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Research note

Renewable energy potential and adoption of renewable portfolio standards

Gregory B. Upton Jr. *, Brian F. Snyder

Center for Energy Studies, Louisiana State University, Energy Coast & Environment Building, Nicholson Extension Drive, Baton Rouge, LA 70803, United States

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ABSTRACT

Thirty states have adopted renewable portfolio standards (RPSs) that set targets for renewable energy generation by mandating electric power utilities obtain a minimum percentage of their retail load from renewable sources. To date, a number of studies have consistently found that political and economic factors impact RPS adoption. Studies have also examined the impact of renewable energy potential in a state on the probability of RPS adoption, but results have largely been statistically weak and inconclusive. After controlling for political and economic factors, we estimate that a one standard deviation increase in wind potential is associated with an approximately 4.2 percentage point increase in the probability of having an RPS, and a one standard deviation increase in solar potential is associated with a 6.1 percentage point increase in the probability of having an RPS.

1. Introduction

This paper analyzes factors that predict renewable portfolio standard (RPS) adoption. In addition to considering political and economic factors that have been consistently shown to be strong predictors, we focus on another factor that has received less attention, namely "renewable energy potential" or "renewable energy resource endowment," hereafter simply referred to as "renewable potential." Consistent with previous findings, we find that political and economic factors impact RPS adoption, but in addition we find evidence that renewable potential is also a strong predictor.

Renewable portfolio standards are state-level policies in the U.S. that legislatively mandate that a portion of a state's electrical retail load be produced by renewable sources by a specified future date. RPS policies target utilities and other electricity providers and require that they comply with the regulatory mandate. RPS policies commonly include a system of renewable energy credits (RECs), in which renewable energy producers generate one REC for every MWh of renewable electricity produced. RECs can be bought and sold to help electricity providers meet their RPS obligations. States might implement RPS standards for a number of reasons; they may want to diversify their electricity portfolio, encourage investment in the renewable energy sector, improve state air quality, or reduce CO_2 emissions to combat climate change (Lyon and Yin, 2010).

It has consistently been shown that political and economic factors can impact a state's decision to implement an RPS (Fowler and Breen, 2013; Chandler, 2009; Huang et al., 2007; Lyon and Yin, 2010). In addition, some studies have tested whether states with significant renewable potential have been more likely to adopt RPS policies (Matisoff, 2008; Chandler, 2009; Lyon and Yin, 2010; Yi and Feiock, 2012). States with high renewable energy resource endowments are hypothesized to be more likely to implement an RPS. The first obvious reason for RPS adoption is that states with relatively high renewable potential may expect that compliance with an RPS policy will be relatively inexpensive for utilities and ratepayers as a fixed investment will produce relatively more electricity. On the other hand it might be cost prohibitive, and potentially not feasible, for states with relatively little wind and/or solar potential to meet an RPS requirement without purchasing a large number of RECs from interstate markets. In addition, states may implement an RPS in an attempt to stimulate in-state economic activity. States with relatively large resource endowments might expect that a larger proportion of the economic benefits associated with renewable projects' construction and operation may occur within state bounds, and therefore be more likely to

* Corresponding author.
E-mail address: gupton3@lsu.edu (G.B. Upton).

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implement RPS policies. Conversely, states without a large natural resource potential may have concerns that an RPS will result in a subsidy from in-state ratepayers for renewable projects across state lines.

To our knowledge, Huang et al. (2007) were the first to analyze factors that impact the probability of RPS adoption, finding that adoption is nonrandom and is influenced by political factors, education levels, gross state product (GSP), and the population growth rate. They observed that states with relatively high GSP per capita and more Democratic state legislators were more likely to have adopted an RPS than states with relatively low GSP and more Republican state legislators.

Matisoff (2008) also found that GSP per capita and liberal citizen ideologies were positively related to the probability of RPS adoption and in addition examined the effects of renewable energy resource endowments on the adoption of climate change policies. Results were largely inconclusive, providing no evidence of the impact of natural resource endowments in one specification and weakly significant evidence of solar potential (but not wind potential) on RPS adoption in another. In part, Matisoff's failure to find conclusive results may be due to two factors. First, the paper utilized data on wind resource endowments that is based on a 30-m hub height compared to an 80-m hub height that was more standard over the time period in which RPSs were being adopted. This database was constructed in 1993, while the bulk of the RPSs were adopted a decade later. Second, Matisoff relied on relatively small sample sizes with only cross-sectional variation across forty-eight states in one specification and limited variation across time in another. Using similar empirical techniques, Chandler (2009) again found that political and economic factors impact RPS adoption but found no effect of renewable potential.[1]

Lyon and Yin (2010) utilized a logistic regression model and again found that political and economic variables are associated with the adoption of RPS policies. This is also the first paper to find a statistically significant effect of both wind and solar potential on RPS adoption. This finding is in contrast to the results of Chandler (2009) (who found no effect) and Matisoff (2008) (who found mixed and weak effects).

Most recently, Yi and Feiock (2012) included a rough proxy of renewable energy generation potential, namely the number of sunny days and the state average wind speed, in a model of RPS adoption. They found inconsistent and statistically weak evidence of the effect of these rough proxies of renewable potential on RPS adoption.

Thus, there is no consensus as to the effect of renewable resource endowments on the adoption of RPSs. Potentially due to lack of previous evidence, several of the most recent studies examining RPS adoption have failed to include natural resource variables in any specification (Carley and Miller, 2012; Fowler and Breen, 2013; Coley and Hess, 2012). The failure to find consistent results, and the exclusion of these variables in recent studies, may indicate that wind and solar potential simply do not guide policy decisions about RPS adoption. But this may also stem from methodological issues, especially the use of poor or antiquated indicators of renewable energy generating potential, and relatively small sample sizes might also play a role in poor statistical strength. We improve upon these previous studies by using recent data specifically developed to quantify renewable generating potential for both solar and wind. In addition, we utilize a panel of forty-nine states over more than two decades with time-variant political and economic variables as well as time-invariant wind and solar potential to estimate the marginal effect of each of these factors on RPS adoption.

Whether or not renewable potential impacts RPS adoption is of relevance to policymakers who are interested in understanding the impact of RPSs on outcomes of interest, such as renewable energy generation and emissions. For example, simply observing differences in the change in levels of renewable generation in RPS states and non-RPS states will not provide an unbiased estimate of the effectiveness of RPSs in spurring renewable generation *if* states with high renewable potential are also more likely to implement an RPS *and* are more likely to invest in renewable resources regardless of whether an RPS is in place. An observed increase in renewable energy generation might be falsely attributed to the RPS. Therefore, understanding the range of relevant factors that impact potential policy outcomes is critical.

2. Methods

2.1. Data

We utilize the U.S. Department of Energy's National Renewable Energy Laboratory's (NREL) estimate of wind and solar resource potential by state (NREL, 2010a). The solar resource is defined as the average irradiance received per day by the average m^2 of area in the state. The irradiance is then averaged over the year to give irradiance in $kWh/m^2/day$. Direct normal irradiance (DNI) is a measure of the irradiance received by a unit of area that is always normal (perpendicular) to the sun's rays. DNI is used by NREL because it is the industry standard used to assess solar resources available at potential sites for utility scale projects.

NREL (2010b) provides estimates of the maximum wind energy potential by state. NREL defines "windy" areas as those with wind speeds above 6.5 m/s at an 80-m hub height, again consistent with benchmarks commonly used in considering construction sites of utility-scale systems.[2] NREL then subtracts land area that is unsuitable for wind development to generate an estimate of the potential electricity generation if all of the commercially viable (windy) land area in a state were to be used to generate electricity after excluding incompatible land use. Together, these are the most thorough measures of wind and solar potential utilized in any study to date.

We also include the political and economic variables that have consistently been shown to impact RPS adoption in our model. Data on the number of Democrats and Republicans in each chamber of each state's legislature and the party of the governor are used to measure the political climate or leanings of each state at a given time (Klarner et al., 2012).

Data on the total gross state product and the mining and manufacturing gross state products were collected from the U.S. Bureau of Economic Analysis (BEA, 2014). The population of each state in each year is used to normalize these economic variables on a per-capita basis. Yearly state level population estimates come from the U.S. Centers for Disease Control's (CDC) National Center for Health Statistics (CDC, 2014). Basic summary statistics are presented in Table 2.

2.2. Empirical model

Equation (1) shows the empirical specification used to test

[1] Chandler's renewable potential variable differed from Matisoff (2008) in that it included biomass in addition to wind and solar.

[2] As of 2015, hub heights above 80-m are common, but 80-m was a standard hub height for utility scale systems over much of the period of this analysis.

Table 1
Overview of renewable portfolio standards.

State	Year	State	Year
Arizona	2001	Montana	2005
California	2002	Nevada	1997
Colorado	2004	New Hampshire	2007
Connecticut	1999	New Jersey	2001
Delaware	2005	New Mexico	2002
Hawaii	2004	New York	2004
Illinois	2005	North Carolina	2007
Iowa	1983	Ohio	2008
Kansas	2009	Oregon	2007
Maine	1999	Pennsylvania	2004
Maryland	2004	Rhode Island	2004
Massachusetts	1997	Texas	1999
Michigan	2008	Washington	2006
Minnesota	1997	West Virginia	2009
Missouri	2008	Wisconsin	1999

Source: Eastin (2014) and authors' independent research. Notes: West Virginia's RPS was repealed in 2015. Vermont passed an RPS in 2015, but was not included in the analysis due to its passage occurring beyond the time frame of our analysis.

whether wind and solar potential predict RPS adoption. We utilize a panel of forty-nine states from 1990 to 2012.[3] $RPS_{s,t}$ is an indicator variable for whether state s has an RPS policy in year t. The year of RPS implementation by state is listed in Table 1.

$$RPS_{s,t} = \alpha + \beta_1 Wind_s + \beta_2 Solar_s + X'_{s,t}\gamma + \theta T + \varepsilon_{s,t} \quad (1)$$

The variables for renewable energy resource potential, $Wind_s$ and $Solar_s$ do not vary over time as these endowments do not change from year to year. β_1 and β_2 are the parameters of interest as they represent the effect of a one unit increases in wind and solar potential on the probability of having an RPS in a given year. $X'_{s,t}$ is a vector of controls that includes the percent of the state legislature that is Democratic, an indicator variable for the political party of the governor, the GSP per person, mining-sector GSP per person and manufacturing-sector GSP per person. θT is a linear time trend and is included in all regressions. Parameters were estimated using logistic regression, with standard errors clustered at the state level for all specifications.

3. Results

Table 3 shows the estimated effect of wind and solar potential on RPS adoption. First, we show the estimated effect of wind and solar potential on RPS adoption using no covariates. We do not find either a statistically significant or economically significant effect of either variable on RPS adoption.[4] Thus, when analyzed in isolation, we do not find evidence that renewable potential is predictive of RPS adoption.

Next, we provide corollary estimates of the impact of political and economic conditions that have been consistently shown to be predictors of RPSs. The percentage of the state's legislature that is Democratic as well as the GSP per person and mining GSP per person are all found to be significant predictors of RPS adoption.

Thus, baseline estimates suggest that political and economic characteristics are predictive of RPS adoption while natural resource endowments are not. These results are limited in scope, as they only consider renewable potential and the political and economic factors by themselves, without considering the marginal effect of these factors in conjunction with one another.

[3] Alaska is not included in this analysis due to lack of reasonable estimates of renewable energy potential due to the vast size of the state. Washington DC is also not included.

[4] The only covariate used is a linear time trend.

Table 2
Summary statistics.

	Sample average	Std. Dev.	N
Resource Endowments			
Wind Resource Potential (PWh/yr)	0.754	1.38	49
Solar Resource Potential (kWh/m^2/day)	4.64	1.02	49
Political Characteristics			
Percent Legislature Democratic	53.4%	15.7%	1077
Democratic Governor	47.2%	49.5%	1077
Economic Characteristics			
GSP per Person	$38,395	$10,889	1077
Mining GSP Per Person	$971	$2422	1077
Manufacturing GSP Per Person	$5074	$2246	1077

Our next specification controls for natural resource potential and the political and economic characteristics simultaneously. Once we control for all of these factors, the results change significantly. With all covariates included, we estimate that an increase in wind potential of 1 PWh/year is associated with a 3.1 percentage point increase in the probability of a state having an RPS in a given year. To put this into perspective, the median state has a total of 0.75 PWh/year of solar potential with the standard deviation across states of 1.4 PWh/year. Thus, the estimated effect of a one standard deviation increase in wind potential is associated with an approximately 4.2 percentage point increase in the probability of a state having an RPS in a given year.

The estimated effect of solar potential, controlling for political and economic factors, is also shown in Table 3. An increase in solar potential by one kWh/m^2/day is associated with an approximate 6.1 percentage point increase in the probability of having an RPS. Again for perspective, the average solar resource is 4.6 kWh/m^2/day with a standard deviation of 1 kWh/m^2/day. Thus, a one standard deviation increase in solar potential is associated with an approximate 6.1 percentage point increase in the probability of a state having an RPS.

Consistent with previous results reported in the literature, we also find that political and economic factors influence RPS adoption; specifically we find that a legislature moving from 100 percent Republican to 100 percent Democratic is associated with an approximate 60.6 percentage point increase in the probability of having an RPS. For perspective, if a state's legislature moves from being 40 percent Democratic to 60 percent Democratic, which would be a sizable change of more than one standard deviation, the probability of RPS adoption increases by 12.1 percentage points.

We further find that a one thousand dollar increase in GSP per person is associated with a 1.25 percentage point increase in probability of adoption. Mining GSP per person is found to have a negative impact on RPS adoption; specifically a one thousand dollar increase in mining-sector GSP per person in a state is associated with a 2.33 percentage point decrease in the probability of RPS adoption. The political party of a state's governor and the manufacturing GSP per person are not found to be statistically significant predictors of RPS adoption, although, point estimates are in the expected directions.

4. Discussion

We find that wind and solar resource potential are both statistically significant predictors of whether a state adopts an RPS when controlling for political and economic covariates. Given the reliability of the data sources used, as well as utilization of a state-level panel spanning more than twenty years, this result represents the strongest evidence to date that policy-makers consider natural resource endowments when considering whether to adopt an RPS. These results further highlight the need to consider all potential

Table 3
Predicting RPS adoption.

	(1) Resources	(2) Political	(3) Economic	(4) All
Wind Potential (PWh/year)	−0.00312 (0.0284)			0.0307**(0.0156)
Solar Potential kwh/m^2/day	0.0331 (0.0302)			0.0611***(0.0207)
Percent Legislature Dem.		0.597***(0.148)		0.606***(0.123)
Democratic Gov.		0.0266(0.0397)		0.0464(0.0301)
GSP Per Person			0.0149***(0.00278)	0.0125***(0.00219)
Mining GSP Per Person			−0.0215**(0.00838)	−0.0233***(0.00786)
Manufacturing GSP Per Person			−0.0177(0.0109)	−0.00299(0.0103)
Trend	0.0334***(0.00302)	0.0335***(0.00268)	0.0242***(0.00426)	0.0231***(0.00385)
Observations	1,077	1,077	1,077	1,077

Standard errors clustered at state level. Economic variables normalized to $1,000 per person. Logistic regression used to obtain parameter estimates. Marginal effects—not parameter estimates—are shown.

influences on RPS adoption. Not surprisingly, any analysis that considers these time-invariant factors is incomplete without the inclusion of pertinent time-varying factors.

Consistent with previous literature, we find that the political leanings are a significant predictor of state RPS adoption. We find that state GSP per person is positively related to RPS adoption, while mining-sector GSP per person is negatively related to RPS adoption.

Ample opportunity remains for additional research on this topic and we propose several extensions. First, while we have found that statewide renewable resource potential impacts RPS adoption, policymakers might also consider other factors associated with the viability of these resources, such as resource location and feasibility of their incorporation into the electricity grid. In addition, policymakers might take into account the estimated cost to develop specific resources within their state.

Second, perceptions about the availability and economic feasibility of renewable resources might also impact RPS adoption. Plausibly, the economic viability of renewable projects and perceptions about the viability of these resources have both changed over time. While these factors might be correlated with actual resource potential in the state, this topic could be explored.

Third, not all RPSs are created equally. Some states have relatively stringent RPSs that require a large share of the state's energy to come from renewable sources, while other states have less ambitious goals. Yin and Powers (2010) consider RPS stringency when estimating the impact of RPSs on in-state renewable generation, but we have found no studies that have examined factors that impact stringency level. Potentially, states with high renewable energy potential would choose more ambitious renewable energy generation requirements.

Finally, REC markets also have the potential to affect a state's decision to implement an RPS. If RECs are both available and inexpensive, then states may have little concern about passing an RPS because compliance will be perceived as more feasible, perhaps especially if utilities are unable to meet the requirement entirely from in-state generation in the short run. On the other hand, expensive RECs might indicate that compliance will be expensive for the utilities and therefore expensive to ratepayers. Such a scenario might deter RPS adoption.

5. Conclusions and policy implications

The results presented in this paper are pertinent to researchers and policymakers interested in understanding the effectiveness of RPS policies on outcomes such as renewable energy generation and carbon emissions. The first step to unbiased estimation of policy impact of any policy is to understand what affects selection into the policy.

Social scientists rarely have the luxury of random treatment, and in the case of RPSs this is no exception. If we are interested in the impact of RPS policies on outcomes of interest, we cannot simply rely on observations after an RPS is implemented and assume that any changes were caused by the RPS policy. Neither can we simply observe outcomes across RPS and non-RPS states and conclude that differences are associated with RPS adoption.

The effectiveness of RPS policies in achieving increases in renewable energy generation and reductions in carbon emissions has been evaluated in a number of studies (Menz and Vachon, 2006; Carley, 2009; Yin and Powers, 2010; Sekar and Sohngen, 2014; Eastin, 2014), but despite the growing literature on non-random selection into RPS policies, none of these studies have considered the non-random selection into the empirical specification; any results that do not take this non-random selection into account cannot be interpreted as causal. Therefore, understanding the factors that influence a state's probability of RPS adoption is the first step in understanding the policy effectiveness in achieving desired outcomes. For this reason, further research is needed that tests for the impact of RPS policies while taking this non-random selection into account.

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