar kWh displaces an otherwise dirty kWh and commensurately mitigates several of the following factors: greenhouse gases, Sox/Nox emissions, mining degradations, ground water contamination, toxic releases and wastes, etc., which are all present or postponed costs to society (i.e., the taxpayers).

The environmental value, EV, of each kWh produced by PV (i.e., not produced by another conventional source) is given by:

$$EV = \sum_{i=0}^n x_i EC_i$$

Where EC_i is the environmental cost of the displaced conventional generation technology and x_i is the proportion of this technology in the current energy mix.

Several exhaustive studies emanating from such diverse sources as the nuclear industry or the medical community ([20], [21]) estimate the environmental/health cost of 1 MWh generated by coal at \$90-250, while a [non-shale¹³] natural gas MWh has an environmental cost of \$30-60.

Considering New Jersey and Pennsylvania's electrical generation mixes (Table 11) and conservatively assuming that (1) nuclear energy has no environmental cost¹⁴ and (2) that all natural gas is conventional, the environmental value of each MWh displaced by PV, hence the taxpayer benefit, is estimated at \$48 to \$129 in Pennsylvania and \$20 to \$48 in New Jersey.

We retained a value near the lower range of these estimates for the present analysis.

¹³ Shale gas environmental footprint is likely higher both in terms of environment degradation and GHG emissions.

¹⁴ Because the environmental cost of nuclear generation covers such a wide and controversial range to reflect the probability of catastrophic accidents, and the environmental footprint of the existing uranium cycle, an environmental liability of zero is used for nuclear generation for the present study. In addition, the levels of penetration considered and valued in this study correspond to intermediate and peak loads hence do not imply nuclear generation displacement.

Table 11. Environmental input calculation.

	Generation Mix		Prorated Environmental Cost (\$/MWh)		
Pennsylvania	48%	Coal	43.2	to	120.0
	15%	Natural Gas	4.5	to	9.0
	34%	Nuclear	0.0	to	0.0
	3%	Other	0.0	to	0.0
	Environmental Value for PA		47.7	to	129.0
New Jersey	10%	Coal	9.0	to	25.0
	38%	Natural Gas	11.4	to	22.8
	50%	Nuclear	0.0	to	0.0
	2%	Other	0.0	to	0.0
	Environmental Value for NJ		20.4	to	47.8

Fuel Price Hedge Value

Introduction

Solar-based generation is insensitive to the volatility of fuel prices while fossil-based generation is directly tied to fuel prices. Solar generation, therefore, offers a “hedge” against fuel price volatility. One way this has been accounted for is to quantify the value of PV’s hedge against fluctuating natural gas prices [6].

Methodology

The key to calculating the Fuel Price Hedge Value is to effectively convert the fossil-based generation investment from one that has substantial fuel price uncertainty to one that has no fuel price uncertainty. This can be accomplished by entering into a binding commitment to purchase a lifetime’s worth of fuel to be delivered as needed. The utility could set aside the entire fuel cost obligation up front, investing it in risk-free securities to be drawn from each year as required to meet the obligation. The approach uses two financial instruments: risk-free, zero-coupon bonds¹⁵ and a set of natural gas futures contracts.

Consider how this might work. Suppose that the CCGT operator wants to lock in a fixed price contract for a sufficient quantity of natural gas to operate the plant for one month, one year in the future. First,

¹⁵ A zero coupon bond does not make any periodic interest payments.

the operator would determine how much natural gas will be needed. If E units of electricity are to be generated and the heat rate of the plant is H , $E * H$ BTUs of natural gas will be needed. Second, if the corresponding futures price of this natural gas is $P^{NG\text{ Futures}}$ (in \$ per BTU), then the operator will need $E * H * P^{NG\text{ Futures}}$ dollars to purchase the natural gas one year from now. Third, the operator needs to set the money aside in a risk-free investment, typically a risk-free bond (rate-of-return of $r^{risk-free}$ percent) to guarantee that the money will be available when it is needed one year from now. Therefore, the operator would immediately enter into a futures contract and purchase $E * H * P^{NG\text{ Futures}} / (1 + r^{risk-free})$ dollars worth of risk-free, zero-coupon bonds in order to guarantee with certainty that the financial commitment (to purchase the fuel at the contract price at the specified time) will be satisfied.¹⁶

This calculation is repeated over the life of the plant to calculate the Fuel Price Hedge value.

T&D Capacity Value

Introduction

The benefit that can be most affected by the PV system's location is the T&D Capacity Value. The T&D Capacity Value depends on the existence of location-specific projected expansion plan costs to ensure reliability over the coming years as the loads grow. Capacity-constrained areas where loads are expected to reach critical limits present more favorable locations for PV to the extent that PV will relieve the constraints, providing more value to the utility than those areas where capacity is not constrained.

Distributed PV generation reduces the burden on the distribution system. It appears as a "negative load" during the daylight hours from the perspective of the distribution operator. Distributed PV may be considered equivalent to distribution capacity from the perspective of the distribution planner, provided that PV generation occurs at the time of the local distribution peak.

Distributed PV capacity located in an area of growing loads allows a utility planner to defer capital investments in distribution equipment such as substations and lines. The value is determined by the avoided cost of money due to the capital deferral.

Methodology

It has been demonstrated that the T&D Capacity Value can be quantified in a two-step process. The first step is to perform an economic screening of all areas to determine the expansion plan costs and load

¹⁶ $[E * H * P^{NG\text{ Futures}} / (1 + r^{risk-free})] * (1 + r^{risk-free}) = E * H * P^{NG\text{ Futures}}$

growth rates for each planning area. The second step is to perform a technical load-matching analysis for the most promising locations [18].

Market Price Reduction Value

Two cost savings occur when distributed PV generation is deployed in a market that is structured where the last unit of generation sets the price for all generation and the price is an increasing function of load. First, there is the direct savings that occur due to a reduction in load. This is the same as the value of energy provided at the market price of power. Second, there is the indirect value of market price reduction. Distributed generation reduces market demand and this results in lower prices to all those purchasing power from the market. This section outlines how to calculate the market savings value.

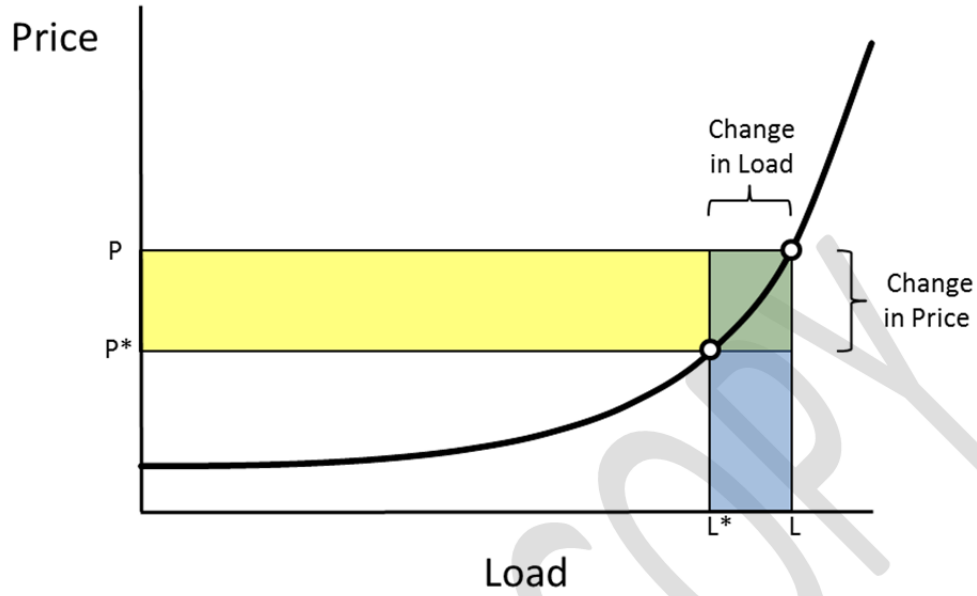
Cost Savings

As illustrated in Figure 9, the total market expenditures at any given point in time are based on the current price of power (P) and the current load (L). The rate of expenditure equals $P L$. Total market expenditures after PV is deployed equals the new price (P^*) times the new load (L^*), or P^*L^* . Cost savings equal the difference between the total before and after expenditures.

$$\text{Cost Savings} = P L - P^*L^* \quad (1)$$

The figure illustrates that the cost savings occur because there is both a change in load and a change in price.

Figure 9. Illustration of price changes that occur in market as result of load changes.



Equation (1) can be expanded by adding $-P^*L + P^*L$ and then rearranging the result.

$$\text{Cost Savings} = PL + (-P^*L + P^*L) - P^*L^*$$

$$= (P - P^*)L + P^*(L - L^*)$$

(2)

$$= \left[\left(\frac{P - P^*}{L - L^*} \right) L + P^* \right] (L - L^*)$$

Let $\Delta L = L - L^*$ and $\Delta P = P - P^*$ and substitute into Equation (2). The result is that

$$\text{Cost Savings} = \left[P + \frac{\Delta P}{\Delta L} L - \Delta P \right] \Delta L$$

(3)

Per unit cost savings is obtained by dividing Equation (3) by ΔL .

$$\text{Per Unit Cost Savings} = \overbrace{\tilde{P}}^{\text{Direct Savings}} + \overbrace{\frac{\Delta P}{\Delta L} L - \Delta P}^{\text{Market Price Reduction Value}} \quad (4)$$

Discussion

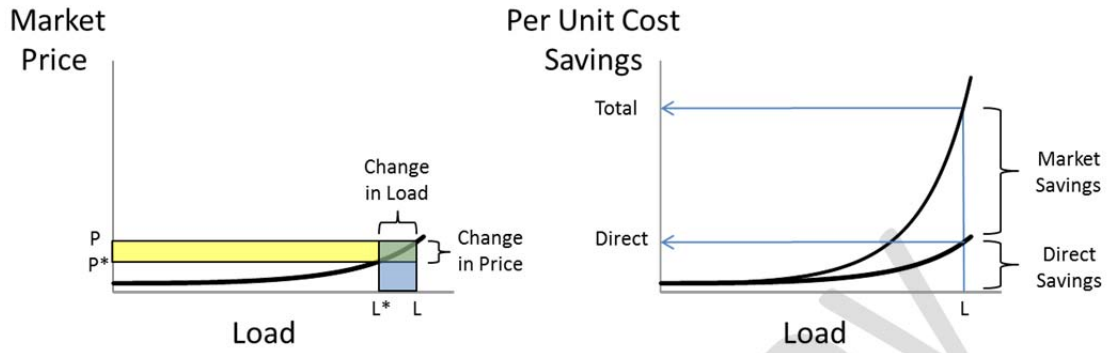
Equation (4) suggests that there are two cost savings components: direct savings and market price suppression. The direct savings equal the existing market price of power. The market price reduction value is the savings that the entire market realizes as a result of the load reduction. These savings depends on the change in load, change in price, and existing load. It is important to note that the change in load and the existing load can be measured directly while the change in price cannot be measured directly. This means that the change in price must be modeled (rather than measured).

It is useful to provide an interpretation of the market price reduction component and illustrate the potential magnitude. The market price reduction component in Equation (4) has two terms. The first term is the slope of the price curve (i.e., it is the derivative as the change in load goes to zero) times the existing load. This is the positive benefit that the whole market obtains due to price reductions. The second term is the reduced price associated with the direct savings.

The left side of Figure 10 presents the same information as in Figure 9, but zooms out on the y-axis scale of the chart. The first term corresponds to the yellow area. The second term corresponds to the overlapping areas of the change in price and change in load effects.

The market price curve can be translated to a cost savings curve. The right side of Figure 10 presents the per unit cost savings based on the information from the market price curve (i.e., the left side of the figure). The lower black line is the price vs. load curve. The upper line adds the market price suppression component to the direct savings component. It assumes that there is the same load reduction for all loads as in the left side of the figure. The figure illustrates that no market price suppression exist when the load is low but the market price suppression exceed the direct cost savings when the load is high. The saving is dependent upon the shape of the price curve and the size of the load reduction.

Figure 10. Direct + market price reduction vs. load (assuming constant load reduction).



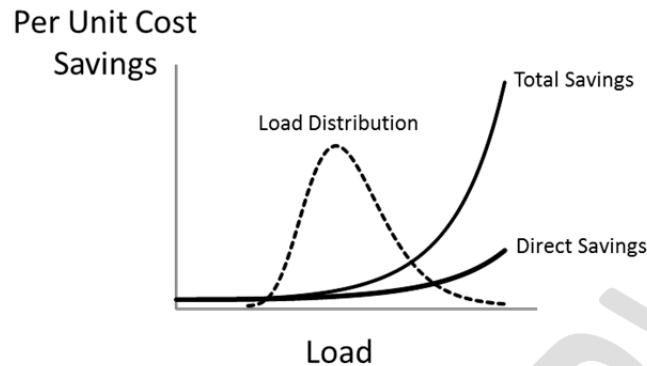
Total Value

The previous sections calculated the cost savings at a specific instant in time. The total cost savings is calculated by summing this result overall all periods in time. The per unit cost savings is calculated by dividing by the total energy. (Note that it is assumed that each unit of time represents 1 unit). The result is that:

$$\text{Per Unit Cost Savings} = \frac{\text{Total Cost Savings}}{\text{Total Energy}} = \frac{\sum_{t=1}^T \left[P_t + \frac{\Delta P_t}{\Delta L_t} L_t - \Delta P_t \right] \Delta L_t}{\sum_{t=1}^T \Delta L_t} \quad (5)$$

This result can be viewed graphically as the probability distribution of the load times the associate cost savings curves when there is a constant load reduction. Multiply the load distribution by the total per unit savings to obtain the weighted average per unit cost savings.

Figure 11. Apply load distribution to calculate total savings over time.



Application

As discussed above, all of the parameters required to perform this calculation can be measured directly except for the change in price. Thus, it is crucial to determine how to estimate the change in price.

This is implemented in four steps:

1. Obtain LMP price data and develop a model that reflects this data.
2. Use the LMP price model and Equation (4) to calculate the price suppression benefit. Note that this depends upon the size of the change in load.
3. Obtain time-correlated PV system output and determine the distribution of this output relative to the load.
4. Multiply the PV output distribution times the price suppression benefit to calculate the weighted-average benefit.

Historical LMP and time- and location-correlated PV output data are required to perform the analysis. LMPs are obtained from the market and the PV output data are obtained by simulating time- and location-specific PV output using SolarAnywhere.

Figure 12 illustrates how to perform the calculations using measured prices and simulated PV output for PPL in June 2012. The left side of the figure illustrates that the historical LMPs (black circles) are used to develop a price model (solid black line). The center of the figure illustrates how the price model is used with Equation (4) is used to calculate the price suppression benefit for every load level. Since this benefit depends upon the size of the change in the load, the figure presents a range. The solid blue line is the benefit for a very small PV output. The dashed blue line corresponds to the benefit for a 1,000 MW PV output. The right side of the figure presents the distribution of the PV energy relative to the load. The weighted-average price suppression benefit is calculated by multiply the PV output

distribution times the price suppression benefit. Note that in practice, the actual calculation is performed for each hour of the analysis since the price suppression benefit is a function of both the load and the PV output.

Figure 12. Illustration of how to calculate benefit using measured data for June 2011.

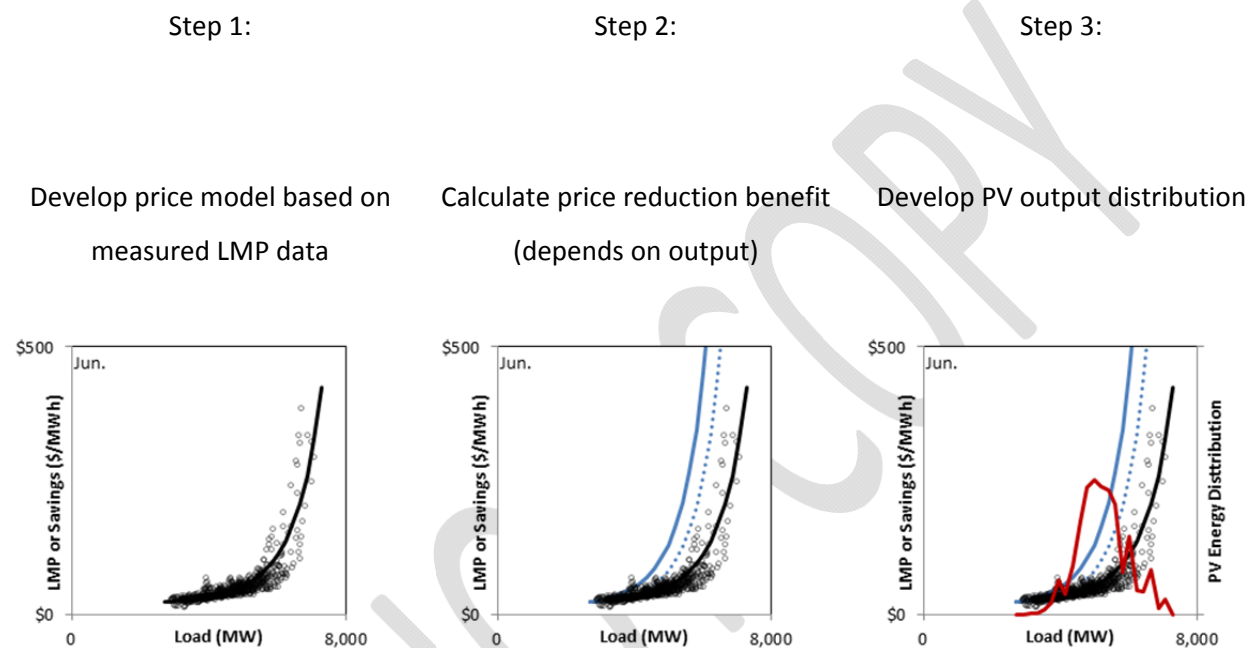
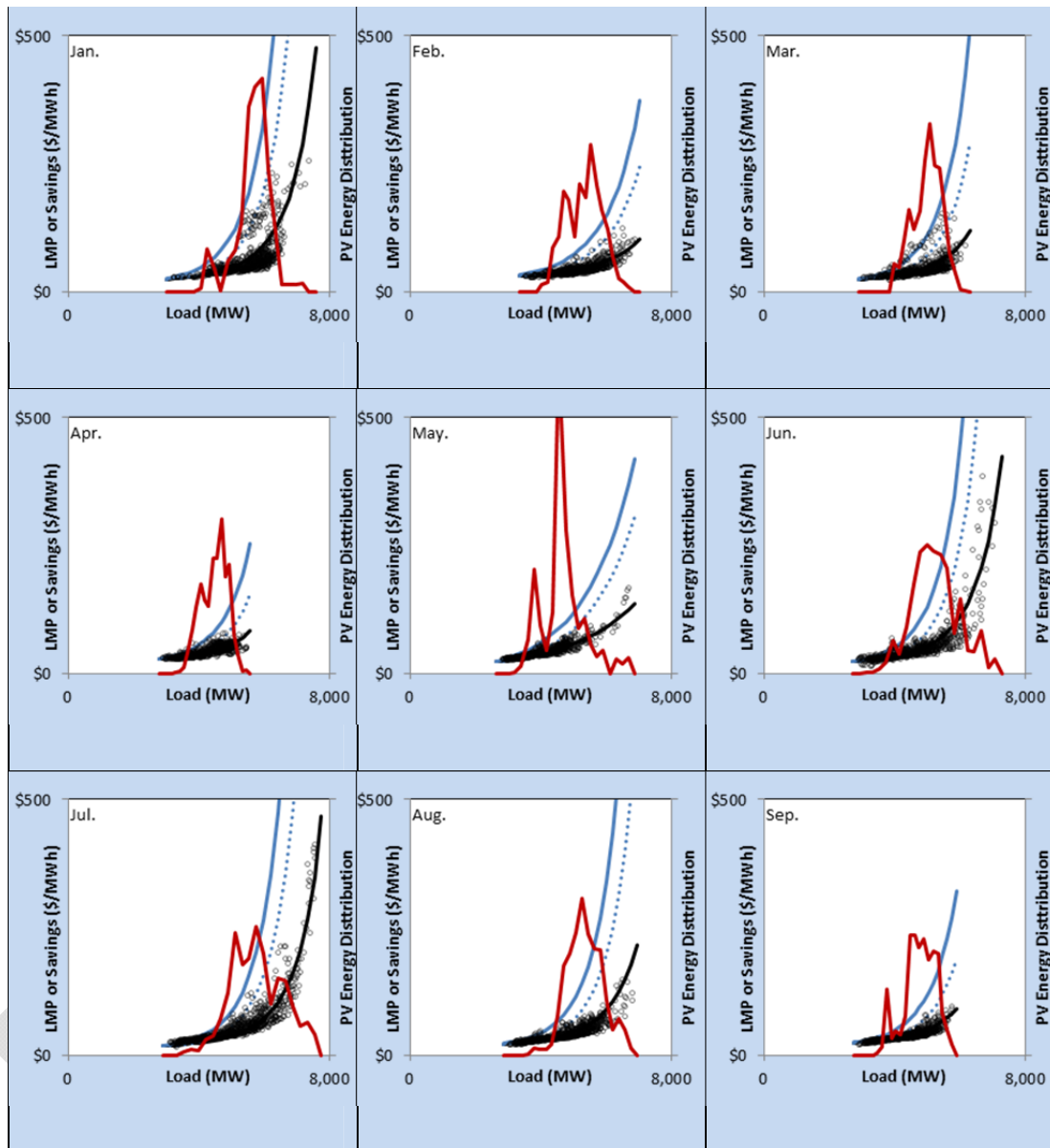
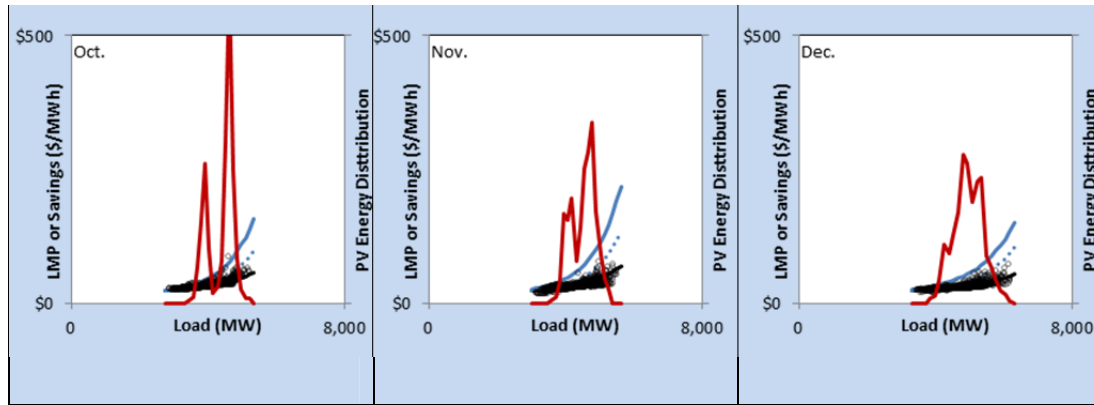


Figure 13 presents the results for the three steps for each month in 2011.

Figure 13. Measured and modeled LMPs (black circles and lines), price suppression benefit (solid blue for small output and dashed blue for 1,000 MW of output) and PV output distribution (PPL 2011).





Results

As illustrated in Table 12 the price reduction benefits are more than double the direct savings for a 100 MW of PV and slightly exceed the direct saving for 1,000 MW PV, for a combined value ranging from \$127/MWh to \$180/MWh.

Table 12. Market savings illustration.

	100 MW	1,000 MW
Direct Savings	\$58	\$58
Market Price Reduction	\$122	\$69
Total	\$180	\$127

A comparison of direct market savings and energy savings as calculated in this study is shown in Table 13. Fuel cost savings and O&M cost savings are combined because they represent the same costs that are included in market price. Direct savings were calculated for each hour as $P \cdot \Delta L$, summed for the year, and escalated at the same rate each year as natural gas futures beyond the 12 year limit.

Table 13. Direct market savings comparison (Newark, South-30).

	Value (\$/kW)	Value (\$/MWh)
Fuel Cost Savings	\$709	38.8
O&M Cost Savings	\$345	18.9
Total Energy Savings	\$1,054	57.7
Direct Market Savings	\$1,470	80.4

The results show that direct market savings are 39% above the energy savings. This discrepancy reflects the fact that the two quantities, while representing the same value components, use entirely different approaches. Fuel cost savings are derived from natural gas futures, discounted at the utility discount rate, and applied against an assumed CCGT heat rate. Direct market savings are based on hourly PJM zonal prices for 2011.

The energy savings achieved by the utility is based on avoided market purchases. However, historical market prices are not necessarily and indicator of future years, especially for 30 years into the future. For this reason, the energy savings methodology used in this analysis is more closely tied to the fundamentals of the cost: fuel and O&M costs that must be recovered by the marketplace for generation to be sustainable in the long run.

Zonal Price Model

To calculate the market price reduction in equation (4), a zonal price model was developed as follows. A function $F()$ may be defined whose value is proportional to market clearing price using the form:

$$F(\text{Load}) = Ae^{B \times \text{Load}^{C+D}}$$

where coefficients A, B, C, and D are evaluated for each utility and for each month using hourly PJM zonal market price data, amounting to a total of 84 individual models.

P is the zonal wholesale clearing price, and P^* is given by:

$$\frac{P^*}{P} = \frac{F(\text{Load} - \text{FleetPower} - \text{LossSavings})}{F(\text{Load})}$$

The market price reduction (in \$/MWh) is calculated using the relevant term in Equation (4) and multiplying by the change in load, including loss savings.

Economic Development Value

The German and Ontario experiences as well as the experience in New Jersey, where fast PV growth is occurring, show that solar energy sustains more jobs per unit of energy generated than conventional energy ([21], [22]). Job creation implies value to society in many ways, including increased tax revenues, reduced unemployment, and an increase in general confidence conducive to business development.

In this report, only tax revenue enhancement from the jobs created as a measure of PV-induced economic development value is considered. This metric provides a tangible low estimate of solar energy's likely larger multifaceted economic development value. In Pennsylvania and New Jersey, this low estimate amounts to respectively \$39 and \$40 per MWh, even under the very conservative, but thus far realistic, assumption that 80% of the PV manufacturing jobs would be either out-of-state or foreign (see methodology section, below).

Methodology

In a previous (New York) study [24], net PV-related job creation numbers were used directly based upon Ontario and Germany's historical numbers. However this assumption does not reflect the rapid changes of the PV industry towards lower prices. In this study a first principle approach is applied based upon the difference between the installed cost of PV and conventional generation: in essence this approach quantifies the fact that part of the price premium paid for PV vs. conventional generation returns to the local economy in the form of jobs hence taxes.

Therefore, assuming that:

- Turnkey PV costs \$3,000 per kW vs. \$1,000 per kW for combine cycle gas turbines (CCGT)
- Turnkey PV cost is composed of 1/3 technology (modules & inverter/controls) and 2/3 structure and installation and soft costs.
- 20% of the turnkey PV technology cost and 90% of the other costs are traceable to local jobs, while 50% of the CCGT are assumed to be local jobs, thus:
 - The local jobs-traceable amount spent on PV is equal to: $\left(\frac{0.2}{3} + \frac{0.9 \times 2}{3}\right) \times 3000 = \$1,990/kW$
 - And the local jobs-traceable amount spent on CCGT is equal to: $0.5 \times 1000 = \$500/kW$
- PV systems in NJ and PA have a capacity factor of ~ 16%, producing 1,400 kWh per year and CCGT have an assumed capacity factor of 50%, producing 4,380 kWh per year, therefore
 - The local jobs-traceable amount spent per PV kWh in year one is: $1,990/1,400 = \$1.42$

- The local jobs-traceable amount spent per CCGT kWh in year one is: $500/4,380 = \$0.114$
- The net local jobs-traceable between PV and CCGT is thus equal to $1.42 - 0.11 = \$1.30$
- Assuming that the life span of both PV and CCGT is 30 years, and using a levelizing factor of 8%, the net local jobs-traceable amount per generated PV kWh over its lifetime amounts to:
- $1.30 \times \frac{0.08 \times 1.08^{30}}{1.08^{29}} = \$0.116/\text{kWh}$
- Assuming that locally-traceable O&M costs per kWh for PV are equal to the locally-traceable O&M costs for CCGT,¹⁷ but also assuming that because PV-related T&D benefits displace a commensurate amount of utility jobs assumed to be equal to this benefit (~0.5 cents per kWh), the net lifetime locally-traceable PV-CCGT difference is equal to $0.116 - 0.005 = \$0.111/\text{kWh}$
- Finally assuming that each PV job is worth \$75K/year after standard deductions – hence has a combined State and Federal income tax rate of 22.29% in PA and 22.67% in NJ¹⁸ -- and that each new job has an indirect job multiplier of 1.6,¹⁹ it can be argued that each PV MWh represents a net new-job related tax collection increase for NJ equal to a levelized value of $\$111/\text{MWh} \times 0.2267 \times 1.6 = \$40/\text{MWh}$, and a tax collection increase for PA equal to $\$111/\text{MWh} \times 0.2229 \times 1.6 = \$39/\text{MWh}$.

Long Term Societal Value

This item is an attempt to place a present-value \$/MWh on the generally well accepted argument that solar energy is a good investment for our children and grandchildren's well-being. Considering:

1. The rapid growth of large new world economies and the finite reserves of conventional fuels now powering the world economies, it is likely that fuel prices will continue rise exponentially fast for the long term beyond the 30-year business life cycle considered here.
2. The known very slow degradation of the leading (silicon) PV technology, many PV systems installed today will continue to generate power at costs unaffected by the world fuel markets after their guaranteed lifetimes of 25-30 years

One approach to quantify this type of long-view attribute has been to apply a very low societal discount rate (e.g., 2% or less, see [25]) to mitigate the fact that the present-day importance of long-term expenses/benefits is essentially ignored in business as usual practice. This is because discount rates are used to quantify the present worth of future events and that, and therefore, long-term risks and attributes are largely irrelevant to current decision making.

¹⁷ This includes only a fraction of the fuel costs – the other fraction being imported from out-of-state.

¹⁸ For the considered solar job income level, the effective state rate = 3.07% in PA and 3.54% in NJ and the effective federal rate = 19.83%. The increased federal tax collection is counted as an increase for New Jersey's taxpayer, because it can be reasonably argued that federal taxes are (1) redistributed fairly to the states and (2) that federal expense benefit all states equally.

¹⁹ indirect base multipliers are used to estimate the local jobs not related to the considered job source (here solar energy) but created indirectly by the new revenues emanating from the new [solar] jobs

Here a less controversial approach is proposed by arguing that, on average, PV installation will deliver, on average, a minimum of 10 extra years of essentially free energy production beyond the life cycle considered in this study.

The present value of these extra 10 years, all other assumptions on fuel cost escalation, inflation, discount rate, PV output degradation, etc. remaining the same, amounts to ~ \$25/MWh for all the cities/PJM hubs considered in this study.

Security Enhancement Value

Because solar generation is closely correlated with load in much of the US, including New Jersey and Pennsylvania [26], the injection of solar energy near point of use can deliver effective capacity, and therefore reduce the risk of the power outages and rolling blackouts that are caused by high demand and resulting stresses on the transmission and distribution systems.

The effective capacity value of PV accrues to the ratepayer (see above) both at the transmission and distribution levels. It is thus possible to argue that the reserve margins required by regulators would account for this new capacity, hence that no increased outage risk reduction capability would occur beyond the pre-PV conditions. This is the reason this value item above is not included as one of the directly quantifiable attributes of PV.

On the other hand there is ample evidence that during heat wave-driven extreme conditions, the availability of PV is higher than suggested by the effective capacity (reflecting of all conditions) -- e.g., see [27], [28], on the subject of major western and eastern outages, and [29] on the subject of localized rolling blackouts. In addition, unlike conventional centralized generation injecting electricity (capacity) at specific points on the grid, PV acts as a load modulator that provides immediate stress relief throughout the grid where stress exists due to high-demand conditions. It is therefore possible to argue that, all conditions remaining the same in terms of reserve margins, a load-side dispersed PV resource would mitigate issues leading to high-demand-driven localized and regional outages.

Losses resulting from power outages are generally not a utility's (ratepayers') responsibility: society pays the price, via losses of goods and business, compounded impacts on the economy and taxes, insurance premiums, etc. The total cost of all power outages from all causes to the US economy has been estimated at \$100 billion per year (Gellings & Yeager, 2004). Making the conservative assumption that a small fraction of these outages, 5%, are of the high-demand stress type that can be effectively mitigated

by dispersed solar generation at a capacity penetration of 15%,²⁰ it is straightforward to calculate, as shown below, that, nationally, the value of each kWh generated by such a dispersed solar base would be of the order of \$20/MWh to the taxpayer.

The US generating capacity is roughly equal to 1000 MW. At 15% capacity penetration, taking a national average of 1500 kWh generated per year per installed kW, PV would generate 225,000 GWh/year. By reducing the risk of outage by 5%, the value of this energy would thus be worth \$5 billion, amounting to \$20 per PV-generated MWh.

Solar Penetration Cost

It is important to recognize that there is also a cost associated with the deployment of solar generation on the power grid which accrues to the utility and to its ratepayers. This cost represents the infrastructural and operational expense that will be necessary to manage the flow of non-controllable solar energy generation while continuing to reliably meet demand. A recent study by Perez et al. [31] showed that in much of the US, this cost is negligible at low penetration and remains manageable for a solar capacity penetration of 30%. For utilities representative of the demand pattern and solar load synergies found in Pennsylvania, this penetration cost has been found to range from 0 to 5 cents per kWh when PV penetration ranges from 0% to 30% in capacity. Up to this level of penetration, the infrastructural and operational expense would consist of localized load management, [user-sited] storage and/or backup.²¹ At the 15% level of penetration considered in this study, the cost of penetration can be estimated from the Perez et al. study¹⁸ at \$10-20/MWh.

²⁰ Much less than that would have prevented the 2003 NE blackout. See [30].

²¹ At the higher penetration levels the two approaches to consider would be regional (or continental) interconnection upgrade and smart coupling with natural gas generation and wind power generation – the cost of these approaches has not been quantified as part of this study.

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Appendix 2: Detailed Results

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Pittsburgh

Table A4- 1. Technical results, Pittsburgh.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	475	475	475	475
Annual Energy Production (MWh)	716,621	631,434	595,373	892,905
Capacity Factor (%)	17%	15%	14%	21%
Generation Capacity (% of Fleet Capacity)	41%	43%	45%	48%
T&D Capacity (% of Fleet Capacity)	31%	32%	32%	32%

Table A4- 2. Value (\$/kW), Pittsburgh.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	813	719	678	1,011
O&M Cost Savings	396	350	331	493
Total Energy Value	1,209	1,069	1,009	1,503
Nonenergy				
Fuel Price Hedge	613	542	512	763
Generation Capacity Value	432	446	468	505
T&D Capacity Value	127	127	130	129
Market Price Reduction	696	718	715	740
Environmental Value	1,064	940	888	1,322
Economic Development Value	870	769	726	1,081
(Solar Penetration Cost)	-446	-394	-372	-554
Total Nonenergy Value	3,355	3,149	3,067	3,987
Other				
Security Enhancement Value	446	394	372	554
Long Term Societal Value	557	493	465	693
Total Other Value	1,003	887	837	1,247
Total				
All Components	5,568	5,105	4,913	6,737

Table A4- 3. Levelized Value (\$/MWh), Pittsburgh.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	41	41	41	41
O&M Cost Savings	20	20	20	20
Total Energy Value	61	61	62	61
Nonenergy				
Fuel Price Hedge	31	31	31	31
Generation Capacity Value	22	26	29	21
T&D Capacity Value	6	7	8	5
Market Price Reduction	35	41	44	30
Environmental Value	54	54	54	54
Economic Development Value	44	44	44	44
(Solar Penetration Cost)	-23	-23	-23	-23
Total	170	181	187	162
Other				
Security Enhancement Value	23	23	23	23
Long Term Societal Value	28	28	28	28
Total	51	51	51	51
Total				
All Components	282	293	300	274

Figure A4- 1. Value (\$/kW), Pittsburgh.

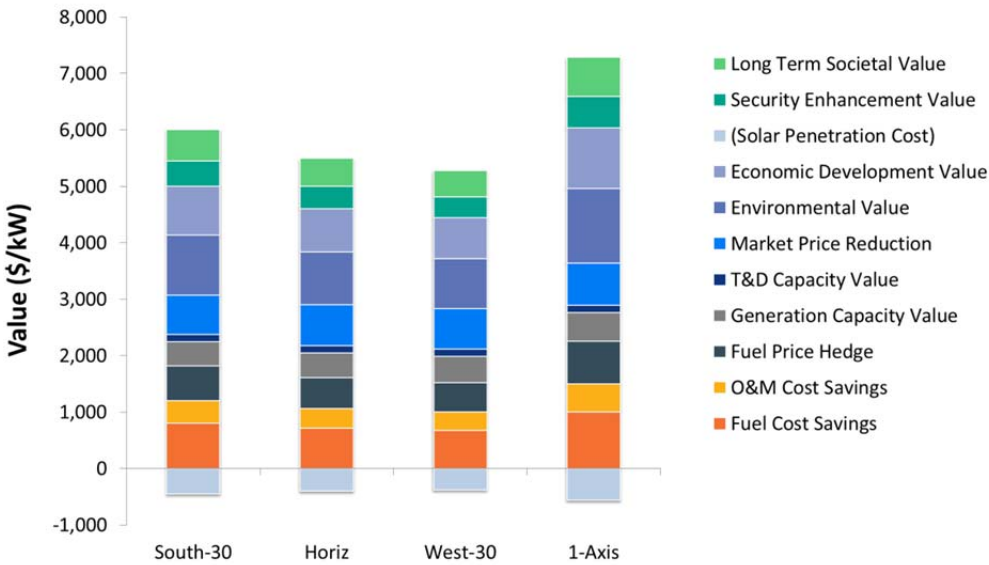
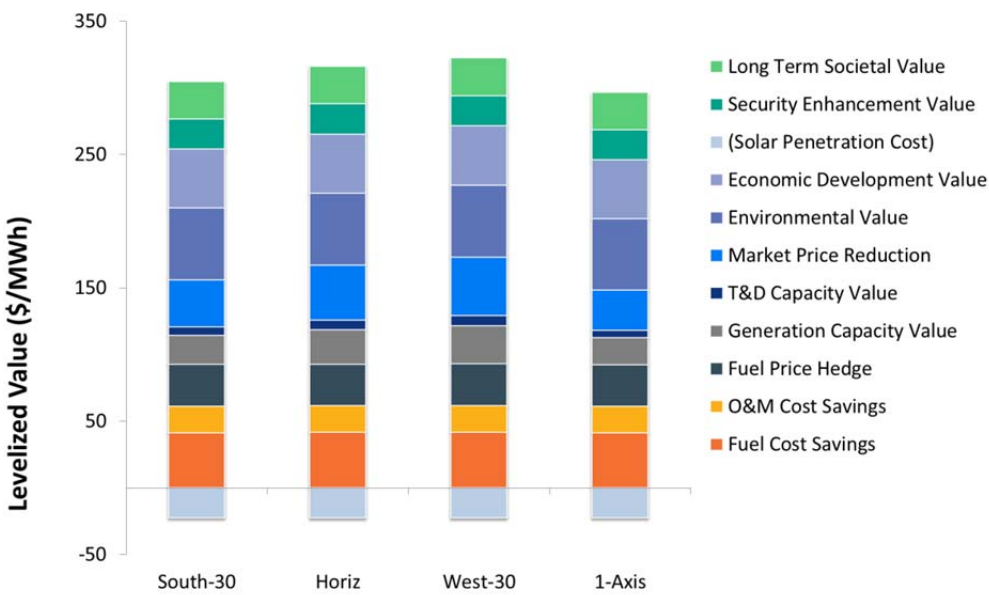


Figure A4- 2. Levelized Value (\$/MWh), Pittsburgh.



Scranton

Table A4- 4. Technical results, Scranton.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1129	1129	1129	1129
Annual Energy Production (MWh)	1,698,897	1,479,261	1,386,699	2,123,833
Capacity Factor (%)	17%	15%	14%	21%
Generation Capacity (% of Fleet Capacity)	28%	27%	26%	32%
T&D Capacity (% of Fleet Capacity)	14%	14%	14%	14%

Table A4- 5. Value (\$/kW), Scranton.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	706	616	577	880
O&M Cost Savings	344	300	281	429
Total Energy Value	1,050	916	859	1,309
Nonenergy				
Fuel Price Hedge	738	644	604	921
Generation Capacity Value	290	283	276	336
T&D Capacity Value	24	24	24	24
Market Price Reduction	1,206	1,193	1,157	1,311
Environmental Value	950	829	777	1,185
Economic Development Value	777	678	636	969
(Solar Penetration Cost)	-398	-348	-326	-497
Total Nonenergy Value	3,586	3,303	3,148	4,249
Other				
Security Enhancement Value	398	348	326	497
Long Term Societal Value	498	435	407	621
Total Other Value	896	782	733	1,118
Total				
All Components	5,532	5,001	4,740	6,676

Table A4- 6. Levelized Value (\$/MWh), Scranton.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	41	41	41	41
O&M Cost Savings	20	20	20	20
Total Energy Value	60	61	61	60
Nonenergy				
Fuel Price Hedge	42	43	43	42
Generation Capacity Value	17	19	19	15
T&D Capacity Value	1	2	2	1
Market Price Reduction	69	79	82	60
Environmental Value	55	55	55	55
Economic Development Value	45	45	45	45
(Solar Penetration Cost)	-23	-23	-23	-23
Total	206	218	222	196
Other				
Security Enhancement Value	23	23	23	23
Long Term Societal Value	29	29	29	29
Total	52	52	52	51
Total				
All Components	318	331	334	307

Figure A4- 3. Value (\$/kW), Scranton.

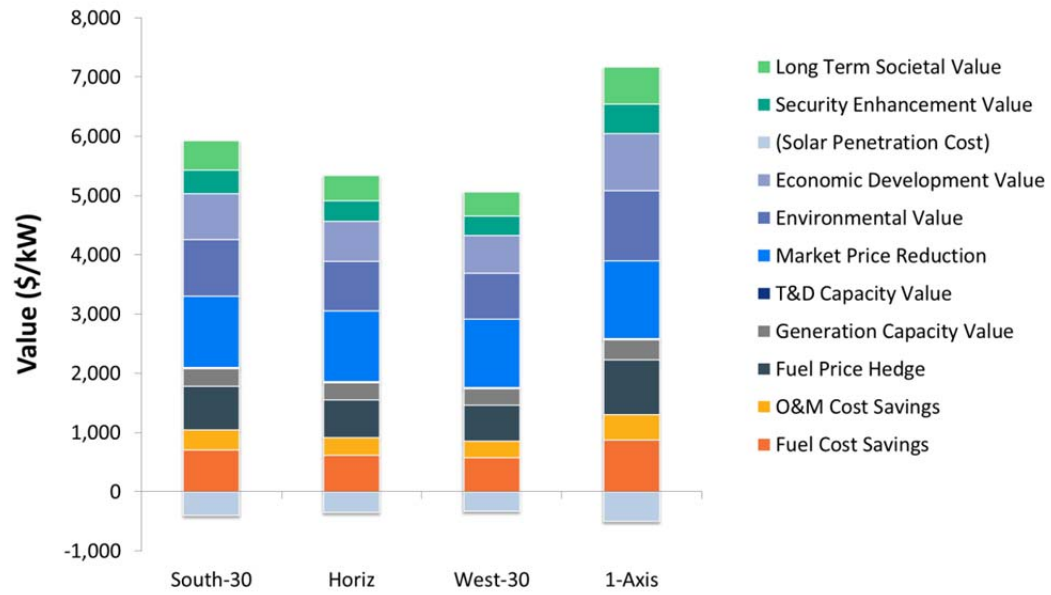
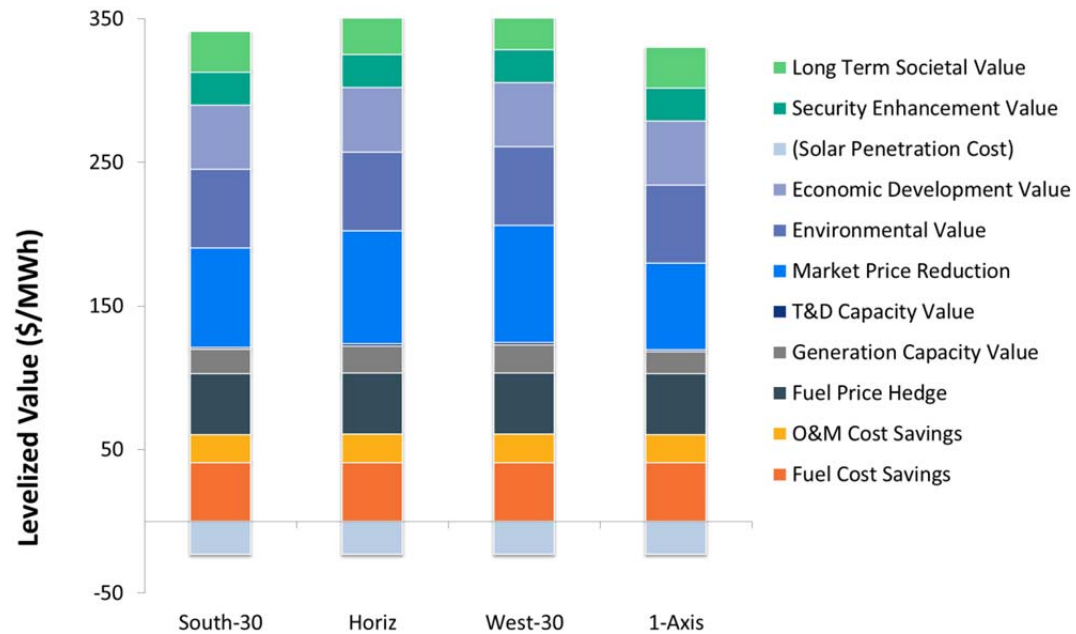


Figure A4- 4. Levelized Value (\$/MWh), Scranton.



Harrisburg

Table A4- 7. Technical results, Harrisburg.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1129	1129	1129	1129
Annual Energy Production (MWh)	1,809,443	1,565,940	1,461,448	2,274,554
Capacity Factor (%)	18%	16%	15%	23%
Generation Capacity (% of Fleet Capacity)	28%	27%	26%	32%
T&D Capacity (% of Fleet Capacity)	14%	14%	14%	14%

Table A4- 8. Value results (\$/kW), Harrisburg.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	751	652	608	942
O&M Cost Savings	366	318	296	459
Total Energy Value	1,117	969	904	1,401
Nonenergy				
Fuel Price Hedge	786	682	636	985
Generation Capacity Value	297	287	274	336
T&D Capacity Value	24	24	24	24
Market Price Reduction	1,241	1,224	1,171	1,335
Environmental Value	1,011	877	819	1,268
Economic Development Value	827	717	669	1,037
(Solar Penetration Cost)	-424	-368	-343	-532
Total Nonenergy Value	3,761	3,444	3,249	4,454
Other				
Security Enhancement Value	424	368	343	532
Long Term Societal Value	530	460	429	665
Total Other Value	954	827	772	1,196
Total				
All Components	5,832	5,240	4,925	7,051

Table A4- 9. Levelized Value results (\$/MWh), Harrisburg.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	41	41	41	40
O&M Cost Savings	20	20	20	20
Total Energy Value	60	61	60	60
Nonenergy				
Fuel Price Hedge	42	43	43	42
Generation Capacity Value	16	18	18	14
T&D Capacity Value	1	1	2	1
Market Price Reduction	67	76	78	57
Environmental Value	55	55	55	55
Economic Development Value	45	45	45	45
(Solar Penetration Cost)	-23	-23	-23	-23
Total	203	215	217	191
Other				
Security Enhancement Value	23	23	23	23
Long Term Societal Value	29	29	29	29
Total	52	52	52	51
Total				
All Components	315	327	330	303

Figure A4- 5. Value (\$/kW), Harrisburg.

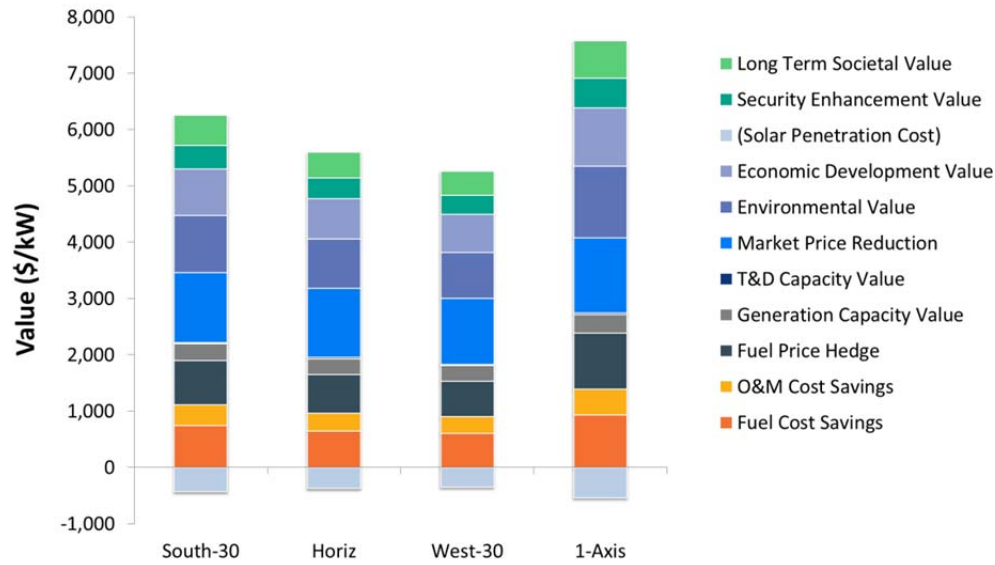
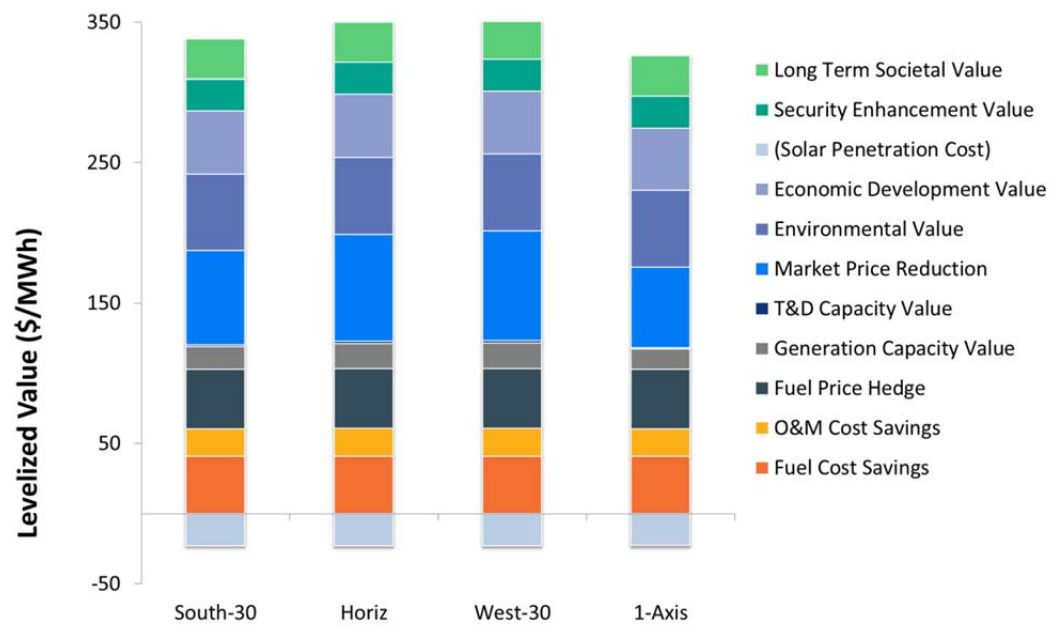


Figure A4- 6. Levelized Value (\$/MWh), Harrisburg.



Philadelphia

Table A4- 10. Technical results, Philadelphia.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1348	1348	1348	1348
Annual Energy Production (MWh)	2,339,424	1,991,109	1,847,394	2,943,101
Capacity Factor (%)	20%	17%	16%	25%
Generation Capacity (% of Fleet Capacity)	38%	40%	43%	46%
T&D Capacity (% of Fleet Capacity)	21%	21%	21%	21%

Table A4- 11. Value results (\$/kW), Philadelphia.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	706	602	559	886
O&M Cost Savings	344	294	273	432
Total Energy Value	1,049	896	832	1,318
Nonenergy				
Fuel Price Hedge	876	747	694	1,100
Generation Capacity Value	401	418	452	483
T&D Capacity Value	65	65	65	65
Market Price Reduction	1,013	1,027	1,018	1,103
Environmental Value	967	825	766	1,214
Economic Development Value	790	675	626	993
(Solar Penetration Cost)	-405	-346	-321	-509
Total Nonenergy Value	3,706	3,412	3,300	4,449
Other				
Security Enhancement Value	405	346	321	509
Long Term Societal Value	507	432	402	636
Total Other Value	912	778	723	1,145
Total				
All Components	5,667	5,086	4,855	6,912

Table A4- 12. Levelized Value results (\$/MWh), Philadelphia.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	38	38	38	38
O&M Cost Savings	18	19	19	18
Total Energy Value	56	57	57	56
Nonenergy				
Fuel Price Hedge	47	47	47	47
Generation Capacity Value	22	26	31	21
T&D Capacity Value	3	4	4	3
Market Price Reduction	54	65	69	47
Environmental Value	52	52	52	52
Economic Development Value	42	43	43	42
(Solar Penetration Cost)	-22	-22	-22	-22
Total	199	215	224	190
Other				
Security Enhancement Value	22	22	22	22
Long Term Societal Value	27	27	27	27
Total	49	49	49	49
Total				
All Components	304	321	330	295

Figure A4- 7. Value (\$/kW), Philadelphia.

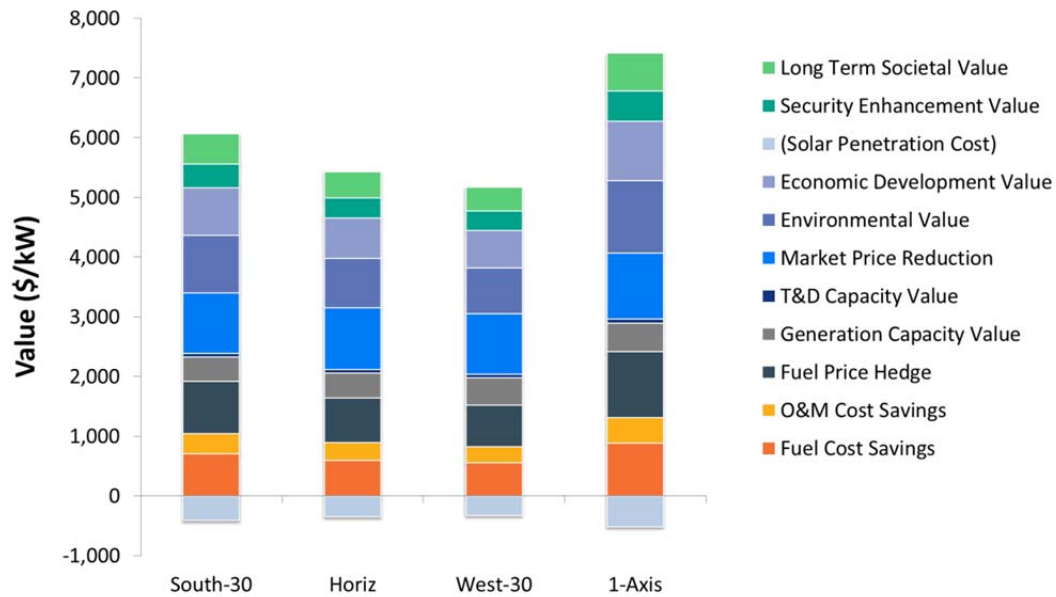
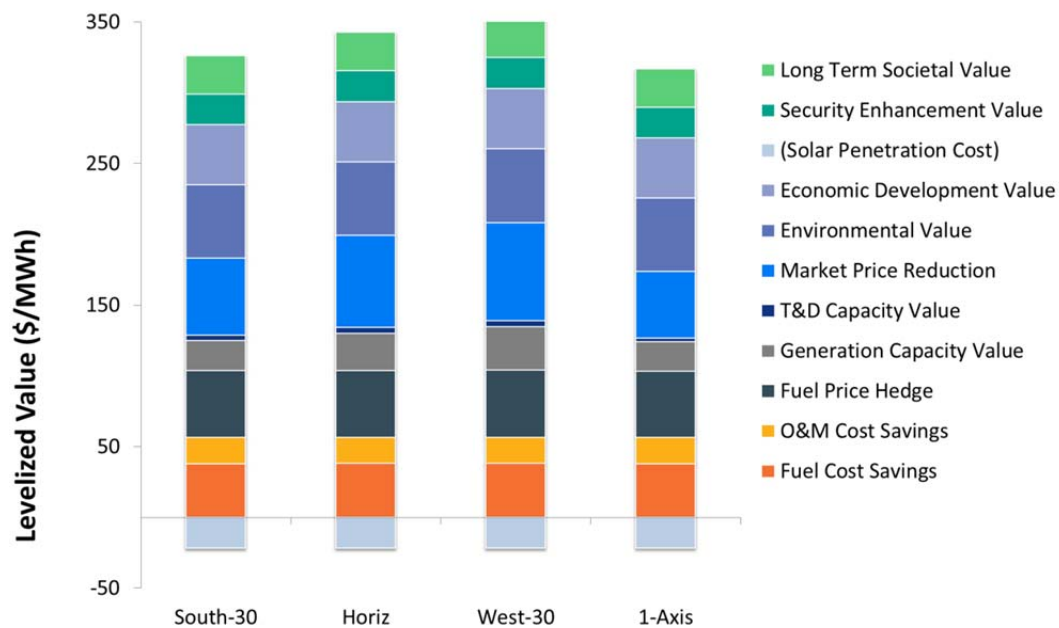


Figure A4- 8. Levelized Value (\$/MWh), Philadelphia.



Jamesburg

Table A4- 13. Technical results, Jamesburg.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	991	991	991	991
Annual Energy Production (MWh)	1,675,189	1,431,899	1,315,032	2,102,499
Capacity Factor (%)	19%	16%	15%	24%
Generation Capacity (% of Fleet Capacity)	45%	47%	51%	52%
T&D Capacity (% of Fleet Capacity)	29%	31%	29%	26%

Table A4- 14. Value results (\$/kW), Jamesburg.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	1,020	878	808	1,276
O&M Cost Savings	497	428	394	622
Total Energy Value	1,517	1,306	1,203	1,898
Nonenergy				
Fuel Price Hedge	586	504	465	733
Generation Capacity Value	468	496	531	546
T&D Capacity Value	23	25	23	21
Market Price Reduction	1,266	1,306	1,315	1,363
Environmental Value	560	482	444	700
Economic Development Value	1,097	944	870	1,373
(Solar Penetration Cost)	-549	-472	-435	-686
Total Nonenergy Value	3,451	3,285	3,212	4,050
Other				
Security Enhancement Value	549	472	435	686
Long Term Societal Value	686	590	544	858
Total Other Value	1,234	1,062	978	1,544
Total				
All Components	6,202	5,653	5,393	7,492

Table A4- 15. Levelized Value results (\$/MWh), Jamesburg.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	42	42	43	42
O&M Cost Savings	21	21	21	21
Total Energy Value	63	63	63	63
Nonenergy				
Fuel Price Hedge	24	24	24	24
Generation Capacity Value	19	24	28	18
T&D Capacity Value	1	1	1	1
Market Price Reduction	52	63	69	45
Environmental Value	23	23	23	23
Economic Development Value	45	46	46	45
(Solar Penetration Cost)	-23	-23	-23	-23
Total	143	159	169	134
Other				
Security Enhancement Value	23	23	23	23
Long Term Societal Value	28	29	29	28
Total	51	51	52	51
Total				
All Components	257	274	284	247

Figure A4- 9. Value (\$/kW), Jamesburg.

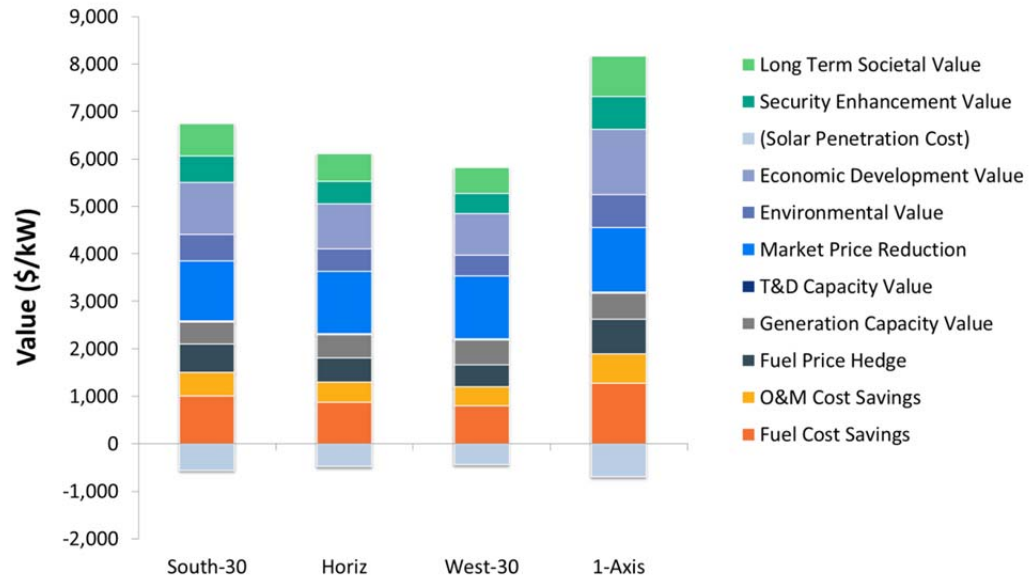
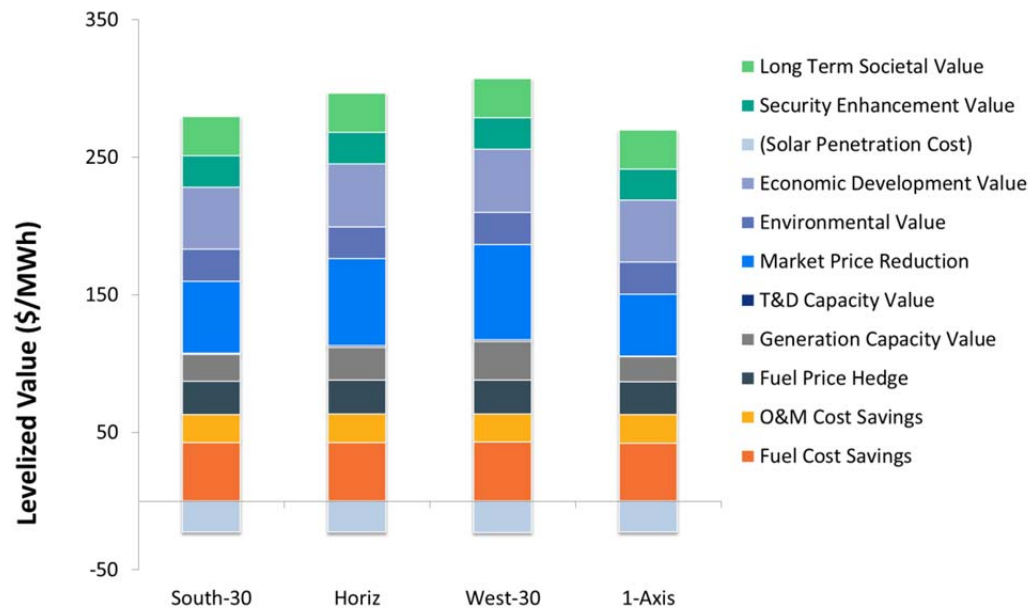


Figure A4- 10. Levelized Value (\$/MWh), Jamesburg.



Newark

Table A4- 16. Technical results, Newark.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	1640	1640	1640	1640
Annual Energy Production (MWh)	2,677,626	2,303,173	2,118,149	3,350,313
Capacity Factor (%)	19%	16%	15%	23%
Generation Capacity (% of Fleet Capacity)	45%	47%	51%	54%
T&D Capacity (% of Fleet Capacity)	56%	57%	57%	57%

Table A4- 17. Value results (\$/kW), Newark.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	709	612	564	885
O&M Cost Savings	345	298	275	431
Total Energy Value	1,054	911	839	1,317
Nonenergy				
Fuel Price Hedge	798	689	635	996
Generation Capacity Value	470	489	534	568
T&D Capacity Value	147	151	151	151
Market Price Reduction	927	959	958	989
Environmental Value	411	355	327	513
Economic Development Value	806	696	641	1,007
(Solar Penetration Cost)	-403	-348	-321	-503
Total Nonenergy Value	3,156	2,991	2,926	3,721
Other				
Security Enhancement Value	403	348	321	503
Long Term Societal Value	504	435	401	629
Total Other Value	907	783	721	1,132
Total				
All Components	5,117	4,685	4,486	6,170

Table A4- 18. Levelized Value results (\$/MWh), Newark.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	39	39	39	39
O&M Cost Savings	19	19	19	19
Total Energy Value	58	58	58	58
Nonenergy				
Fuel Price Hedge	44	44	44	44
Generation Capacity Value	26	31	37	25
T&D Capacity Value	8	10	10	7
Market Price Reduction	51	61	66	43
Environmental Value	22	23	23	22
Economic Development Value	44	44	44	44
(Solar Penetration Cost)	-22	-22	-22	-22
Total	173	190	202	163
Other				
Security Enhancement Value	22	22	22	22
Long Term Societal Value	28	28	28	28
Total	50	50	50	50
Total				
All Components	280	298	310	270

Figure A4- 11. Value (\$/kW), Newark.

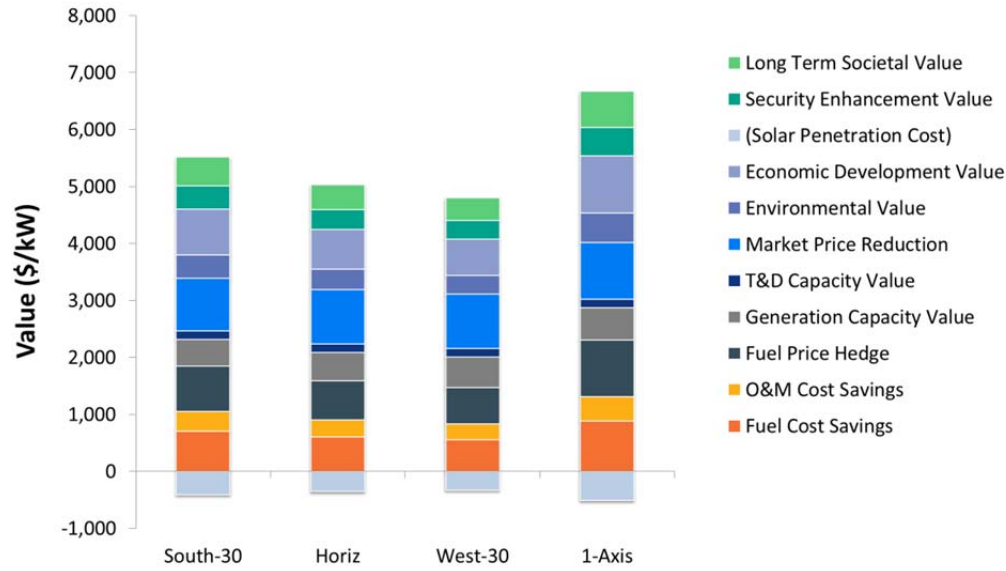
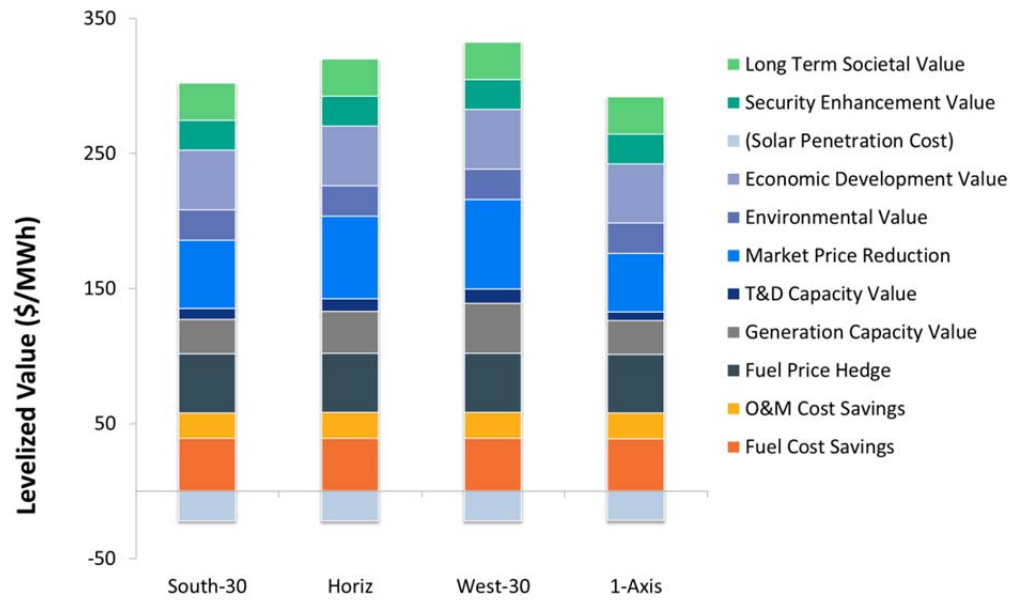


Figure A4- 12. Levelized Value (\$/MWh), Newark.



Atlantic City

Table A4- 19. Technical results, Atlantic City.

	South-30	Horiz	West-30	1-Axis
Fleet Capacity (MWac)	443	443	443	443
Annual Energy Production (MWh)	827,924	705,374	654,811	1,039,217
Capacity Factor (%)	21%	18%	17%	27%
Generation Capacity (% of Fleet Capacity)	46%	48%	54%	57%
T&D Capacity (% of Fleet Capacity)	36%	37%	38%	36%

Table A4- 20. Value results (\$/kW), Atlantic City.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	1,081	927	863	1,354
O&M Cost Savings	527	452	421	660
Total Energy Value	1,609	1,380	1,283	2,015
Nonenergy				
Fuel Price Hedge	662	567	528	828
Generation Capacity Value	478	503	569	600
T&D Capacity Value	49	51	52	49
Market Price Reduction	1,412	1,485	1,508	1,503
Environmental Value	596	511	475	746
Economic Development Value	1,168	1,002	932	1,463
(Solar Penetration Cost)	-584	-501	-466	-732
Total Nonenergy Value	3,781	3,618	3,598	4,458
Other				
Security Enhancement Value	584	501	466	732
Long Term Societal Value	730	626	582	914
Total Other Value	1,314	1,127	1,048	1,646
Total				
All Components	6,704	6,125	5,929	8,119

Table A4- 21. Levelized Value results (\$/MWh), Atlantic City.

	South-30	Horiz	West-30	1-Axis
Energy				
Fuel Cost Savings	41	42	42	41
O&M Cost Savings	20	20	20	20
Total Energy Value	61	62	62	61
Nonenergy				
Fuel Price Hedge	25	25	25	25
Generation Capacity Value	18	23	27	18
T&D Capacity Value	2	2	2	1
Market Price Reduction	54	66	73	46
Environmental Value	23	23	23	23
Economic Development Value	45	45	45	44
(Solar Penetration Cost)	-22	-22	-22	-22
Total	144	162	174	135
Other				
Security Enhancement Value	22	22	22	22
Long Term Societal Value	28	28	28	28
Total	50	50	51	50
Total				
All Components	256	274	286	247

Figure A4- 13. Value (\$/kW), Atlantic City.

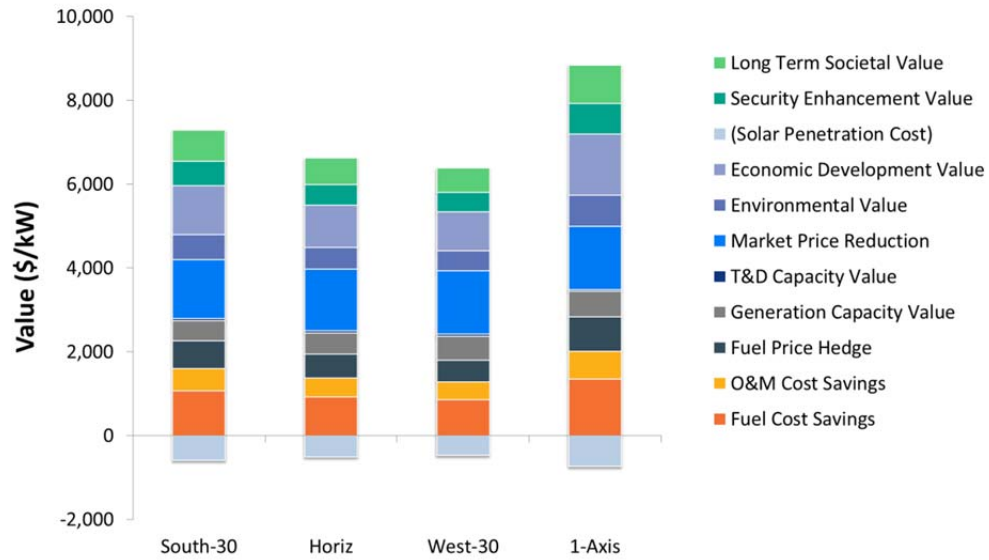


Figure A4- 14. Levelized Value (\$/MWh), Atlantic City.

