Conference Proceedings

ASES National Solar Conference 2016

San Francisco, CA, USA July 10-13, 2016

Assessing demand impact of solar capacity growth in Philadelphia

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Abstract

SolarPVAnalyst 2.0 is a tool, currently under development, that supports spatial decision making related to solar energy. This paper demonstrates a case study of SolarPVAnalyst 2.0, applied to assesses the impacts of PV siting and capacity growth on regional utility loads. In the absence of large-scale storage or other alternative forms of mediation, increased PV capacity is expected to lead to rapid changes in load that will require rapid response from traditional generation, and have been cited as an obstacle to successful growth of distributed rooftop solar generation. Rooftop segments identified by SolarPVAnalyst 2.0 were used to simulate deployment of PV installations throughout the city of Philadelphia. The installations were categorized by their approximate azimuth and tilt. Different solar growth strategies emphasizing a mix of solar deployment distributed among the cardinal directions azimuth groups were compared with regard to their impact on the regional net electricity demand, and load ramp rates throughout the year. Similar analyses enabled by SolarPVAnalyst could be used to predict the degree of challenge that increased growth of solar capacity poses to utility operation, and to create strategies to encourage development (e.g. through the use of targeted incentives) that could favorably mitigate the net demand impacts. Analyses can be multi-scalar, by examining spatially explicit load profiles at the city scale, neighborhood scale, or at the scale of an individual sub-station.

Keywords: *duck curve, spatially-resolved analysis, GIS, urban rooftop PV*

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1. Introduction

As renewable energy deployment expands throughout the United States, a variety of energy stakeholders will experience a rising need for analysis tools to assist with decision making. These stakeholders include grid operators, urban planners, policy makers, and government agencies to name only a few. Many decisions made by these stakeholders will require analyses that can be conducted on a variety of spatial and temporal scales. For example, a single rooftop PV array may have a negligible impact on grid operations, but broad adoption throughout a region may produce significant aggregate effects. As such, tools are needed to support these analyses, allowing decision makers to investigate operations on scales from rooftop to city to region. A spatial decision making tool, SolarPVAnalyst 2.0, is currently under development to meet this need.

SolarPVAnalyst 2.0 integrates solar modelling with Geographic Information System (GIS) information to display data to users via a mapping interface. The solar modelling is provided using the System Advisor Model (SAM) Simulation Core (National Renewable Energy Lab, 2014). Initial development has targeted ArcGIS as a platform to provide a spatial interface. While development is still ongoing, this paper presents a case study of the data analysis potential of this tool for rooftop solar in the City of Philadelphia.

2. Background

The case study analysis investigated in this paper considers the impacts of wide-scale solar deployment in the City of Philadelphia on net loads at a utility scale. As renewable penetration increases, increased impacts are expected on the electrical grid. The famously titled “Duck Curve” phenomenon describes the rapid daily swings in net load resulting from expected solar generation growth in California. In the case of California, overgeneration has the potential to result in both economic and reliability challenges (Lew et al., 2015). Some of these challenges can be met by accounting for the variability of renewables as an intrinsic part of the grid planning and operations (Denholm et al., 2015). A variety of strategies have also been proposed to mitigate these effects and to allow continued exploitation of solar energy opportunities, while maintaining grid stability. Schwartz et al. (2012) recommend that renewable siting be planned such that generation coincides with utility load profiles. Lazar (2016) specifically identifies orienting solar toward the west as a potential strategy for ameliorating high net load ramp rates, among other strategies such as strategically locating storage facilities and aggressive demand-side management. In this case study, we will consider the ability of deployment strategies based on array azimuth, as proposed by Lazar, to reduce ramp rates with high levels of solar PV deployment. Analysis of these types of strategies is an ideal application for a solar modelling tool with spatially-resolved capabilities.

As a demonstration, in order to estimate the effects of solar development on the net electric load, solar PV systems were modelled on each available rooftop segment within the City of Philadelphia. An automated procedure was used to identify rooftop segments based on Light Detection and Ranging (LIDAR) data, using a technique adapted from Bayrakci Boz et al. (2015). The workflow of the rooftop extraction model is shown in Figure 1.

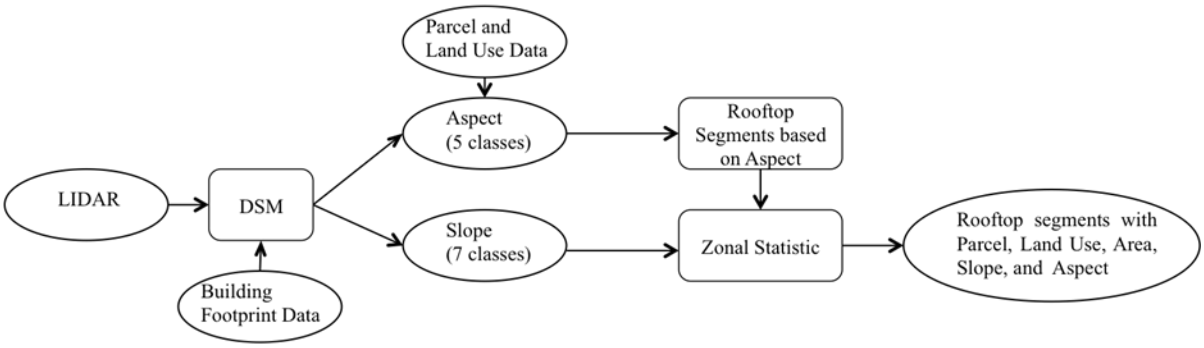

Fig. 1: Workflow of the ArcGIS model

Two key parameters are considered: slope(tilt) and aspect(azimuth). All geo-processing steps were conducted within the ArcGIS environment. Slope and aspect layers were created from the Digital Surface Model (DSM) using LIDAR dataset. First, the aspect (azimuth) layer were classified into five azimuth bins representing the four cardinal directions along with “flat” rooftops. Next, the slope layer was divided into seven classes, the first class representing flat roof. All rooftops with measured slope less than 10° were assumed to be flat. If the slope was greater than 60 degrees, the polygon was eliminated since it is not ideal for PV rooftop panels. Slope layer was grouped into 10° bins (e.g. 10° - 20°) with the midpoint used for analysis. Finally, rooftop segments were created based on aspect and slope for these segments were calculated using zonal statistic. Additionally, parcel numbers and land usage information were added. A summary of the rooftops identified in Philadelphia using this procedure is presented in Table 1.

Tab. 1: Rooftop segments identified by the LIDAR technique

Bin	Tilt Range	Aspect Range	# Surfaces	Area (m^2)	Avg. Area per Surface (m^2)
Flat	<10°	Any	836,581	27,236,240	32.6
North	10°-60°	315° - 45°	121,357	4,466,487	36.8
East	10°-60°	45° - 135°	79,479	3,314,164	41.7
South	10°-60°	135° - 225°	78,032	3,385,850	43.4
West	10°-60°	225° - 315°	78,871	3,364,420	42.7
TOTAL			1,194,320	41,767,161	35.0 (avg)

Load data for PECO (the utility serving Philadelphia) was obtained from PJM (PJM, 2016), the Regional Transmission Organization serving the region including Philadelphia. Hourly load data for 2014 were used to compute the average daily load for each month from that year. PV systems were modelled on each rooftop using SAM, with average daily AC production for each month serving as an output. Array wiring was computed by stringing together modules, but remaining within the chosen inverter string voltage rating. Complete systems were then sized by generating an integer number of strings capable of maximally filling the rooftop area. The inverter capacity was sized to be 15% greater than the DC rated capacity of the resultant array. Typical Meteorological Year (Wilcox, 2012) data for Philadelphia was used to represent the solar resource. A workflow of this process is shown in Figure 2.

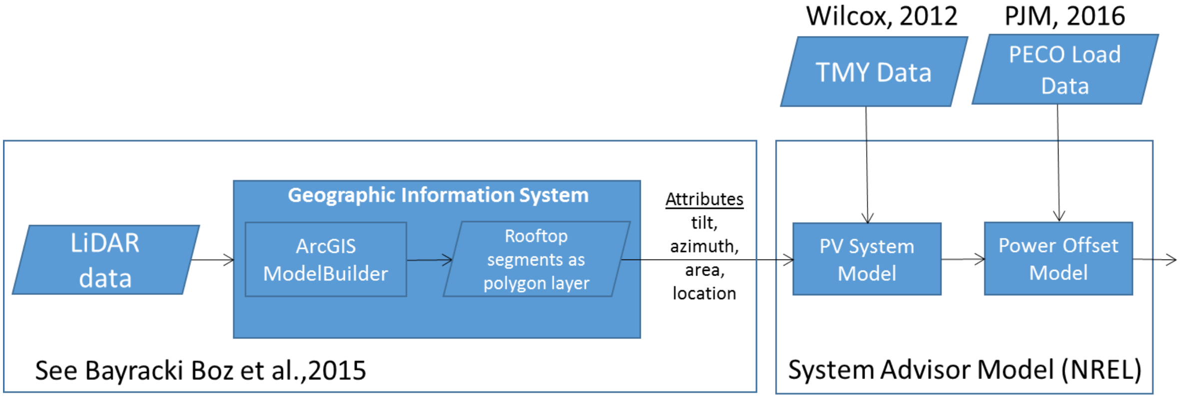

Fig. 2: Workflow of the process for computing net utility load

3. Results

The total theoretical energy production potential, accounting for all modelled systems, is estimated to be as much as 19% of the total PECO demand (i.e., 42,000,000 MWh/year). The total energy results for systems modelled in each direction are summarized in Table 2. Flat rooftops account for the largest amount of energy, in that they consist of approximately 6 times as much surface area as rooftops facing any other direction. To compare the bins directly, we compute the annual AC per unit system area, with results coinciding closely with expectations based on incidence angle effects. Flat, east- and west-facing systems produce about the same amount of energy per unit area, while north-facing systems underperform and south-facing systems perform above this mark.

Tab. 2: Annual energy produced by each azimuth bin

Bin	Tilt Range	Aspect Modelled	Area (m^2)	Annual AC (MWh)	Ann AC/area (kWh/m^2)
Flat	<10°	Any	27,236,240	5,170,000	190
North	10°-60°	0°	4,466,487	577,000	129
East	10°-60°	90°	3,314,164	596,000	180
South	10°-60°	180°	3,385,850	743,000	219
West	10°-60°	270°	3,364,420	602,000	179
TOTAL			41,767,161	7,688,000	179 (avg)

The month-by-month loads can be best visualized as a contour plot, shown in Figure 3. The minimum loads occur overnight, with fall and spring having relatively light loads. Winter is characterized by morning (~10AM and evening (~7PM) peaks, while summer is characterized by a very large peak that lasts afternoon into evening. Interestingly, the ramp rates appear to be relatively constant throughout the year as shown in Figure 4. This indicates that although the absolute loads may increase or decrease throughout the year, the rate at which changes in load must be accommodated does not.

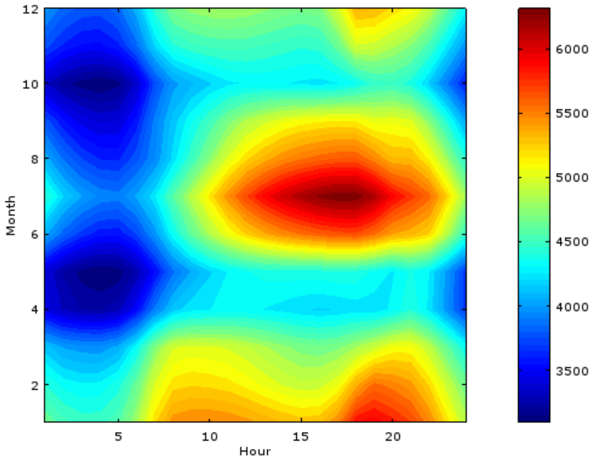

Fig. 3: PECO 2014 average daily loads by month. Color axis units are MWh.

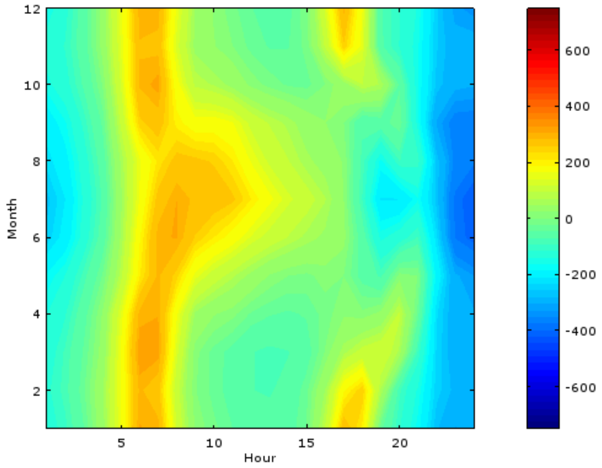

Fig. 4: Ramp rates for PECO 2014 average daily loads by month. Color axis units are MWh per hour.

When investigating the effect of solar on the known loads, we considered the variation associated with collectors in each of the azimuth bins. Figure 5 shows the daily variations in energy density for collectors facing each direction. Flat, north and south collectors all produce with approximately the same daily shape, with north-facing collectors having a much lower energy density. East-facing collectors favor morning production, resulting in steep-sloping morning ramp rate with a shallow evening. West-facing collectors favor evening production and follow an opposite trend; their morning production ramps up slowly, while dropping off quickly in evening. These variations have implications on the use of collector orientation as a strategy for mitigation of duck curve ramp rate effects.

In addition to favoring collector cardinal direction, an additional strategy was investigated. Figure 6 shows a comparison of south-facing collectors with a scaled mix of east and west (E&W) facing collectors. Scaling was achieved by requiring that the annual energy produced by south facing collectors match that produced by the E&W combination. While winter is similar between both strategies, it is evident that the E&W combination results in broadened production both toward morning and evening in spring and summer, with reductions in the midday peak. This may be advantageous in attempting to reduce the morning and evening ramp rates exhibited by the duck curve.

We can directly compare the effect of different solar deployment strategies on ramp rates. Figure 7 shows the average ramp rates throughout the entire year for each of the solar strategies. The effects seen on this average graph are similar to those observed when viewing individual months. As compared to the “real” orientation case, using the mixture of E&W deployment strategy mitigates the morning and evening ramp rates slightly. East-only and west-only cases provide different advantages; east-only reduces the evening ramp rate for most cases, but at the expense of increases in the morning ramp rate, while west-only has the opposite effect. The increase in evening ramp rate for west-only case is significant. We can compare the effects on a month-by-month basis looking contour plots of the net-load ramp rate for each of the strategies, as shown in Figure 8.

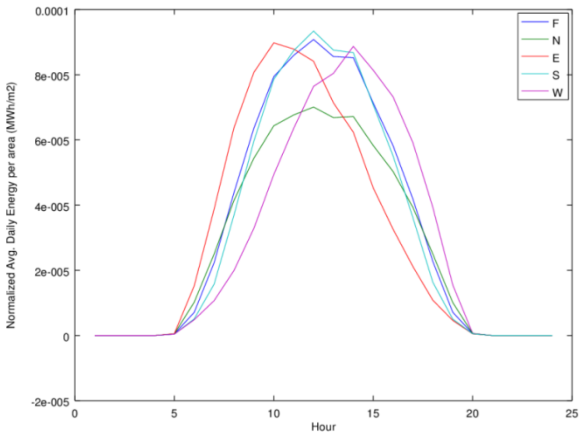

Fig. 5: Daily AC production per collector area for each of the collector azimuth bins.

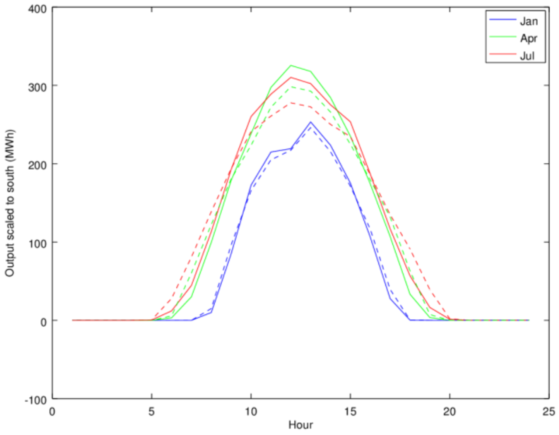

Fig. 6: Comparison of south (solid) and E&W-facing (dashed) collector orientation strategies for three months

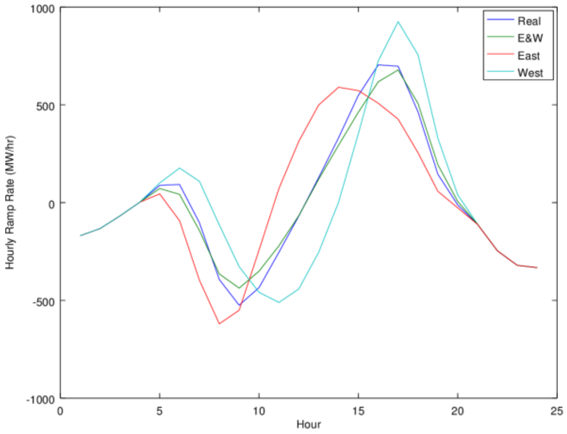

Fig. 7: Average daily ramp rates for each of the solar strategies.

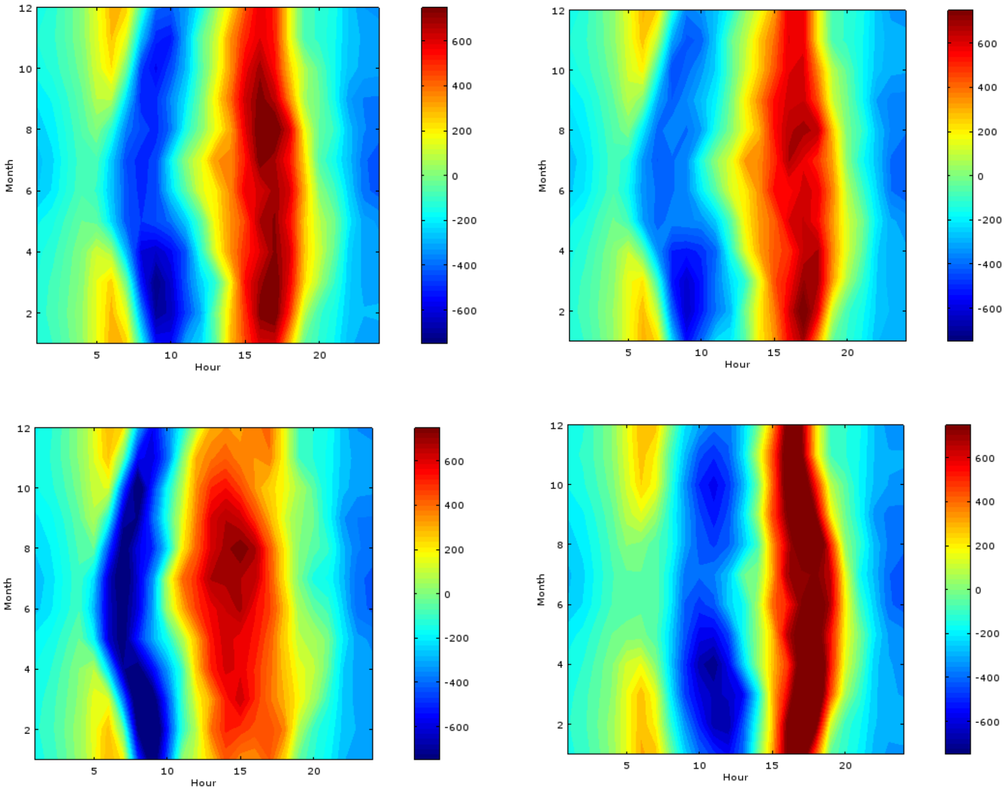

Fig. 8: Comparison of ramp rates for different solar strategies, all scaled to match the real orientation output level. (Top Left)-Real rooftop orientations, (Top Right)-E & W scaled, (Bottom Left)-East only, (Bottom Right)-West Only

Considering these results, it appears that for the City of Philadelphia, when installing solar on 100% of rooftops, only the E&W and east-only strategies provide observable benefits as compared to the natural orientations of the rooftops. While it is possible that other strategies demonstrate benefits at lower rates of solar adoption and at different scales (e.g., at the sub-station level), the present results indicate that promoting the dominance of west-facing solar has the effect of increasing the afternoon ramp rate while providing very little benefit in the morning, outside of shifting the ramp rate peak to later hours. Use of an E&W combination slightly reduces both morning and afternoon ramp rates, while east-only solar mitigates the evening ramp rate at the expense of morning. These results may provide some insight for utility planning purposes, in that during situations requiring curtailment or other drastic control measures, targeting specifically oriented arrays may provide sufficient control authority while affecting fewer arrays.

4. Conclusion

Increased deployment of solar energy has the potential to introduce challenges to grid operations and reliability. Anticipating and planning for these challenges is a possibility from a technological standpoint, but spatially resolved analysis tools are necessary to support the planning process. In this study, we demonstrate the ability of such a tool to provide information on net electrical loads in the City of Philadelphia resulting from an extremely high level of rooftop solar PV development. Comparisons were made between strategies for solar deployment, comparing installing solar at actual rooftop orientations with installing exclusively east- and west-facing arrays. The comparison shows that the E&W strategy has the potential to slightly reduce morning and evening ramp rates associated with the duck curve in the PECO region. While this orientation comparison demonstrates the ability of this tool to provide relevant data to decision makers with a stake in solar energy, other comparisons are facilitated by the tool as well. A few examples include identification of ideal levels of deployment with respect to reductions in ramp rate, identification for strategies for targeting of specific problem times in the net load profile, or planning of potential economic incentives to achieve a desired load profile based on solar development. Further development of spatially-resolved decision making tools for renewable energy is needed to provide avenues for these questions to be investigated and answered.

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