Government Policies Promoting the Accelerated Deployment of Non-Hydro Renewable Electricity Generation Resources

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Abstract

This paper ascertains which state policies are accelerating deployment of non-hydropower renewable electricity generation capacity into a state's electric power industry. A state fixed-effects model and seemingly unrelated regressions (SUR) model are used to estimate the effects of multiple state policies in all fifty states on all emerging renewable electricity capacity. As would be expected, renewables portfolio standards with either capacity or sales requirements lead to significant increases in actual renewable capacity in that state. A surprising result is that required green power options, a policy that merely requires all utilities in a state to offer the option for consumers to purchase renewable energy at a premium rate, has a sizable impact on non-hydro renewable capacity in that state.

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1 Introduction

Renewable energy has recently become an important aspect in the U.S. electricity generation mix and a primary focus of government policy for environmental and energy security/price volatility reasons. First, the public's growing concern for the environment and progressively stringent regulation of emissions in the electric power industry has driven policies to increase the amount of renewable energy in the electricity generation portfolio. Electricity production from renewable resources creates little, and often zero, emissions of the pollutants that result from traditional fossil fuel generating technologies. More renewable energy use helps utilities in their emissions compliance obligations. Moreover, the prospect of compliance with any future carbon emissions regulation would further strengthen the incentive to shift toward cleaner electricity generating technologies.

Second, there has been recent uncertainty in the U.S. energy supply due to political concerns in the Middle East countries and other foreign oil producing countries as well as volatility in oil and natural gas prices. This uncertainty has led to a push to increase U.S. energy independence through a greater domestic energy supply and to decrease the impacts on the economy from any price shocks in the fossil fuel markets, such as the natural gas price spikes in 2000-2001 and following the 2004 and 2005 hurricane seasons, and the recent oil price spikes in 2008.[1]

Complementing federal policies such as the production tax credit, state governments have taken actions to increase renewable energy capacity and generation, with 42 of the 50 states enacting policies to encourage the use of renewable energy in their state. Individual state policies show a great deal of variance. The objective of this paper is to determine which state policies have led to increased deployment of non-hydro renewable energy capacity, and to estimate the size of these increases on a state's electric power industry renewable capacity.[2]

[1] Bird et al. (2005) explains the market factors behind wind power deployment, which include the volatility of natural gas prices. GDS Associates (2001) supported this factor as well in the reasoning behind the enactment of Hawaii's renewables portfolio standard. The delivered price of natural gas to electric utilities has risen from \$2.62 per 92 903.1 cubic meters (million cubic feet) in 1999 to \$8.45 per 92 903.1 cubic meters (million cubic feet) in 2005 (EIA Annual Energy Review 2005).

[2] Hydropower is not included in the renewable energy capacity because most hydropower was created well before the mid-1990s, with few changes in capacity or costs over the time period being analyzed. These

The literature on state renewable energy policies consists mainly of case studies on policy effectiveness. Only one previous paper uses econometric methods to estimate the effects of various state policies on renewable capacity. Menz and Vachon (2006) measure the impacts on wind capacity in 39 states for 1998-2002.

This paper expands the literature in four distinct ways. First, this paper estimates the effects on total non-hydro renewable and separately estimates impacts on wind, biomass, geothermal, and solar capacity deployment. Second, it simultaneously estimates the effects of multiple detailed policy designs while controlling for differences in the electricity market and political environments of a state. Third, this paper considers the long-run impacts of state renewable energy policies by focusing on capacity construction instead of the short-run impacts on renewable-based electricity generation. Finally, it uses a larger panel data set including data for all fifty states for 1996-2007.

Results of this paper show that two types of policies are found to be effective at expanding non-hydro renewable capacity deployment: a command-and-control policy, known as a renewables portfolio standard (RPS), and a market-based policy where consumers are given the option to express their preferences to buy power from renewable resources at a premium price. The command-and-control policy targets the utility by mandating a specified level of capacity or sales that must come from renewable energy. The market-based policy, the required green power option, creates a differentiated demand by mandating that utilities must offer their customers the choice to purchase green power, which allows consumers to express their preferences through paying an extra, utility commission-approved charge for green power.

As would be expected, over 90 % of estimated policy impacts on total non-hydro renew-

aspects allow hydropower to be considered a type of current generating technology, which includes steam or gas turbines fired by natural gas, coal, petroleum, or nuclear power. For hydropower to be a viable power option there must be an available river or stream as well as a significant change in elevation. Most of these sites in the U.S. already have hydropower capacity in place. Removing hydropower from the dependent variable allows the focus of the paper to be on the policy effects on the emerging technologies of wind, solar, biomass, and geothermal power. The electric power industry accounted for 91% of renewable energy net generation in 2007 (Table 3 of the EIA Renewable Energy Consumption and Electricity Preliminary 2007 Statistics).

able capacity are are result of wind capacity deployment. The econometric results of this paper support the conclusions from the literature that RPSs with capacity requirements and required green power options have increased renewable capacity, and expand the literature by estimating the size of the policy impacts. Unlike previous studies, renewables portfolio standards with sales requirements are found to have a statistically significant impact on renewable capacity. The results vary from previous case studies regarding the effectiveness of clean energy funds. Clean energy funds (CEFs) have awarded funding to projects that would have been undertaken to meet future RPS sales requirements regardless of the government's financial support. CEF funding may have been used as the "carrot" to minimize electric power industry opposition while implementing the RPS sales requirement as the "stick" to ensure renewable deployment. Clean energy funds are only found to have a statistically significant impact on geothermal capacity while state government green power purchasing and voluntary renewables portfolio standard Goals only have statistically significant impacts on biomass capacity.

2 Literature Review

The bulk of the literature in this area uses case studies to determine the specific characteristics of effective state renewable energy policies. There are two main types of case studies: (1) analysis of a specific policy enacted in a particular state; and (2) a summary of the general impacts of a specific policy mechanism used across multiple states, including policy design characteristics that are effective across multiple states. Langniss and Wiser (2003) analyze the Texas renewables portfolio standard, including the achievements of the policy mechanism and the design characteristics that allowed the policy to be effective at increasing renewable energy capacity. It was found that the clearly defined capacity requirements have been effective in increasing renewable capacity in Texas.

Wiser et al. (2004) considered all renewables portfolio standards and found pitfalls in current policy designs. Key problems in policy designs include insufficient duration and stability of targets, weak enforcement, and narrow applicability of the policy. Other conditions that may impact a policy's effectiveness are the presence of long-term power purchasers and political and regulatory stability.

Petersik (2004) provides a non-econometric analysis of the effectiveness of different types of renewables portfolio standards as of 2003 for the United States Energy Information Association (EIA). He finds that only renewables portfolio standards that mandate a certain level of capacity (number of megawatts) have had any significant impact on renewable capacity deployment. Policies with renewable generation or sales requirements as well as voluntary policy programs were found to have no significant effect.

Chen et al. (2007) compares the results from 28 policy impact projections for state or utility-level renewables portfolio standards and finds that (1) the impact on electricity prices is minimal, (2) wind power is expected to be the primary renewable used to meet policy requirements, and (3) the benefit-cost estimates rely heavily on uncertain assumptions, such as renewable technology costs, natural gas prices, and possible carbon emissions policy in the future.

Bolinger et al. (2001) describe in detail 14 different state Clean Energy Funds, enumerating the regulatory background, funding approaches, the current status of the fund, and the resulting impacts on renewable energy. Programs that fund utility-scale projects are found to be the most effective at increasing renewable capacity deployment.[3] Bolinger et al. (2004, 2006) summarize the same 14 clean energy funds. They find that due to delays and canceled projects actual capacity often is much lower than initially obligated capacity.

Bird et al. (2008) examine participation in more than 850 utility green power programs. They find local green power programs have residential participation rates ranging from 0.0 % to 20.4 % and averaging 2.0 % in 2007. Renewable energy sales in 2007 range between 0.0 % to 5.7 % of total sales in a state with an average of 0.8% and a median of 0.3%. However, this study does not look at any state-level required green power options that require all utilities in a state to offer consumers the option to purchase renewable energy. The paper focuses on participation rates of the utility-based programs, but does not analyze the impact of these local programs on renewable energy generation or capacity.

Bird et al. (2005) summarize federal renewable energy policies, general market factors,

[3] Funding is usually based on actual production, but it is paid in a lump sum once the capacity has been constructed.

and state-specific factors, such as state policies, that are driving the deployment of wind power. The key market factors are the volatility in natural gas prices during the early 2000s and the lowered wind energy generation costs due to larger wind turbines, which have combined to make wind power more competitive with natural gas-fired generation.

Brown and Busche (2008) rates states based on the effectiveness of their renewable energy policies and summarizes the best practices for state renewable energy policy design. The paper finds a significant correlation of renewables portfolio standards with increased renewable energy generation in a state. Production incentives are found to significantly increase both renewable generation and capacity.

Only one paper to my knowledge has attempted to econometrically estimate the effects of state renewable energy policy on renewable energy capacity. Menz and Vachon (2006) use ordinary least squares to estimate state policy effects on wind power capacity and generation with a panel dataset for 39 states for 1998-2002 while controlling for wind power availability, retail choice, and policy dummy variables for public benefits fund, renewables portfolio standard, required green power option, and fuel mix disclosure.[4] renewables portfolio standards, which require a minimum amount of renewable energy capacity or sales, and required green power options, which require all utilities in a state to offer renewable-based electricity to all consumers for a premium price, are found to have a statistically significant effect on wind capacity deployment. No statistically significant effects were found for public benefits funds, which aid both the funding of energy efficiency and for clean energy funds that fund renewable energy programs and projects.

[4]Public benefits funds often include clean energy funds, but also fund energy efficiency projects. Fuel mix disclosure is a policy that requires the fuel mix a power producer uses in its electricity generation to be disclosed to the public. Menz and Vachon (2006) asserts that consumers may use this information to purchase electricity from power producers that use cleaner burning fuels or alternative energy.

3 Models: Fixed-Effects and Seemingly Unrelated Regressions

This paper uses two different types of econometric models to estimate policy results: state fixed-effects model and seemingly unrelated regressions (SUR) model with state fixed-effects.

3.1 State Fixed-Effects Model

The first model includes state-fixed effects, year dummy variables, detailed policy variables, and control variables for a state's electricity market and political environment. Without variables controlling for differences in market size and political environments, the results could be biased and lead to incorrect policy interpretations. State dummy variables are used to control for renewable availability and capacity constructed prior to 1996, which is in large part due to the implementation of prior federal policy at the state level as well as the effects of environmental preferences not captured by other variables. The model estimates total non-hydro renewable capacity (C_{it}) for 1996-2007:

$$C_{it} = \alpha_0 + \beta * \mathbf{R}_{it} + \delta * \mathbf{W}_{it} + \gamma \mathbf{S}_i + \theta \mathbf{T}_t + \epsilon_{it},$$

Where "i" is the state, and "t" is the year of the specific observation; R_{it} is the vector of six regulatory policies (clean energy fund, renewables portfolio standard with capacity requirements, renewables portfolio standard sales requirements in the state or adjacent states, renewables portfolio standard sales goals in the state or adjacent states, state government green power purchasing, and required green power option); W_{it} is the vector of nine political and economic control variables; S_i is the vector of state fixed-effects dummy variables; and T_t is the vector of year variables. The year variables, most of the control variables, and two of the policy variables are interacted with each state's electricity generation level to control for market size in each state.

The dependent variable is total non-hydro renewable capacity: the sum of wind, biomass, geothermal, and solar nameplate capacity. Nameplate capacity in the electric power industry includes all nameplate capacity of utilities, independent power producers (IPPs), and industrial or commercial combined heat and power producers.[5] Nameplate capacity is the appropriate dependent variable because several policies mandate or fund a specific amount of renewable capacity. Policies that do not set specific renewable capacity requirements can be measured in capacity terms by controlling for each state's market size, which will be discussed in more detail in Section 4.

3.2 Seemingly Unrelated Regressions Model

The second model is a Seemingly Unrelated Regressions (SUR) model, which is used to jointly estimate a system of equations with cross-equation parameter restrictions and correlated error terms. Regressions that estimate different dependent variables using the same data for the explanatory variables may have correlated error terms. If the error terms are correlated, the use of a SUR model will lead to more efficient coefficient estimates over an fixed-effects approach.

A SUR model is used in this paper to jointly estimate the impacts of state policies on wind, biomass, geothermal, and solar capacity using the same explanatory variables. The model includes state fixed-effects, year dummy variables, detailed policy variables, and control variables for a state's electricity market and political environment in estimating the vector of wind, biomass, geothermal, and solar capacity (c_{nit}) for 1996-2007:

$$c_{nit} = \alpha_n + \beta_n * \mathbf{R}_{it} + \delta_n * \mathbf{W}_{it} + \gamma_n \mathbf{S}_i + \theta_n \mathbf{T}_t + \epsilon_{nit},$$

Where "n" denotes the renewable capacity types: wind nameplate capacity, geothermal nameplate capacity, biomass nameplate capacity and solar nameplate capacity in the electric power industry (c_{nit}). The same variables as in the fixed effects model are included in the SUR model regressions. The error terms ϵ_{nit} are assumed to be correlated.[6]

[5]Nameplate capacity is the amount of capacity the generator produces under ideal conditions. Non-hydro renewable nameplate capacity is derived from EIA Historical State Electricity Databases found on the EIA website in which solar, biomass, geothermal, and wind nameplate capacity are reported.

[6]For additional information, see Greene (2003,P.360).

4 Variables and Data

4.1 Dependent Variables: $\mathbf{C}_{it}$ and $\mathbf{c}_{nit}$

The dependent variable that will be central to this paper is total non-hydro renewable capacity in the electric power industry (RENEWABLE CAP), which is the sum of wind, biomass, geothermal, and solar capacity in a state ($C_{it} = \sum c_{nit}$). The use of RENEWABLE CAP as the dependent variable in the fixed-effects model allows for cross-state comparison of policy effects of states with different available renewable energy resources. For example, comparing the effects of a policy on Maine and Texas using only wind power capacity excludes the policy effects on biomass capacity, which is a more likely renewable choice for Maine. Both types of renewable resources must be included to directly compare the effectiveness of policies across states.

There are four dependent variables in the SUR model considering different types of renewable energy: wind nameplate capacity (WIND CAP), biomass nameplate capacity (BIOMASS CAP), geothermal nameplate capacity (GEOTHERMAL CAP), and solar nameplate capacity (SOLAR CAP). Different policy designs may be targeting specific types of renewable capacity deployment. There may also be non-policy factors that are driving, or hindering, renewable capacity construction. Table 1 summarizes the data for the dependent variables.[7]

INSERT TABLE 1 HERE

4.2 Regulatory Policy Variables: $\mathbf{R}_{it}$

Six of the explanatory variables are policy variables capturing the effects of different types of renewable energy regulation, either by a state's legislature or Public Utility Commission (R_{it}): RPS: CAP REQ, RPS: REGIONAL SALES REQ, RPS: REGIONAL SALES GOAL, CEF: CAP AWARDED, STATE GP PURCHASING: PCT REQ, and REQ GREEN

[7]Data sources are listed in the Appendix. Data on capacity and generation are found in the Historical Databases of the Electric Power Annual survey on the EIA website. Electricity summary data is available at the state level from the EIA.

POWER OPT.[8] Most policies are enacted through state legislation, and then enforced by the state's public utility commission (PUC). There are a few instances, however, in which a PUC adopts guidelines without state legislation. No legislation or PUC action is required for state governors to use executive orders to create a state government green power purchasing agreement or to set voluntary goals for generation.

Policy dummy variable values are determined by a policy's enactment date, zero before enactment and one after enactment. The enactment date is the year that the policy is passed by the state legislator, created through an executive order, or announced as a mandate under new PUC guidelines. Some of these policies allow a grace period for power producers to meet the new regulations. The effective date is the year that the policy requirements must be met. The average lag from the enactment to effective date is a little over one year, but can be longer for renewables portfolio standards. The enactment year is a better choice to determine when the policy begins to impact the power producers. Once a power producer becomes aware of a future requirement, it may begin to construct any necessary renewable capacity. These actions could lead to large amounts of renewable capacity being constructed between the enactment date and effective date.

Regulatory policies described below include a renewables portfolio standard with a capacity requirement, renewables portfolio standard with a sales requirement, renewables portfolio standard with a sales goal, clean energy fund, State Government Green Power Purchasing, and required green power options. Table 2 summarizes the data for the policy variables.

INSERT TABLE 2 HERE

The renewables portfolio standard specifies the amount of a state's electricity sales or capacity that must be renewable-based. Renewables portfolio standards can be differentiated into three main structural forms, policies that set (1) mandatory renewable sales levels, (2) voluntary renewable sales goals, and (3) mandatory renewable energy capacity requirements.

[8]Information on renewable policies is available on the Database of State Incentives for Renewable Energy (DSIRE) website, www.dsireusa.org, which is a project of the Interstate Renewable Energy Council and funded by the U.S. Department of Energy. The information is compiled from many different sources, including federal and state officials, public utility commissions, and renewable energy organizations. The source of the information is included within each policy description. Bollinger et al. (2001) includes additional information on the enactment and design of public benefits funds.

The first type of renewables portfolio standard sets a percentage of total sales for each power producer/retailer that must originate from renewable sources, usually increasing every year or every few years. For example, Arizona's tiered renewable levels that have to be met began at 0.2 % in 2001 and increased by 0.2 % each year for 2002-2005, 0.25 % for 2006-2009, and 0.5 % for 2010-2015. Most other states' renewables portfolio standards have similar structures, but vary in percentage levels and enforcement dates.[9]

Six states (Illinois, Hawaii, North Dakota, Minnesota, Vermont, and Virginia) have at one time had renewables portfolio sales goals (not requirements). Illinois, Hawaii, and Minnesota have since been transitioned to renewables portfolio standards with a sales requirement. A policy variable is created to control for these voluntary goals.

Iowa, Minnesota, Texas, and Wisconsin have mandated utilities to install a certain level of megawatts of renewable capacity.[10] As long as the requirements are implemented effectively, renewable capacity requirements should increase renewable capacity by the same number of megawatts required by the mandate. These capacity requirements will make this type of Renewables Portfolio Standards more effective in this model because they target actual capacity construction versus sales-based Renewables Portfolio Standards.

The differences between renewables portfolio standards can be accounted for in the model by three variables: two variables that measure the size of the renewable sales requirement (RPS: REGIONAL SALES REQ) or goal (RPS: REGIONAL SALES GOAL) within the state or adjacent states, and a variable that measures the size of the capacity requirement (RPS: CAP REQ) within the state.[11] The capacity requirement size and date are used to extrapolate the expected requirement for each year assuming a linear function, where the power producers increase capacity by the same amount each year until they meet the final requirements, to form the variable RPS: CAP REQ.

RPS: REGIONAL SALES REQ and RPS: REGIONAL SALES GOAL are more complex

[9] In 1998, Wisconsin introduced mandatory capacity levels before it enacted a renewables portfolio standard with mandatory sales in 1999.

[10] Minnesota has enacted all three types of Renewables Portfolio Standard. A capacity requirement was enacted in 1997, a voluntary sales goal in 2001, and a sales requirement in 2007.

[11] Capacity requirements range from 50 to 2280 MW for 2007, and sales requirements range from 0 % to greater than 30 %.

variables. The sales requirement or goal, which usually sets a target five or more years after enactment, is linearly interpolated backwards to the enactment date of the policy. For example, a policy enacted in 1996 with a sales requirement of 1.0 % beginning in 2000 would be linearly interpolated to be 0.2 % in 1996 and increase by 0.2 % each year until it reaches 1.0 % in 2000. Although the requirement is not enforced until 2000, it would be necessary for power producers to begin construction at least several years before 2000 to get the necessary capacity constructed in time to meet the sales requirement. If the policy is updated or overridden by new legislation, the variable value is adjusted to account for the change in policy requirement or goal. Differentiating between sales requirements and voluntary goals is important because the power provider's incentive structures are different. This requirement is multiplied by the total electricity sales in the state for that year to estimate the total renewable-based sales that should be sold within the state.

An RPS with a sales requirement or goal allows a utility to meet their sales requirement with out-of-state electricity, either by generating the renewable electricity, directly purchasing renewable electricity from another power producer, or buying the rights to the electricity's renewable characteristics through a Renewable Energy Certificate (REC) trading program authorized by the state. Restrictions on out-of-state generation differs by state. Illinois and Hawaii do not allow any out-of-state RECs to be used to meet the sales requirement. The range of other requirements are (1) generator must have direction interconnection to the state, (2) renewable electricity must be delivered to the state, (3) renewable electricity must be generated in the control area, and (4) no restriction.[12] Since out-of-state RECs must originate from nearby states, the sum of renewable-based sales requirement in adjacent states is added to the within-state requirement to control for the impact of interstate REC sales. RPS: REGIONAL SALES REQ is constructed by taking the sales requirement for each adjacent state multiplied by the sales within that adjacent state for the given year, and then summing the sales requirements for all adjacent states and the sales requirement within the state. RPS: REGIONAL SALES GOAL is constructed in the same manner as RPS: REGIONAL SALES REQ.

Requirements or goals on renewable energy sales either within a state or in an adjacent

[12] Only Colorado has no restriction.

state should increase renewable generation demanded from the state of interest, which should increase renewable capacity within the state.[13] The results from the models will determine how much more effective strict requirements are at increasing renewable capacity relative to voluntary goals where regulators accept in "good faith" that the utilities will in fact increase renewable energy-based electricity sales.

A clean energy fund is a state-level program that is often, but not always, created through the restructuring of the electricity market and is used to fund grants, loans, and production incentives for both research and development and actual deployment of alternative energy. Many clean energy funds focus on funding actual renewable capacity deployment, which should lead to more renewable capacity in a state.

Clean energy funds are paid for through system benefits charges (SBCs), which are additional charges paid by all consumers on their electricity consumption. SBCs can be considered a consumption tax on electricity to fund deployment of renewable capacity in the industry. In Minnesota, a settlement with the electric utility Xcel Energy created a similar fund that is paying for renewable energy research and deployment. Maine created a voluntary fund similar to a clean energy fund for the state's customers to donate money.[14]

Similar to renewables portfolio standards, clean energy funds must be differentiated to understand how effective these policies are at increasing renewable deployment in a state. The amount of capacity to date (lagged four years) that has been awarded funding for utility-scale projects from clean energy funds (CEF: CAP AWARDED) is the variable used to control for these policy effects.[15] The variable is lagged four years because that is the

[13] Some state renewables portfolio standards with a sales requirement allow the use of some hydropower electricity to meet the requirement. However, there are normally specific requirements as to which facilities will be eligible, including restrictions on a unit's maximum capacity, type of hydropower, and year of installation. For example, some states do not allow generating units greater than 30 MW to be eligible. One state does not allow any hydropower to originate from dammed hydropower plants. Another state only allows electricity from new hydropower capacity to be eligible. These restrictions will decrease the effectiveness of these policies to increase renewable capacity in a state. However, the complexities of the restrictions make it difficult to create an appropriate measure for these effects.

[14] Database of State Incentives for Renewable Energy (DSIRE) does not include New Mexico as having a clean energy fund, while Bolinger et al. (2001) verifies that New Mexico does have a clean energy fund.

[15] The data for the clean energy fund variables originated from the 2006 Database of Utility-Scale Renew-

average amount of time as of 2006 it takes between awards being issued and actual capacity construction of those projects. For example, a project that is awarded funding in 2000 will, on average, be online in 2004.

State government green power purchasing policies require that some percentage of a state government's electricity purchases be from renewable sources. These purchase agreements range from 2.5 % to 50 % of a state government's electricity purchases. Similar to Renewables Portfolio Standards with sales requirements, a State Government Green Power Purchasing agreement increases the need for renewable-based electricity generation. As state government electricity use rises, the renewable generation needed to meet the requirement increases. If the new generation needs cannot be met by current renewable capacity, power producers will need to construct new renewable energy capacity. The size of the State Government Green Power Purchasing requirement, in terms of a percentage of the state government's electricity purchases (STATE GP PURCHASING: PCT REQ), is interacted with GEN to control for both the state's purchase requirement and the state's market size (STATE GP PURCHASING: PCT REQ*GEN).[16] The data is linearly interpolated backward from the effective year for years between enactment and effective dates.[17]

A required green power option requires utilities to offer customers the option to purchase renewable power at a premium. There are two versions of how these options are implemented. The most common type gives consumers the option to make voluntary contributions, called voluntary renewable energy tariffs in return for the guarantee that some of the consumer's electricity consumption is produced from renewable sources. Consumers purchase electricity at the market price and then pay a premium for blocks of green electricity, usually about $2 per 100 kWh. The second type allows the producers to charge consumers a higher rate per kilowatt-hour, but only to cover the additional costs for electricity from renewable sources. Both the premium block rate and premium per kilowatt-hour rate must be approved by the state's Public Utilities Commission (PUC).

Required green power options elicit customer preferences and a crude measure of will-

able Energy Projects from the Clean Energy States Alliance (CESA).

[16]GEN will be defined in the following subsection.

[17]The policy design assumes all state governments consume the same constant percentage of total electricity consumed in a state throughout the dataset.

ingness to pay for renewable energy by allowing consumers to voluntarily pay higher prices for the knowledge that they are supporting renewable-based electricity. The creation of this niche market for renewable energy generation should have a positive impact on renewable capacity. There should be minimal overlapping effects with renewables portfolio standards because green power sold at a premium cannot be counted towards RPS requirements in most states.[18] The variable REQ GREEN POWER OPT is a dummy variable, which is interacted with GEN in the model to measure the effect of the policy based on the state's market size (REQ GREEN POWER OPT*GEN).

4.3 Economic and Political Variables: $\mathbf{W}_{it}$

Nine variables account for non-policy variability (W_{it}) in nameplate non-hydropower renewable capacity in the electric power industry of each state for 1996-2007: GEN, PCT HYDRO, PCT NUCLEAR, PCT COAL, PCT NAT GAS, PCT OTHER, NAT GAS PRICE, SUGARCANE PROD, AND LCV SCORE. The economic variables measure market size, natural gas prices, sugarcane production, and the percentage of non-renewable capacity from hydropower, nuclear power, coal, natural gas, and "other" capacity in a state. The political variable, LCV SCORE, measures a state's preferences for renewable capacity. These variables, excluding GEN and SUGARCANE PROD, are lagged by one year to remove any endogeneity concerns, and interacted with net generation to control for different market sizes across states. Table 1 summarizes the data for the control variables.

Total net generation (GEN) is the total amount of electricity generated (in terawatt-hours) in a state for a given year.[19] It is expected that more renewable capacity will be found in states that generate more electricity to help meet the higher demand for electricity found in those states.[20] The other control variables as well as some of the policy variables are interacted with generation to account for market size across states. For example, an

[18] Bird and Lokey, 2007)

[19] A terawatt-hour (TWh) is the same as 1,000 GWh or 1 billion kWh.

[20] Total generation in a state is chosen instead of total sales because some of the electricity demand for a state's power producers may come from other states. Generation is not contaminated with these interstate sales, which may otherwise inflate or deflate the market size measure. Generation and sales are highly correlated (0.951).

increase in natural gas costs will have a larger impact on renewable capacity in California than in Rhode Island. Larger states should have more funding to pay for projects to increase renewable capacity. Renewables portfolio standards with sales requirements set requirements on the percent of generation that must originate from renewable sources. States with more generation will have more total generation that is required to originate from renewable resources, which should lead to more renewable capacity in those states.

Seven variables are included in the model to control for market structure, each lagged one year because capacity construction will be a result largely due to factors from the previous year. Five of these variables are hydropower capacity (PCT HYDRO), nuclear power capacity (PCT NUCLEAR), coal capacity (PCT COAL), natural gas capacity (PCT NAT GAS), and other capacity (PCT OTHER) as a percentage of total capacity excluding non-hydro renewable capacity.

Hydropower should lead to less non-hydro renewable capacity because hydropower has low marginal production costs, and the capacity typically was constructed many years ago. With lower marginal costs and sunk capital costs associated with hydropower, hydropower will be the first renewable energy to be implemented because it is more economically competitive than most non-hydropower renewables available to the electric power industry. Consumer and/or policy driven demand for renewable-based electricity may not differentiate between hydropower and other renewable sources, which allows hydropower to be a substitute of non-hydro renewables.

Similar to hydropower, nuclear power has low marginal costs of producing base load electricity, has sunk capital costs, and has no emissions. If non-hydro renewable capacity is deployed based on economic factors, given similar emissions profiles, greater nuclear or hydropower capacity should decrease the amount of non-hydro renewable capacity deployed.

An alternative possibility is that regulators in states with large amounts of nuclear power encourage power producers to use other resource types to meet new demand. Renewable energy may be used by utilities to alleviate pressure from environmentalists over nuclear power, thus leading to greater deployment of renewable energy capacity in states with large amounts of nuclear capacity. The sign of PCT NUCLEAR will depend on which of these two factors has the larger effect on power producers.

The remaining three capacity-based variables control for fossil fuel-based capacity. Coal capacity is primarily used as baseload capacity due to its low operating costs. Coal is the dirtiest fuel used in electricity production and leads to large amounts of pollutant emissions: sulfur dioxide emissions that increases acid rain, nitrogen oxides that increase smog, and carbon dioxide emissions that contribute to climate change. Larger amounts of coal capacity could encourage more renewable capacity deployment to decrease the average emissions levels in the state's fuel mix, lower the negative impacts from electric power emissions, and prepare the state for climate change policy.

Natural gas capacity is the cleanest fossil fuel, has the highest operating costs of fossil fuel capacity, and is most commonly used as peak load capacity. Assuming that renewables are deployed for economic reasons, larger amounts of natural gas capacity should lead to less renewable capacity. Natural gas is the best substitute for renewable capacity for three reasons. First, the relative costs of using renewables is more competitive with natural gas than any other capacity type. Second, most renewable capacity in the U.S. tends to generate electricity during peak times, in particular wind power and biomass facilities. Third, natural gas has a much lower emissions rate relative to coal, and can be used to significantly decrease pollution levels from electricity production.

"Other" capacity includes all other capacity types, primarily petroleum and "other gases" such as propane or waste gases from fossil fuels, which account for a small portion (6 %) of the capacity in the U.S as of 2007. Since this variable includes a number of different capacity types, there is no expectation for the impact of this variable.

A state's annual average natural gas price (in 2007 dollars) per million Btus (NAT GAS PRICE) paid by the electric power industry measures the impact the cost of natural gas has on renewable capacity in a state.[21] If renewable capacity is a substitute for natural gas capacity, higher natural gas prices will lead to more renewable capacity as utilities shift

[21]Natural gas cost data can be found on the EIA website in the Natural Gas Navigator section. The data are deflated using the Consumer Price Index for all goods from the Federal Reserve Bank of St. Louis. There are 30 missing observations for 16 different states. A simple average of natural gas costs of the surrounding states is used as an estimate for natural gas prices for all states excluding Hawaii. The industrial price paid for natural gas is used for Hawaii, which is highly correlated with electric power natural gas prices across the U.S. There remain observations missing for Hawaii for 1996 and 1997.

production to the relatively cheaper renewable capacity.

Florida, Hawaii, Louisiana, and Texas use the byproduct of sugar production from sugarcane as a biomass fuel. For example, in Hawaii sugarcane is one of the primary sources of biomass. Due to market conditions most of the sugarcane farms in Hawaii were shut down over the 1990s, removing the fuel source for much of the biomass capacity in the state. Changes in sugarcane production are likely to have an impact on the amount of biomass capacity in a state. The total tons of sugarcane production (SUGARCANE PROD) is included in the model estimating biomass capacity. SUGARCANE PROD is the only control variable not lagged or interacted with generation, and is only included in the regressions for total non-hydro renewable capacity and biomass capacity.

A political variable is included to measure changes in renewable energy preferences in a state. The League of Conservation Voters (LCV) rating is used to determine if policy preferences for environmental protection increase renewable energy capacity independent from its policy effects. The League of Conservation Voters (LCV) annually publishes the National Environmental Scorecard, which rates all congressional votes on conservational issues by each representative.[22] For example, if there are ten total votes in a year on environmental issues and a congressperson voted in favor of conservation six times, his or her LCV rating would be 60.

An average of all the votes by a state's representatives is taken to get the average House of Representatives score (LCV SCORE). The scores from the House of Representatives are used instead of the Senate because representatives have a shorter term in office than senators, two years versus six years. The shorter term creates greater pressure on representatives to act according to their constituents' preferences.

A high LCV rating for a state indicates that the state's constituents are environmentally friendly and are more likely to demand electricity from renewable energy, all other things being equal. Consumers or environmental groups in states with higher LCV ratings may be more likely to pressure utilities to use greater amounts of renewable energy no matter which,

[22]Data from the National Environmental Scorecard is available from the League of Conservation Voters website, www.lcv.org. The LCV rating has been used in prior studies, including Baldwin and Magee (2000), Kalt and Zupan (1984), and Nelson (2002).

if any, policies have been enacted by the state.

Policies may be endogenous to higher LCV ratings because states with congresspersons who vote for federal pro-environmental policies may be more likely to enact state pro-environmental policies. The policy endogeneity issue is not addressed in the body of this paper because lagging the variable by one year decreases these concerns, LCV SCORE is not a strong enough predictor of state policies to be a satisfactory instrument, and removing LCV SCORE from the regression does not change the results.

4.4 State-Fixed Effects and Time Dummy Variables: $\mathbf{S}_i$ and $\mathbf{T}_t$

State fixed-effects are included in the regressions to control for two factors: capacity installation prior to 1996 in a state and factors that differ across states that are constant over time. A large amount of renewable capacity created before 1996 originated from the Public Utilities Regulatory Policy Act (PURPA), a federal policy passed in 1978 requiring utilities to purchase electricity from "qualifying facilities," which are IPPs that meet specific requirements and include renewable-based facilities. For a variety of reasons, the effects of PURPA varied from state to state. State dummy variables (S_i) measure these effects and other unchanging state factors, such as renewable resource availability.[23]

Year dummy variables interacted with GEN are used to control for national trends, such as general renewable energy economic viability and federal policy impacts. The average levelized cost of production for renewable energy in the U.S. have consistently decreased over time. As the costs of production decrease, renewable energy becomes more competitive and will enter the market in larger amounts. Federal policies like the Federal Renewable Energy Production Tax Credit aid in renewable deployment by subsidizing production of electricity from renewable resources. The combination of these two factors should increase

[23](Morris, 2003). There is some concern that expiration and buyouts of PURPA contracts during the 1990s have led to decreases in renewable capacity, especially in California where deregulation in the early to mid-1990s created competition based on price without any consideration of costs or environmental impacts. Any capacity shut down due to PURPA contract expiration after 1996 will decrease the positive effects of any enacted policy. There is also the possibility of a state changing its interpretation and enforcement of PURPA after 1996, which would not be captured in the model.

renewable capacity over time across the entire U.S.

5 Results

Table 3 reports the regression results for both the state fixed-effects model and the SUR model with state-fixed effects. The results are summarized below by each of the five dependent variables: total non-hydro renewable capacity in Specification 1, wind capacity in Specification 2, biomass capacity in Specification 3, geothermal capacity in Specification 4, and solar capacity in Specification 5.

INSERT TABLE 3 HERE

5.1 Total Non-hydro Renewable Capacity

5.1.1 Regulatory Policy Variables: $\mathbf{R}_{it}$

Table 4 estimates the statistically significant effects from both the control variables and the policy variables based on a state with median generation levels for Specification 1. Renewables portfolio standards with capacity requirements, renewables portfolio standards with sales requirements, and required green power options have statistically significant effects on total non-hydro renewable capacity in the electric power industry.

INSERT TABLE 4 HERE

The coefficient on RPS: CAP REQ is positive and statistically significant. For each megawatt of capacity required by the renewables portfolio standard approximately 1.14 MW is constructed. The coefficient is not statistically significantly greater than one, which is the expected outcome given the policy design.[24] The linear interpolation approach taken in designing RPS: CAP REQ is effective at capturing the policy effects by allowing variation in the timing of renewable capacity construction.

RPS: REGIONAL SALES REQ has a statistically significant coefficient. An increase in the sales requirement within the region of one TWh increases non-hydro renewable capacity in the state by 0.13 MW. A one standard deviation in RPS: REGIONAL SALES

[24] $F(1,524) = 0.81; Prob > F = 0.3694$

REQ (290.65 TWh) would increase capacity by 37 MW. Impacts will be more economically significant in larger states. For example, the impact of RPS: REGIONAL SALES REQ on California in 2007, which has a regional renewable energy sales requirement of 4 282.74 TWh, leads to an estimated increase of 548 MW of total non-hydro renewable capacity. Renewables portfolio standards with sales requirements have regional impacts on total non-hydro renewable capacity because of the common option of interstate electricity sales and REC trading. REC trading allows renewable-based electricity to be generated where it is most cost-effective, allowing a state to meet their sales goal even if it does not increase renewable capacity within their state borders.

The coefficient on RPS: REGIONAL SALES GOAL is statistically insignificant. The stricter regulations from sales requirements lead to greater impacts on renewable capacity than voluntary goals where state governments assume in "good faith" that the electric power industry will take action.

CEF: CAP AWARDED, which measures the amount of capacity that the fund has agreed to help finance, has a statistically insignificant coefficient. This includes capacity that has been agreed upon, but has not yet been built, either because the project has not been finished or the project is later canceled. This is a surprising result because over 42% of all capacity funded through CEFs had come online as of 2007. Many states with a CEF have also implemented an RPS with a sales requirement, which allows the state to encourage renewable capacity by assisting in the financing of a renewable project while requiring sales of electricity from renewable sources. The results show that capacity funded through CEFs would have been installed regardless of the financial aid given to the investors, and the installation would likely be due to the RPS. However, the use of the two policy approaches in tandem was likely more politically viable because it would allow a state to use both the "stick" (command-and-control) and the "carrot" (tax-and-subsidy) to reach the desired goal.

The most interesting result is the effect that required green power options have on renewable capacity. The coefficient for REQ GREEN POWER OPT*GEN has a positive and statistically significant coefficient, where enactment leads to renewable capacity increasing by 2.65 MW per terawatt-hour of generation. A state with a median generation level (104.2 TWh) that enacts a required green power option would have an increase of 276 MW. Washington has the largest electricity market of states that have enacted a required green power option (214 TWh), which would lead to an increase in renewable capacity of 567 MW.[25] To give some perspective on these results, the estimated impacts in total renewable capacity can be expressed in terms of a percentage of total capacity in a state. Depending on the state, a required green power option leads to an increase of about 1.0 % to 1.7 %.[26] These estimations are slightly lower than the average participation rate for all local green power programs of 2.0 % in 2007.[27] The statistically and economically significant increase implies that required green power options, which create a niche market for green power by requiring states to offer renewable-based electricity to their consumers at a premium, are very useful in increasing the amount of renewable energy capacity in a state. These impacts may persist or even increase over time because participation rates continue to increase across the country, with some local participation rates as high as 20 % as of 2007.

The coefficient for STATE GP PURCHASING: PCT REQ*GEN is statistically insignificant. State government purchases of green power are not large enough to significantly increase total non-hydro renewable capacity in a state.

5.1.2 Economic and Political Variables: $\mathbf{W}_{it}$

The coefficients on the percentage of capacity excluding non-hydro renewables comprised of coal-fired capacity interacted with GEN (PCT COAL*GEN), nuclear power capacity interacted with GEN (PCT NUCLEAR*GEN), and other capacity interacted with GEN (PCT OTHER*GEN) are positive and statistically significant. A one standard deviation increase in PCT COAL (27.2 percentage points) increases renewable capacity by 156 MW for a median generation state (104.2 TWh). States with large amounts of coal capacity appear to be diversifying their fuel mix to decrease emissions and prepare for climate change policy.

[25] The change in actual renewable energy capacity in Washington was 1158 MW from before the policy enactment in 2001 (356 MW in 2000) to 1514 MW in 2007.

[26] These estimates are made by taking the estimated effect of a required green power option in a state on total renewable capacity in 2007, and then dividing that value by total capacity in the state for 2007. The resulting impact is a measure of the change in renewable capacity in percentage terms of total capacity.

[27] The slightly lower values may be due to current renewable capacity already constructed and operating in the state allowing utilities to meet demand without installing new renewable capacity.

A one standard deviation increase in PCT NUCLEAR (12.2 percentage points) increases renewable capacity by 99 MW for a median generation state. PCT NUCLEAR appears to be capturing a state's preference for greater fuel diversity through alternative energy sources. A standard deviation increase in PCT OTHER (15.93 percentage points) increases renewable capacity by 40 MW. Given that all three of these variables are statistically significant, more natural gas capacity in a state leads to less renewable capacity. This is a reasonable result because natural gas is the closest substitute for renewable energy due to its lower emissions rate and peak time use, particularly wind power that usually produces its largest amount of power during peak demand.

The coefficient for natural gas price interacted with generation (NAT GAS PRICE*GEN) is statistically significant, but has the opposite sign than would be expected if economics is driving renewable capacity installation. A one standard deviation in NAT GAS PRICE ($2.42 per 92 903.1 cubic meters (million cubic feet)) decreases total non-hydro renewable capacity by 22 MW for a median generation state. Renewable capacity does not appear to be competing with natural gas on a purely economic standpoint.

The coefficients on LCV SCORE, PCT HYDRO*GEN, and SUGARCANE PROD are statistically insignificant.

5.2 Wind Capacity

A seemingly unrelated regressions (SUR) model is used in this paper to estimate wind, biomass, geothermal, and total non-hydro renewable capacity. A Breusch-Pagan test of independence was run and found that the error terms are correlated, which supports the use of a SUR model.[28]

The results from the wind power capacity regression (Specification 2) are similar to the results from the total non-hydro renewable capacity regression (Specification 1). This is not surprising because 91 % of new renewable capacity since 1996 has been wind power capacity while biomass accounts for 8 % and geothermal power and solar power combined account for the remaining 1 %.

[28] $\chi^2 = 11.580; P = 0.0720$. The covariance matrix is available to interested readers.

5.2.1 Regulatory Policy Variables: $\mathbf{R}_{it}$

Similar to the results in the total non-hydro renewable regression, renewables portfolio standards with capacity requirements, renewables portfolio standards with sales requirements, and required green power options have statistically significant effects on wind capacity in the electric power industry.

The policy coefficients for wind power are slightly smaller than on total non-hydro renewable capacity regression, but still capture over 90 % of the estimated policy impacts relative to Specification 1. The coefficient on RPS: CAP REQ is positive and statistically significant. For each megawatt of renewable capacity required by the renewables portfolio standard approximately 1.11 MW of wind capacity is constructed. Most but not all of the installation from RPS capacity requirements is wind power: 97 % of the estimated impact from Specification 1.

The coefficient for REQ GREEN POWER OPT*GEN has a positive and statistically significant coefficient, where enactment leads to renewable capacity increasing by 2.41 MW per TWh of generation. A state with a median generation level that enacts a required green power option would have an increase of 252 MW: 91 % of the estimated impact from Specification 1.

RPS: REGIONAL SALES REQ is statistically significant when only wind power capacity is considered. One terawatt-hour of sales requirements in the region increase renewable capacity in a state by 0.1 MW. Wind capacity would increase by 415 MW in California for 2007. A large portion of renewable capacity installation from RPS sales requirements is wind power: 76 % of the estimated impact from Specification 1.

As in Specification 1, RPS: REGIONAL SALES GOAL and STATE GP PURCHASING: PCT REQ*GEN have statistically insignificant coefficients.

5.2.2 Economic and Political Variables: $\mathbf{W}_{it}$

The coefficient for PCT COAL*GEN is positive and statistically significant. A one standard deviation increase in PCT COAL increases wind capacity by 190 MW for a median generation state (104.2 TWh). States with large amounts of coal capacity appear to be diversifying their fuel mix through wind power to lower emissions rates.

The coefficient for NAT GAS PRICE*GEN is statistically significant, but has the opposite sign than would be expected if economics is driving wind capacity installation. A one standard deviation in NAT GAS PRICE decreases wind capacity by 33 MW for a median generation state. As in Specification 1, wind power does not seem to be competing with natural gas on a purely economic standpoint.

The coefficient on the average LCV score for the House of Representatives interacted with generation (LCV SCORE*GEN) is statistically significant. A one standard deviation increase in LCV SCORE decreases wind capacity by 63 MW. Preferences for renewable capacity do not appear to lead to deployment of wind capacity without the enactment of policy.

The coefficients on PCT HYDRO*GEN, PCT NUCLEAR*GEN, and PCT OTHER*GEN are statistically insignificant.

5.3 Biomass Capacity

Specification 3 estimates the policy and control variable impacts on biomass capacity. The regression results are different from both Specifications 1 and 2, both in terms of control and policy variable interpretations.

5.3.1 Regulatory Policy Variables: $\mathbf{R}_{it}$

Similar to results from Specification 1, renewables portfolio standards with capacity requirements and required green power options have statistically significant, positive effects on biomass capacity. The policy coefficients for biomass capacity are much smaller for these two policies relative to the total non-hydro renewable capacity regression: 4 % and 9 %, respectively. For each megawatt of renewable capacity required by the renewables portfolio standard approximately 0.05 MW of biomass capacity is constructed. Enactment of a required green power option leads to biomass capacity increasing by 0.24 MW per terawatt-hour of generation. A state with a median generation level that enacts a required green power option would have an increase of 25 MW.

There are three important differences between Specification 3 relative to Specifications 1 and 2. First, RPS: REGIONAL SALES REQ is statistically insignificant. Second, RPS: REGIONAL SALES GOAL is statistically significant in Specification 3. A one standard deviation increase in RPS: REGIONAL SALES GOAL increases biomass capacity by 4 MW. The small magnitude of this effect is a result of the low number of voluntary sales goals across the U.S. Third, STATE GP PURCHASING: PCT REQ*GEN is statistically significant. An agreement by the state government to purchase 10 % of its electricity from renewable sources increases biomass capacity by 0.17 MW per TWh of generation in the state, or 18 MW in the median generation state. The magnitude of the impact is small because the state government only accounts for a portion of a state's electricity use. Impacts from state government green power purchasing agreements will vary by size of a state's electricity market and the size of the agreement, which ranges from 2.5 % in Massachusetts to 50.0 % in Maine in 2007.

As in Specifications 1 and 2, CEF: CAP AWARDED has a statistically insignificant coefficient.

5.3.2 Economic and Political Variables: $\mathbf{W}_{it}$

Only one of the statistically significant control variable coefficients in Specification 3 have the same sign as the total non-hydro renewable regression. PCT NUCLEAR*GEN is positive and statistically significant. A standard deviation increase in PCT NUCLEAR increases biomass capacity by 47 MW for a median generation state. As in Specification 1, this PCT NUCLEAR*GEN is capturing some preferences for a more diverse fuel mix, and biomass is an effective peak load capacity to complement baseload nuclear power.

Two statistically significant coefficients have the opposite sign than in Specification 1. The coefficient on PCT COAL*GEN is negative and statistically significant. A one standard deviation increase in PCT COAL decreases biomass capacity by 30 MW for a median generation state. There are two possible reasons for this relationship. First, co-firing of coal and biomass fuels, where there is a mix of biomass with coal to lower overall emissions without requiring new capacity construction, could be replacing coal capacity with biomass capacity. Second, unlike wind power, states are not constructing biomass capacity to lower emissions rates because biomass still creates non-negligible levels of carbon dioxide, nitrogen oxide, and particulate matter emissions.

LCV SCORE*GEN has a positive and statistically significant coefficient, with a one standard deviation in LCV SCORE increasing biomass capacity by 19 MW for a median generation state. The impact is not economically significant, but the sign of the coefficient is useful in understanding deployment of different renewable capacity types. Environmental preferences in a state have a positive impact on biomass capacity. Biomass capacity is constructed at a small scale and has a high and uncertain operating cost, which makes its long-run viability questionable and investment risk high. These conditions make it important for biomass capacity to have state government support to minimize these risks.

Unlike in Specification 1, the coefficient for PCT HYDRO*GEN is statistically significant. A one standard deviation in PCT HYDRO (20.35 percentage points) increases biomass capacity by 25 MW for a median generation state. States with higher amounts of hydropower are less likely to deploy biomass capacity, although the magnitude of the impact is relatively small.

The coefficients on NAT GAS PRICE*GEN, PCT COAL*GEN, PCT OTHER*GEN, and SUGARCANE PROD are statistically insignificant.

5.4 Geothermal Capacity

The results from the geothermal power capacity regression (Specification 4) are much different than the results from previous specifications, with fewer significant control and policy variable coefficients.

5.4.1 Regulatory Policy Variables: $\mathbf{R}_{it}$

The policy impacts on geothermal capacity are minimal. The only policy variable with a statistically significant and positive coefficient is CEF: CAP AWARDED. For each megawatt of renewable capacity for which a clean energy fund has awarded funding, 0.05 MW of geothermal capacity has been constructed. The coefficient for REQ GREEN POWER OPT*GEN has a negative and statistically significant coefficient. A state with a median generation level that enacts a required green power option would have an decrease of 5 MW of geothermal capacity, which is not economically significant. RPS: CAP REQ, RPS: REGIONAL SALES REQ, RPS: REGIONAL SALES GOAL, and STATE GP PURCHASING: PCT REQ*GEN have statistically insignificant coefficients.

5.4.2 Economic and Political Variables: $\mathbf{W}_{it}$

As in Specifications 1 and 2, the coefficient for NAT GAS PRICE*GEN is statistically significant. A one standard deviation in NAT GAS PRICE decreases geothermal capacity by 1 MW for a median generation state. The minimal impact is not surprising because geothermal power is baseload capacity and is not a reasonable substitute for natural gas-fired capacity.

As in Specification 3, PCT HYDRO*GEN has a negative and statistically significant coefficient. A one standard deviation increase in hydropower capacity decreases geothermal capacity by 8 MW. Hydropower is a substitute for geothermal power because both are used to meet baseload electricity demand and both have little to no emissions rates.

The coefficients on PCT COAL*GEN, PCT NUCLEAR*GEN, PCT OTHER*GEN, and LCV SCORE*GEN are statistically insignificant (10% level).

5.5 Solar Capacity

The results from the solar power capacity regression (Specification 5) are much different than the results from any of previous specifications, with statistically significant, but economically insignificant impacts.

5.5.1 Regulatory Policy Variables: $\mathbf{R}_{it}$

The policy impacts on solar capacity are minimal because of the small amount of solar capacity currently installed in the U.S. electric power industry. The only positive and statistically significant policy coefficient is on RPS: REGIONAL SALES REQ, where a one standard deviation increase in RPS: REGIONAL SALES REQ increases solar capacity by 3 MW. The impact on California in 2007 is estimated to be 47 MW. The reason for the strong significance level (1 %) is that RPS with sales requirements often include "multipliers" that allow solar generation to count for as much a three times the baseline renewable generation towards RPS requirements. So if a utility-scale solar farm generates 1,000 MWh of electricity, the RECs earned are worth up to 3000 MWh of electricity originating from other renewable resources.

There are two policy variables that are statistically significant and negative, STATE GP PURCHASING: PCT REQ*GEN and CEF: CAP AWARDED. For every megawatt of capacity awarded funding from a clean energy fund, solar capacity decreases by 0.02 MW. If a state government green power purchasing agreement is for 10 % of state agency electricity use for a median generation state, solar capacity decreases by 0.4 MW for a median generation state. These negative impacts could be driven by a reduction of a single solar farm due to the small number of states with any solar capacity (6 states) and the small total quantity of solar capacity in the U.S. (503 total MW) in 2007. California accounts for 404 MW (80 %) and had a reduction in nameplate solar capacity from 413 MW in 2000 to 404 MW in 2007 while no other state had a reduction in solar capacity. This reduction is enough to drive the negative impacts for STATE GP PURCHASING: PCT REQ*GEN and CEF: CAP AWARDED.

RPS: CAP REQ, RPS: REGIONAL SALES REQ, RPS: REGIONAL SALES GOAL, and REQ GREEN POWER OPT*GEN have statistically insignificant coefficients.

5.5.2 Economic and Political Variables: $\mathbf{W}_{it}$

The coefficient for NAT GAS PRICE*GEN is positive and statistically significant. A one standard deviation in NAT GAS PRICE decreases solar capacity by 0.7 MW for a median generation state. The impact is not economically significant.

PCT HYDRO*GEN has a positive and statistically significant coefficient. A one standard deviation increase in hydropower capacity increases solar capacity by 3 MW in a median generation state. Preferences for more renewable capacity may be captured in PCT HYDRO*GEN.

PCT COAL*GEN has a negative and statistically significant coefficient. A one standard deviation increase in coal capacity increases solar capacity by 4 MW in a median generation state.

The coefficients on PCT NUCLEAR*GEN, PCT OTHER*GEN, and LCV SCORE*GEN are statistically insignificant.

5.6 State Fixed-Effects Variables: $\mathbf{S}_{it}$

Forty-nine state dummy variables are included to control for state interpretation of federal policies enacted prior to 1996 as well as any time-invariant differences across states.[29] Time-constant variation across states includes the availability of renewable energy resources and the initial level of a state's preferences for renewable energy use. The coefficients should be highly correlated to the amount of renewable capacity that existed in 1995. The correlation between a state's initial total non-hydro renewable capacity and its state dummy variable coefficients is 0.955. The state dummy variables seem to effectively control for the impact of existing regulation and the market environment prior to 1996.

5.7 Year Variables: $\mathbf{T}_{it}$

Year dummy variables interacted with GEN are used to control for national trends, such as general renewable energy economic viability and federal policy impacts. Specifications 1-4 show the same general national trend. Impacts are more positive as time goes on. In Specifications 1,2, and 4, the coefficients are statistically insignificant early during the study period. Beginning in the early 2000s, there is a significant increase in national trend impacts that continues to rise year over year through 2007. For Specification 1, the impact is 1.87 MW per terawatt-hour of generation in a state. A state with median generation has an increase of 194 MW from 1996 to 2007.

6 Conclusions

States have enacted many policies to increase the deployment of non-hydro renewable capacity into the electric power industry in that state. The literature evaluating the effectiveness of these programs consists of case studies and one econometric study, which only

[29] One state must be dropped from the model to remove multi-collinearity of the fixed-effects variables.

explains the use of wind power. This study adds to the literature by utilizing both a state fixed-effects and a SUR model with larger panel, a greater number of more detailed policies, and more control variables than previously considered to explain the deployment of total non-hydro renewable capacity as well as the four different types of non-hydro renewable energy (wind, biomass, geothermal, and solar) and total non-hydro renewable capacity in a state.

Three regulatory policies appear to have been effective at increasing renewable capacity deployment in a state to date. The significant results from two of these regulatory policies confirm some of the findings from the literature, which find renewables portfolio standards with capacity requirements and Mandatory Green Power Options increase capacity deployment in a state. This paper expands on the literature by estimating the varying magnitude of the policy effects across all states.

The Petersik case study found that renewables portfolio standards with capacity requirements have increased renewable capacity. This paper expands on these results by finding evidence on the size of the policy effect holding other policies fixed. Each megawatt of capacity mandated by renewables portfolio standards with Capacity Requirements results in the deployment of 1.14 megawatt of additional non-hydro renewable capacity in a state, with approximately 1.11 MW from wind capacity and 0.05 MW of biomass capacity.

Statewide required green power options have a surprisingly large effect on total non-hydro renewable, wind, and biomass capacity deployment. Forcing utilities to offer customers the option to purchase renewable-based electricity at a reasonable premium rate increases renewable capacity in a state by up to 2 % of total capacity. The policy has a greater impact in larger electricity markets and appears to be effective regardless of a state's political environment or other policy implementations. There are major renewable policy implications if these results hold or strengthen over time due to increasing green power program participation rates. Only seven states had implemented required green power options as of 2007 even though creating a statewide green power market appears to be effective at increasing renewable energy capacity. It will be important to determine if these impacts persist over time as the supply of renewable energy catches up with current market demand.

The Petersik case study found that renewables portfolio standards with sales requirements or goals have not had any statistically significant effects in a state. Meanwhile, Menz and Vachon found that an RPS (including capacity requirement, sales requirement, and voluntary goal) is correlated to more wind capacity in a state. This paper finds that RPS with sales requirements have an impact on renewable capacity within the state's region, either within the state or adjacent states.

Menz and Vachon (2006) found public benefits funds, which include any clean energy fund in a state, to be insignificant in their model while Bolinger et al. (2001, 2004, 2005) case studies on clean energy funds find hundreds of megawatts have been installed using CEF financing. This paper finds that clean energy funds targeting utility-scale projects do not increase the deployment of total non-hydro renewable, wind, and geothermal capacity in a state. Instead the financing is used to fund projects that would have occurred otherwise, likely due to RPS sales requirements also adopted by the state or neighboring states around the same time. Clean energy funds are used as the "carrot" to minimize opposition in the electric power industry while RPS with sales requirements are used as the "stick" to ensure that action will be taken to increase renewable-based generation.

Biomass capacity has been the only beneficiary of RPS with sales goals and state government green power purchasing agreements, realizing small increases in capacity as a result.

The important policy implications that arise from the results indicate policymakers have an array of tools, both command-and-control and market-based, at their disposal to promote renewable energy deployment in a state to meet environmental and energy security policy goals. Both policy approaches can be used in conjunction to allow power producers to take advantage of green power market differentiation while encouraging market penetration through new requirements on non-green power market electricity capacity or sales. An RPS with sales requirements may be more economically preferred because it still increases renewable capacity, but allows it to be constructed wherever is most cost-effective. These policy mechanisms will become even more useful to state governments if the prospect of U.S. climate change/carbon emissions policy becomes a reality.

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Appendix: Data Sources

Data Source	Data Description
EIA Historical State Electricity Databases	Generation, sales, and capacity
EIA Natural Gas Price Navigator	Delivered natural gas prices
LCV National Environmental Scorecard	Congress. voting ratings
DSIRE	Policy design and enactment/effective dates
CESA Utility-Scale Ren. Energy Proj. Database	Project number/size
USDA Sugarcane production	Annual tons of sugarcane production
Fed. Reserve Bank of St. Louis CPI	National avg. annual price inflation

Table 1: Dependent and Control Variables

Dependent Variable	Mean.	Std. Dev.	Min.	Max.	Median.
RENEWABLE CAP (MW)	405.01	889.37	0.00	6760.00	210.00
WIND CAP (MW)	112.39	376.85	0.00	4490.00	0.00
BIOMASS CAP (MW)	223.02	271.26	0.00	1217.00	138.00
GEOTHERMAL CAP (MW)	61.48	386.69	0.00	2821.00	0.00
SOLAR CAP (MW)	8.11	55.31	0.00	413.00	0.00
	.	.	.	.	.
Control Variable	Mean.	Std. Dev..	Min.	Max.	Median.
GEN (TWh)	152.59	136.78	9.88	810.99	104.22
PCT HYDRO (Percentage)	13.81	20.35	0.00	92.23	6.05
PCT NUCLEAR (Percentage)	10.78	12.20	0.00	56.36	7.47
PCT COAL (Percentage)	38.17	27.15	0.00	98.36	38.87
PCT NAT GAS (Percentage)	26.39	22.34	0.00	98.90	21.79
PCT OTHER (Percentage)	10.84	15.93	0.00	90.72	4.59
NAT GAS PRICE (2007 $/MMBtu)	5.27	2.42	1.75	19.02	4.63
LCV SCORE (0 to 100)	43.25	26.61	0.00	100.0	38.50
SUGARCANE PROD (tons)	608.55	2672.75	0.00	17083.0	0.00

Table 2: Policy Variables

Variable	States with Policy	Non-Zero Observations
CEF: CAP AWARDED (4 Year Lag)	10	28
RPS: CAP REQ	4	42
RPS: REGIONAL SALES REQ	44	234
RPS: REGIONAL SALES GOAL	16	69
STATE GP PURCHASING: PCT REQ	11	50
REQ GREEN POWER OPT	7	34

Table 3: Regressions Results

	(1)	(2)	(3)	(4)	(5)
VARIABLES	TOTAL RENEW.	WIND CAP	BIOMASS CAP	GEOTHERMAL CAP	SOLAR CAP
CEF: CAP AWARDED	0.006	0.011	-0.036	0.051***	-0.019***
	(0.194)	(0.178)	(0.068)	(0.012)	(0.007)
RPS: CAP REQ	1.143***	1.106***	0.051***	-0.001	-0.001
	(0.159)	(0.046)	(0.018)	(0.003)	(0.002)
RPS: REGIONAL SALES REQ	0.128**	0.097*	0.021	-0.001	0.011***
	(0.063)	(0.056)	(0.022)	(0.004)	(0.002)
RPS: REGIONAL SALES GOAL	0.169	0.029	0.143*	0.002	0.004
	(0.288)	(0.195)	(0.075)	(0.013)	(0.008)
STATE GP PURCHASING: PCT REQ * GEN	0.001	-0.01	0.017***	-0.001	-0.002***
	(0.020)	(0.016)	(0.006)	(0.001)	(0.001)
REQ GREEN POWER OPT * GEN	2.651***	2.414***	0.237**	-0.034*	0.016
	(0.674)	(0.263)	(0.101)	(0.018)	(0.010)
LCV SCORE * GEN	-0.011	-0.017***	0.007***	0.000	0.000
	(0.008)	(0.004)	(0.002)	(0.000)	(0.000)
NAT GAS PRICE * GEN	-0.088**	-0.097***	0.009	-0.005***	0.002**
	(0.039)	(0.027)	(0.010)	(0.002)	(0.001)
PCT COAL * GEN	0.041***	0.050***	-0.008*	0.001	-0.001***
	(0.013)	(0.011)	(0.004)	(0.001)	(0.000)
PCT HYDRO * GEN	0.007	0.021	-0.012*	-0.004***	0.001**
	(0.023)	(0.017)	(0.006)	(0.001)	(0.001)
PCT NUCLEAR * GEN	0.058**	0.018	0.037***	0.001	0.001
	(0.027)	(0.030)	(0.012)	(0.002)	(0.001)
PCT OTHER * GEN	0.018*	0.015	0.006	0.001	0.000
	(0.010)	(0.011)	(0.004)	(0.001)	(0.000)
SUGARCANE PROD	0.016		-0.005		
	(0.021)		(0.005)		
YR1997 * GEN	0.052	0.059	-0.004	0.006	-0.001
	(0.118)	(0.114)	(0.044)	(0.008)	(0.004)
YR1998 * GEN	0.004	0.045	-0.029	0.006	-0.001
	(0.114)	(0.113)	(0.044)	(0.008)	(0.004)
YR1999 * GEN	-0.089	-0.034	-0.04	-0.012	0.011***
	(0.117)	(0.111)	(0.043)	(0.008)	(0.004)
YR2000 * GEN	-0.230*	-0.119	-0.080*	-0.018**	0.011**
	(0.136)	(0.111)	(0.043)	(0.008)	(0.004)
YR2001 * GEN	0.233	0.397***	-0.148***	0.004	0.005
	(0.147)	(0.129)	(0.050)	(0.009)	(0.005)
YR2002 * GEN	0.269*	0.446***	-0.159***	0.005	0.000
	(0.145)	(0.139)	(0.054)	(0.009)	(0.005)
YR2003 * GEN	0.360***	0.512***	-0.133***	-0.002	-0.001
	(0.132)	(0.119)	(0.046)	(0.008)	(0.005)
YR2004 * GEN	0.583***	0.719***	-0.142**	0.018*	-0.007
	(0.205)	(0.152)	(0.058)	(0.010)	(0.006)
YR2005 * GEN	0.785***	0.907***	-0.138**	0.020*	-0.008
	(0.221)	(0.163)	(0.063)	(0.011)	(0.006)
YR2006 * GEN	1.268***	1.356***	-0.094	0.034**	-0.013
	(0.299)	(0.211)	(0.081)	(0.014)	(0.008)
YR2007 * GEN	1.865***	1.883***	-0.033	0.027**	-0.006
	(0.381)	(0.176)	(0.067)	(0.012)	(0.007)
CONSTANT	22.801	-250.427	-259.998**	79.296***	-28.545**
	(80.559)	(295.895)	(115.855)	(20.063)	(11.499)
OBSERVATIONS	598	598	598	598	598
R-SQUARED	0.7809	0.9248	0.9786	0.9997	0.995

Robust Standard Errors in Parentheses;* significant at 10%;** significant at 5%;*** significant at 1%
State dummy variable coefficients are not reported.

Table 4: Variable Effects: Total Non-hydro Renewable Capacity

Variable	Mean	Std. Dev.	Increase Per Unit per TWh	Std. Dev. in Median Gen. State
PCT COAL*GEN	38.17	27.15	0.041 MW	156 MW
PCT NUCLEAR*GEN	10.78	12.20	0.058 MW	99 MW
PCT OTHER*GEN	10.84	15.93	0.018 MW	40 MW
NAT GAS PRICE*GEN	5.27	2.42	-0.088 MW	-22 MW

Effect of Enacting a Policy	States	Range	Per Unit Effect	Impact in Median Gen. State
RPS: REGIONAL SALES REQ	44	0.0-4282.7 MW	0.128 MW per 1.0 TWh req.	NA
RPS: CAP REQ	4	16.7-2280.0 MW	1.14 MW per 1.0 MW	114% of Req. Cap.
REQ GREEN POWER OPT*GEN	7	52.5-216.4 TWh	2.65 MW per TWh	276 MW

Note 2: All other variables are statistically insignificant.