ROLE OF STATE POLICIES IN PROMOTING DEPLOYMENT OF RESIDENTIAL PHOTOVOLTAIC SYSTEMS AND EVALUATION OF USE OF STATE SOLAR "CARVE-OUTS" IN REDUCING STATE CO_2 EMISSIONS

by
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Abstract

This paper focuses on addressing questions including the impact of state policies on residential solar deployment, the impact of residential solar on U.S. emission and the justification for state photovoltaic (PV) "carve-outs" in view of that impact. Official estimated value of solar panel, independent grading systems for state solar policies and value of social cost of carbon (SCC) are used. Results find that state policies generally promote the deployment of residential solar but the impact vary depending on kinds and support levels of policies. After analyzing the physical benefit of a typical solar system in each state and its social value, result shows that the current Solar Renewable Energy Credits (SREC) prices created by solar carve-outs are not justified by the value of the emission reductions resulting from residential solar PV.

Mentor: Dr. Robert Means, Adjunct faculty, EPC program

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Introduction

This Capstone Project will focus on three major topics regarding residential solar PV. (i) The impact of state policies on the deployment, (ii) the impact of residential PV on U.S. emissions, and (iii) the justification for state PV "carve-outs" in view of that impact.

This Capstone Project collects official estimated value of solar panel in different states in the United States and independent grading systems for state solar policies to analyze the relationship between deployment of solar energy and favorable state policies. Results show that the impacts vary depending on kinds of policies and levels of support. With respect to overall state policies, result shows that states with high level of favorable policies tend to have a higher deployment of residential solar, and the power increases with overall level of supportive policies.

Annual greenhouse gas (GHG) emission reductions of a typical $4kW_{DC}$ residential solar PV system in the U.S. will be as high as 4.78 tons CO_{2Eq} to 1.67 tons CO_{2Eq}, with overall median 2.78 to 3.69 tons CO_{2Eq} and the overall average 2.50 to 3.72 tons CO_{2Eq}. Throughout the 20-year lifetime of a typical residential solar PV, the value of social cost of carbon (SCC) saved is $1,038 to $2,973 nationwide, in 2007 $, depending on the type of energy displaced.

According to the results above, this article provides an ideal value of solar carve-outs for residential solar PV system, i.e., the target long-term market SREC value. The target price is $20 to $30 per MWh, in which situation the SREC market will be optimized.

Based on the assumptions used in this analysis, the current SREC prices created by solar carve-outs are not justified by the value of the emission reductions resulting from residential solar PV.

The Impacts of State Policies on Residential Solar PV Deployment

Analysis in this part first examines the overall relationship between deployment of residential PV and the value of PV panels and then examines that relationship separately for different levels of state policies with respect to net metering, interconnections, and overall favorableness.

Summary

The analysis in this part finds that there is a positive relationship between the deployment of residential solar PV and the value of solar panels in a state; however, other factor also contributes to this relationship significantly.

More obvious relationships between deployment of residential solar PV and the value of solar panels are shown when states are grouped by level of favorable policies. The results of evaluating net metering policy and interconnection policy indicate that the impact of net metering policy increases with the degree of support, and the impact of interconnection policy increases significantly in high-level support.

In another analysis of overall state policies, result shows that states with high level of favorable policies tend to have a higher deployment of residential solar, and the power increases with overall level of supportive policies.

In addition, once the economic value of solar PV reaches a certain amount, it turns to play a significant role in the high deployment even the level of state policy support is mediocre. Example is Hawaii.

Relationship between deployment of residential solar and its value

Hypothesis

The initial hypothesis regarding the deployment of residential solar energy is it is proportional to the product of the average solar panel output in that state and the state's average retail rate, i.e., the value of solar panels. This hypothesis is based on three assumptions. First, the installed cost of residential solar panel does not vary significantly between states. Second, states' housing stocks are equally suitable for PV. For example, individual states do not have an above-average or below-average share of rental units. Third, state policies are equally favorable to residential solar panels. To the extent those assumptions obtain, a reasonable result would be that state PV deployment rate increases with the value of residential solar panels.

Methods and Sources

Two parts of data and information are collected in order to find out if facts correspond to the hypothesis above. One part is a measurement of actual deployment rates of each state, which is determined and normalized in relation to the size of each state's market, called "Penetration Index (PI)" in this article. Then the economic values of residential solar PV installed in each state are collected.

In detail, the installation capacities of PV in each state (a) are collected from Interstate Renewable Energy Council (IREC)'s Solar Market Trends Report 2012 and 2013 (Sherwood), both providing annual installed PV capacity in residential sector. Data are chosen from only two latest reports as the increasing speed of solar PV development in recent years is far higher than before, which means capacity installed in residential sector in recent two years weighs most part of the total installation capacity.

By using PVWatts tool (NREL), annual amounts of energy produced by a residential PV panel in each state (b) are calculated. In order to get a comparable result, all the settings used in this step are by default in the tool, including the capacity of $4kW_{DC}$ (See Appendix 1).

Multiplying (a) and (b) gets the annual energy consumption from residential solar for each state. To normalize this energy consumption in relation to the market size of different states, total energy consumption in residential sector are collected by state (c) from U.S. EIA's website (U.S. EIA). Production of (a) and (b) divided by (c) results in a degree of deployment for each state. This result is called "Penetration Index" after being expanded by 10^4 times for a clear view of the numbers.

By using the same settings as in Appendix 1 in PVWatts, economic values of residential PV in different states from generating solar energy, i.e. annual values of energy generated from a solar PV panel are obtained.

Inputs and methods of this part are listed in Table 1.

Table 1 Methods and Inputs used for calculating Penetration Index and value of solar PV

Items	Input
State-by-state deployment of residential PV (a)	Solar Market Trends Report 2013, Solar Market Trends Report 2012 (Sherwood).
Converting PV capacity to electricity output (b)	NREL's PVWatts tool (NREL) considers isolation impacts of each state in the U.S. and providing PV outputs for different location.
Total residential energy consumption for each state (c)	U.S. EIA's State Profiles and Energy Estimates webpage provides annual energy consumption of

	residential sector for each state (U.S. EIA).
Penetration Index	(a)*(b)/(c) * 10^4 will be used as PI
Annual value of residential PV for each state (d)	This can be obtained by using NREL's PVWatts tool.

Analysis and Results

Figure 1 and Table 2 show the results of a linear regression between Penetration Index and value of a solar panel nationwide. The estimate value of slople (0.009951) is greater than 0, which means the PI and value is positively related. The Pr value (0.00956) indicates the possibility when this result is false. In this situation, it means less than 1% the results are not true. The R^2 value measures how well these points locate along with the line. If every point is exactly locates on the line, the value of R^2 is 1; otherwise it will be less than 1.

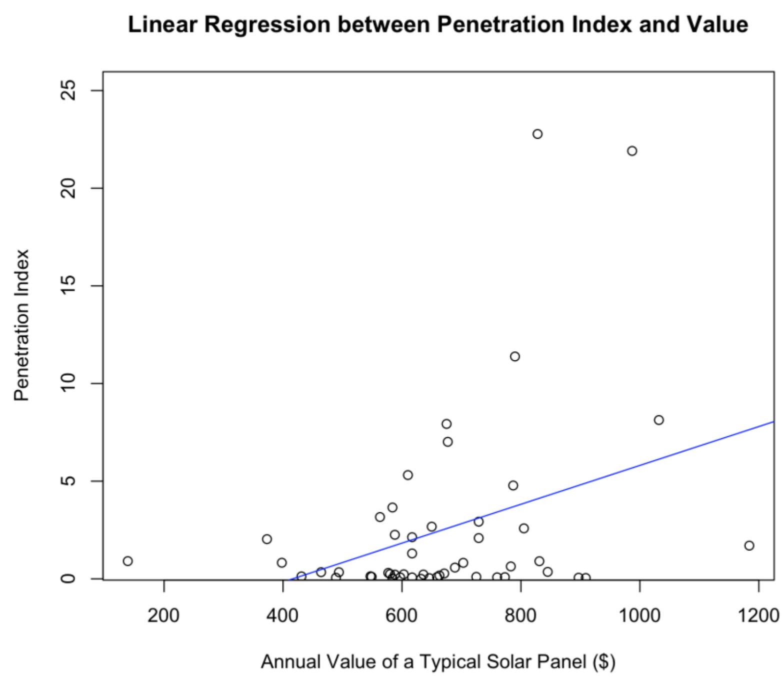

Figure 1 Linear regression between PI and annual value of a solar panel

Points represent different states in the U.S. (except Hawaii) and blue solid line shows trend

Table 2 Results of linear regression between Penetration Index and value of solar panel

	Estimate	Std. Error	t value	Pr (>|t|)
(Intercept)	-4.144858	2.536761	-1.634	0.10882
Value	0.009951	0.003686	2.699	0.00956
Multiple R-squared: 0.1318, Adjusted R-squared: 0.1137				

This positive relationship indicates that adding value to a solar PV system will increase Penetration Index of that state. Since Penetration Index is normalized by energy consumption market, adding value to a solar PV system will increase state solar energy deployment. To add value to a solar panel, one can either try to increase its amount of annual output or value of output.

However, since the R^2 value is far from 1 (the multiple R^2 is 0.1318 and the adjusted R^2 is 0.1137), this result also indicates that variation of the relationship is significant. Thus there probably exist other factors contributing to this relationship significantly. In a given state, the amount of output is hard to change unless advanced technologies are used. But the value of output can be increased by state favorable policies.

To sum, the linear regression of degree of deployment against value of solar panels shows somewhat a positive correlation. However, it is obvious that there are other factors that are contributing significantly since the R^2 value is far from 1 (less than 0.2 in this analysis). Considering state policies would have a significant impact on deployment of solar energy, the remainder of the first part focuses on this factor.

Relationships are shown when states are grouped by level of favorable policies

Hypothesis

Considering state policies would have a significant impact on deployment of solar energy (Chediak), analyzing the relationship by group of state solar policy levels is reasonable.

The hypotheses for the impacts of policies in the relationship with value of residential solar PV and deployment are, first, for any given level of economic value of residential solar, Penetration Index is higher for a higher level of policy support; and for any given level of policy support, the degree of deployment of residential solar PV increases with value.

The hypotheses will be tested for two evaluations of state policies. One separately evaluates net metering and interconnection policies; the other evaluates overall state policies.

Net Metering and Interconnection Policies

Methods and Sources

IREC and Vote Solar published "Freeing the Grid 2014" in November 2014 (Auck, Barnes and Culley), which provided separate letter grades evaluation of policies in terms of net metering and interconnection for each state in the United States. A glimpse result of this grading system is shown in Figure 2 (IREC).

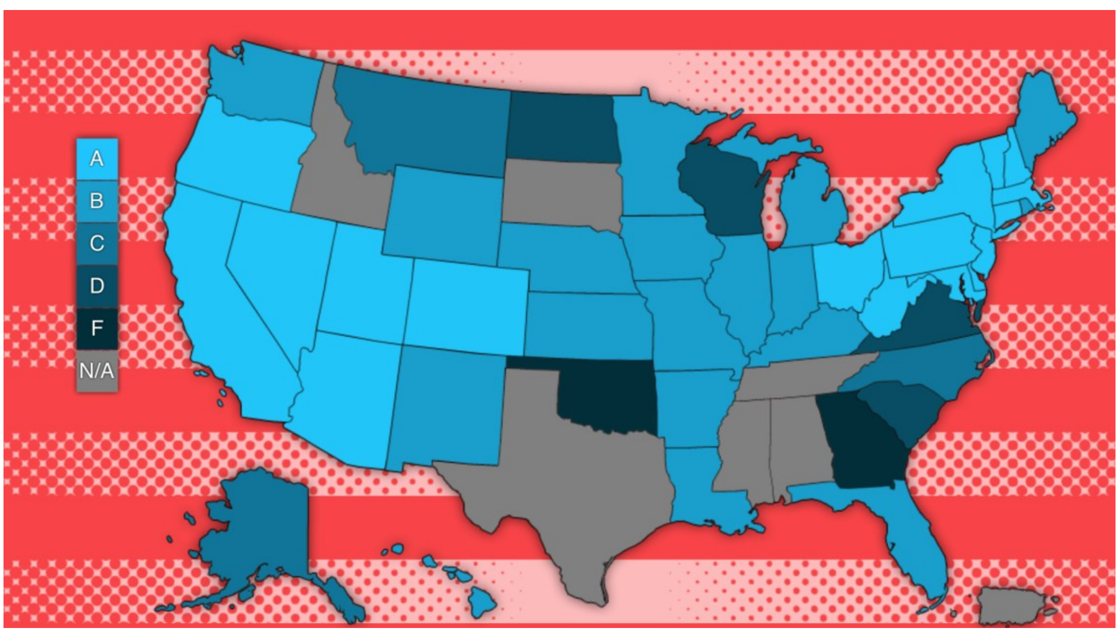

Figure 2 Solar Policy Grades by Freeing the Grid

This grading system contains two kinds of popular measurements, net metering policy and interconnection policy. The system evaluated policies and concluded a score and letter grade separately in terms of net metering and interconnection. Grade A represents a state has most favorable level of policies among the states and F or N/A represents low policy support in terms of net metering or interconnection. Inputs and sources are listed in Table 4.

Analysis and Results

Figure 3 and Figure 4 show the results of linear regressions between Penetration Index and value of a solar panel grouped by letter grade of net metering and interconnection policies.

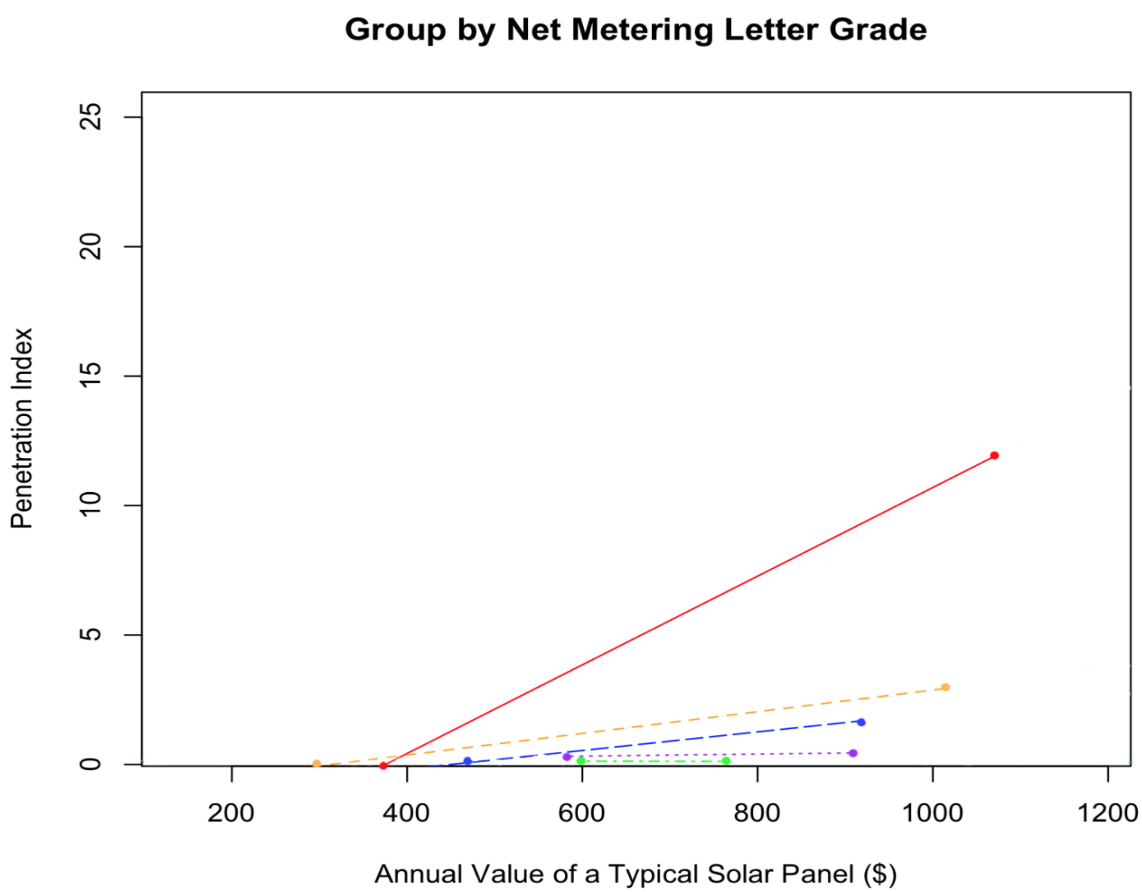

Figure 3 Linear regression results between PI and PV value grouped by net metering policy grade

Grade A = red solid, Grade B= orange dashed, Grade C = purple dotted, Grade D = green dotdash, Grade F & N/A= blue longdash.

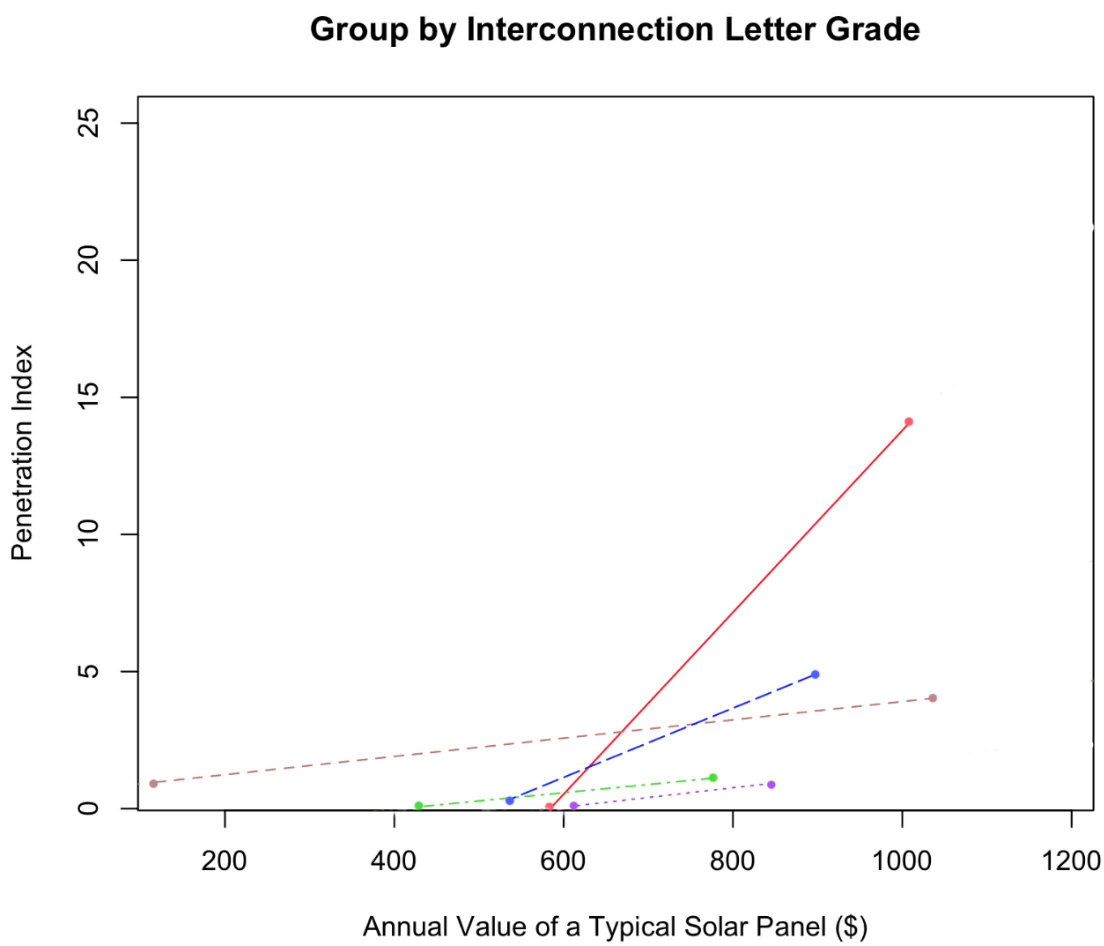

Figure 4 Linear regression results between PI and PV value grouped by interconnection policy grade Colors and styles of lines represent the same as in Figure 3.

Table 3 Slope values of different lines in Figure 3 and Figure 4

Letter Grade	Value of Slope	
	Net Metering	Interconnection
A	0.01713	0.03315
B	0.004184	0.003333
C	0.000398	0.003543
D	<0.0001	0.003303
F/NA	0.003594	0.01263

Results in Figure 3, Figure 4 and Table 3 indicate several conclusions.

i) For both interconnection and net metering policies, the relationship between Penetration Index and value of solar panel shows a positive trend;

ii) For a given level of value, a higher level of net metering policies almost always means an overall better performance of solar deployment than a state with lower grade, which is obviously shown in Figure 3;

iii) For a given level of value, for policies regarding interconnection (shown in Figure 4), a higher grade almost always produces higher PI if the grades are separated by two or more steps (i.e., A vs. C, A vs. D, B vs. D). But this result is not so clearly for adjoining grades, especially for A vs. B;

iv) For net metering policy, a higher level of support means a more powerful incentive on the deployment of solar panels (as in Figure 3, except Grade F/NA– very few net metering policies). In another words, the slope of the relationship between Penetration Index and value of solar PV for higher grades is greater than or nearly equal to that of less favorable net metering policies. In specific, as listed in Table 3, the value of slope of the relationship is 0.17 for Grade A, which is over 4 times as Grade B (0.004184); the slope of Grade B is over 10 times as Grade C (0.000398);

v) Under most circumstances, a higher level of state interconnection policy means a more powerful incentive on the deployment of solar panels (except Grade F/NA – very few favorable interconnection policies), and the power descends quickly from higher level to lower levels of interconnection support. As shown in Table 3, the value of slope is 0.033 for Grade A, which is almost 10 times higher than Grade B (0.003333); however, the slopes of Grade B, C (0.003543) and D (0.003303) are nearly the same. This probably indicates that the power of favorable interconnection polices will not become obvious until the policy support reaches a certain level;

vi) The reason that Grade F/NA is not consistent with conclusion (iv) and (v) may be caused by the fact that some states with little interconnection or net metering policies support the alternative option of policy quite well. For example, among all 16 states with a Grade F/NA interconnection, 1 has an A, 6 have B and 1 has C in net metering;

vii) The reason why Table 3 does not provide a R^2 value is that the amount of states in each group is not large, which means R^2 value cannot compare the degree of fitting of points in each group.

To sum, the relationship between Penetration Index and value of solar panel shows a positive trend for both interconnection policy and net metering policy. In general, states performing better in net metering policies also perform better in residential solar deployment. A higher level of support in net metering and interconnection means a more powerful incentive on the deployment of residential solar, but it descends quickly as level of interconnection support decreases. Results also indicate that states with lower grades are not consistent with the conclusions, which could be explained that the actual incentive is a combination of different kinds of favorable policies. Thus the following part refers to a comprehensive grading system provided by solarpowerrock.com, which considers a mix of favorable policies of solar in each state.

Overall State Policies

Methods and Sources

Another independent grading system used in this analysis is created by solarpowerrocks.com (SolarPowerRocks.com), which provides a comprehensive letter grade and score considering about a dozen aspects of state policies for supporting solar energy, including state solar incentives, rebates, tax exemption, etc., which is shown in Figure 5 (SolarPowerRocks.com) and listed in Appendix 3. Inputs and sources for this part are shown in Table 4, and results of state policies in the two grading systems used in this analysis are listed in Appendix 4.

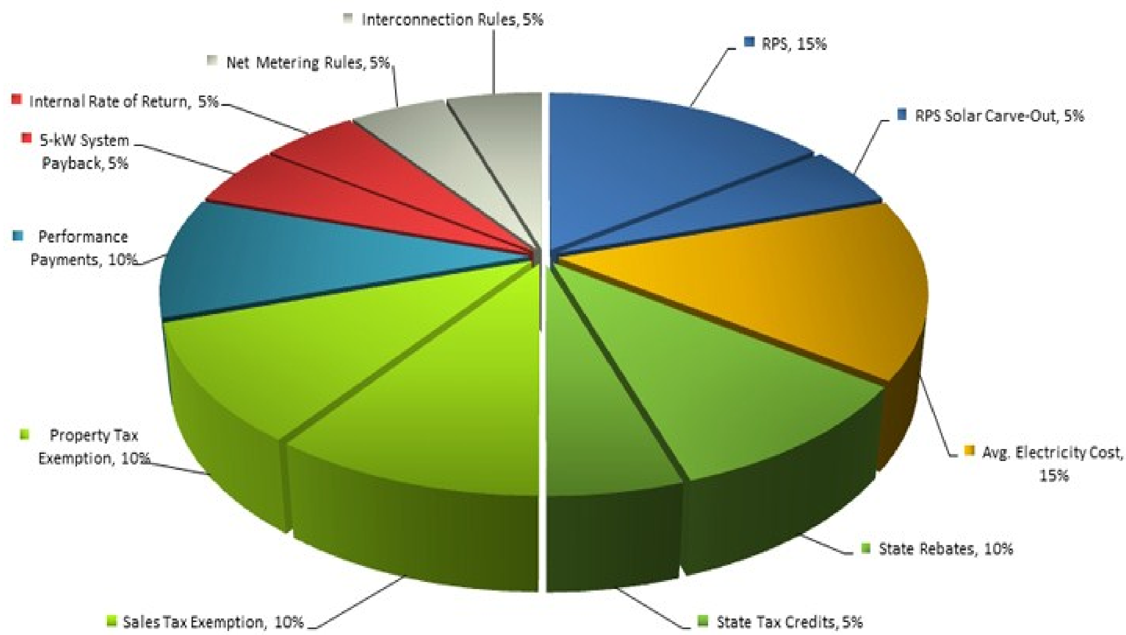

Figure 5 Criteria of grading overall state policies in solarpowerrocks.com system

Table 4 Methods and Inputs for analysis in part 1, cont.

Items	Input
Grouping states by the level of policy support	"Freeing the Grid 2014" report by IREC and Vote Solar (IREC) Solar Power State Rankings (SolarPowerRocks.com)
Relationship between value of residential solar (d) and PI by level of overall state policies	Conducting linear regression in each group for Penetration Index and (d)

Analysis and Conclusions

For this comprehensive policy grading system, linear regression analysis is conducted between the Penetration Index and score of policy. The results are shown in Figure 6, Figure 7 and Figure 8.

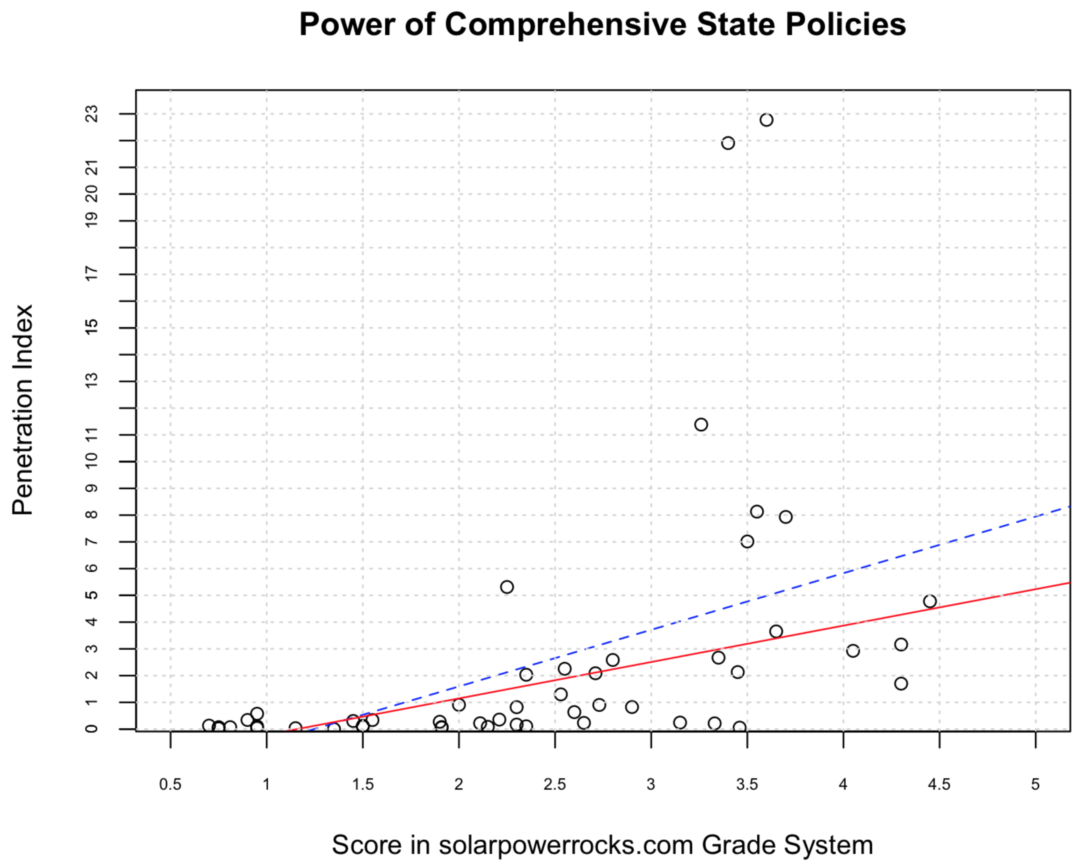

Figure 6 Relationship between PI and overall state policies score in solarpowerrocks.com system

Points represent states in the U.S. excluding Hawaii, red solid line represents trend and blue dashed line shows the trend excludes the two states with Penetration Index over 20.

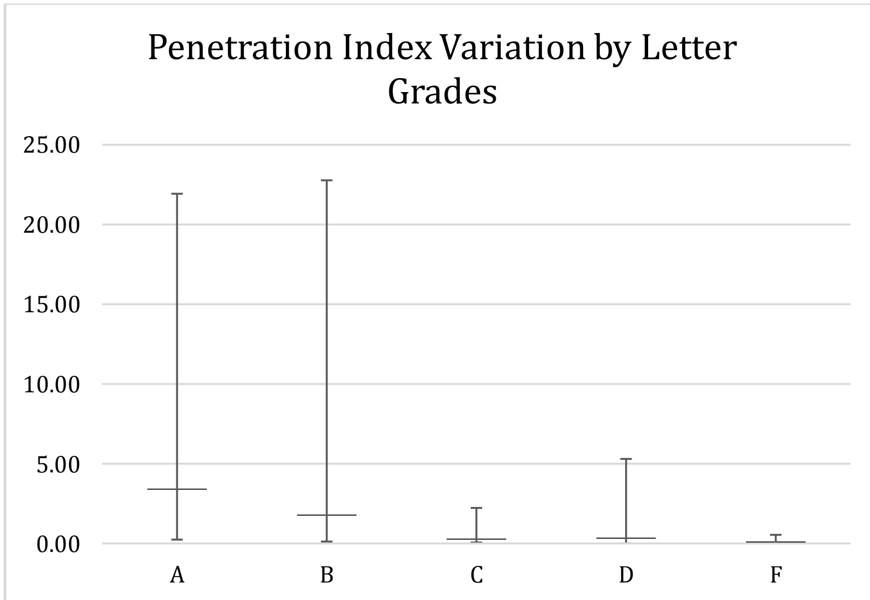

Figure 7 Variation of Penetration Index, by letter grades in solarpowerrock.com system

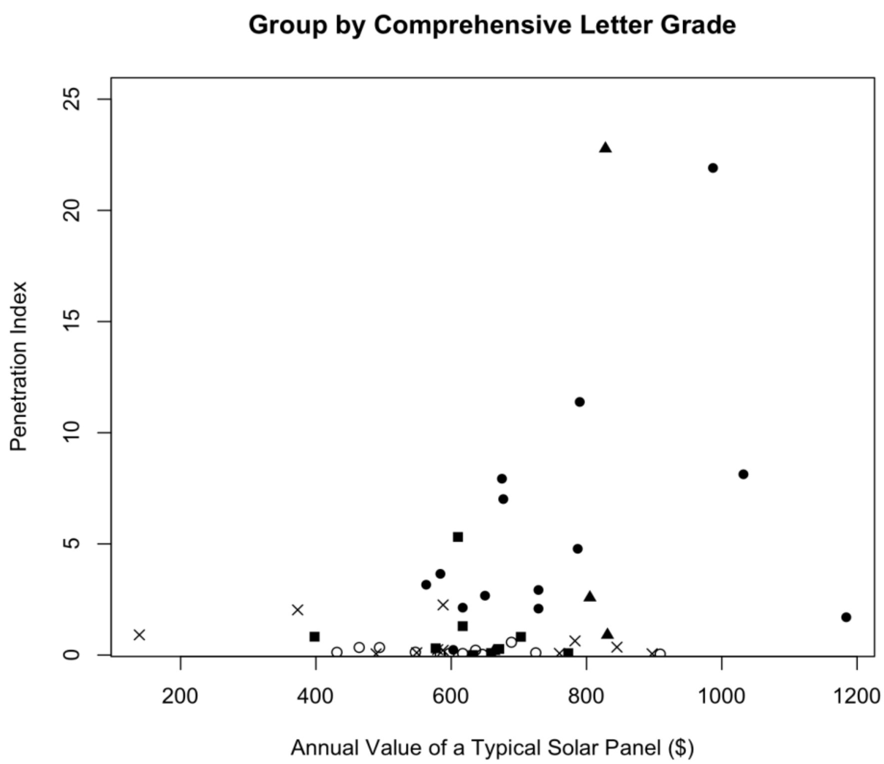

Figure 8 Scatter graph of relationship between PI and solar panel value, grouped by letter grade in solarpowerrock.com system

•=Grade A, ▲=Grade B, ▯=Grade C, ▯=Grade D, ○=Grade F

For overall state policies, conclusions are generally similar to the ones for net metering and interconnection. Besides, two additional conclusions are worthy being noted:

i) The analysis shows that Penetration Index and overall policy grades has a clear positive relationship, even excluding some outlier points (Figure 6). An explanation could be that although the value calculated by PVWatts does not include the installation and operation costs of PV systems, however, more favorable state policies will add value or decrease the cost of installation and operation in some extent, which means favorable state policies have a positive impact on state deployment.

ii) States with higher grades of policies perform much better than lower-grade states. Figure 7 shows that the deployment level of best performers of states with Grade A and B is much higher than other grades, and most states with PI greater than 5 have Grade A/B in terms of overall favorable policies, as shown in Figure 8.

Once the economic value of solar PV reaches a certain amount, it turns to play a significant role in deployment

In analyses above, the state of Hawaii is eliminated from the raw data as an outlier in this part. Besides its special location, the high value of insolation in the state of Hawaii probably plays a considerable important role.

Hypothesis

Even policies play a significant role in the deployment of residential solar, once economic value of PV panel is high enough in a state, the impact of state policy will be relatively weakened.

Analysis and Results

The PI of the state of Hawaii is over 200 while the highest PI of other states is 22.8 in Arizona and overall median PI is 0.47 nationwide. Meanwhile, evaluation results of policies in the state of Hawaii are mediocre. Letter grades for net metering and interconnection are both Bs and comprehensive score is 2.88/5.0.

The value of solar panel in the state of Hawaii is several times higher than any other state, and this probably is the significant reason of its high Penetration Index. We can infer that when value of solar panel reaches a certain amount, the economic incentives are significant enough for residents and industries choosing solar power, as long as policymakers do not restrict to use it. Thus, the fact that the state of Hawaii has a high PI with mediocre policy supporting is consistent with the hypothesis.

Physical and economic impacts of residential solar PV on U.S. emissions

Summary

Analysis of the impact on U.S. emissions involves two issues: (i) the physical reduction in emissions and (ii) the social economic value of that reduction. The metric for the physical reduction will be the physical reduction per typical residential solar system, i.e. how many U.S. emissions are reduced by alternating current (AC) output and/or direct current (DC) capacity of a residential solar PV. The social economic value of reduction will be measured as net present value (NPV) per residential solar PV system during its lifetime.

The results indicate that annual GHG emission reductions of a typical 4 kW_{DC} residential solar PV system will be as high as 4.78 tons CO_{2Eq} for New Mexico panels that displace natural gas combustion turbines (NGCT), and at least 1.67 tons CO_{2Eq} for Alaska panels that displace combined cycle natural gas (NGCC). Overall median of annual emission reductions is 2.78 to 3.69 tons CO_{2Eq}, and the overall average in all U.S. states is 2.50 to 3.72 tons CO_{2Eq}, depending on the kind of generation displaced.

Throughout the 20-year lifetime of a typical residential solar PV, the amount of net present value of social cost of carbon saved is $1,038 to $2,973 (in 2007 $, the same below). Overall median SCC saved is $1,540 to $2,292, and overall average SCC saved among the states is $1,554 to $2,313.

The social cost of carbon saved by solar panel will increase significantly if the actual discount rate is lower than the assumption used in this analysis (3%).

Methods and Resources

First, this part calculates direct annual carbon emission avoided by a typical household PV system, i.e. how much greenhouse gas emissions will be produced if not using this PV system. This is determined by two factors. One is how much energy it can displace, another one is the amount of emission reduction of each unit of energy it displaces.

To calculate the amount of energy a solar panel can displace, this article assumes that a typical installation for a southerly facing rooftop on a typical detached single- family home is 4kW (Denholm and Margolis), and residents will use it whenever it can work. The life of a residential solar panel is set as 20 years based on typical length of power purchasing agreement (PPA) in the U.S. In addition, performance degradation of a solar panel will be set as 1% per year. Since solar energy output is impacted by insolation, i.e., location, this part uses PVWatts tool (NREL) and its default settings to calculate the first year AC output (b) of a typical solar panel, same as we got in part one.

The amount of emissions avoided is determined by what kind of energy will be displaced. Solar energy will be produced during daytime and its peak happens in the afternoon. Thus, based on current U.S. electricity system structure, solar energy will mainly replace peak load, i.e., NGCT and NGCC. It is hard to provide a precise percentage of these two energy sources, so this article uses a range (e) to show the impacts on GHG emission reductions.

The total amount of emission a solar panel displaced is the amount of emission that would be emitted by NGCC or NGCT minus the amount of emission emitted by a solar panel (during manufacturing, transportation, etc.). NREL's Life Cycle Assessment (LCA) Harmonization Project (NREL) provides LCA emission data for different type of energy sources.

When physical emission reduction is calculated, the social economic value will be calculated by using the concept of Social Cost of Carbon. According to EPA, this concept meant to be a comprehensive estimate of climate change damages and includes, but is not limited to, changes in net agricultural productivity, human health, and property damages from increased flood risk (U.S. EPA). Thus, the social economic value of emission reduction is the SCC saved.

A technical support document provides SCC value for the coming years (Interagency Working Group on Social Cost of Carbon). This part chooses the value in 3% discount rate scenario (f) in that technical support document because the scenario lies in average. Thus multiplying (e) by (f) will get the economic value of emission reduction for each year, and NPV method will be used to convert this to a single dollar amount. The interest rate will be 3.2% in this article based on 20-year AAA bond rate (Yahoo Finance).

Table 5 Methods and Inputs for calculation physical and economic impacts of solar panels

Items	Input
Physical impacts on emission reduction (e)	(b) provides annual energy displaced, and NREL's LCA Harmonization Project provides emission data for natural gas. (NREL)
SCC value for the coming years (f)	A technical document by Interagency Working Group on SCC provides the most recent SCC estimates. (Interagency Working Group on Social Cost of Carbon)
Total social economic value of residential PV for each state (g)	Using NPV function on (e)*(f) for each year, each state.

Analysis and Results

The amount of physical GHG emission reductions in the first year and total social cost of carbon saved by one typical residential solar panel with 4kW capacity in 20 years (from 2015 to 2034) in different U.S. states are listed in Table 6.

Annual energy output is decided by solar insolation, i.e. location. The result shows solar panel installed in the State of New Mexico produces the most amount of solar energy per year, 7133 kWh, while in Alaska the least, 3710 kWh annually. The overall median 1st-year amount of energy produced is 5500 kWh. In average, a typical solar panel in the U.S. produces 5,550 kWh under 100% performances.

As mentioned above, since solar panel produces energy when there is sunlight, under most circumstances the energy it replaces is peak load electricity. For U.S. electricity deployment structure, residential solar energy will most likely replace NGCT or NGCC. Generally, electricity produced through NGCT emits more greenhouse emissions than produced by NGCC, thus the greenhouse gas emission reduction by a residential solar panel exists between the amount of greenhouse gas emitted via NGCC (floor) and via NGCT (cap). According to the result table, if all solar energy replaces NGCT, GHG emission reduction will be as high as 4.78 tons CO_{2Eq} in New Mexico, and a typical residential solar panel will help reduce at least 1.67 tons CO_{2Eq} if replacing NGCC in Alaska. Depending on whether the output displaces NGCC or NGCT, overall median of 1st-year emission reduction is 2.78 to 3.69 tons CO_{2Eq}, and the overall average in all U.S. states is 2.50 to 3.72 tons CO_{2Eq}.

The net present value of social cost of carbon saved through the lifetime of a solar panel is proportional to greenhouse gas it saved. Thus, solar panels installed in New Mexico and replacing NGCT will saved the most net present value of social cost of carbon through 20 years, $2,973 (in 2007 $, the same below), and solar panels will saved at least $1,038 if installed in Alaska and replaces NGCC. Overall median SCC saved through replacing NGCT and NGCC are $2,292 and $1,540 respectively. Among all U.S. states, the overall average SCC saved if replacing NGCT is $2,313, and this number will be $1,554 if replacing NGCC electricity.

The amount of social cost of carbon saved is also determined by what discount rate is chosen. 3% discount rate is used in this analysis; however, the social cost of carbon saved by solar panel will increase significantly if the actual discount rate is lower than 3%. For example, if 2.5% discount rate is used for calculating SCC, the maximum SCC saved by a typical solar panel in 20 years in the State of New Mexico could be over $4,700, rather than $2,973 under the 3% discount rate.

Table 6 Physical and economic impacts of a typical residential PV system in different states

Name of State	Annual AC Energy/kWh	1^{st} year emission reduction /ton CO_{2Eq}		NPV of SCC saved in 2015, (2007$)	
		NGCT	NGCC	NGCT	NGCC
Alabama	5,680	3.8056	2.5560	$ 2,367.48	$ 1,590.10
Alaska	3,710	2.4857	1.6695	$ 1,546.37	$ 1,038.60
Arizona	6,919	4.6357	3.1136	$ 2,883.91	$ 1,936.96
Arkansas	5,646	3.7828	2.5407	$ 2,353.31	$ 1,580.58
California	6,329	4.2404	2.8481	$ 2,637.99	$ 1,771.79
Colorado	6,116	4.0977	2.7522	$ 2,549.21	$ 1,712.16
Connecticut	5,129	3.4364	2.3081	$ 2,137.82	$ 1,435.85
Delaware	5,343	3.5798	2.4044	$ 2,227.02	$ 1,495.76
District of Columbia	5,321	3.5651	2.3945	$ 2,217.85	$ 1,489.60
Florida	5,927	3.9711	2.6672	$ 2,470.44	$ 1,659.25
Georgia	5,628	3.7708	2.5326	$ 2,345.81	$ 1,575.54
Hawaii	5,376	3.6019	2.4192	$ 2,240.77	$ 1,505.00
Idaho	5,829	3.9054	2.6231	$ 2,429.59	$ 1,631.81

Illinois	5,401	3.6187	2.4305	$ 2,251.19	$ 1,512.00
Indiana	5,330	3.5711	2.3985	$ 2,221.60	$ 1,492.12
Iowa	5,500	3.6850	2.4750	$ 2,292.46	$ 1,539.71
Kansas	5,968	3.9986	2.6856	$ 2,487.53	$ 1,670.73
Kentucky	5,236	3.5081	2.3562	$ 2,182.42	$ 1,465.80
Louisiana	5,501	3.6857	2.4755	$ 2,292.88	$ 1,539.99
Maine	5,373	3.5999	2.4179	$ 2,239.52	$ 1,504.16
Maryland	5,293	3.5463	2.3819	$ 2,206.18	$ 1,481.76
Massachusetts	5,287	3.5423	2.3792	$ 2,203.68	$ 1,480.08
Michigan	4,897	3.2810	2.2037	$ 2,041.12	$ 1,370.90
Minnesota	5,352	3.5858	2.4084	$ 2,230.77	$ 1,498.28
Mississippi	5,565	3.7286	2.5043	$ 2,319.55	$ 1,557.91
Missouri	5,669	3.7982	2.5511	$ 2,362.90	$ 1,587.02
Montana	5,325	3.5678	2.3963	$ 2,219.52	$ 1,490.72
Nebraska	5,989	4.0126	2.6951	$ 2,496.28	$ 1,676.61
Nevada	6,800	4.5560	3.0600	$ 2,834.31	$ 1,903.64
New Hampshire	5,238	3.5095	2.3571	$ 2,183.25	$ 1,466.36
New Jersey	5,369	3.5972	2.4161	$ 2,237.86	$ 1,503.04
New Mexico	7,133	4.7791	3.2099	$ 2,973.11	$ 1,996.87
New York	5,100	3.4170	2.2950	$ 2,125.73	$ 1,427.73
North Carolina	5,664	3.7949	2.5488	$ 2,360.82	$ 1,585.62
North Dakota	5,419	3.6307	2.4386	$ 2,258.70	$ 1,517.04
Ohio	4,940	3.3098	2.2230	$ 2,059.04	$ 1,382.94
Oklahoma	6,091	4.0810	2.7410	$ 2,538.79	$ 1,705.16
Oregon	5,810	3.8927	2.6145	$ 2,421.67	$ 1,626.49
Pennsylvania	4,846	3.2468	2.1807	$ 2,019.86	$ 1,356.63
Rhode Island	5,331	3.5718	2.3990	$ 2,222.02	$ 1,492.40
South Carolina	5,665	3.7956	2.5493	$ 2,361.23	$ 1,585.90
South Dakota	5,765	3.8626	2.5943	$ 2,402.91	$ 1,613.90
Tennessee	5,558	3.7239	2.5011	$ 2,316.63	$ 1,555.95

Texas	6,402	4.2893	2.8809	$ 2,668.42	$ 1,792.22
Utah	5,983	4.0086	2.6924	$ 2,493.78	$ 1,674.93
Vermont	5,028	3.3688	2.2626	$ 2,095.72	$ 1,407.58
Virginia	5,720	3.8324	2.5740	$ 2,384.16	$ 1,601.30
Washington	4,361	2.9219	1.9625	$ 1,817.71	$ 1,220.85
West Virginia	4,842	3.2441	2.1789	$ 2,018.20	$ 1,355.51
Wisconsin	5,266	3.5282	2.3697	$ 2,194.92	$ 1,474.20
Wyoming	6,081	4.0743	2.7365	$ 2,534.63	$ 1,702.36
Mean	5,550	3.7185	2.4975	$2,313.31	$1,553.71

Justification for State PV "Carve-outs"

Summary

Based on achievements obtained in the first two parts, this part will focus on the justification for state PV "carve-outs" in view of the impact mentioned above.

The fact that residential solar PV system can reduce social cost of carbon shows that residential PV has a positive externality, indicating there is a social value of residential solar PV for governments.

By analyzing the impacts of residential solar PV in part 1 and part 2, this part gives a reference of how much value is reasonable for long-term SRECs in terms of its positive externality from social cost of carbon saved. Since SREC is based on the measurement of 1 MWh solar electricity output, unit in this section will be turned from kWh to MWh. Results show that the value of positive externality of residential solar PV in a 20-year term is $20.3 to $30.2 (in 2007 $) per MWh, depending on the type of generation displaced by solar.

Currently, there are not many long-term SREC contracts but spot SREC markets are viable in some states. However, the fluctuation of short-term SREC price is huge, and it reflects not only the value of SRECs but market risks as well. The analysis provides a theoretical target value of "carve-outs" for residential solar PV system, i.e., the target long-term market SREC value. The theoretical price is $20 to $30 per MWh in order to optimize the SREC market.

Based on the assumptions used in this analysis, the SREC prices created by solar carve-outs are not justified by the value of the emission reductions resulting from residential solar PV.

Hypothesis

To find out whether the level of solar "carve-outs", which is through the price of SRECs, is justified by residential PV's positive externality, the analysis assumes that without SREC, residential PV owners are compensated for the conventional benefit their solar panels provide, i.e. electricity supply, but receive no compensation for the positive externalities. More specifically, it assumes that net metering rules do not result in over-compensate or under-compensate, and that there are no other subsidies in this case for analysis.

Methods and Sources

This part will compare value of carve-outs with social value of reduced emissions. Social and economic value of reduced emissions is measured by using SCC avoided by residential solar panels, and value of carve-outs will be measured by the price of SRECs. For states with well-developed SREC markets, the spot price can be obtained from website srectrade.com (SREC Trade).

The value of positive externalities of residential solar PV each year (h) comes from the social cost of carbon it saved based on the task force's SCC values for the 20-year period and the two alternative assumptions regarding the generation displaced (NGCC and NGCT). This can be used in calculating the net present value of SCC saved of one MWh for the 20-year period (i). 3.2% discount rate is applied in this step. Diving (i) by 20 results in a levelized social value per MWh output of solar energy, i.e. spreading the NPV evenly over 20 MWh (1 MWh each year for 20 years). After that this part will compare the levelized value with current spot price of SRECs. Table 7 shows methods and inputs used in the calculation.

Table 7 Methods and Inputs used for calculating value of positive externalities per MWh

Items	Input
SREC spot price for states with viable SREC market	Website providing SREC Trade prices. (SREC Trade)
Value of positive externalities of residential solar PV each year (h)	Economic value of solar panels calculated in part 2 (g), SCC values for the 20-year period and the two alternative assumptions regarding the generation displaced
NPV of SCC value of 1 MWh (i)	Apply NPV function on (h), using 3.2% discount rate
Levelized social value per MWh solar energy output	Divide (i) by 20

Although annual output of a solar panel and its value differs between states, given SCC saved by a solar system is relative to its annual AC output, the levelized social value per MWh does not depend on where the residential solar PV system is installed.

Analysis and Results

Solar Renewable Energy Credits are tradable environmental commodities, which each represent 1000 kilowatt-hours (i.e. 1 MWh) of solar energy generated by an eligible solar renewable energy system (Solsystems). This gives additional value to eligible solar renewable energy system rather than conventional value of electricity supply, as in states with Renewable Portfolio Standard (RPS), electricity providers have to contain a certain portion of renewable energy in their total generations. Such utilities can either install their own renewable energy systems, or buy SRECs from those who have already met his assignment.

However, not all states in the U.S. have a viable SREC market, as there are no solar carve-outs. States with viable SREC markets that have ever been quite developed include New Jersey, Pennsylvania, Maryland, Massachusetts, District of Colombia, Ohio, Delaware, California and North Carolina. Some other states without a viable SREC market may have opportunities to join other state markets, for example, Florida does not currently have a viable SREC market but solar owners in Florida may be eligible to participate in the NC SREC market (SREC Trade).

Currently, there are not many long-term SREC contracts but spot SREC markets are viable in some states. Table 8 (SREC Trade) below shows current SREC markets in the U.S. with price accessed in January 2015 and historical range. The table indicates that the fluctuation of SREC spot price is huge, as in Ohio the price touched as low as $1 and as high as $401, while its latest price for 2015 is $48. The reason could be that the price of SREC not only reflects utility's total cost of installation and operation for a solar system, but is also impacted by supply and demand in that market. Spot prices for SRECs are generally higher than prices found in long-term contracts since the system owner is taking on market risk. If increases in supply outpace the growing demand, spot prices could fall (Bird, Heeter and Kreycik). In addition, existing a tradable SREC market does not necessarily mean the state is in a good policy condition because the letter grade system takes many other policy factors into consideration.

Table 8 Current SREC markets in the U.S.

State	Latest Auction Price for 2015 (Date)	History Range from Dec 2009	Overall Policy Grade
DC	$490 (Jan 2015)	$49.49 to $490	A
MA	$274.01 (Nov 2014)	$181.5 to $570	A
MD	$152 (Jan 2015)	$107 to $390.09	A
NJ	$196 (Dec 2014)	$70 to $680	A
OH	$48 (Jan 2015)	$1 to $401	C
PA	$50.51 (Jan 2015)	$4.01 to $310	D

The fact that residential solar PV system can reduce SCC shows that residential PV has a positive externality, i.e., it has additional benefit rather than saving utility costs for residents. This kind of social and climate benefit comes from greenhouse gas emission reductions, and applies to not only the owner of residential PV, but also his neighborhood and even around the global. Thus it is necessary for local and federal governments to know the social and climate value of solar PV system so that the owner of solar PV system could receive both the direct economic incentive and the positive externalities. That value can be reflected in the price of SRECs in states with RPS.

Using SCC values for the 20-year period and the two alternative assumptions regarding the generation displaced (NGCC and NGCT), the NPV of SCC saved per 1MW can be calculated. This result, i.e. the value of positive externalities from residential solar energy, does not vary between different states because it is a value per amount of output. Range of this value is $20.3 per MWh to $30.2 per MWh (in 2007$, the same below), depending on the portion of NGCT or NGCC displaced by solar energy.

This means the ideal target price for residential solar PV system SRECs is about $20 to $30 per SREC. That is to say, in this case, if all SRECs are produced from residential solar PV, the long-term theoretical price should be set as $20 to $30, depending on the type of generation displaced in that state. In this situation, the SREC market will be optimized.

Since the difference between theoretical price and current market price of SRECs are obvious, based on the assumptions used in this analysis, the current SREC prices created by solar carve-outs are not justified by the value of the emission reductions resulting from residential solar PV.

The target value of SRECs is far less than currently spot market price. This could be resulted by the hypotheses of this analysis. First, price of SRECs are an overall value of solar energy, while this analysis only consider residential solar system. Second, spot market prices reflect not only the value of solar energy, but also market risks. Obviously, risks of short-term and long-term contracts are different, thus the price for spot market and 20-year long-term contract cannot be same. Third, market price also reflects the relationship of supply and demand. For example, a tight requirement of SRECs that increases the demand will increase the market price. And the penalty and punishment of not meeting requirements could also impact market price of SRECs.

Even there is a gap between results in this analysis and spot market prices, governments will benefit more from their expectation on promoting residential solar because other social factors will enhance the impacts of favorable policies. One example is peer pressure effect, the study of which shows someone is almost 50% more likely to go solar if their close neighbor has solar panels installed (Graziano and Gillingham). However, such effect is not significantly seen on other kinds of favorable clean energy policies such as hybrid or electric vehicles.

To sum, the theoretical value of long-term SRECs are $20 to $30 per SREC so that the market can be optimized. In the case of this analysis, the SREC current prices created by solar carve-outs are not justified by the value of the emission reductions resulting from residential solar PV.

Summary and Limitations of the Results

Three issues are discussed in this Capstone Project. Linear regression results show a positive relationship between PI and state policy supports on solar energy, and the detail differences of impacts of net metering, interconnection and overall state policies. For a typical residential solar PV system, the annual GHG emission reductions will be 1.67 tons to 4.78 tons CO_{2Eq} in the U.S., and the net present value of SCC saved by the emission reduction is $1,038 to $2,973 nationwide, depending on the type of generation displaced. At last, this article provides a theoretical value of positive externalities of residential solar PV system, $20 to $30 per MWh, based on the value of SCC saved. However, there is significant difference between this value and current SRECs market prices, thus current SREC prices created by solar carve-outs are not justified by the value of emission reductions resulting from solar PV.

There are several limitations for the results of this article:

i) The analysis is only applicable for residential solar PV. Results for other kinds of solar technologies including solar heating and concentrated solar power will probably be different.

ii) Also, results calculated in part 2 and part 3 are under the assumption of 3.2% interest rate and 3% discount rate scenario in SCC value. A lower discount rate and interest rate will increase the current value of residential solar PV.

iii) At last, the lifetime of residential solar is set as 20 years in the discussion.

Appendices

Appendix 1 Detail settings used in calculating annual solar output and value in PVWatts

Items	Value
DC System Size (kW)	4
Module Type	Standard
Array Type	Fixed (open rack)
System Losses (%)	14
Tilt (deg)	20
Azimuth (deg)	180
DC to AC Size Ratio	1.1
Inverter Efficiency (%)	96
Ground Coverage Ratio	0.4
Initial Economics	Default
Available Incentives	Default

Appendix 2 Results of Penetration Index, by U.S. state

State	Penetration Index	State	Penetration Index
Alabama	0.0430	Montana	0.9028
Alaska	0.0580	Nebraska	0.0348
Arizona	22.7760	Nevada	2.5839
Arkansas	0.1303	New Hampshire	2.0885
California	21.9087	New Jersey	7.0142
Colorado	7.9311	New Mexico	8.1304
Connecticut	2.6715	New York	1.7001
Delaware	2.9263	North Carolina	0.2143
District of Columbia	3.6521	North Dakota	0.0719
Florida	0.6351	Ohio	0.2440
Georgia	0.1001	Oklahoma	0.0717
Hawaii	232.1548	Oregon	2.1321
Idaho	0.3414	Pennsylvania	0.8249
Illinois	0.0554	Rhode Island	0.0760
Indiana	0.1049	South Carolina	0.0853
Iowa	0.3561	South Dakota	0.0000
Kansas	0.0922	Tennessee	0.3047
Kentucky	0.1236	Texas	0.8197
Louisiana	5.3123	Utah	1.2997
Maine	2.0320	Vermont	11.3839
Maryland	3.1640	Virginia	0.2188
Massachusetts	4.7793	Washington	0.9075
Michigan	0.2738	West Virginia	0.3383
Minnesota	0.2324	Wisconsin	0.1699
Mississippi	0.0245	Wyoming	0.5751
Missouri	2.2550		

Appendix 3 Solar Power Rankings Grading Criteria, solarpowerrock.com

Item	Weight (%)	Category
Years to system payback accounting for all available incentives	20	Solar Incentives
Tying residential solar incentives to system performance by opening the state market to SREC trading or large scale adoption of feed-in tariffs	10	
Strength of utility and state rebates	10	
Personal tax credits	10	
Property tax exemption status	7	
Sales tax exemption status	3	
Strength of a solar specific set aside in the state's renewable portfolio standard	10	Utility Policies
Strength of the overall state RPS	5	
Existing electric rates	5	
Interconnection	10	Interconnection
Net metering	10	Net metering
Total	**100**	**-**

Appendix 4 Evaluation Results for State Level Solar Policies

I = Interconnection; II= Net Metering; III= Comprehensive Evaluation

State	Grade for I	Grade for II	Score and Grade for III		State	I	II	III	
Alabama	-	-	0.95	F	Montana	C	C	2.73	B
Alaska	C	-	1.91	C	Nebraska	B	-	1.15	F
Arizona	A	-	3.6	B	Nevada	A	B	2.8	B
Arkansas	B	-	0.7	F	New Hampshire	A	D	2.71	A
California	A	A	3.4	A	New Jersey	A	B	3.5	A
Colorado	A	B	3.7	A	New Mexico	B	A	3.55	A
Connecticut	A	B	3.35	A	New York	A	B	4.3	A
Delaware	A	B	4.05	A	North Carolina	C	B	3.33	C
District of Columbia	A	B	3.65	A	North Dakota	D	F	0.81	F
Florida	B	D	2.6	C	Ohio	A	A	3.15	C
Georgia	F	-	0.95	F	Oklahoma	D	-	0.75	F
Hawaii	B	B	2.88	A	Oregon	A	A	3.45	A
Idaho	-	-	0.9	F	Pennsylvania	A	B	2.9	D
Illinois	B	B	3.46	C	Rhode Island	B	B	1.91	C
Indiana	B	B	2.35	C	South Carolina	D	F	2.15	D
Iowa	B	B	2.21	C	South Dakota	-	C	1.35	D
Kansas	B	-	1.5	D	Tennessee	-	-	1.45	D
Kentucky	B	D	1.5	F	Texas	-	D	2.3	D
Louisiana	B	-	2.25	D	Utah	A	A	2.53	D
Maine	B	B	2.35	C	Vermont	A	B	3.26	A
Maryland	A	B	4.3	A	Virginia	D	A	2.11	F
Massachusetts	F	A	4.45	A	Washington	B	B	2	C
Michigan	B	C	1.9	D	West Virginia	A	B	1.55	F
Minnesota	B	C	2.65	A	Wisconsin	D	D	2.3	B
Mississippi	-	-	0.75	F	Wyoming	B	-	0.95	F
Missouri	B	-	2.55	C					

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Curriculum Vitae

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