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Non-utility Photovoltaic Deployment: Evaluation of U.S. State-level Policy Drivers

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ABSTRACT

This article examines whether policies to incentivize solar photovoltaic (PV) systems in the United States are achieving their objectives. We focus on non-utility solar PV, i.e., solar energy systems owned by homes, businesses, and other institutions besides electric utilities. Our study compares the impacts of these policy approaches to those of other non-policy factors such as per capita income, electricity costs, and the availability of solar energy resources. Using a hierarchical regression analysis with cross-sectional data from the years 2012-2013, we find that the most important drivers of non-utility PV deployment are retail electricity rates and available solar energy resources, followed by the presence of personal or corporate income tax credits and net metering policies. These findings indicate a need for stronger net metering policies, adoption of income tax credits over property or sales tax exemptions, and more aggressive renewable portfolio standards that create a more effective solar renewable energy credit market.

INTRODUCTION

This study investigates the uncertainty surrounding U.S. state-level policies to encourage residential and commercial solar photovoltaic (PV) deployment. Our research examines the extent to which these policies are achieving their objectives, while controlling for other explanatory factors that could influence solar PV capacity. These potential factors include population, per capita income, educational attainment, cost of living indices, electricity prices, solar resources, and sensitivity to environmental issues, among others [1,2]. By investigating the efficacy of policy forms such as net metering, income tax credits, and other incentives, we aim to provide clarity for state policymakers and help overcome some of the decision-making challenges they face regarding solar energy policy [3].

We focus on residential and commercial solar PV systems, otherwise known as distributed non-utility solar PV, as opposed to larger utility-scale PV. We emphasize non-utility solar PV for two reasons: first, because many of the policies that states have adopted (e.g., personal income tax credits) are oriented toward non-utility solar PV system owners; and second, because of recent controversies in some states over net metering laws for non-utility solar PV. The following sections of this article review U.S. state policy approaches for solar PV and the results of prior research on those policies. We then discuss the methodology and results of our analysis, and conclude by reflecting on both the policy implications of these results and opportunities for further research.

U.S. State Policy Approaches for Solar PV

Governments around the globe have played an increasing role in implementing energy policy since the spike in energy rates in the 1970s, often to meet objectives such as reliability, economic growth, environmental protection, and resource diversification [4,5,6]. Since the rise of New Federalism in the 1980s, U.S. states have proactively addressed the issues of energy production and consumption via legislation, taxation, energy conservation standards, subsidies, and other forms of incentives [3,7,8].

Though oil and gas resources continue to dominate today's industrialized world, their standing is already beginning to decline [9]. Numerous scholars have noted the increasing role of energy efficiency and renewable energy, and subsequent reductions in air pollution, carbon emissions, and other environmental impacts [10-14]. Increased renewable energy integration is important considering fossil fuels' influence on carbon dioxide and other greenhouse gas emissions being trapped in the Earth's atmosphere, posing major threats to global development, human health, and the environment via global warming [15,16]. Policymakers' recent focus on rising energy prices, energy security, and environmental sustainability has led to a greater emphasis on energy conservation and the pursuit of alternative sources of energy such as biomass, wind, hydro and solar PV [17-19].

Solar PV systems are one of the most practical ways for homeowners and businesses to participate in the transition to cleaner and more sustainable forms of energy. However, since most policies to encourage solar PV are enacted by state governments, opportunities to invest in solar PV vary widely [20]. The various policies that support solar PV can be divided into three categories: market-opening policies, renewable portfolio standards (RPS) and financial subsidies.

Market-opening policies include interconnection standards and net metering laws, both of which are intended to remove obstacles to solar PV investments and homogenize market access for interested parties [1,21]. These policies are generally perceived to be low-cost to government, and have become relatively common in the U.S. interconnection standards, outlining the processes for connecting an energy generating system to the electrical grid [22]. These standards can institute fees for interconnection, place limits on system capacity, and require different types of certification procedures [23]. All states have some sort of interconnection procedure, but the extent to which they ease solar PV integration varies [24].

Net metering legislation has been adopted in 44 of the 50 states [25]. They create a repayment system for selling energy back to the grid once a solar PV system is interconnected [26,27]. Typically, such arrangements are a direct kilowatt hour (kWh)-for-kWh offset on a residential or commercial utility invoice for all energy produced, credited over a 12-month period [28]. These standards are vital for non-utility solar PV projects since they allow consumers to receive benefits for all of the electricity generated by their systems, even when the system's production exceeds the needs of the building on which it lies [29]. Such arrangements also allow solar PV system owners to use electricity from the grid at times when their systems are not producing (e.g., at night), negating the need for expensive battery storage, and potentially achieving net-zero electricity consumption during a given month or year. However, in some states, net metering laws are less supportive as they may limit system capacities, establish fees, or restrict the types of energy systems that are eligible for the program [30].

Under an RPS, electric utilities are required to meet annual targets for obtaining a portion of their electricity supply from renewable sources such as solar and wind power (e.g., 15% by the year 2020) [31]. Over half of the U.S. states have a mandatory portfolio standard, while eight others have a voluntary RPS program [32]. In Virginia, utility providers are able to raise their base electric rates if they meet the voluntary RPS standard [33]. Sixteen states include a solar carve-out in their RPS, requiring that a percentage of the utility's electrical supply be specifically from solar power [34].

Both RPS and net metering laws have come under scrutiny over allegations that they create costs for utilities that are passed to ratepayers. Regulations to repeal RPS laws have been introduced in at least 13 states, but as of 2016, have only passed in West Virginia [35,36]. Meanwhile, some states are considering stand-by charge policies, which undermine net metering by allowing utilities to apply a monthly fee to owners of solar PV systems [37]. Virginia first allowed these charges in 2011, followed by Arizona in early 2014 [38,39]. Similar policies have been considered in several other states (e.g., Georgia, Idaho, Maine, Vermont and Wisconsin) [40,41].

The third primary category of state solar energy policies, financial subsidies, includes property or sales tax exemptions, income tax credits, low or zero-interest loans, and the ability to sell credits from PV systems within a solar renewable energy credit (SREC) [42]. These incentives increase the governing authority's costs, and thus arguably indicate an even greater level of commitment toward promoting solar energy [1,43].

A number of states offer various loan programs for solar PV investments, often with zero or very low interest rates. Other financial incentives include exempting solar PV equipment from state property or sales taxes, or offering personal and/or corporate tax deductions for solar PV investments, similar to the investment tax credit offered by the U.S. federal government [44,45].

Finally, SREC markets are most often present in states with a mandatory RPS, as utilities can count SRECs purchased from local solar PV owners towards their RPS requirements, usually at a rate of one credit per megawatt-hour (MWh) of solar electricity produced [45]. However, PV system owners in states without an RPS can sometimes sell their SRECs to an out-of-state market. This is common in the mid-Atlantic region of the U.S. [46].

Literature Review

A small number of prior studies have evaluated the effectiveness of solar PV policy mechanisms through comprehensive statistical analysis of the factors driving solar PV capacity at the state level. These studies have primarily employed multiple regression analyses to weigh the effects of various state policies against other non-policy factors such as solar insolation, electricity prices, and various demographic conditions.

Table 1 summarizes the results of these seven prior studies that are most similar to our research. A check, √, signifies that the study found a variable to be a significant driver of installed PV capacity, while an X indicates that a variable was found insignificant. Some studies use the non-policy variables as controls, C, but do not individually analyze their unique effect on solar PV capacity. Cells in the table are blank if the variable was not addressed. The demographic factors column includes all variables related to economic strength, income, population or environmental preferences.

Table 1. Key drivers of solar PV identified in prior studies.

Authors, Publication Year (Years studied)	*Net Metering*	*Interconnection*	*RPS*	*Loans*	*Tax Credit*	*Property Tax*	*Sales Tax*	*Insolation / PV Potential*	*Electricity Prices*	*Demographic Factors*
Carley, 2009 [69] (1998–2006)			√	√	X	X	X	√	X	√[a]
Doris and Gelman, 2011[b] (2007–2009)		X	√		√[c]		X			√
Krasko and Doris, 2013 (2010)	√	√	√							√
Sarzynski *et al.*, 2012[d] (1997–2009)	X		√			X	X		√	X
Shrimali and Kniefel, 2011 (1991–2007)			√						X	X
Steward & Doris, 2014 [70] (2007–2012)	√	√	√					C	C	C
Steward *et al.*, 2014 (2011)	√	√	√					C	C	C

[a] While state GDP had a positive result, income and educational attainment were deleted from the model due to insignificance.
[b] Net metering and electricity price variables were deleted from model due to multi-collinearity issues.
[c] Personal tax incentives are positively associated with PV capacity, yet corporate tax incentives show a negative relationship.
[d] Cash incentives resulted in greater PV market deployment, but not property or sales tax incentives.

Examined holistically, this prior research has produced mixed results about the relative importance of market-opening policies, financial incentives, and other non-policy factors in support of the growth of solar PV capacity. All of the studies in Table 1 found RPS policies to be a significant, positive driver of PV capacity. Those that included net metering or interconnection variables generally found them to be significant drivers. There were exceptions [42,47]. Other types of financial incentives were sporadically included, and often found to be insignificant. Electricity prices, somewhat surprisingly, had insignificant results in two of three studies, while a variety of demographic factors had mixed results.

A number of other studies have evaluated certain state-level policy approaches to solar PV, but without comprehensively assessing a range of policy and non-policy variables such as in the studies previously described. Several of these concur that state RPS and solar carve-outs have a strong positive impact on solar PV deployment [48-50]. However, others indicate that RPS and market-opening policies are insufficient to spur market growth on their own, and several have argued that financial incentives most strongly encourage solar PV investments [51-53]. For instance, Burns and Kang [45] found that RPS solar carve-outs and net metering were important drivers for successful solar PV markets, but only when combined with SREC market access. Shrimali and Jenner [54] found that interconnection standards have a key role in residential solar PV investment, but financial incentives are a more powerful driver in the commercial sector.

Other studies have emphasized the role of demographic factors such as income [54-56], education [57], and awareness of environmental concerns [58] as principal drivers of solar PV or renewable energy investment. Other non-policy factors found to be important include electricity prices [42,59], state political culture [60], and the availability of solar energy resources and technology [59].

Our research builds upon those previous studies with a unique and improved methodology. First, the previous literature has focused primarily on total solar PV capacity figures (i.e., residential, commercial and utility scale), while others have focused on the residential sector only. We consider the more important division to be between utility and non-utility solar, with the latter being a greater challenge in the current political climate. Therefore, we include all non-utility (residential and commercial sector) solar PV capacity in our dependent variable. Our study also includes a more comprehensive range of both policy and non-policy variables than prior studies, some of which are measured in a more refined manner (e.g., we use a more narrowly defined electricity price variable, and measure solar potential by averaging statewide insolation scores, rather than estimating solar rooftop technical potential).

Our study is also original in its use of SREC market access as an independent variable, rather than state RPS programs. None of the studies shown in Table 1 included SREC market access as an independent variable. We believe that SREC market access is a more appropriate variable for studying non-utility solar PV deployment, given that RPS policies are aimed at the utilities themselves, and resulting SREC markets are the means by which those policies create incentives for residential and commercial solar PV customers.

Data and Methods

Our study employs a hierarchical series of ordinary least squares (OLS) multiple regression analyses, each of which adds a new category of predictors [61]. Using this method, we evaluate the impacts of 10 policy and non-policy variables on the amount of non-utility solar PV capacity installed annually within each U.S. state, plus the District of Columbia. The model covers the years 2012-2013, the only ones for which our dependent variable data is available, and thus has 102 total observations. All variables are operationalized using data from secondary sources. The full data set of dependent and independent variable measurements for each state (year 2013 only) is provided in Appendix A. Pooling the data and using these expanding OLS models is applicable since large differences exist in the installed non-utility solar PV capacity by year, in addition to several of the state policy variables. Further, since the variance in 2012 and 2013 were roughly the same, the pooled regression was more efficient approach. Protracted longitudinal analyses or panel data analyses were not suitable since our dataset only covers a 2-year period.

The dependent variable is the *amount of grid-tied non-utility solar PV capacity installed in each state per year*, per 100,000 residents, as found in annual U.S. Solar Market Trends reports by the Interstate Renewable Energy Council (IREC) [62,63]. While these IREC studies date to 2008, they have only separated solar PV capacity by sector (i.e., utility, commercial and residential) since 2012 [62], and these reports ended after the 2014 version (which contained 2013 data) (J. Pulaski, personal communication, March 17, 2016). These reports define the capacity of a solar PV installation as "the maximum power that a system can produce," measured "in direct current (DC) watts under Standard Test Conditions (WDC-STC) of 1,000 W/m^2 solar irradiance and 25°CPV module temperature" [63:27-28]. Other similar studies have relied on separate data sets from the Open PV Project [e.g., 52,64], yet the IREC reports are more detailed in their data collection methodology (i.e., they do not simply rely on data from willing contributors) and offer a robust set of data concerning grid-tied PV installations [42]. Thus, we consider the IREC reports to be the best measures of present *non-utility solar PV* deployment in the U.S.

The U.S. state policy variables are divided into two categories: market-opening policies and financial incentives. The first category includes the variables *interconnection* standards and *net metering*. Both variables are measured via complex grading systems developed by the IREC and Vote Solar in their annual Freeing the Grid reports [24]. The grading system "awards points for elements that promote participation, expand renewable energy generation, or otherwise advance the goals sought by (interconnection and) net metering. Conversely, the index issues demerits for program components that discourage participation or limit renewable energy generation" [24:16].

The remaining policy variables reflect various types of financial incentives. The *loan programs* variable refers to whether or not a state offers zero or low-interest loan programs for solar PV investments. The next three variables measure whether or not U.S. states offer personal and/or corporate income tax deductions for solar PV investments, or if solar equipment qualifies for a *property tax exemption* or *sales tax exemption*. The final financial variable indicates whether or not solar PV system owners in a given state can access an *SRECS* market, allowing them to sell credits for every MWh of solar electricity created. These financial incentives are operationalized using dummy variables, with a value of 1 if the state has adopted a given policy, and a value of 0 if it has not, using data from the Database of State Incentives for Renewables and Efficiency (2015).[1] Policies are only counted if adopted statewide, not if they exist only in certain cities, counties, or utility service areas.

Unlike some similar studies, we exclude state RPS policies, as these are geared toward utilities, and are only relevant to non-utility solar PV investments if they provide a mechanism for residential and commercial solar PV owners to sell *SRECS* to utilities. Given that solar PV owners in some non-RPS states, such as Virginia, can access SREC markets in other states (in this case Pennsylvania), access to an SREC market is the more pertinent variable for our purposes. We also exclude leases or other cash rebate programs, as they are costly to government, often suffer from a lack of funding, and are not guaranteed on a year-to-year basis within a state. Such cash incentive programs are also difficult to quantify, and in some cases, are only available at the local- or utility-level (e.g., Florida Power and Light's Solar Rebate Program). Previous studies have also excluded cash incentive variables for similar reasons [e.g., 45,65].

The final category of independent variables includes three non-policy determinants: *solar energy resources* (i.e., average amount of sunlight), *electricity prices*, and *per capita income*. Solar energy resource data comes from the National Renewable Energy Laboratory (NREL)[3] and is measured by the variable solar *insolation*, or the average amount of solar radiation energy, in kilowatt-hours per square meter per day (kWh/m^2/day), available to south-facing fixed-tilt solar collectors. NREL provides this data for 239 major cities across the country, including at least one per state, and our variable is measured as the average solar insolation score among all cities in each state.

Electricity prices are included because the baseline cost of electricity that one pays is an important factor for measuring the cost-effectiveness of a given solar PV investment (i.e., the average cost per kWh of electricity produced by the PV installation must be compared to the price that one would otherwise pay for that electricity). We measured the *electricity cost* variable as the average retail price paid by residential, commercial, and industrial customers per state, as reported by the U.S. Energy Information Administration's 'State Electricity Profiles' database.

One demographic variable, per capita *income*, recognizes the fact that solar PV systems have an up-front cost and are presumably more prevalent in higher-income locales. This data was drawn from the U.S. Census Bureau's annual mid-year population estimates [66]. Other studies have used educational attainment as an independent variable, based on the premise that the higher educated are more apt to invest in environmentally sensitive technologies [64,67]. However, our results showed high multi-co-linearity between *income* and educational attainment (measured as the percentage of persons over 25 years old with a bachelor's degree or higher). Consequently, we removed the latter variable and retained per capita *income*, which we believed more directly measured a potential driver of solar PV installations.

We then employed a three-tiered hierarchical regression model to test the extent to which the three categories of independent variables influence the dependent variable. The final full model is as follows:

NON_UTILITY_PV = β_0 + β_1 INTERCONNECTION + β_2 NET_METERING + β_3 SRECS + β_4 LOANS + β_5 TAX_CREDITS + β_6 PROPERTY_TAX_EXEMPTION+ β_7 SALES_TAX_EXEMPTION +β_8 INSOLATION+ β_9 ELECTRICITY_COST+ β_{10} INCOME + error

In which:

- NON_UTILITY_PV = Grid-connected, newly installed solar PV (MW_{DC}) (residential and commercial)
- INTERCONNECTION = Interconnection score from Freeing the Grid report
- NET_METERING = Net metering score from the Freeing the Grid report
- SRECS = 1 if customers can sell credits within an SREC market, 0 if otherwise
- LOANS = 1 if state loan programs exist, 0 if otherwise
- TAX_CREDITS = 1 if personal and/or corporate income tax credit exists, 0 if otherwise
- PROPERTY_TAX_EXEMPTION = 1 if property tax exemption exists, 0 if otherwise
- SALES_TAX_EXEMPTION = 1 if sales tax exemption exists, 0 if otherwise
- INSOLATION = Average yearly solar insolation measurement ($kWh/m^2/day$)
- ELECTRICITY_COST = Average retail electricity price (cents/kWh)
- INCOME = Per capita income (thousand U.S. dollars)

A few limitations to our methodology bear mentioning. First, the use of secondary data sources means that we cannot maintain variable control, which introduces potential bias with some variables such as those derived from the Freeing the Grid report. However, developing our own criteria for grading interconnection and net metering was unfeasible. Freeing the Grid is a well-respected source that is frequently cited in academic research. We also acknowledge that our model does not contain a particularly large number of observations (*N*=102) for a regression analysis. This situation is unavoidable given the limited availability of data on non-utility solar PV deployment per state. However, the model still has an acceptable ratio of over 10 observations per independent variable.

Additionally, our focus on state-level factors does not capture all of the dynamics that would influence solar PV capacity within states, at the city, county or regional levels. Some of our variables, particularly per capita *income*, vary considerably within a state. Numerous local jurisdictions and utility providers offer solar PV financial incentives that are not captured in our generalized dummy measurements. This could be problematic in states where such incentives are offered by primate cities that represent a large portion of their state's population. Regardless, no reasonable alternative exists to control for this dynamic, as data on solar PV capacity at the jurisdictional level is extremely limited.

We performed versions of the model that employed a logarithmic transformation for all non-dichotomous variables to correct non-normality. This approach accounted for skewness due to pre-hoc concerns over the nature of the data, allowing the resulting coefficients to be interpreted as elasticities via a log-log model. Due to the fact that the natural log of zero is undefined, we added the number one to all relevant variables. In turn, this left each data point in constant proportion to one another, and allowed all zeros to become ones, meaning that they were not dropped from the model as a result of the logarithmic transformation. Nevertheless, while this approach helped normalize variables and reduce coefficient estimation bias, the transformed variables neither improved the model nor offered any significantly different results. Therefore, we opted to keep the original variable forms for ease of interpretation and analysis, using the standardized correlates as the measure of uniformity.

Despite these limitations, our model serves to identify correlations between our policy and non-policy variables and the extent of newly installed solar PV capacity. While such results do not prove direct causation, uncovering the extent of the linear relationship between the variables advances knowledge about how different policy approaches correspond to PV capacity growth, relative to other non-policy factors.

Results

The descriptive statistics in Table 2 show the minimum, maximum, and mean values of the variables employed in this analysis from our 102 observations. The negative minimum value for interconnection reflects the fact that the Freeing the Grid report levies a negative grade for those states in which it is particularly burdensome to interconnect a residential or commercial solar PV system. All financial incentive policies are dichotomous dummy variables, and their mean values thus indicate the percentage of states that have adopted each of those policies. It is notable that our non-policy variable figures differ dramatically among states, particularly electricity costs, where Hawaii's per/kWh prices are roughly five times of those in the state of Washington.

Table 2.
Summary statistics: all values by U.S. state.

	Minimum	*Maximum*	*Mean*	*Std. Deviation*
NON_UTILITY_PV	.00	10.02	.55	1.371
INTERCONNECTION	-5.50	27.50	9.67	8.354
NET_METERING	.00	25.00	11.34	6.808
SRECS	.00	1.00	.31	.466
LOANS	.00	1.00	.45	.500
TAX_CREDITS	.00	1.00	.40	.493
PROPERTY_TAX_EXEMPTION	.00	1.00	.53	.502
SALES_TAX_EXEMPTION	.00	1.00	.40	.493
INSOLATION	2.42	5.45	4.24	.530
ELECTRICITY_COST	6.90	34.04	10.67	4.055
INCOME	33.45	75.95	44.24	7.827

As shown in Table 3, our results demonstrate that policy-factors alone do not adequately explain the variation in state-level non-utility solar PV capacity growth. In fact, the majority of the variation appears to be attributable to non-policy factors. The first two models result in very low adjusted R^2 values of 0.075 and 0.111, meaning that these policy models explain only 7.5% and 11.1% of the variance in the dependent variable, respectively. With the inclusion of the non-policy variables (Model 3), the adjusted R^2 increases to 0.782, indicating that the full model explains 78.2% of the variance in state-level non-utility solar PV capacity additions. In short, including the non-policy factors in the model considerably increases its predictive ability. Simply performing a non-policy model (including only *insolation*, *electricity prices* and *in-*

come) produces an adjusted R^2 of 0.769, compared to the 0.111 value for the policy-only model. More telling is the fact that our F-stat increases dramatically between these same two models, from 2.806 to 113.191, and our constant, which is originally statistically insignificant, becomes so at the 99% level. These results, coupled with the lack of heteroscedasticity issues, convincingly demonstrate that our dependent variable is more strongly influenced by non-policy determinants than state policy mechanisms. Since our resulting variance inflation factors were all well below two, no issues with variable multi-collinearity were observed.

Given these overall results, it is no surprise that our full model finds solar *insolation* and *electricity costs* to be the most significant predictors of installed non-utility solar PV capacity. The coefficients indicate

Table 3.
Policy and non-policy impacts on non-utility installed PV capacity.

Variable	*Model 1* *Market-Opening Policy*	*Model 2* *All State Policy*	*Model 3* *All Factors Policy and Non-policy*
INTERCONNECTION	.022 (.019)	.029 (.020)	-.007 (.010)
NET METERING	.042 (.023)*	.059 (.025)**	.024 (.013)*
SRECS	–	-.391 (.313)	.214 (.161)
LOANS	–	-.005 (.272)	-.105 (.140)
TAX CREDITS	–	.659 (.271)**	.326 (.139)**
PROPERTY TAX EXEMPTION	–	-.208 (.279)	.123 (.142)
SALES TAX EXEMPTION	–	-.240 (.305)	-.078 (.152)
INSOLATION	–	–	.675 (.139)***
ELECTRICITY COST	–	–	.285 (.018)***
INCOME	–	–	-.000 (.000)
Constant	-0.138	-0.329	-5.105***
N	102	102	102
R^2	0.093	0.173	0.804
Adjusted R^2	0.075	0.111	0.782

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

that a one-unit change in a state's solar insolation metric provokes, on average, 0.675 megawatts (MW) of newly installed capacity per 100,000 residents, whereas a $0.01/kWh increase in average state retail electricity prices leads to roughly 0.285 MW per 100,000. These findings are logical, as solar PV systems in locations with high solar *insolation* and high *electricity cost* have relatively shorter payback periods compared to those in low *insolation* and/or low *electricity cost* locations. While some prior studies suggest that U.S. states with higher incomes would have greater levels of solar PV installation, this variable is surprisingly not significant in our model.

These results should not be interpreted to suggest that policy approaches are not relevant to the growth of solar PV. Table 3 shows both *net metering* and personal or corporate income *tax credits* to be statistically significant and meaningful predictors of non-utility solar PV installations. The coefficient for the income *tax credits* variable in the full model indicates that a state that has adopted these credits would have an expected increase of 0.326 MW of newly installed capacity per 100,000 residents over one that has not adopted them. For context, Virginia (population 8.27 million) had 2.1 MW of newly installed solar PV capacity in 2013, or 30 kilowatts (kW) per 100,000 residents, without income *tax credits*. Had the commonwealth adopted these credits, the results suggest an additional 27 MW would have been installed (0.326 MW per 100,000 times 82.7), assuming all other variables are held equal.

Net metering laws were another statistically significant state policy variable, showing that a one-unit change in a state's net metering grade, via the Freeing the Grid report, leads to 0.024 MW of newly installed capacity per 100,000 residents. This is a meaningful difference considering how frequently and by what ranges the states' Freeing the Grid scores vary on a year-to-year basis. Virginia's net metering score of 5.0 ranked it among the bottom 10 states in 2013. An increase to a median score of 12.0 would produce an expected increase of 0.168 MW per 100,000 residents, or just under 14 MW of additional capacity, assuming that all other variables remain constant.

Other than personal or corporate income *tax credits*, all of our other financial incentive independent variables are statistically insignificant in the full model. The variables for loans and sales tax exemptions also had negative coefficients. However, this result could be an oversimplification, stemming from the use of dichotomous dummy variables, as the details of these financial incentive policies vary widely from state to state.

We also investigated the standardized regression coefficients for our independent variables, to determine their relative influence on non-utility solar PV installations when controlling for the different units in which they are measured, as shown in Table 4.

Table 4.
Standardized correlates of non-utility installed solar PV capacity.

Variable	*Model 1 Market-Opening Policy*	*Model 2 All State Policy*	*Model 3 All Factors Policy and Non-policy*
INTERCONNECTION	.134	.178	-.044
NET METERING	.209*	.291**	.120*
SRECS	–	-.133	.073
LOANS	–	-.002	-.038
TAX_CREDITS	–	.237**	.117**
PROPERTY TAX EXEMPTION	–	-.076	.045
SALES TAX EXEMPTION	–	-.086	-.028
INSOLATION	–	–	.261***
ELECTRICITY COST	–	–	.843***
INCOME	–	–	-.081
Constant	-0.138	-0.329	-5.105***
Adjusted R^2	0.075	0.111	0.782

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$
Note. Inclusion of all policy and non-policy determinants makes the constant in our most comprehensive model statistically significant at the 99% level.

According to these standardized coefficients, *electricity cost* has, by far, the strongest influence on non-utility solar PV installation, followed by solar *insolation*, then *net metering* and income *tax credits*. These results reinforce the earlier points that non-policy factors are most important, specifically those that help determine the payback period for a solar PV investment, and that *net metering* and income *tax credits* are the most important state policy factors.

In order to fully discern the impact of our independent variables on the amount of newly-installed non-utility solar PV capacity, we also performed a supplementary analysis using *total installed PV capacity* (including utility-scale installations) in 2012-2013 as the dependent variable.

Table 5.
Standardized correlates of total installed solar PV capacity (utility and non-utility).

Variable	*Model 1 Market-Opening Policy*	*Model 2 All State Policy*	*Model 3 All Factors Policy and Non-policy*
INTERCONNECTION	.123	.131	.109
NET METERING	.218*	.409***	.346***
SRECS	–	-.284***	-.197*
LOANS	–	-.247**	-.206**
TAX_CREDITS	–	.002	-.069
PROPERTY TAX EXEMPTION	–	.131	.138
SALES TAX EXEMPTION	–	-.259**	-.226**
INSOLATION	–	–	.251**
ELECTRICITY COST	–	–	.142
INCOME	–	–	-.006
Constant	-67.346	-21.931	-678.780**
Adjusted R^2	0.074	0.165	0.215

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

Table 6.
Standardized correlates using log-transformed variables.

Variable	*Model 1 Market-Opening Policy*	*Model 2 All State Policy*	*Model 3 All Factors Policy and Non-policy*
INTERCONNECTION	.145	.167	-.061
NET METERING	.303***	.330***	.214***
SRECS	–	-.095	.079
LOANS	–	-.005	-.008
TAX_CREDITS	–	.210**	.150**
PROPERTY TAX EXEMPTION	–	.001	.062
SALES TAX EXEMPTION	–	-.014	.034
INSOLATION	–	–	.368***
ELECTRICITY COST	–	–	.699***
INCOME	–	–	-.004
Constant	-0.104	-0.195	-5.442***
Adjusted R^2	0.139	0.156	0.667

* $p < 0.10$ ** $p < 0.05$ *** $p < 0.01$

As presented in Table 5, these results suggest that state retail electricity rates, as expected, do not have a statistically significant or meaningful role in encouraging solar PV when incorporating utility installations, though insolation remains a major driver. However, more telling is how this analysis confirms net metering's role as the most influential state policy, which is consistent with prior research that examines aggregate solar PV installation figures. While the availability of *tax credits* no longer serves as a meaningful predictor, this comparison strengthens our results by verifying the influence of available solar energy resources and net metering policies at incentivizing solar PV installations.

Finally, we also performed models with continuous variables that had been corrected for skewness via a logarithmic transformation. While this resulted in a slightly lower adjusted R^2 value of 0.667, this analysis also confirms the statistical significance, and importance of net metering and state tax credits as policy variables, as well as *insolation* and *electricity cost* as non-policy variables.

Discussion

Prior studies have provided substantial evidence that state-level solar energy policies help to increase solar PV market penetration. Our analysis differs from past research by strictly considering the factors influencing non-utility solar PV capacity at the state level. This distinction is important, as many of the state solar energy policy incentives are directed at residential and commercial solar PV customers.

Our findings show that non-policy factors—specifically solar insolation and electricity prices—have the greatest overall influence on the extent of annual PV capacity installations at the state level. This result is reasonable. The amount of electricity that a solar PV installation produces is a direct function of the amount of solar insolation energy received, and the price of electricity that the solar PV owner would otherwise purchase represents the effective value of the electricity that the system produces. Combine these two factors, and an investment in solar PV is most cost-effective in locations with high insolation and high electricity prices.

However, these results should not be interpreted to suggest that state-level solar PV policy is an ineffective or irrelevant factor in the growth of solar PV. Rather, the more compelling and valuable findings come from examining the results for the individual policy variables to determine which ones have been most effective. In this regard, we conclude that income tax credits and net metering are the key state policies for encouraging solar investments. While the vast majority of distributed solar installations in the U.S. are net-metered [62], the effectiveness of net metering policies and the extent to which they ease PV investment varies greatly [24]. These findings are particularly significant in the context of recent state efforts to limit net metering, such as through the stand-by charge system pioneered in Virginia, or to eliminate it altogether [38,40].

We also found evidence that other financial incentive policies—sales and property tax exemptions, state loan programs for solar PV, and SREC markets—were relatively ineffective within the years we studied. The poor results for SRECs likely reflect the fact that SREC market prices declined considerably between 2011-2013 in every market except for the District of Columbia due to increasing supply and decreased demand [68]. It is noteworthy that SREC markets are typically only found in the east coast states (e.g., mid-Atlantic and some mid-west states) of the U.S.

There are a few possible explanations for the poor results of the other remaining financial incentive variables (i.e., *property tax exemptions*, *sales tax exemptions*, and *loans*). First, such policies may be popular among states that wish to kick-start nascent solar markets, and as other studies have suggested, a lag may occur before they become effective [47]. Second, loans and tax exemptions may be deemed unnecessary in pro-solar states that have instead adopted more aggressive personal or corporate income tax credits. Such weaker incentives may also be unnecessary in states where a combination of other policy and non-policy factors already create a favorable environment for solar. These suppositions are supported by the fact that among the top five states for per capita non-utility solar PV capacity (Hawaii, Massachusetts, Arizona, New Jersey and California), only Hawaii had a loan program in 2013 and only Massachusetts and New Jersey had SREC markets. Meanwhile, three of the top five states had a combination of personal/corporate income tax credits and above-average net metering scores (Hawaii, Massachusetts and Arizona), while the other two (California and New Jersey) had very high net metering scores (among top six in the country), and all had top seven insolation scores and/or electricity prices.

Conclusions and Policy Implications

Our study expands the current body of research on U.S. state-level solar energy policy by evaluating the impacts of a comprehensive range of policy and non-policy factors on the growth of non-utility residential and commercial solar PV capacity by state, weighted by population. We conclude that solar PV capacity growth is highest in states with high electricity costs and better solar insolation resources. In addition, we find that better net metering policies and the availability of personal or corporate income tax credits for solar PV systems are also significant positive drivers of capacity growth. These latter findings are particularly valuable in light of the uncertainty that states face in determining how to regulate and incentivize their solar energy markets.

We find that other types of state financial incentives, such as property and sales tax exemptions, loans, and SREC markets, have so far been less productive at promoting non-utility solar PV investments. The results for the tax exemptions and loans are perhaps unsurprising, given that these policies have a more marginal impact on the cost-effectiveness of a solar PV system, compared to a personal or corporate income tax credit. The poor result for SREC markets seems counter-intuitive, but it likely reflects the reduced SREC prices during the years of our study (2012-2013). Further research could refine the analysis by providing more precise data on the actual SREC market prices or loan and tax credit terms for each state in each year, rather than using dummy variables. Alternatively, using the age of a given policy, rather than a dummy variable, could produce better results by accounting for the policy lag factor. However, data availability will be a challenge for either of these approaches. Future studies could also include additional policy approaches, such as participation in regional climate agreements or availability of third-party financing programs, which can make PV investments more desirable to state residents. The incorporation of cash incentives may also be valuable to these analyses. The addition of these independent variables will be possible as more data become available on year-to-year non-utility solar PV installations, thus increasing the number of cases in the model.

State officials and solar energy supporters can use this evidence to craft more effective policy approaches for solar energy. For example, our findings show that among financial incentive programs, personal or corporate income tax credits are far more important than loan programs or sales or property tax exemptions. While these findings do not end the debate on which financial incentive policies ought to be developed or enhanced to encourage non-utility installations, they provide strong evidence that income tax credits are powerful facilitators for investment. Stronger RPS programs with higher solar PV requirements are needed to create greater demand in the SREC markets to improve the effectiveness of those policies. Finally, strong net metering policies are arguably the most effective state-level policy incentive. This finding supports arguments for raising net metering system caps, removing fees, and allowing community or virtual net metering arrangements. This is a particularly important finding given the recent political movements against net metering and the adoption of solar PV stand-by charges in several U.S. states. These stronger, more refined policy approaches will be needed to advance non-utility solar PV, particularly in those states where circumstantial non-policy factors are less favorable.

End Notes

1. Data source: Database of State Incentives for Renewables and Efficiency (2015). *Find policy and incentives by state*. Retrieved from http://www.dsireusa.org.
2. Data source: SRECTrade (2015). *SREC markets*. Retrieved from http://www.srectrade.com/srec_markets/introduction.
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Appendix A

Summary of all Variable Measurements by State, 2013

Table A-1 demonstrates the entire data set of dependent and independent variable measurements for each state, based on year 2013 data. The summary row at the bottom shows average scores for all continuous variables, and the number of states that have adopted each policy measured by a dummy variable (indicated with an asterisk).

Table A-1.
Data set for all dependent and independent variables.

State	*PV MW / 100K*	*Net Metering*	*Interconnection*	*SRECs*	*Loans*	*P/C Tax Credit*	*Property Tax*	*Sales Tax*	*Insolation*	*Elec. Price*	*Per Cap. Income*
Alabama	0.02	0	0		√				4.45	9.56	36.48
Alaska	0.03	7	0		√				2.42	16.19	50.15
Arizona	2.66	17	0			√	√	√	5.45	10.96	36.98
Arkansas	0.01	14.5	0						4.55	8.27	36.70
California	1.71	22.5	27.5				√		4.98	15.89	48.43
Colorado	1.08	25	18.5		√		√	√	4.88	10.42	46.90
Connecticut	0.88	20	20		√		√	√	3.80	15.50	60.66
Delaware	1.31	23.5	19.5	√	√				4.10	10.87	44.82
D.C.	0.40	17	18.5	√			√		4.20	11.99	75.33
Florida	0.08	12	10	√		√	√	√	4.80	10.29	41.50
Georgia	0.22	0.5	0						4.58	10.31	37.85
Hawaii	10.02	14	20		√	√			5.13	32.86	45.20
Idaho	0.05	0	0		√	√			4.35	8.15	36.15
Illinois	0.00	14.5	21	√	√		√		4.00	8.21	46.98
Indiana	0.02	11.5	18	√			√	√	4.00	8.82	38.62
Iowa	0.11	10.5	17.5		√	√	√	√	4.05	9.11	44.76
Kansas	0.02	11.5	0				√		4.63	10.07	44.42
Kentucky	0.07	11.5	9	√		√		√	4.07	7.84	36.21
Louisiana	0.60	10	0		√	√	√		4.58	8.43	41.20
Maine	0.19	12	19.5						3.75	11.53	40.92
Maryland	0.99	22.5	20.5	√	√	√	√	√	4.00	12.21	53.83
Massachusetts	2.91	18.5	22.5	√		√	√	√	3.90	14.74	57.25
Michigan	0.02	10	14	√					3.72	11.71	39.06

Table A-1 (*continued*).
Data set for all dependent and independent variables.

State	*PV MW / 100K*	*Net Metering*	*Interconnection*	*SRECs*	*Loans*	*P/C Tax Credit*	*Property Tax*	*Sales Tax*	*Insolation*	*Elec. Price*	*Per Cap. Income*
Minnesota	0.03	14.5	10.5		√			√	3.76	10.08	47.50
Mississippi	0.01	0	0		√				4.55	9.49	33.91
Missouri	0.50	13.5	0		√		√		4.30	10.62	40.66
Montana	0.09	6	12.5		√	√	√		3.92	8.76	39.37
Nebraska	0.01	9	0		√	√		√	4.34	9.49	47.16
Nevada	0.44	18.5	19.5		√		√	√	5.02	10.00	39.24
New Hampshire	0.31	18	9	√	√				3.90	13.85	51.01
New Jersey	2.15	22	20.5	√			√	√	3.95	14.62	55.39
New Mexico	1.15	9.5	22.5			√	√	√	5.40	10.22	35.97
New York	0.29	16	16.5		√	√	√	√	3.76	16.52	54.46
North Carolina	0.26	7	20.5	√		√	√		4.42	9.61	38.68
North Dakota	0.01	5	0			√	√		3.90	8.89	53.18
Ohio	0.12	15	19	√	√		√		3.80	9.56	41.05
Oklahoma	0.01	3	0			√			4.65	8.34	41.86
Oregon	0.16	18.5	24		√	√	√		3.92	8.29	39.85
Pennsylvania	0.12	23	17.5	√	√				3.84	10.06	46.20
Rhode Island	0.00	11	18.5				√	√	3.90	13.90	46.99
South Carolina	0.01	4.5	5		√	√			4.53	9.45	35.83
South Dakota	0.00	0	15				√	√	4.18	9.37	46.04
Tennessee	0.30	0	0				√	√	4.30	9.63	39.56
Texas	0.11	0	8.5			√	√		4.91	9.10	43.86
Utah	0.21	15.5	25			√		√	4.80	8.85	36.64
Vermont	1.10	17	21.5			√	√	√	3.70	14.41	45.48
Virginia	0.03	5	22	√					4.22	9.32	48.84
Washington	0.11	12.5	19.5					√	3.50	6.97	47.72
West Virginia	0.03	18	17.5	√					3.87	7.93	35.53
Wisconsin	0.02	5.5	9.5				√	√	3.86	11.22	43.24
Wyoming	0.07	10.5	0						4.44	7.61	52.83
Totals* / Avgs.	**0.61**	**11.83**	**12.85**	**16***	**23***	**21***	**29***	**22***	**4.24**	**10.98**	**44.48**

Note. Data gathered from the Interstate Renewable Energy Council and The Vote Solar Initiative (2013), the Database of State Incentives for Renewables and Efficiency (2014)[1], and SRECTrade (2015).[2]