Solar Renewable Energy Credit Price Volatility and Investment Returns

Have Policies Stranded Capital Investment?

SOMAYEH YOUSSEFI
University of Maryland

PATRICK L. GURIAN
Drexel University

Pennsylvania is one of a number of U.S. states that provide incentives for the generation of electricity by solar energy through Solar Renewal Energy Credits (SRECs). This article develops a return on investment model for solar energy generation in the PJM (mid-Atlantic) region of the United States. Model results indicate that SREC values of roughly $150 are needed for residential scale systems to break even over a 25-year project period at 3% interest. Market prices for SRECs in Pennsylvania have been well below this range from late 2011 through the first half of 2016, indicating that previous capital investments in solar generation have been stranded as a result of steep declines in the value of SRECs. A simple conceptual supply and demand model is developed to explain the sharp decline in market prices for SRECs. Also discussed is a possible policy remedy that would add unsold SRECs in a given year to the SREC quota for the subsequent year.

Over the last decade, interest in generating green electricity has increased, however, renewable energy sources have high up-front costs. To incentivize renewable electricity generation, a number of U.S. states have developed *renewable portfolio standards* (RPS). Renewable Portfolio Standards require electricity companies to generate a growing quantity of their energy from renewables. Each state has developed renewable

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energy targets. The quantity of electricity generated from qualifying sources is tracked by *renewable energy credits* (REC), which are tradable commodities, allowing electricity utilities to meet their RPS requirements by purchasing power from generators using renewable sources.

In the United States, RPS policies have remarkably expanded the application of wind energy (Menz and Vachon 2006). The reason for slower growth in solar electricity is the high initial investment required for photovoltaic (PV) systems. To alleviate the high capital cost of PV systems and make them competitive with other renewable technologies, most states with RPS laws have initiated set-asides for solar generation. A solar set-aside requires that a certain amount of electricity consumed in a state must be generated by PV facilities. If a utility provider fails to meet set-aside obligations, it must pay a penalty called the *solar alternative compliance payment* (SACP). These penalties are aggregated by the government and invested on research to expand renewable energy usage (Holt and Wiser 2007).

RECs specified for solar energy are called solar renewable energy credits or certificates (SRECs). To trade SRECs some states have set up viable markets, which are in their initial stages. While a few studies of these markets have been undertaken (Burns and Kang 2012), the Pennsylvania SREC market has not been studied in depth. In its initial years it grew considerably; however, its early success was not stable and was followed by a dramatic collapse in SREC prices and its solar industry (Solar Foundation 2016). Exploring Pennsylvania's market in depth can provide insights into solar markets' structure and help establish more functional markets. Thus, the objective of this article is to explore the Pennsylvania SREC market and effective returns on investment in solar electricity generation, given historical market fluctuations in SREC value. The implications of proposed plans to strengthen the Pennsylvania market are also discussed.

The preceding introduction is followed by five main sections: (1) a background overview; (2) a history of the Pennsylvania SREC market, its current status, and the challenges it faces; (3) the cost estimation and economic returns of a typical PV system; (4) the results of the analysis and strategies to improve the stability of the market; and (5) the Conclusion.

Background

Support mechanisms for renewable resources were first introduced in Europe through feed-in-tariff programs in the 1980s. FIT programs incentivize various energy production technologies according to their cost. Furthermore, the government ensures purchase of all produced green energy by signing long-term contracts with producers. As a result solar electricity production, which is relatively expensive, is well supported in Europe (Lipp 2007; Dusonchet and Telaretti 2010). In the United States, however, green energy production is supported through RPS, which is implemented at the state level. There is no requirement for long-term contracts in the RPS program, although the requirement that a growing percentage of consumed electricity be produced from renewable resources should provide ongoing incentives over time. As of 2016, 29 states, the District of Columbia, and Puerto Rico have instituted a renewable portfolio standard (RPS). States are free to structure their RPS program according to their specific goals and associated characteristics. For instance, while New Jersey does not have any constraints on the capacity of the PV systems, Pennsylvania requires that PV systems be smaller than 50 kW to be eligible to register and trade their generated electricity in the market.

Several researchers have discussed advantages and disadvantages of RPS programs and examined its potential to advance use of renewable energies (Agnolucci 2007; Bergek and Jacobsson 2010; Buckman 2011; Butler and Neuhoff 2008; Cory and Swezey 2007; Finon and Perez 2007; Kildegaard 2008; Lauber 2004; Lipp 2007; Michaels 2008; Midttun and Gautesen 2007; Mitchell, Bauknecht, and Connor 2006; Pourhashem et al. 2013; Toke 2005; Wiser, Porter, Bolinger, et al. 2005; Wiser, Porter, and Grace 2005). Lauber (2004) compared RPS policies and feed-in-tariff models. He concluded that while RPS is beneficial, it does not contribute to the technological assortment and as indicated by Buckman (2011) it lacks "dynamic efficiency." Similarly, Meyer and Koefoed (2003) found that most RPS policies do not differentiate between renewable resources, therefore, they do not provide much support for energy sources that are currently high cost but have potential to achieve economic competitiveness over time, such as PV. However, Langniss and Wiser (2003) reviewed RPS application in Texas and concluded that if an RPS is carefully designed and implemented, it can proliferate solar electricity generation at a low cost. Still, the success of RPS in Texas is primarily due to wind power, and solar electricity has a very small role in the success of Texas RPS policies.

To promote more expensive technologies such as PV and make them competitive with other renewable technologies, RPS allows for dedicated support mechanisms. Credit multipliers and solar carve-out (or set-aside) are two common programs adopted by 16 states, as well as the District of Columbia. A solar set-aside obligates that a certain amount of electricity consumed in a state must be generated by PV facilities. However, credit multipliers encourage PV installation by devoting a higher credit to RECs generated by PV facilities compared with other renewable resources. As mentioned earlier, RECs specified for solar energy are called *solar renewable energy credits* or *certificates*

(SRECs). An SREC is equal to one-megawatt hour of green electricity generated by utility companies, homeowners, or by any private entity, and it can be traded in a solar market. Unlike tax credit or cash rebates that compensate individual investment near the time of the PV installation SRECs shift the return on solar investment to the future. One major concern about SRECs is that they do not have a fixed value. Thus, changing prices makes financing projects supported by SRECs risky.

To date eight states (Delaware, Massachusetts, Maryland, North Carolina, New Hampshire, New Jersey, Ohio, and Pennsylvania) and the District of Columbia have set up markets and associated tracking facilities to trade SRECs. In these markets, commercial solar energy generators, as well as individual PV installers can sell their SRECs to utility providers. To be permitted to participate in such markets, generators are required to get a participation number and then register in an eligible market. Furthermore, they are required to install a monitoring device to allow counting of their generated SRECs. One drawback of such markets is that residential PV installers usually do not possess the knowledge to perform successfully in these markets. However, there are SREC brokers that can act as intermediaries. States with no SREC market (New York, Illinois, Indiana, Kentucky, Michigan, Tennessee, Virginia, Wisconsin, and West Virginia) can sell their SRECs in out-of-state eligible markets. For instance, solar investors in West Virginia are allowed to participate in the Pennsylvania market.

In addition to SRECs, there are other support mechanisms for PV installations. For example, the federal investment tax credit (ITC) is a nonrefundable personal tax credit that only residential PV owners can apply for. Since January 1, 2006, the federal government gives residential PV installers a credit equal to 30% of their PV systems' expenditures up to $500 per 0.5 kW of power (DSIRE 2014a). The ITC will expire in December 2016. Furthermore, some states, like Massachusetts and North Carolina, offer PV installers tax credits, and cash rebates, which are a dollar amount paid per watt-capacity of the PV system. However, cash rebates usually suffer from lack of funding. They are offered on a first-come, first-served basis and are not guaranteed.

SREC markets are at their initial stages in the United States and few studies have been completed on them. Burns and Kang (2012) presented a short history of SREC markets and current regulations in eight U.S. states. They performed a financial analysis for a residential case study to compare the returns on investment in existing SREC markets. However, they left Pennsylvania and North Carolina out of their economic analysis due to the high uncertainty of SREC markets there. Gual and Carely (2012) investigated the effectiveness of solar set-asides in North Carolina. They concluded that obscurity in the

SREC market and uncertainty associated with current and future SREC prices hinder the advancement of solar PV systems in North Carolina.

At the initial years of its SREC market, Pennsylvania had a secure solar market and achieved notable growth in its local solar industries. However, its early success was not stable and was followed by a dramatic collapse in SREC prices and its solar industry (Solar Foundation 2016). Therefore, exploring Pennsylvania's market in depth can provide insights into solar markets' structure and help establish more functional markets. Furthermore, the Pennsylvania market has not been considered by either Gual and Carely or Burns and Kang.

The Pennsylvania SREC Market

The Pennsylvania RPS program is entitled *Alternative Energy Portfolio Standard* (AEPS) and was created by Senate Bill 1030 on November 30, 2004. The solar set-aside program took effect in 2007 as a result of Bill 1203. Pennsylvania aims for 18% green electricity by 2021, and its solar set-aside is 0.5%. Pennsylvania established its solar market in 2009 with the Public Utility Commission and the Pennsylvania Department of Environmental Protection responsible for implementation of the AEPS act (DSIRE 2014a). SRECs generated in Pennsylvania are valid in the year generated and the next two years.

There are several regional electricity transmission grids in the United States, and Pennsylvania is part of the PJM (mid-Atlantic) region. In addition to Pennsylvania, PJM Interconnection is responsible for Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Tennessee, Virginia, West Virginia, and the District of Columbia. Pennsylvania's SREC market is an open market, and any facility smaller than 50 kW that is located in the PJM region can register to trade its SRECs in Pennsylvania's market. However, Pennsylvania's solar electricity generators can sell their SRECs only in Pennsylvania and Ohio. In the PJM region, New Jersey was the first state to initiate an SREC market (in 2005) and has the highest solar target (> 4 GW by 2025). Although Pennsylvania almost has the highest electricity consumption (24%) in the PJM region, it has the smallest target for solar electricity (0.5% by 2021; see Figure 1) and its SREC's requirement is the smallest in the region.

As noted earlier, SACP is a support mechanism to stabilize SREC prices. SACP can act as a price ceiling, and if it is high enough, it could increase the SREC demand and stimulate PV installment. To benefit from SACP supportive potentials, many states have defined a long-term schedule for SACP values. However, Pennsylvania does not have a pre-fixed value for the SACP.

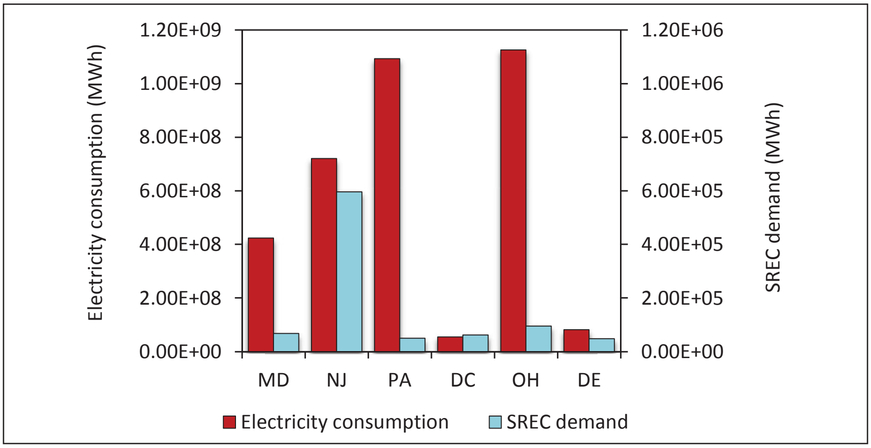

Figure 1. Electricity Consumption and SREC Demands in PJM Region. Pennsylvania has approximately the highest electricity consumption in the mid-Atlantic region, but it has a very small solar market and it aims for 0.5% solar electricity by 2021. To find electricity consumption for each state, electricity consumption per capita is multiplied by its population. Note that scales of the two axes are not similar. *(H. K. Trabish, "Which State Has the Best Solar REC Market? GreenTech Solar," 2012, available at www.greentechmedia.com/articles/read/Which-State-Has-the-Best-Solar-REC-Market. Electricity consumption per capita from U.S. Energy Information Administration, "Total Energy Consumed Per Capita," 2016, available at www.eia.gov/state/rankings/?sid=PA#series/12. State population from U.S. Census Bureau, available at www.census.gov/popest/data/national/totals/2015/index.html.)*

It is calculated at the end of the compliance year (June 1 to May 31), and it is approximately twice the average SAEC (SREC) price traded during that year. Therefore, it is very difficult to predict SREC prices in Pennsylvania.

SREC price trends for markets in the PJM region are shown in Figure 2. In 2011, SREC values in the Pennsylvania market began to decrease and dropped from an average of $290 to $10. The Pennsylvania House of Representatives reacted and Rep. Chris Ross introduced House Bill 1580 on October 3, 2011, to strengthen the Pennsylvania SREC market. The amendment would have modified the eligibility criteria and not allowed out-of-state SRECs to be traded in Pennsylvania. Furthermore, the bill required an increase in the state's solar carve-out for the period from 2012 to 2015 in order to stabilize the SREC market and resolve the oversupply issue (SRECTrade 2016d). The bill's implementation would have increased electricity prices and would have imposed approximately $120 million in costs distributed among all residential and commercial power users in Pennsylvania. However, this increase would not have exceeded fourteen cents per Pennsylvanian homeowner over five years (Gaul and Carley 2012). Still, utility providers did not support the bill and it failed, as did a similar bill, Senate Bill 1350, also in the 2011–2012

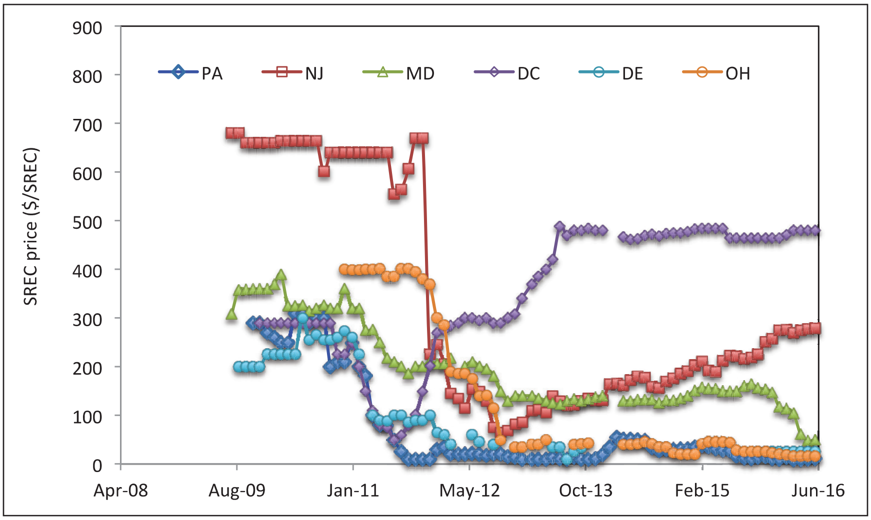

Figure 2. SREC Price Trends in PJM Region. *(From Flettexchange, available at www.markets.flettexchange.com/pennsylvania-srec/; SRECTrade, "PA Market Update," available at www.srectrade.com/blog/tag/pa-srec.)*

session. Consequently, Pennsylvania's SREC prices continued to decrease and reached $15 by the end of 2012. For energy year 2013 (June 2012 to May 2013), SRECs generally fluctuated between $10 and $20. There was a rally in early 2014 with prices in the $50–$60 range in the first half of the year but falling into the $30–$40 range in the later part of the year and into early 2015. Prices eroded over the course of 2015 and were at or near $10 for the first half of 2016 (Flettexchange 2016; SRECTrade 2016a). House Bill 100, which had been introduced in the 2013–2014 session and the 2015–2016 session, would also increase the SREC requirements for Pennsylvania (Pennsylvania General Assembly 2016; Noucas 2013).

One of the reasons for the Pennsylvania market oversupply is the coincident emergence of different incentive programs. In 2009, when the Pennsylvania SREC market was instituted, there were two other major support programs incentivizing PV installations: the federal investment tax credit (ITC) and the Pennsylvania Sunshine Program. The ITC returns PV installers 30% of their initial investment in the form of a tax credit. The Pennsylvania Sunshine Program was initiated in 2009, and it returns 35% of the PV system installation cost in the form of rebate (DSIRE 2014b). The overlapping of these generous incentive programs as well as high SREC prices jump-started the PV installation, which caused too many SRECs to be generated, resulting in eventual oversupply of the market.

Furthermore, Pennsylvania's RPS requirement for PV installation is very small, and as is shown in Figure 3, the capacity of PV systems installed greatly exceeded the RPS mandated capacity for 2015. By the end of 2016, increases in the RPS requirement were forecast to slightly exceed installed capacity but only if no new capacity were built. The prevailing SREC price of $7 at the close of 2016 indicated that the market was still oversupplied (SRECTrade 2017). Given that Pennsylvania has the smallest SREC requirement in the PJM region and allows out-of-state SRECs to be used to meet the Pennsylvania requirement, its market is very sensitive to oversupply.

When the generation capacity for SREC exceeded what the RPS law required utility companies to buy, there was a dramatic drop in SREC prices. This may be understood by considering the shape of the supply and demand curves for SRECs. As shown in Figure 4, utilities will pay p* (where p* is the

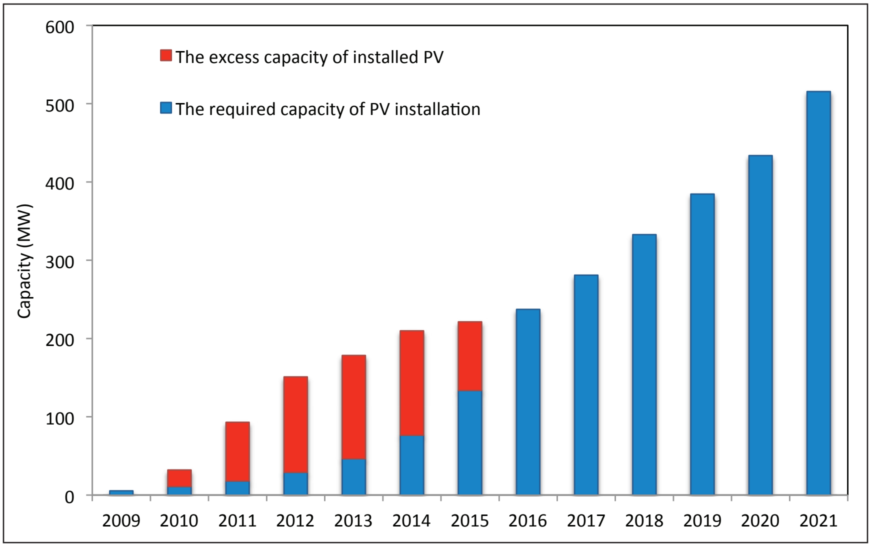

Figure 3. Pennsylvania Solar RPS Requirement (SRECTrade 2016c) and Current Installation Capacity (SRECTrade 2016b, 2016e, 2016f, 2016g, 2016h). The overlapping of generous incentive programs (the federal tax credit and Solar Sunshine rebate program) and high SREC prices caused a short-term boom in PV system installation. *(From SRECTrade, "Pennsylvania," available at www.srectrade.com/srec_markets/pennsylvania; SRECTrade, "PA Market Update," available at www.srectrade.com/blog/tag/pa-srec; SRECTrade, "SREC Markets Report: February 2013," available at www.srectrade.com/blog/capacity-summary/srectrade-srec-markets-report-february-2013; SRECTrade, "SRECTrade SREC Markets Report," available at www.srectrade.com/blog/2015/12; SRECTrade, "Pennsylvania Update: SRECTrade Markets Report," available at www.srectrade.com/blog/2015/12; SRECTrade, "Pennsylvania Update: SRECTrade Markets Report," available at www.srectrade.com/blog/2014/12.)*

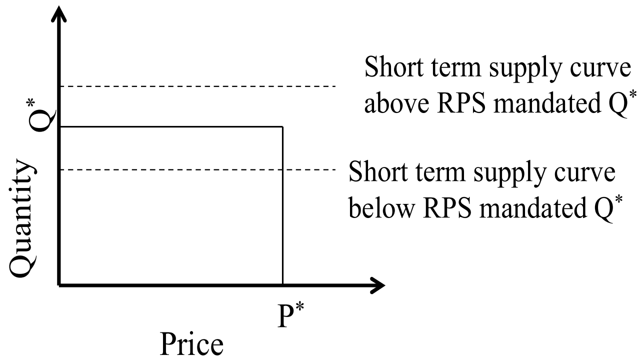

Figure 4. SREC Demand Curve. The solid line indicates the SREC demand curve. Utilities are willing to pay the SACP, P*, up to the mandated minimum quantity Q*. Above Q*, willingness to pay declines to zero. When the short-term supply curve (shown by the dashed line) for SRECs is below Q*, the equilibrium price is P*. When the short-term supply curve exceeds Q*, the price collapses to zero.

SACP value, the legislated penalty for failing to obtain sufficient SRECs) for quantities up to Q* (where Q* is the legislated mandatory quantity of SRECs to purchase). Given that the marginal costs of generation electricity from PV panels is essentially zero (once the panels have been installed), once PV facilities are built, the generators are essentially price-takers and generate their maximum capacity, regardless of price. This leads to a stable price p* until capacity exceeds Q*, at which point the price collapses to zero. A legislative mandate increasing Q* can restore price stability (at the expense of higher electricity costs) at least until installed capacity grows further.

There is a great deal of volatility and risk associated with the SREC market. Such volatility creates a risk of stranded capital in which an investment is made under conditions conducive to a positive return but subsequent market changes erode the return on investment. In this article we conduct an economic analysis to determine whether SREC prices have created a problem of stranded capital for investors.

Methods

This section first describes briefly the assumptions we made to estimate the capital cost for a PV system. Then, it offers a cost-benefit analysis for the system. Also, breakeven point analysis is done to determine the SREC floor price. The PV system design and the cost estimation model are described fully in the supplement.

Cost Estimation Model

Residential PV systems usually have power between 2 and 10 kW_p (Burns and Kang 2012). We have assumed the mean value of 6 kW_p for the PV array size. Furthermore, it is assumed that the PV system is connected to the electric grid. Therefore, there is no need for storage batteries and the system can benefit from the net metering. On sunny days when generated electricity exceeds the building's demand, surplus energy can be fed to the grid, and on cloudy days when the amount of energy produced does not meet the building's electricity requirement, grid electricity will be used.

Economic Analysis

The objectives of the economic analysis are 1) to find out if the asset's benefits would outweigh the costs during the lifetime of the PV system and 2) to determine the required SREC value to allow investors to recoup their costs. Financial criteria used in this study are net present value (NPV) and time to achieve zero project balance. A positive NPV indicates that a PV system project's discounted cash inflows during the PV system's lifetime exceed the discounted cash outflows. Time to achieve zero project balance is the duration needed for an investor to gain back their initial investment. The shorter this time is, the more profitable the project is.

To find NPV, the annual cash flow of the system must be calculated. Annual cash flow is the difference between the cash inflows and outflows during any year. The SREC revenue, electricity savings, and incentives are the inflows to the system. Depending on the location, different incentives are available. In this study we consider the federal investment tax credit. However, we ignore state-level programs such as rebates, grants, and loans because they are not always available. During the lifetime of a PV system, it requires maintenance and insurance, which are outflows and are negative. The PV system annual cash flows can be estimated as follows:

$$CF_n = \frac{V_{SREC} * E_p}{1000} + V_E * E_p + FTC + STC - C_M - C_I \qquad \text{Eq.(1)}$$

Where CF_n is the cash flows in year n, V_{SREC} is the annual average price of SREC in \$/Mwh in year n, E_P is the amount of produced electricity in kWh in year n and V_E is the electricity price per kWh in year n. FTC is the federal tax credit in dollars (as a percentage of the initial cost) assumed to be paid at the end of the first year. STC is the state tax credit if it is available. Only

Maryland has a tax credit for PV installers. It gives $0.0085/kWh for the produced electricity for the first five years of PV system (DSIRE 2014c). C_M and C_I are the annual maintenance and insurance fees, and they are 0.5% of the PV system capital cost (Burns and Kang 2012). Electricity price is not constant and is based on a 20-year average escalation rate reported by Burns and Kang (2012). SREC, electricity prices, and the electricity escalation rates are shown in Table 1.

To calculate the net present value of the PV system, annual cash flows during the lifetime of the PV system are first discounted, then they are summed, and finally the initial investment, C_0, is subtracted as illustrated in Eq.(2).

$$NPV = \sum_{n=1}^{N} \frac{CF_n}{(1+i)^n} - C_0 \qquad \text{Eq.(2)}$$

The discount rate is i and N is the project lifespan, which is 25 years. The discount rate used in this study is 3% (Burns and Kang 2012). Project balance at early years of the PV system is negative due to the substantial initial investment. It gradually increases because of savings of electricity production and

Table 1. Electricity Prices, Escalation Rates, and SREC Prices Used in This Study; PV Capital Costs; NPVs; and Payback Times for a PV System with a Capacity of 6 kW Located in Different States

State	Electricity Price[a] ($/kWh)	Electricity Escalation Rate[a]	SREC Price[b] ($/MWh)	PV Capital Cost ($/watt)	NPV ($)	Time to Zero Project Balance (Year)
DC	0.1401	0.002807	480	5.88	60920	7
DE	0.1380	0.002199	25	5.62	–5102	Not within project lifetime
MD	0.1432	0.002329	140	5.9	–4517	Not within project lifetime
NJ	0.1657	0.001778	131	5.94	32031	10
OH	0.1132	0.000178	16	5.87	–18282	Not within project lifetime
PA	0.1270	0.000735	10.75	5.99	–11596	Not within project lifetime

[a] *Source:* J. E. Burns and J. S. Kang, "Comparative Economic Analysis of Supporting Policies for Residential Solar PV in the United States: Solar Renewable Energy Credit (SREC) Potential," *Energy Policy* 44 (2012): 217–225.

[b] *Source:* SRECTrade, Historical SREC prices and historical price charts, 2016, available at www.srectrade.com/srec_markets/, accessed June 17, 2016.

SREC generation. Time to zero project balance, *pb,* is the first time when the project balance becomes equal or bigger than zero:

$$\sum_{n=1}^{pb} \frac{CF_n}{(1+i)^n} - C_0 = 0 \qquad \text{Eq.(3)}$$

Also, in order to find the required SREC value to allow investors to recoup their costs in different states, a breakeven point analysis is done. This threshold is the minimum SREC price required to make the net present value greater than zero at the end of the PV system's lifetime, 25 years. Any factor in Eq.(1) that affects the NPV can affect the breakeven point value: the capital cost, electricity price, the amount of produced electricity, maintenance and insurance fees, federal and state tax credits. One factor that affects the SREC breakeven point and is not apparent in Eq.(1) is the PV system size: the smaller a PV system is, the higher initial investment per watt ($/watt) it requires. To find SREC floors, we first estimated the capital cost of PV systems with capacities between 2–10 kW_p using the model developed in this article. We then calculated the NPV with ascending values of SREC and recorded the value where NPV became positive.

Results and Discussion

Table 1 outlines the capital cost of the system, NPV and time to achieve zero project balance (discounted payback time) for each of the states. Also, electricity price, electricity escalation rates, and SREC prices used in economic analysis are illustrated in Table 1. The project balance of the system over time for each state is shown in Figure 5. Unlike the analysis of Burn and Kang (2012), which found that the initial investment would be recovered in all states approximately within 15 years, our study shows that in four states (Delaware, Maryland, Ohio, and Pennsylvania) current market prices do not allow for positive return on investment. Only in the District of Columbia and New Jersey the returns on investment happen within 7 and 10 years respectively. Consequently, there is a concern that past PV investments have become stranded capital in the other four states.

NPV calculations are based on SREC prices in June 2016, and it is assumed that they will be constant and equal to the values reported in Table 1 during the lifetime of the PV system. PV installation is economically beneficial only in the District of Columbia and New Jersey. The reason for the success of the District of Columbia, and New Jersey is the higher value of SRECs ($480 and $279.50, respectively) in these markets compared with other states. This is

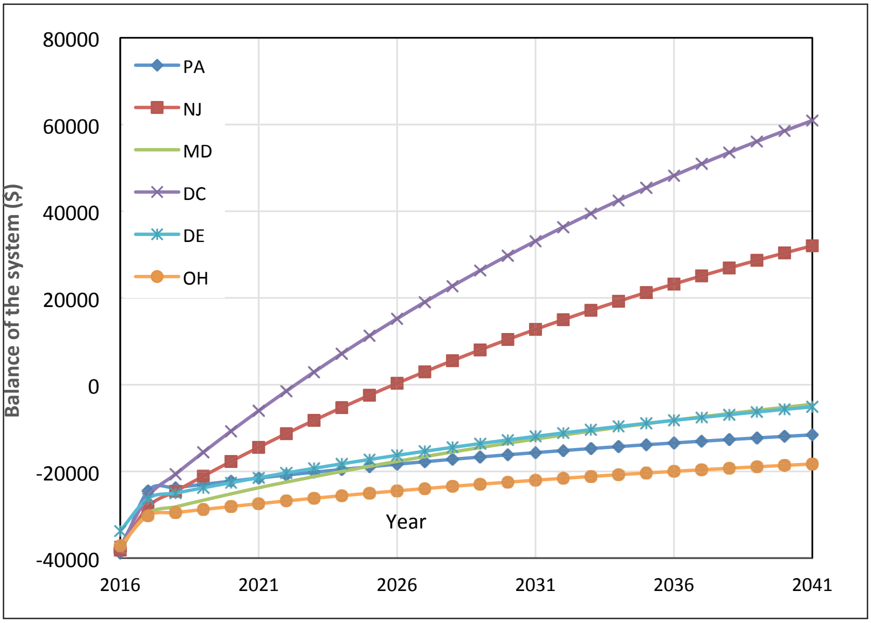

Figure 5. Project Balance of PV System Investments by Jurisdiction.

an indication of the important role of SREC in PV system cost recovery. As illustrated in Figure 5, Pennsylvania and Ohio are the worst states for PV installation. They are both severely oversupplied, and there is a high risk of stranded capital.

Pennsylvania and Ohio cannot recover their initial investments due to the oversupplied market and low SREC prices. One reason for the severe oversupply in these states is that their SREC markets are both open and accept SRECs from out-of-state facilities. However, Ohio accepts out-of-state SRECs at a lower price than in-state SRECs. Until November 2015, a total of 523.3 MW PV systems were certified in Pennsylvania. A considerable percentage, 58% (301.9 MW), of the total Pennsylvania certifications were from out-of-state facilities (SRECTrade 2016h). This percentage has increased from the similar period in 2014 and 2013 where 43% (160.5 MW out of a total of 370.4 MW) and 41% (126.6 out of 311.9 MW) of the certifications were for facilities outside of Pennsylvania. Apparently, Pennsylvania is attracting out-of-state PV installation rather than supporting local solar industry. Therefore, one way to support Pennsylvania's oversupplied market could be to ban out-of-state SREC transactions in the Pennsylvania market. However, Senate Bill 1350 would have continued to allow out-of-state SRECs certification.

While Maryland, Ohio, and Delaware have predetermined values for SACP, SREC markets in these states are still oversupplied. Therefore, it can be concluded that the SACP mechanism is not enough to stabilize SREC markets at a reasonable price that assures investment return (as would be expected from Figure 1, pushing the vertical portion of the demand curve to the right does not avoid the sharp drop to zero above the mandated minimum quantity). According to the historical SREC prices shown in Figure 2, SREC prices have been falling continually in all of the states except the District of Columbia and New Jersey. Prices in the District of Columbia have been stable since 2013, and the reason for its high prices is that it is the only undersupplied SREC market. Its 2015 RPS requirement was approximately 66 MW of which only 37.9 MW have been fulfilled (SRECTrade 2016i). New Jersey has the oldest and largest SREC market in the PJM region, and it also supports PV installation by defining a pre-fixed SACP. It can be concluded that setting aggressive solar carve-out, which prevents oversupply of the market, promotes PV installation.

As mentioned earlier, another means to provide price stability would be to mandate a lower limit on the SREC price. To find the minimum SREC value that allows investors to recoup their costs in different states, a breakeven point analysis was done and the chart of the breakeven points versus system size for different states is illustrated in Figure 6. As the PV system size decreases, the installation cost per watt ($/watt) increases and higher SREC prices are needed. The difference in SREC breakeven prices for different states is due to the different hours of sunshine in each state and also different energy prices. For a system of a certain size, the more sunshine hours a state has, the more electricity will be generated. Consequently more SRECs are generated and a lower SREC price is needed to recover the upfront costs. Also, states with higher electricity prices are better suited for PV systems, because they gain more cash inflows from selling electricity to the grid and consequently they require less incentive to recover the initial investment. As can be seen in Figure 6, in Pennsylvania, if the SREC price falls under $195/MWh, PV systems with small capacities of $2kW_p$ (the low end of the residential size range) will not be able to recover their capital investments. Even systems at the high end of the residential size range ($10\ kW_p$) require around $150/SREC to break even in Pennsylvania and Ohio, while more favorable insolation and electricity costs reduce this to roughly $75–$100/SREC in Maryland, New Jersey, Washington DC, and Delaware. All these breakeven prices are far above the early 2016 market price of about $10/MWh in Pennsylvania.

As noted earlier, the failed Senate Bill 1350 defined an SACP of $285 per SREC until 2019 and then decreases this value by 2% annually. Over 25 years

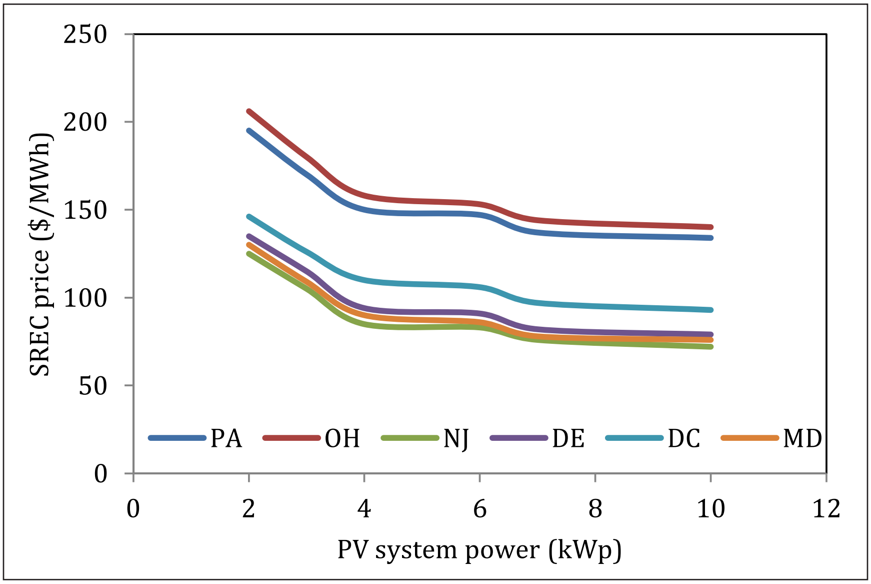

Figure 6. SREC Price Breakeven Values as a Function of the System Size.

(a PV system's lifetime), the average value of SACP will be $248 per SREC, and this alternative compliance value is higher than the breakeven point of $195/SREC. The breakeven analysis above suggests that the SACP is high enough to stimulate investment in solar PV systems. However, taking into account the Pennsylvania oversupplied SREC market (in which generation capacity is three times greater than the RPS requirement) and the absence of incentive to purchase SRECs beyond the mandated minimum (Figure 1), prices may not recover until the RPS mandate reaches current capacity in 2016. At that point SREC prices should recover, potentially providing incentive for further PV system installation. This might lead to a subsequent oversupply and price collapse. The collapse could be mitigated by providing a series of increasing RPS goals that take into account the performance of the solar market in previous years. This would provide the market with price signals that demand is saturated while continuing to provide some level of price support once initial RPS goals are met.

Experiences in other states may provide some guidance as to how Pennsylvania might address this situation. Like Pennsylvania, the Massachusetts market was oversupplied in 2012 and 2013. The Massachusetts Department of Energy Resources (DOER) created the SREC market in January 2010, and only in-state solar photovoltaic installations smaller than 60 kW are eligible to register in the Massachusetts market (DSIRE 2014d). Massachusetts has a unique method to define its solar set-aside, which helps it maintain its solar market balance. At the end of the year, if there are still unsold SRECs in the market, they are deposited in the Solar Credit Clearinghouse Auction (SCCA). The SCCA encompasses three rounds of auctions with prices fixed at $300/SREC minus a 5% administrative fee. If at the end of the third round, the auction is not cleared, then the DOER increases the solar carve-out for the coming compliance year by the amount of unsold SRECs (Greentech Solar 2014). This is a very intelligent way of controlling the market balance: by adjusting the next year's solar requirement based on the previous year's market performance, it is guaranteed that the SREC demand in the market is high enough to maintain the prices and also stimulate new PV installations.

Conclusion

This study explored the developments within Pennsylvania's solar industry following the RPS solar set-aside implementation. Pennsylvania has almost the highest electricity consumption in the mid-Atlantic region; however, it has the smallest target for solar electricity. The Pennsylvania market remained oversupplied at the close of 2016/start of 2017, based on the SREC market price of $7 noted above. The current support mechanisms, including SACP, have not been successful in establishing a stable market in Pennsylvania.

One reason for the Pennsylvania market oversupply is the overlapping of different up-front incentive programs that caused a boom in solar installation and saturated the market. Therefore, to maintain a stable solar market, it is important to coordinate up-front incentives with prospective SREC revenues. Furthermore, Pennsylvania's solar market is an open market and an increasing percentage of SRECs retired in Pennsylvania come from out-of-state facilities. However, the planned modifications to support the solar market still allow out-of-state facilities to register in Pennsylvania. To strengthen the Pennsylvania market, it may be necessary to consider banning out-of-state SRECs or adopt mechanisms that encourage utility companies to buy from in-state solar electricity generators rather than out of state generators.

This study proposed a simple conceptual supply and demand model in which suppliers are price-takers and demand is completely inelastic until the required RPS quota is met, at which point SREC demand collapses. This simple conceptual model accounts for the observed trends of SREC oversupply and price collapse. We developed an economic model that suggests returns are negative for investments in PV in four of the six jurisdictions considered, given market prices for SRECs in early 2016.

Our analysis shows that the current SREC market in Pennsylvania has not been successful. The SREC market is not stable and PV installers are at the risk of losing their investment. To encourage solar electricity, it is important to provide a secure SREC price throughout the life span of the PV system. Regulations could mandate that utility companies sign long-term contracts with SREC producers to provide them with guaranteed SREC prices.

One solution to the market's oversupply is to increase the solar target. Planned increases in the RPS quotas offer the prospect of restoring prices to profitable levels as the proposed SACP values exceed the breakeven values needed for PV investors. However, without some minimum price support or limits on the quantity of installations, the problem may simply be repeated. We could again witness a completely inelastic demand followed by a price collapse once the mandated RPS quota is met. To establish a stable market, solar set-aside is better determined annually by taking into account the previous year's market performance.

Furthermore, to define a minimum price support for SREC, mechanisms similar to the Massachusetts auction can be adopted. At the end of the year, unsold SRECs can be deposited to the auction. It is important that the auction prices be higher than the breakeven point value to assure the return of the investment to the solar electricity generators. If there are still unsold SRECs, they would be added to the next year solar set-aside quota.

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Somayeh Youssefi, PhD, is a postdoctoral researcher in the School of Public Health at the University of Maryland. She has a PhD in environmental engineering, and her research interests include environmental issues, renewable energies, aerosols, bioaerosols, and exhaled-breath biomarkers. Her recent study involves design and development of a sampler to collect exhaled-breath aerosols. These aerosols, which originate from the lung and respiratory tract, contain various biomarkers that can inform us about an individual's health, as well as his or her environmental exposures.

Patrick L. Gurian, PhD, is an associate professor in the Department of Civil, Architectural, and Environmental Engineering at Drexel University. His research involves the application of mathematical models to evaluate alternative regulatory frameworks and resource management strategies. His recent work includes the development of a report for the City of Philadelphia's Office of Sustainability that identifies strategies for reducing the city's greenhouse gas emissions.