USING AVOIDED COST METRICS TO COMMINICATE PRESENT VALUE IN PV SYSTEMS

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ABSTRACT

Costs and benefits of a photovoltaic (PV) system can vary from system to system depending the location and price of local electricity. For example, places with lower annual irradiation compared to the American Southwest can be found to be highly suitable for PV systems due to correspondingly higher electricity prices, thus avoiding higher fuel costs. In this paper, the avoided fuel cost metric, traditionally used in solar thermal economic assessment, is applied to assess potential for PV systems located in 50 cities across the USA. Fixed and variable electricity prices are considered, along with seasonal irradiation and the role of solar renewable energy certificates (SRECs). Additionally, payback times for five cities were analyzed based on alternative scenarios, testing the relative impact of installation cost, interest rates and SRECs. Using PV systems to avoid electricity costs can result in savings from \$3.70 to \$46.80 per year per PV panel (100 W). Given an average installed grid-tied system size of 4 kW, annual avoided costs per system in the USA would range from \$148 to \$1872. Also, avoided costs including SRECs are as much as 15% to 215% higher than without SRECs. In comparison, the metric of payback time can vary from 6 to 24 years, conveying a return far into the future that many clients have trouble integrating into an annual budget. Using these results, economic decisions regarding PV systems are more reliable and businesses have a metric to better communicate the value of PV systems in a given locale.

1. INTRODUCTION

Through history, humans have required sources of fuel in addition to sunlight to satisfy their basic needs or heating and lighting. Most fuels have been known for centuries, such as wood, coal, and oil. As time passes, people's needs change, population grows, the Earth's climate warms, and government policies respond in kind. Meanwhile, the way energy is produced is changing as well. Figure 1 shows the kinds of fuels and how fuel use has changed since 1970.[1]

Gas, nuclear energy, and renewable energy (especially wind and solar) have become important energy sources in recent years (Figure 1).This graph does not show how contentious or ethical some of these energy sources are; whether or not some should be utilized at all is debated. Nuclear energy, for example, is a controversial energy source due to safety and environmental concerns. In contrast, solar energy has been proven to be safe, clean, and widely available.

Given these attractive features of solar energy, attempts to harvest this energy source with novel and efficient technological means have increased in recent decades. Among the solar energy technologies, photovoltaic (PV) systems are unique. They consist of assembled photovoltaic cells made of semiconductor devices and generate electricity directly from sunlight. In the past two decades the demand for PV cells has continued an exponential increase, leading to sustained technology development and dramatic decreases in PV prices.The unit cost of PV cells will continue to decrease, while the reliability and cell efficiency will tend to increase.

It is important to investigate whether or not installing a PV system is economically feasible. A payback time model is usually used to determine such feasibility.

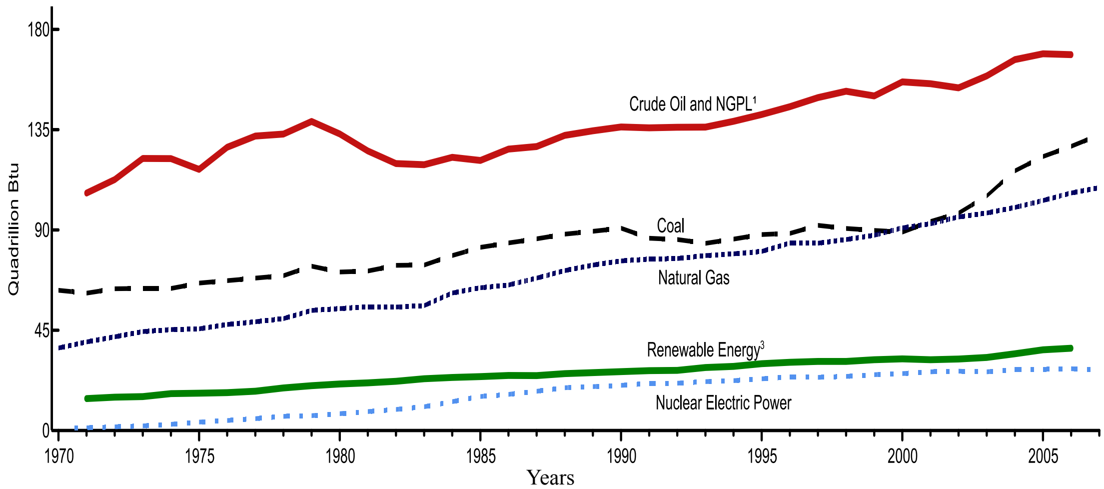

Fig. 1: World primary energy production by source since 1970.[1].

However, the payback model conveys a return far into the future that many clients have trouble integrating into an annual budget. In this study, an avoided cost metric is applied.[2] Using the results of this study, economic decisions regarding PV systems are more reliable and business have a metric to better communicate the value of PV systems in a given locale.

This study applies avoided cost metrics to assess potential for PV systems in 50 cities, one city from each state across the USA, and analyzing payback times for five cities.

2.DATA AND METHODOLOGY

In order to perform economic avoided cost metrics, one city was chosen from each state in the USA. Table 1 displays the list of cities chosen. Additionally, five cities were chosen in order to apply payback time evaluation (marked with boldface type in Table 1).

2.1Solar Energy Simulation Using TRNSYS

Solar energy systems could be optimally designed by creating models in simulation programs.[3] The validity of the algorithms used, the appropriateness of the input data, and parameters affect the accuracy of these models. One such simulation program is TRNSYS (Transient Simulation Program), well known to solar field, which creates energy-system models using a modular, FORTRAN-based structure. TRNSYS was used for its flexibility: component programs can be modified or removed, and new components can be added as required, so the software can be tailored for each project. [4] TRNSYS consists of subroutines, also named types. Each type represents a specific system, inputs, parameters, and outputs.

The component required for this study is type 567. Type 567 models the PV system, its interactions with the environment, and the building in which it is installed. The PV panels were modeled horizontally, slope was zero. PV production was calculated on an hourly basis using TRNSYS for 12 months for each of the 50 cities in this study.

2.2Weather Data

It is important to select the correct weather data for a given location in order to better predict the performance of the solar power system.[5] There are several commonly used weather databases including a typical meteorological year (TMY), also known as a test reference year (TRY). TMY is described as a representative database of weather data for a given location for a one-year duration. This typical one-year duration is formed by choosing 12 months selected from individual years, and is comprised of hourly values of solar radiation and meteorological data, such as ambient temperature. The selection of months is done by the Sandia method, an empirical approach.[6] TMY-2 data was employed as input weather data for this study.

2.3 Local Electricity Price Data

The electricity price per kWh for a residential building was determined by looking online for the tariffs charged by electricity providers in each city of the study. Some companies have tiers in their fee structure. Therefore, an average value for1200 kWh/month was taken as a reference for calculations. Seasonal tiers were considered for calculations as well. It is important to mention that other costs, like taxes and duties, are excluded for the purpose of the analysis.

2.4Solar Renewable Energy Credits (SRECS)

Some states in the USA have been providing solar renewable energy credits (SRECs) as incentives to PV users. In SREC states, the Renewable Portfolio Standard (RPS) requires that electricity suppliers have to supply a portion of their electricity from solar generators. When a solar system produces 1 MWh of electricity, one SREC is awarded. The price of SRECs can change over time due to supply and demand. When supply is greater than demand the price of SRECs decrease. For example, the price of SRECs has fallen dramatically for the last few years in Pennsylvania.[7]

2.5Avoided Cost Metrics

Avoided cost can be defined as the difference in cost for the same amount of energy obtained through alternative methods. Using Equation 1, avoided cost was calculated for a duration of one year. A common modest residential PV system size is 4 kW, so the number of panels was assumed to be 40.[8,9]

$$\begin{aligned} \text{Annual avoided cost(AAC)} &= \sum_{n=1}^{8760} \text{Hourly power output} \\ &\times \text{Electricity cost per kWh} \\ &\times \text{Number of panels} \end{aligned} \quad (1)$$

where n is hours in a year.

Also, the avoided-cost electricity-price and avoided-cost solar-irradiance relationships are studied (Figure 4-Figure 7).

3.5Payback Time Model

Payback time is one common way to evaluate PV systems. There are many methods to calculate payback time. In this study, the time needed for the net present value (NPV) to become zero is chosen to find payback time(Equations 2-4).

$$\begin{aligned} \text{Total Installation Cost} &= \text{Installed System Price} \\ &\times \text{PV System Size} \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Annual SREC Revenue} = \text{SREC Price} \\ \times \text{Annual PV Production} \end{aligned} \quad (3)$$

$$\begin{aligned} \text{NPV} &= -(\text{TIC–CCR}) + (\text{AAC+ASREC})/r \\ &\times (1 - 1/(1+r)^t) \end{aligned} \quad (4)$$

where TIC is the total installation cost, CCR is the capitl cost rebate, AAC is the annual avoided cost, ASREC is te annual SREC revenue, r is the interest rate and t is the PV system life time.

The installation cost over the last few years has changed from \$5.71/W for 5 kW residential rooftop systems to \$6.13/W for systems of 10 kW or smaller.[10,11] Therefore, installation cost is assumed to be \$6/W. Also, residential PV system average size and system life were assumed as 4 kW and 25 years, respectively. Interest rate was assumed to be 5%. Also, it is assumed that there was 30% capital cost rebate through federal income tax credit. Finally, if SRECs were marketed in the city, April 2012 SREC prices were considered.[7] A graph for each city was plotted for net present value with respect to time. From that plot, the payback time is determined to be the point where NPV becomes equal to zero. To illustrate, a plot for Baltimore, MD, is shown in Figure 2.

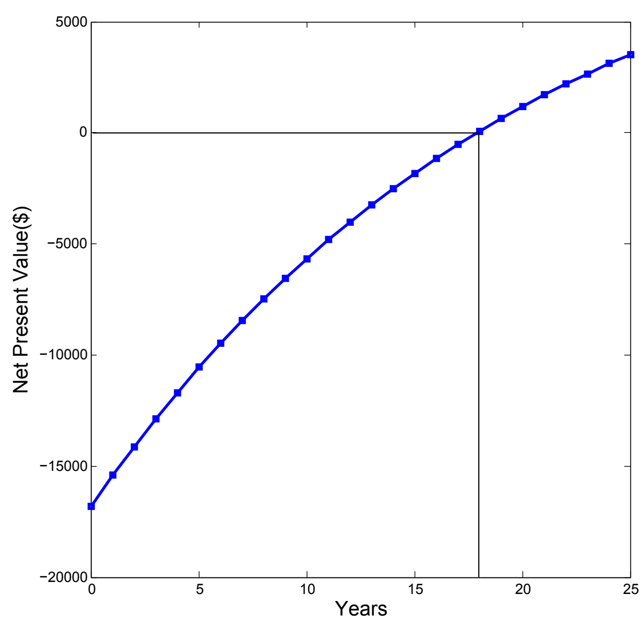

Fig. 2: Payback time calculation plot for Baltimore, MD

4.RESULTS

4.1Avoided Cost Metrics

The avoided-cost calculations for cities are shown in Table 1.To help visualize these results, the calculations were mapped; this map is shown in Figure 3. We found that using PV systems results in savings from $3.70 to $46.80 per year for one PV panel. However, total savings is significantly affected by electricity prices and solar irradiance. For example, in places with higher solar irradiance, such as NM and AZ, the avoided costs are greater. Also, places with higher electricity rates, such as MI and VT, have higher avoided costs.

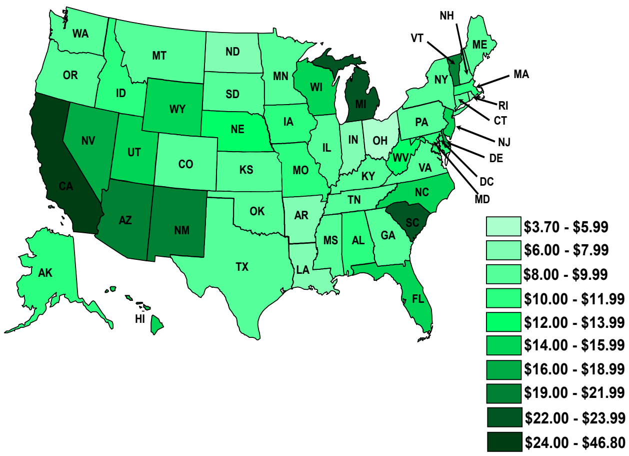

Fig. 3: Avoided cost map for states

Table 1: Annual Avoided Cost (AAC) ($) for each state for one PV panel.

AAC ($)	City State	AAC ($)	City State
46.80	**San Diego, CA**	9.84	Minneapolis, MN
23.67	**Charleston, SC**	9.71	Richmond, VA
22.92	Detroit, MI	9.58	Jackson, MS
21.69	Albuquerque, NM	9.30	Memphis, TN
20.86	**Tucson, AZ**	9.29	Seattle, WA
20.30	Burlington, VT	9.18	Concord, NH
18.79	Las Vegas, NV	8.96	Topeka, KS
16.77	Wilmington, DE	8.95	Sioux Falls, SD
15.37	Honolulu, HI	8.89	Chicago, IL
15.21	Salt Lake City, UT	8.83	Houston, TX
14.87	Atlantic City, NJ	8.70	Oklahoma City, OK
14.71	Cheyenne, WY	8.63	Bridgeport, CT
14.55	Madison, WI	8.62	Boulder, CO
14.27	Raleigh, NC	8.61	Portland, ME
14.06	Miami, FL	8.57	Atlanta, GA
12.64	Omaha, NE	8.54	New York City, NY
12.57	Charleston, WV	8.49	Pittsburgh, PA
11.33	Boise, ID	8.13	**Helena, MT**
10.79	Anchorage, AK	8.04	Portland, OR
10.77	Boston, MA	7.59	Little Rock, AR
11.55	Saint Louis, MO	7.40	Providence, RI
11.43	**Baltimore, MD**	7.31	Indianapolis, IN
10.41	Des Moines, IA	7.18	Fargo, ND
10.14	Mobile, AL	6.87	New Orleans, LA
9.92	Louisville, KY	3.70	Cleveland, OH

Figure 4 shows the relationship between solar irradiance and avoided cost for Charleston, WV. The electricity price is constant during the year for Charleston, WV. As solar irradiance rises, so does avoided cost. Therefore, there is greater avoided cost in summer than winter. There is a positive correlation between solar irradiance and avoided cost.

Figure 5 shows the relationship between electricity price and avoided cost. Sioux Falls, SD, and Cheyenne, WY, have similar solar irradiance but different electricity prices that do not vary during the year. The avoided cost for Cheyenne, WY, is as much as 64% greater than the avoided cost for Sioux Falls, SD, due to the higher electricity price.

The avoided cost also varies during the day. Figure 6 is an hourly one-day snapshot of the avoided cost and solar irradiance relationship on 21 June for Jackson, MS. There is greater avoided cost during the afternoon and evening hours. The electricity price is constant during that day in MS; therefore, the reason of high avoided-cost is high solar irradiance.

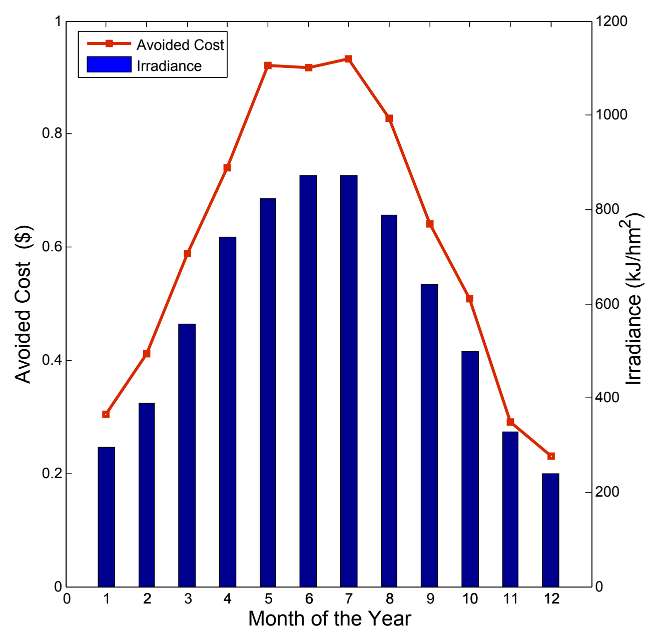

Fig. 4: Avoided cost for Charleston, WV, during the year for one PV panel.

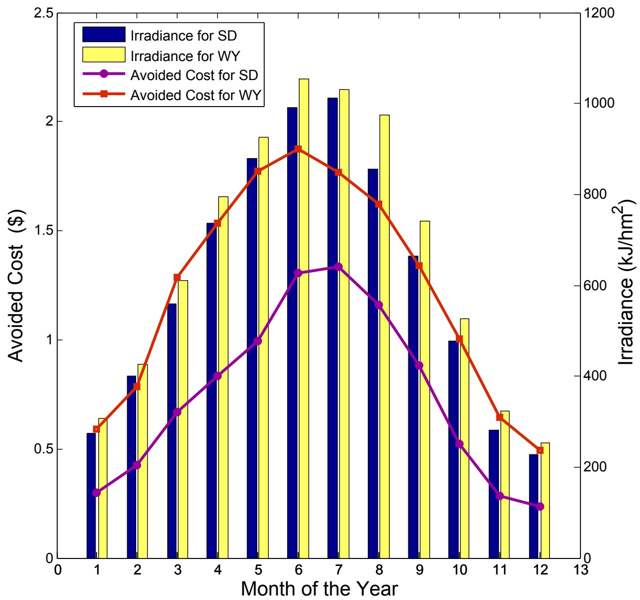

Fig. 5: Avoided cost for Sioux Falls, SD, and Cheyenne, WY, during the year for one PV panel.

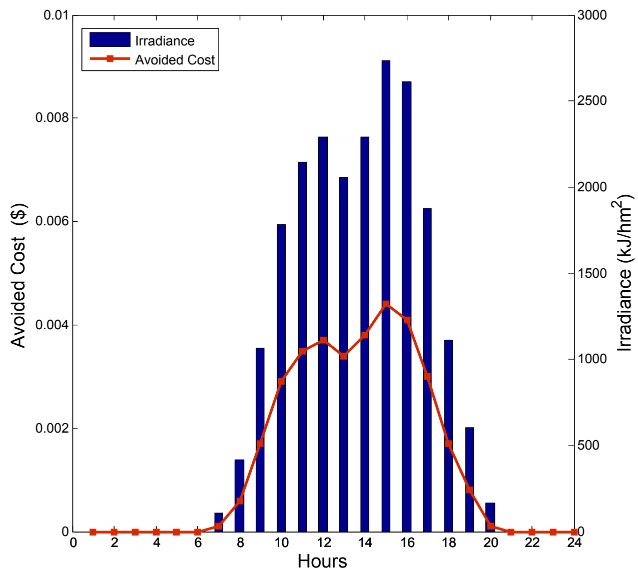

Fig. 6: Hourly avoided cost for Jackson,MS, on 21 June for one PV panel.

Figure 7 shows the avoided cost and solar irradiance relationship for a summer day, 21 June, using regular electricity and time of use (TOU) prices for Miami, FL, and Atlanta, GA. The electricity price is higher for the TOU option. There is a greater demand for electricity during summer afternoons as a result of widespread use of electric air conditioners. The avoided cost based on TOU pricing is greater than avoided cost based on regular pricing by as much as 30% for Miami, FL, and 69% for Atlanta, GA.

To examine how SRECs affect avoided cost, SRECs were added to avoided cost calculations for PA, MD, DE, NJ, and OH. The price of SRECs can change over time. In this study, SREC prices for April 2012 were used.[7] To calculate avoided cost that includes SREC prices for these states, Equation 1 (Section 2.5) was modified. Avoided cost savings were calculated as follows: the electricity price term was replaced with the sum of the electricity price per kWh and the SREC price per kWh. Figure 8 shows that the avoided cost including SRECs are greater (15% for DE, 29% for PA, 85% for NJ, 135% for OH, and 215% for MD) than without SRECs. SRECs have a significant effect on the avoided cost of PV systems

4.2 Payback Time Model

The life of a PV system is usually assumed to be approximately 25 years. Payback time for four cities is less than 25 years (Table 2), which means that PV systems are sustainable. However, Helena, MT, has payback time of more than 25 year, due to lower solar irradiance and lower price of electricity.

Table 2: Payback time for five cities.

City, State	Payback time
Tucson, AZ	6 years
San Diego, CA	12 years
Charleston, SC	24 years
Baltimore, MD	17 years
Helena, MT	over 25 years

4.2.1 Sensitivity Analyses

Sensitivity analyses were needed in order to verify the validity of the payback time calculations. Payback time calculations need to be adjusted since some parameters may change with economic and technical developments, such as installation cost, interest rates, and SRECs. The sensitivity analysis was applied for Baltimore, MD (Table 3).

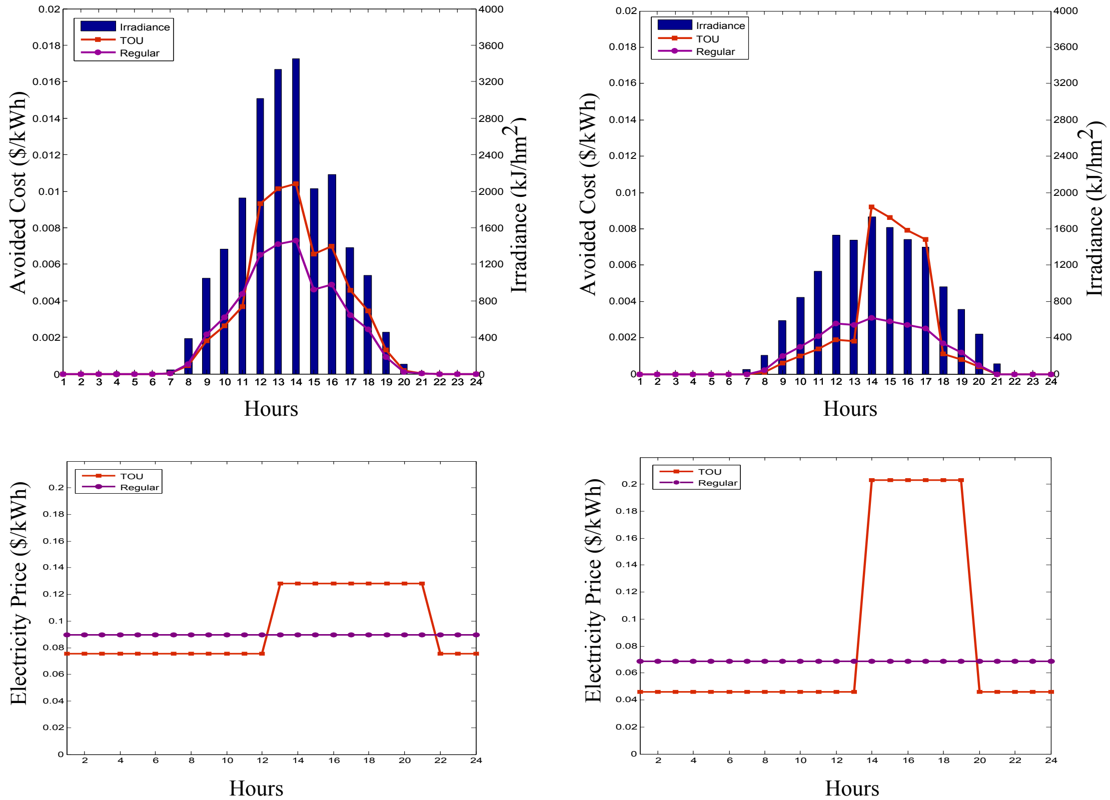

Fig. 7: Avoided cost for one PV panel and electricity prices for Atlanta,GA and Miami,FL, on 21 June.

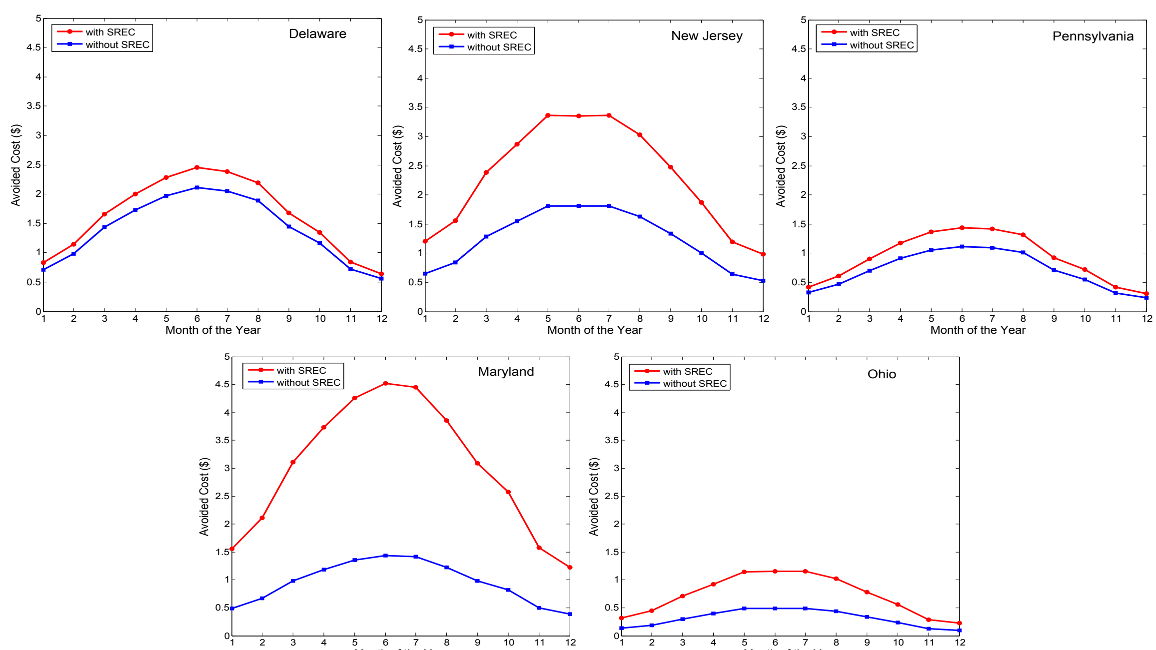

Fig. 8: Avoided cost for one PV panel including and excluding SREC pricing for DE,NJ,OH,MD and PA.

Table 3: Sensitivity analyses of installation costs, SRECs and interest rates for Baltimore, MD.

Parameters	Value	Payback Time
Installation Cost	$4/Wp	9 years
	$5/Wp	13 years
	$6/Wp	17 years
	$7/Wp	24 years
SRECs	$100/MWh	over 25 years
	$185/MWh	17 years
	$200/MWh	16 years
	$250/MWh	12 years
Interest rate	4%	16 years
	5%	17 years
	6%	21 years

5.CONCLUSION

The common perception in society is that PV utility is strongly determined by the annual irradiation budget. However, PV systems can display a wide range of avoided costs when used in residential homes within the continental United States of America—many of which are independent of solar irradiance. These additional factors include time of day, year, local margine electricity price, and SRECs.

We also show how avoided energy costs via PV installations can be a useful element to communicate annual savings to a client in comparison with long tem paybacks. There is a positive correlation between solar irradiance and avoided cost, also electricity price and avoided cost. Additionally, SRECs have a significant effect on avoided cost and payback time. This results of this study will help PV system owners and policy makers understand how solar irradiance, local electricity prices, and SRECs affect avoided costs for a PV system. We believe that this work will help to create a better way to communicate the economic advantages or disavantages of PV system installation to the client in their given state/locale.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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