The Effects of Renewable Portfolio Standards on Renewable Energy Sources

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Abstract

Renewable Portfolio Standard (RPS) programs have experienced increased popularity at the state level with twenty-three states adopting policies. Policy makers implement these programs in the hopes of stimulating renewable energy generation and lessening the state's reliance on nonrenewable sources, by requiring utility companies to provide a specified amount of electricity from renewable sources. I examine the use of renewable energy sources caused by the implementation of these programs, and determine how these renewable source markets interact in an RPS setting. Analysis performed on RPS programs indicates an increase in wind energy generation, suggesting that RPS programs are an effective method to increasing generation and reliance on wind energy. Results do not indicate that the renewable energy sources of wind, solar/photovoltaic, and geothermal, compete with one another to provide the lowest cost energy. This may be due to the infancy of the programs with economies of scale yet to be reached.

Introduction

Many scientists have come to agree that our increasing energy demands and outdated energy technology production, such as coal plants and reliance on fossil fuels, are a large part of this global warming problem. Environmental awareness programs have helped spurn a favorable political climate for "green" policies that encourage protection of the environment and natural resources. One area that has gained more attention is the encouragement and development of renewable energy technologies. Policies that deal with this topic include renewable energy tax credits, tradable energy credits, grants for research, and obligatory generation standards. Increasing renewable energy reduces the reliance on sources which are polluting and environmentally hazardous, such as coal, oil, and nuclear energy.

One commonly used program in the United States that encourages renewable energy has been the Renewable Portfolio Standard (RPS), currently enacted in twenty-three states. RPS programs require utility companies and electricity providers to supply a specified amount of electricity generated from renewable sources. Often the RPS program has a credit option which allows trading among firms, so the specified amount is reached by the industry as a whole rather than by each firm. Because these programs are relatively new, it is important to consider their impacts on renewable generation as well as what renewable sources are most affected. This study examines the effects of RPS initiatives on renewable electricity generation, and analyzes how the different renewable sources interact in markets with RPS regulations.

This paper is organized in the following way. Section 2 reviews the implementation and importance of RPS programs in the United States. In section 3, I build a model to examine how RPS programs have affected renewable energy generation. A review of the data collection process, data caveats, and analysis of the trends in the time series follows. The econometric models developed to analyze the data are discussed in section 5. Results and interpretation are presented in Section 6. I conclude with research suggestions and policy implications.

Review of Renewable Portfolio Standards in the United States

US citizens have become increasingly concerned with the pollution caused by fossil fuels. With global warming and climate change becoming a hot topic in political spheres, state and local governments have begun to address these environmental issues and concerns. Furthermore, the war in Iraq brought increased awareness about the US economy's dependence on foreign oil. Darmstadter (1992) examines how countries control energy use and how that control can affect the lack of conservation. Concerns about pollution, global warming, and foreign affairs have turned many people's attention toward renewable energy sources, and Darmstadter discusses the uncertainty of how much renewable energies would rise if fossil-fuels prices reflected their social cost. For hundreds of years people have tried to capture energy from wind, water, and solar energy for the purposes of cooking or generating power. Switching electricity generation from non-renewable sources to renewable ones would decrease the amount of pollution and hazardous materials created, decrease the US economy's reliance on foreign oil, and reduce the global impact on climate change.

Table 1. Rules, Regulations and Policies for Renewable Energy

State	PBF	Disclosure	Rebates	Grants	Loans	Production Incentive	RPS
Alabama			4-U	1-S	1-S, 1-U	1-U	
Alaska					2-S	1-U	
Arizona			6-U		1-U		1-S
Arkansas							
California	1-S	1-S	3-S, 19-U, 2-L	1-L	1-U, 1-S	1-S	1-S
Colorado	1-L	1-S	4-U, 1-L		3-U, 1-L	1-L	1-S, 1-L
Connecticut	1-S	1-S	1-S	5-S	4-S	1-P	1-S
Delaware	1-S	1-S	1-S	2-S			1-S
Florida		1-S	1-S, 2-U	1-S	1-U		1-U
Georgia			3-U		4-U	1-U	
Hawaii			3-U		2-U, 1-L		1-S
Idaho				2-P	1-S		
Illinois	1-S	1-S	1-S	3-S, 1-P			1-S
Indiana			4-U				
Iowa		1-S	3-U	1-S	2-S		1-S
Kansas				1-S			
Kentucky			1-P, 6-U		1-P, 3-U		
Louisiana					1-S		
Maine	1-S	1-S	1-S	1-S			1-S
Maryland		1-S	1-S, 1-L		2-S		1-S
Massachusetts	1-S	1-S	1-S, 1-U	3-S	2-S, 1-U	1-S, 1-P	1-S
Michigan	1-S	1-S		4-S			
Minnesota	1-S	1-S	1-S, 18-U	3-U	3-S, 1-U	1-S, 3-U	2-S
Mississippi			3-U		1-S	1-U	
Missouri			3-U	1-S	1-S		1-L
Montana	1-S	1-S	1-U	2-P, 1-U	1-S		1-S
Nebraska			3-U		1-S		
Nevada		1-S	1-S			1-S	1-S
New Hampshire			2-U		1-S		
New Jersey	1-S	1-S	2-S		1-S	1-S	1-S
New Mexico						1-U	1-S
New York	1-S	1-S	3-S, 2-U	1-S	2-S		1-S
N. Carolina					1-S	1-U, 1-P	
North Dakota							
Ohio	1-S	1-S		2-S	2-S		
Oklahoma							
Oregon	1-S	1-S	2-S , 6-U	2-P, 1-S	1-S, 5-U		
Pennsylvania	1-S	1-S		3-S, 4-L	2-S, 5-L, 1-U		1-S
Rhode Island	1-S	1-S	1-S, 1-U			1-P	1-S
S. Carolina			1-S, 2-U		5-U		
South Dakota							
Tennessee				1-S	1-S	1-U	
Texas		1-S	6-U				1-S, 1-L
Utah							
Vermont	1-S	1-S	1-S	1-U		1-U	1-S
Virginia		1-S					
Washington		1-S	8-U	2-P	6-U	3-U, 1-S	1-S
West Virginia							
Wisconsin	1-S		1-S, 2-U	2-S, 1-U	1-U	2-U	1-S
Wyoming			1-S, 1-U				
Totals	**18**	**24**	**142**	**53**	**78**	**27**	**28**

S = State/Territory L = Local U = Utility P = Private

Database of State Incentives for Renewables and Efficiency (http://www.dsireusa.org/)

Table 1 shows many of the rules, regulations and policies for renewable energy implemented by state, local, utility, and private authorities. These programs include activities to encourage consumers and producers to use renewable energy. Public benefit funds (PBF) are typically collected from all consumers of electricity and used to support rebates on renewable energy systems, research and development of renewable technology, and renewable energy education programs. States that have enacted such programs include California, Colorado, Connecticut, Delaware, Illinois, Maine, Massachusetts, Minnesota, Montana, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. These states have also enacted general disclosure rules and renewable portfolio standards. Disclosure refers to a requirement that utility companies provide customers with information on the energy being supplied, such as fuel mix percentages and emission statistics. The intention of this policy is to educate the consumer about electricity. Rebate and loan programs promote the installation and financing of renewable energy equipment, while grant programs encourage development of renewable energy technologies. Production incentives, such as the Federal Renewable Energy Production Incentive, provide project owners with cash payments based on electricity production. RPS require that a certain percentage of a utility's energy sales or electricity generation must be derived from “qualifiable” or eligible renewable resources. These different policies have been implemented at the state, local, and utility level throughout the United States.

Many European countries have begun to develop programs that encourage electricity production from renewable sources. Among these are the United Kingdom, Sweden, Belgium and Italy, who implemented national tradable certificates to achieve targets adopted by member states of the European Union under the Renewables Directive. Australia and Japan have also developed RPS programs for wholesale electricity suppliers. (Palmer and Burtraw 2005). These initiatives aboard provide support to the claim that there exists a movement towards encouraging the generation of electricity from renewable sources.

Growing support by voters in the United States for programs that encourage resource sustainability has motivated policy changes. One of the most common policies for encouraging renewable energy generation in US state government is the RPS. In his analysis of renewable energy, Darmstadter (2004) suggests enacting a national RPS. His basis for this policy change is centered on the encouragement of stimulating renewable and sustainable energy sources, and the benefits of reduced environmental damage. RPS initiatives require electricity companies to provide a certain percentage of electricity that is derived from renewable resources. The RPS is a market-driven policy that ensures that the public benefits from renewable sources, such as wind, solar, and geothermal energy. It does this by requiring that a minimum amount of renewable energy is included in the portfolio of electricity resources serving a state.

The supply of electricity starts with different sources generating electricity. Utility companies include investor-owned, publicly owned, cooperatives, and Federal utilities, which produce electricity placed on a regional grid system. Most electricity supplied to customers comes from the same grid system. There exists a level of demand that is constant throughout the year, while seasons cause variability in the demand. This constant level of demand requires a baseload of production that is often filled by coal or nuclear power plants. Electricity from renewable sources is typically variable upon weather, and helps to fill the seasonal demand rather than the baseload capacity. If a utility company is not able to meet the demands of its customers, then it may purchase electricity from other generating sources or utilities. Since all energy is placed on the same grid system, the supply of electricity to the consumer is uninterrupted.

Table 2. RPS program details by State through 2003

State	Beginning and Last Specified Requirements	Accepts Existing Capacity	Out-of-State Supply	Credit Trading
Arizona	0.2-1.1% of sales, 2001-2007	No	Solar only	Yes
California	+1% of sales per year, to 20.0% by 2017	Yes	Yes	No
Connecticut	6.5-10.0% of generation, 2003-2010	Yes	Yes	Yes
Hawaii	9.0% of sales by 2010	Yes	NA	No
Illinois	15.0% of sales by 2020	NS	No	No
Iowa	105 megawatts (no set date)	No	NS	No
Maine	30.0% of sales by 1999	Yes	Yes	Yes
Massachusetts	1.0-4.0% of sales, 2003-2009	No	Yes	Yes
Minnesota	1,125 megawatts wind by 2010+ 125 megawatts biomass	No	Yes	No
Nevada	5.0-15.0% of sales, 2003-2013;5% of requirements must be solar	Yes	Yes	Yes
New Jersey	3.0-6.5% of sales, 2001-2008	Yes	Yes	Yes
New Mexico	5.0-10.0% of sales, 2006-2011	Yes	Yes	Yes
Pennsylvania	Individual agreements with five utilities	NS	NS	NS
Texas	400-2,000 megawatts, 2003-2009	No	Yes	Yes
Wisconsin	0.5-2.2% of sales, 2001-2011	Yes	Yes	Yes

Source: Petersik 2003.

When a state implements an RPS, then a utility company must produce or purchase a specified percentage or amount of electricity from renewable sources. The RPS rules and requirements can vary from state to state. Table 2 shows the breakdown of the different RPS programs in the United States. The goals for required levels range from 1.1% to 30% of sales, while Texas and Iowa require a specific megawatt amount. Most states accept renewable energy from existing capacity, except Arizona, Iowa, Massachusetts, Minnesota, and Texas. Arizona and Illinois are the only two states that do not allow out-of-state supplies, although Arizona does allow solar energy to be imported. Minnesota and California are the only two states that do not have credit trading programs between firms to encourage efficiency. Arizona gives additional credits for solar produced energy.

Table 3. Eligible Renewable Sources by State

State	Bio-mass	Geo-thermal	Hydro-electric	Landfill Gas	Municipal Solid Waste	Ocean or Tidal	Solar	Wind
Arizona	Yes	Yes	No	Yes	NS	No	Yes	Yes
California	Yes	Yes	Small only	Yes	Yes	Yes	Yes	Yes
Connecticut	Yes	No	Small only	Yes	Yes	Yes	Yes	Yes
Hawaii	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Illinois	NS	NS	NS	NS	NS	NS	Yes	Yes
Iowa	Yes	NS	Small only	Yes	Yes	NS	Yes	Yes
Maine	Yes	Yes	Small only	Yes	Yes	Yes	Yes	Yes
Massachusetts	Yes	No	No	Yes	No	Yes	Yes	Yes
Minnesota	Yes	No	Small only	Yes	Yes	No	Yes	Yes
Nevada	Yes	Yes	Small only	Yes	No	No	Yes	Yes
New Jersey	Yes	Yes	Small only	Yes	No	Yes	Yes	Yes
New Mexico	Yes	Yes	Small only	Yes	No	No	Yes	Yes
Pennsylvania	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Texas	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
Wisconsin	Yes	Yes	Small only	Yes	No	Yes	Yes	Yes

NS=Not Specified
Source: Petersik 2003.

Table 3 shows the eligible renewable sources for each of the states through 2003. While all states allow biomass, landfill gas, solar, and wind, most only allow small hydroelectric sources if it is allowed at all. Small hydroelectric refers typically refers to plants smaller than 5 to 30 megawatts; however Wisconsin and Maine accept plants up to 60 and 100 megawatts. A few states that do not have access to geothermal availability, such as Connecticut, Massachusetts, and Minnesota, do not consider it in their RPS programs. California, Connecticut, Hawaii, Iowa, Maine, and Minnesota are the only states to allow municipal solid waste (MSW). Ocean and tidal sources are allowed by most states, however this source of energy is relatively small and as of 2003 no commercial operations used these resources.

The RPS allows for a market-driven approach to the production of renewable electricity. Non-renewable sources are often cheaper to produce than renewable sources, because they fail to fully capture the cost of pollution externalities. Darmstadter (2003) believes that renewable energy cannot exist in the market without subsidization. To justify the need for the subsidies, he considers the distortions of externalities from fossil fuels and nuclear power. However, he further suggests that policies such as tradable credits for meeting RPS requirements are beneficial because they induce a trading mechanism to hedge prices. The requirement for utilities to meet a standard amount of renewable electricity encourages a separation between the two sources of energy. Thus, renewable energies do not have to compete for market share with non-renewable sources. However, with most RPS programs, competition for market share among renewable energy encourages the production of the cheapest forms of renewable energy. The cost of producing electricity from renewable sources varies by the form from which it is derived. Wind, geothermal, and landfill gas are typically the least expensive, while solar and hydroelectric sources have very costly initial start-up as well as expensive maintenance (Darmstadter 2003). Depending on location, some prices have been in the range of 3 to 5.5 cents per kilowatt hour, while the cost of solar has remained much higher around 84 cents per kilowatt hour. Coal and combined-cycle gas (CCG) averaged around 4 cents per kilowatt hour. Thus, RPS programs allow for the private market to increase competition, efficiency, and innovation in the renewable energy sector to deliver renewable energy at the lowest possible cost. Tradable credits help to further this competition.

Palmer and Burtraw (2005) also compare policies meant to encourage the use of renewable resources. They develop a model that predicts future generation under different policies, and find RPS programs to be more cost-effective at increasing renewable generation than a renewable energy production credit (REPC). However, a REPC is more likely to lower electricity prices, while a cap-and-trade policy is the most cost-effective. They further examine which policies are the most effective at reducing carbon emissions. They find RPS to be less effective at decreasing emission than a direct tax. Although RPS programs help reduce carbon emission, the increase in renewable energy displaces mostly natural gas which is less polluting than coal. While the price of electricity and the renewable credits are expected to increase under an RPS, generation from both coal and natural gas sources should decrease. They conclude that RPS programs are superior to the alternative policies.

Comparing policies, technology subsidies and production tax credits encourage renewable energy generation but not in such a competitive framework as RPS. In a non-competitive setting, renewable energy is not necessarily produced in the least expensive form. These policies will help to encourage current renewable energy generation as well as affect investments in the long run. Through these instruments, renewable energy can enter the electricity market with non-renewable energy sources. Madlener, and Stagl (2005) compares feed-in tariffs, that provide a required level of revenue from selling renewable electricity, to tradable green certificates of a RPS and bidding schemes. They find that using socio-ecological economically differentiated feed-in tariffs ensures constant technological diversity and investment among renewable energy, but they point out the trade-off between encouraging diversity and the guarantee of a quota achievement as in the RPS. This shows that RPS may not be the best policy for encouraging a diversity of investment in renewable technology.

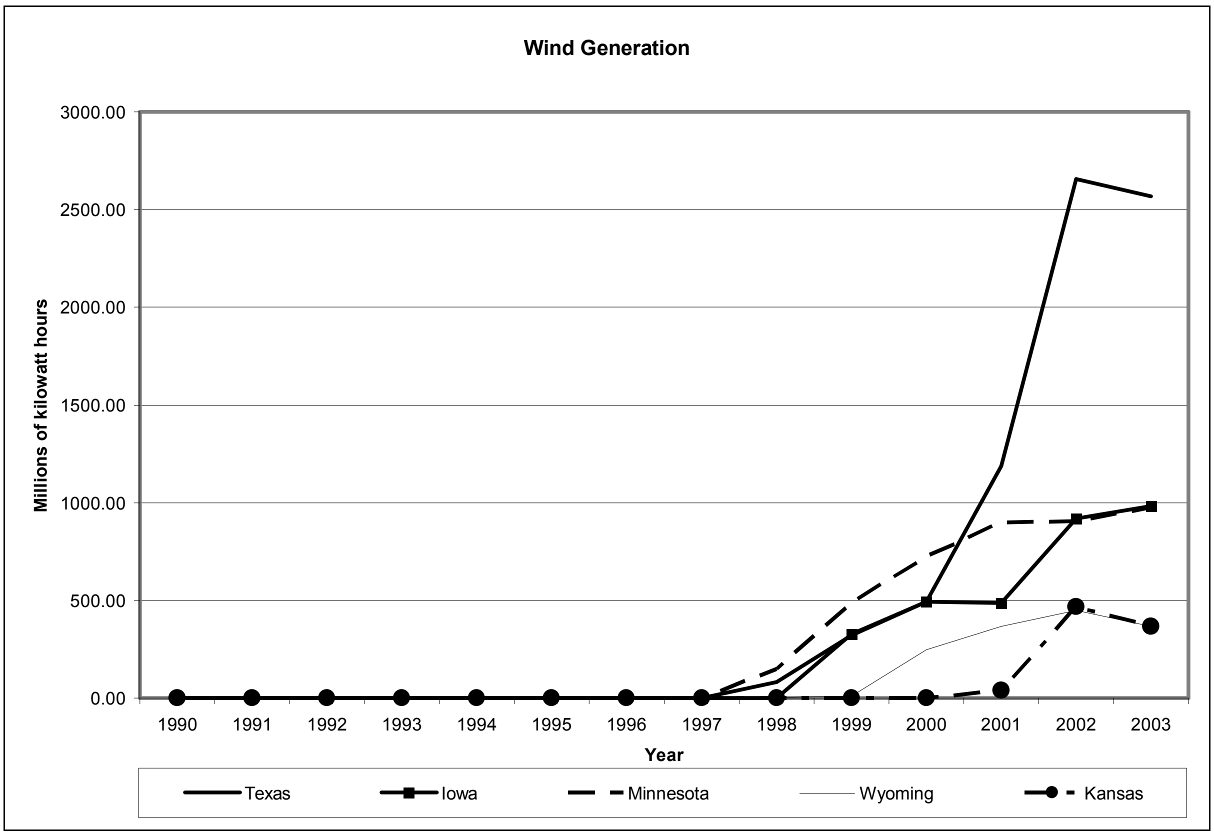
Previous researchers have predicted different impacts from RPS programs. Bernow (1997) examines the impact of a national RPS, comparing several different scenarios and base cases. He finds that under a national RPS of 4%, wind will account for nearly one-third renewable generation not including hydroelectricity by 2010, while geothermal and MSW will account for greater than 25%. Biomass and solar are expected to share 10% and 4% of renewable generation. Palmer and Burtraw (2005) predict that with a RPS program between 5%–10% renewable energy will be mostly met by geothermal and biomass sources, while higher levels (10%-20%) will induce wind generation to become a major component. Macauley et al (2002) finds wind-power to be the most likely to increase in capacity because of its low operating cost and large potential for technological advancements. However, renewable development will also be dependent on the growth of CCG technology.

This study examines if states with RPS programs have experienced an increased amount of renewable energy generation, and if these programs result in the sort of resource use voters intend. Analysis is performed on the generation of wind energy and RPS programs, as well as its interaction with other renewable energy generation, such as solar/ photovoltaic, and geothermal sources.

Model for Wind Energy Production

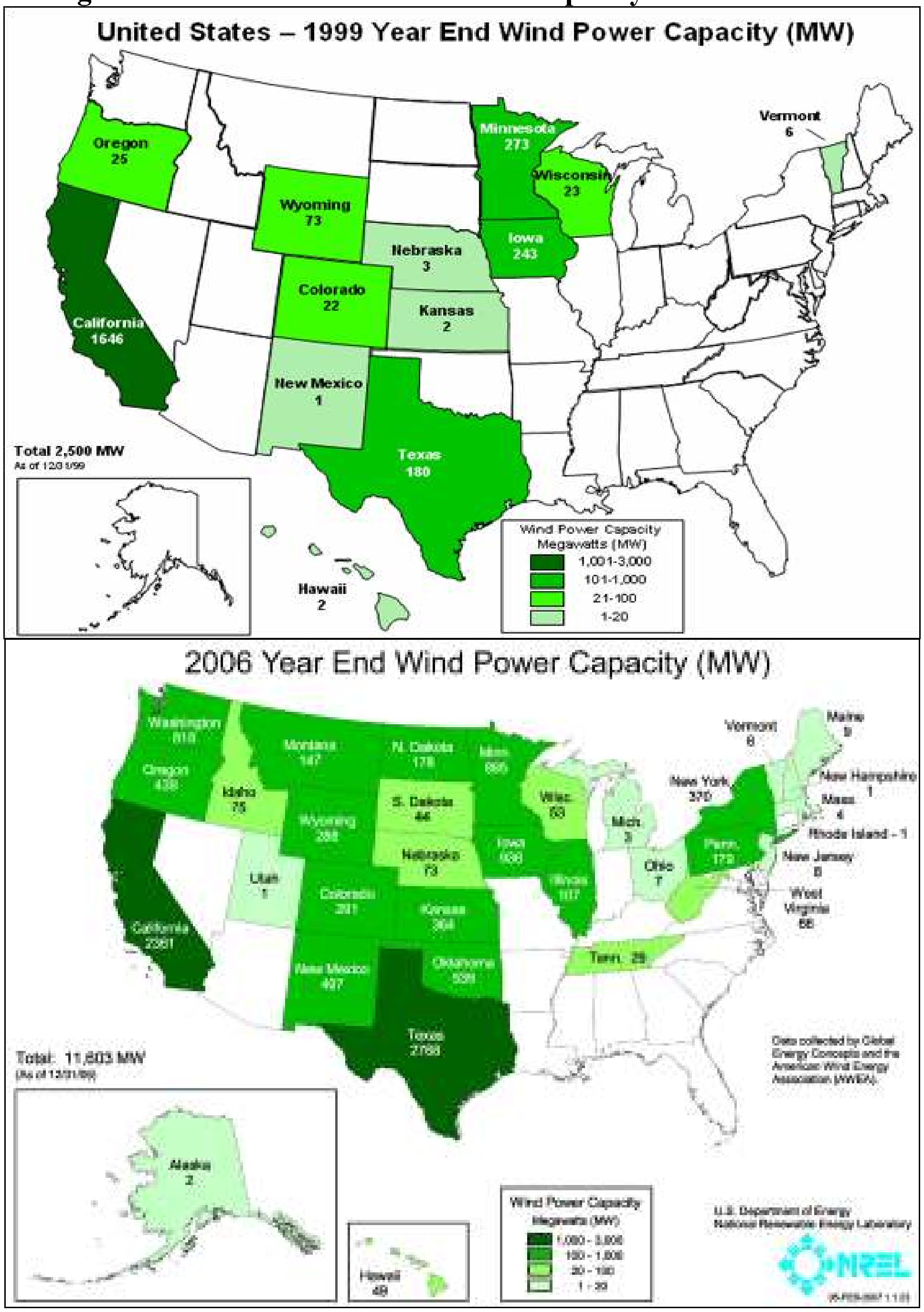
Since RPS programs have grown in popularity, I examine the impact they have on renewable generation. These programs intend to stimulate renewable energy through competitive markets, and this study examines how well RPS programs have performed. From 2000 to 2004, total geothermal generation increased by 1.86%, while solar generation increased by 17.36% and biomass generation decreased 1.13%. However, wind generation increased by 153%. This paper considers only the effects of RPS programs on wind generation.

Figure 2. Wind generation from 1990-2003 for Texas, Iowa, Minnesota, Wyoming, and Kansas



The growth of electricity from wind energy sources is evident within the last two decades. Advances in solar and geothermal sources are not as apparent. Figure 2 shows that wind generation has been growing over time for both non-RPS states such as Wyoming and Kansas as well as RPS states such as Texas, Minnesota, and Iowa. Figure 3 also shows this growth in wind generation between 1999 and 2005. Several states now

Figure 3. United States Wind Power Capacity in 1999 and 2006



Source: Department of Energy – National Renewable Energy Laboratory. http://www.eere.energy.gov/windandhydro/windpoweringamerica/wind_installed_capacity.asp

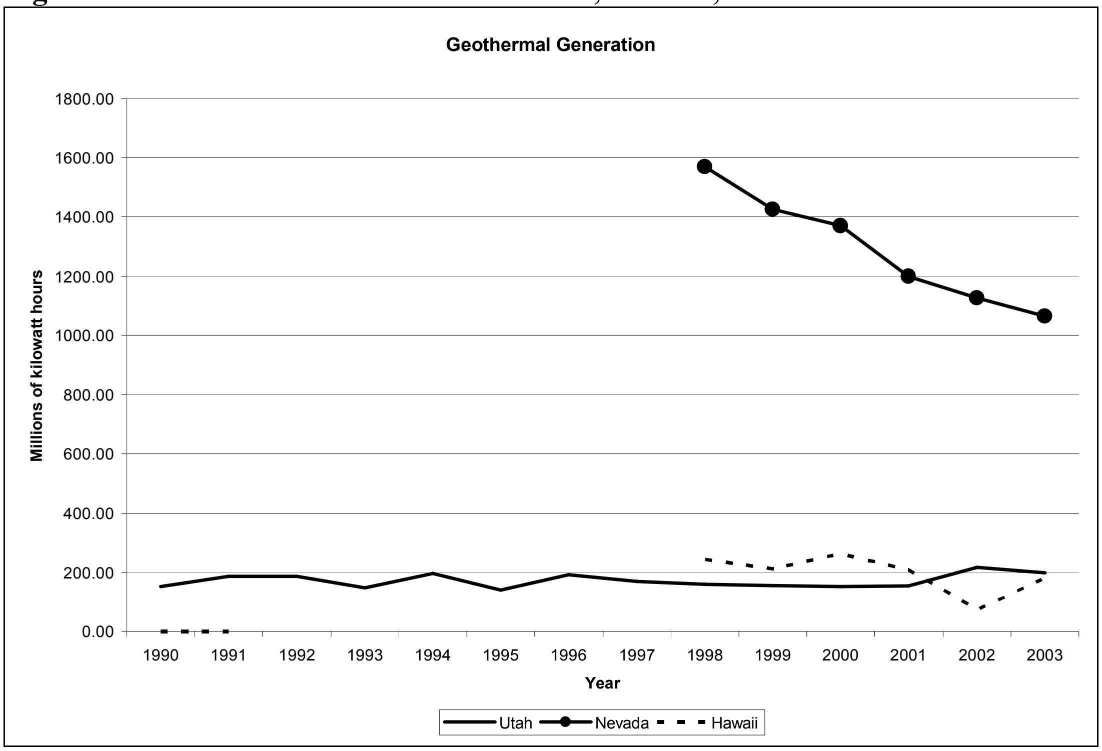
have a much larger capacity to generate wind then in 1999. RPS states with notable increases are again Texas, Iowa, Colorado, and Minnesota. However, some states without RPS programs have also had increased capacity, such as Oregon, Wyoming, New Mexico, Kansas, and Oklahoma.

The trends of solar and geothermal are not distinctly growth oriented. These substitutes for wind energy compete in the renewable energy market and the impacts of RPS programs are unclear by looking at time trends. Figure 4 captures the solar generation for three states with and without RPS programs. Virginia is the only state among the three without an RPS program. While Texas has seen increased generation of solar energy, Virginia and Arizona have experienced declines. This may be due to differences in public policies, such as solar subsidies or credit trading.

Figure 4. Solar Generation for Texas, Virginia, and Arizona

Figure 5 captures geothermal trends for Utah, Nevada, and Hawaii states. Hawaii is the only state of the three with an RPS program. Utah appears to provide consistent levels of electricity from geothermal sources, while Nevada has provided decreasing amounts. These figures and trends demonstrate the impact RPS programs have had on wind capacity and generation. Other sources, such as solar and geothermal energy appear to have been impacted less.

Figure 5. Geothermal Generation for Utah, Nevada, and Hawaii



Observing the market for wind allows for the examination of interactions and competition between potential renewable sources. Furthermore, over the last decade wind generation has made substantial gains while solar and geothermal sources growth have not been as noticeable. The model for the quantity of wind energy can be viewed as an inverse supply function of electricity. A typical supply function from economic theory examines price as a function of the amount produced and price of substitutes with equation 1 demonstrating this function.

$$(1) \qquad P^{supply}=f(Q^{supply}, P^{substitutes}).$$

Inverting the supply function allows for analysis of the quantity produced. Equation 2 expresses this inverted supply function for the quantity of wind energy generated.

Including substitutes in the function allows for analyzing the interaction of renewable sources.

(2) *Wind=g(price electricity, price of alternative renewable generation, price of non-renewable generation, size of market, policy and regulation).*

The amount of electricity generated is a function of the price received for production. As the price increases, the benefits from investing in capital, building turbines and producing wind energy become greater. Given an increasing supply function, more electricity can be supplied at a higher price. Because wind energy produces a relatively small share of electricity consumed, endogeneity from quantity affecting price is not considered.

The prices of substitute goods also affect the quantity produced. Electricity is homogeneous once produced from either renewable or non-renewable sources. These alternative sources provide acceptable substitutes and competition for wind energy generation. Thus, wind energy generation is a function of the cost of generating electricity from both renewable and non-renewable sources. The demand or size of the electricity market also affects the quantity supplied. Larger markets generate more electricity due to a higher demand, while smaller markets have to meet a lower demand and require a smaller baseload or capacity for electricity. The electricity demand is smaller in Rhode Island than in California, thus affecting the amount that needs to be supplied.

Finally, policies and regulations can encourage or discourage the use and ultimately the generation of electricity from wind energy. Kumbaroglu, Madlener, and Demir (2004) find that investment in renewable energy technology is only possible through policy and governmental promotion. The EPACT and RPS policies are considered to have a positive impact on wind generation because it encourages reliance on renewable energy sources. EPACT encourages wind through production tax credits, while RPS encourages wind through competition and guaranteed market share for renewable energy (EIA).

Although input and factor cost are sometimes considered when examining cost functions, I make the assumption that input costs are constant throughout the analysis. This allows for a simpler model when analyzing the impacts of policy on RPS and the competition among renewable energy. Including these factors would account for any investment or technology developments that may have impacted renewable generation. Potential future research for this project would include input costs and technology developments, and examine their effect with RPS programs.

Data Collection and Caveats

While some states such as Iowa, Massachusetts, and Minnesota enacted RPS legislation in the 1990s, other states such as Illinois, Montana, Vermont, and Washington have endorsed programs only in the last two years. This contrast between states and legislation dates provides a natural study of RPS and its effect on renewable energy generation. Table 4 shows the year each state enacted their RPS programs. Although individual program details may change over the years, such as the required percentage or eligible renewable energy, the concept of mandating renewable energy to fill portion of electricity supply remains constant.

Table 4. Year RPS legislation was enacted by State

State	Year Enacted	State	Year Enacted
Arizona	2001	Montana	2005
California	2002	Nevada	1997
Colorado	2004	New Jersey	2001
Connecticut	1999	New Mexico	2002
Delaware	2005	New York	2004
Hawaii	2004	Pennsylvania	2004
Illinois	2005	Rhode Island	2004
Iowa	1991	Texas	1999
Maine	1999	Vermont	2005
Maryland	2004	Washington	2006
Massachusetts	1997	Wisconsin	1999
Minnesota	1997		

Source: Rabe 2006.

The generation and price data were collected from the US Department of Energy-Energy Information Administration (EIA). Data are available from the state electricity profiles on monthly generation by source at the state level from 1990-2003. Twelve

Table 5 – Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Wind	681	91465.07	474422.2	0	3895431
Solar	700	14886.36	106326.7	-5	905739
Geo	677	132921.1	1235853	0	1.49E+07
Price	700	7.947571	2.346516	4.29	15.19
Other Renews	578	6945024	1.43E+07	0	1.05E+08
Price Coal	659	113.0273	55.61307	0	241
Price Natural Gas	679	283.2666	230.5568	0	4520
Cap Total	700	15896.07	14660.06	563	99594
RPS	700	0.091429	0.288424	0	1
EPACT	700	0.571429	0.495226	0	1
Wind-Potential	700	0.84	0.366868	0	1
Solar-Potential	700	0.5	0.500358	0	1
Geo-Potential	700	0.28	0.44932	0	1

states in this study enacted legislation before 2003: Arizona, California, Connecticut, Iowa, Maine, Massachusetts, Minnesota, Nevada, New Jersey, New Mexico, Texas, and Wisconsin. Table 5 shows the summary statistic for each variable.

Electricity price data were collected from the state profiles. *Price* is the average retail price of electricity over all sectors (residential, commercial, and industrial) in each state. Measured in 2005 cents per kilowatt hours from 1990-2003, prices ranged from $4.29 for Washington in 1992 to $15.19 for Hawaii in 2000. *Price* accounts for the increasing marginal cost of electricity produced.

No price data existed for renewable sources, so generation data by source were collected and analyzed in place of prices. Renewable electric power net generation is captured by the variables *Wind, Solar, Geothermal*, and *Other Renewables*, which are measured in thousands of kilowatt hours. This paper only examines the interaction between wind, solar/ photovoltaic, and geothermal heat pump sources. From table 2, solar and wind are eligible renewable sources in all states with RPS programs, while geothermal is eligible for states that have the potential to capture geothermal energy. Hydroelectric plants, however, are not analyzed because only a small number of states allow a particular form of hydroelectric power. Furthermore, the supply of energy from biomass is not analyzed under the RPS programs because of their damage to the environment. Biomass includes energy from landfill gas, wood, wood waste, agricultural by-products, straw, tires, fish oils, paper pellets, tall oil, sludge waste, digester gas, methane, and waste alcohol. Nevertheless, the impacts from these two sources as substitutes are accounted for in the model through the *Other Renewables* variable, which includes hydroelectric, municipal solid waste (MSW), landfill gas, wood and wood waste, and other waste.

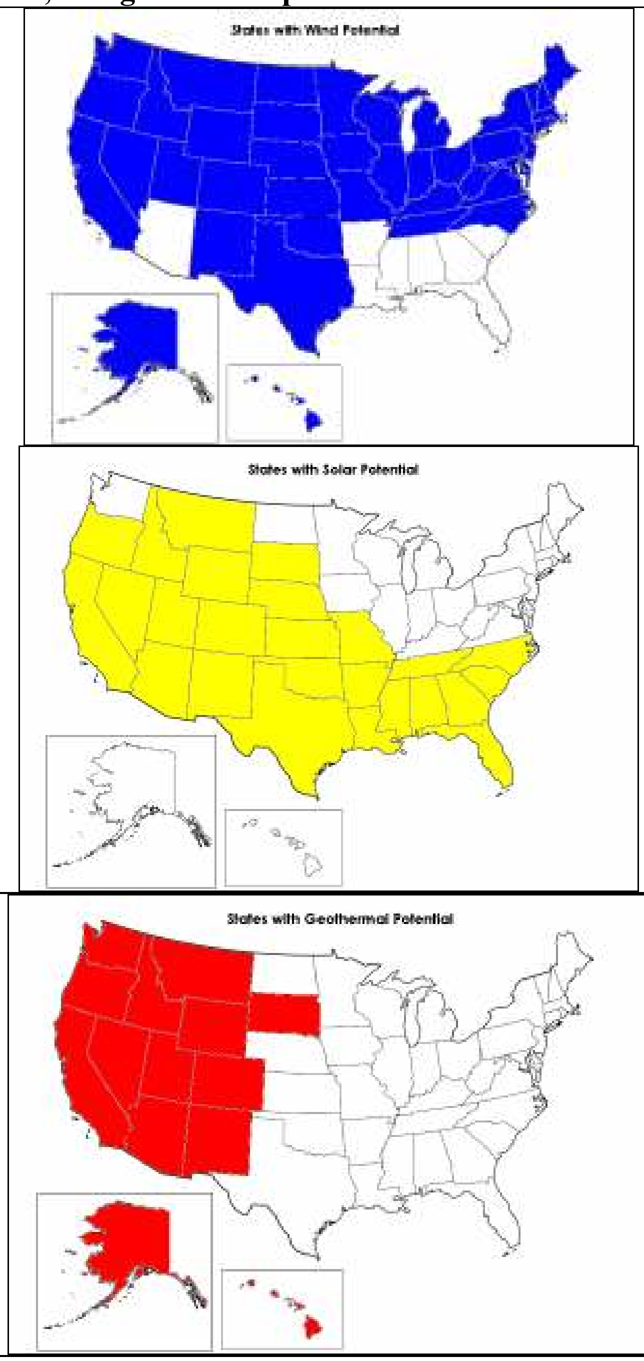
Price data for coal and natural gas were collected to account for the price of substitutes from non-renewable sources. *Price of Coal* and *Price of Natural Gas* captures electric power fuel price for coal and natural gas, which is measured in cents per million Btu. *Price of Coal* ranges from $0 in California to $2.41 in Maine, and averaged $1.13 million Btu. *Price of Natural Gas* averaged $2.83 for a million Btu. Natural gas, nuclear, and hydroelectric plants generate a majority of the electricity in California making a *Price of Coal* of $0 not unusual. In states where other resources generate a majority of the electricity for the state, the *Price of Natural Gas* is often $0.

Total Capacity for each state is the power industries' ability to produce electricity from all sources. The electric power industry capability measured in megawatts for the total electric industry averaged about 15,900 megawatts. Rhode Island had the lowest capacity in 1990 with 563 megawatts. Texas had the highest capacity in 2003 at 99,594 megawatts.

Policies and regulations can encourage or discourage the use and ultimately the generation of electricity from wind energy. The *RPS* and *EPACT* variables control for policy developments over the period. The *RPS* variable is used to capture the effect of policy and RPS programs. This binary variable indicates whether a state had a mandatory RPS law on the books for each year. A one indicates a state with an RPS. Between 1990 and 2003 twelve states adopted RPS policies, with Iowa starting in 1991. *EPACT* is a binary variable that accounts for the years when the federal government's

Energy Policy Act supported wind generation through production tax credits. This policy was enacted in 1992, but was not supported past 1999.

Figure 1. Wind, solar, and geothermal potential in the United States



Source Based on EIA Wind Potential Map:
http://www.eia.doe.gov/cneaf/solar.renewables/ilands/fig13.html
Source Based on EIA Solar Potential Map:
http://www.eia.doe.gov/cneaf/solar.renewables/page/solarthermal/concentsolarpower2.gif
Source Based on EIA Geothermal Potential:
http://www.eia.doe.gov/cneaf/solar.renewables/page/geothermal/geothermal.gif

Wind Potential, Solar Potential, and *Geothermal Potential* are each dummy variables that account for whether a state has the potential to produce renewable energy. Figure 1 shows the wind, solar, and geothermal potential in the United States. Although all states may have some potential, only states with high potential are noted. Wind has 42 states with potential, while solar and geothermal have 25 and 14 states with potential.

The lack of price data for renewable energy creates a problem for evaluating them as substitutes. Instead, quantity or generation data is available. Because of the functional relationship between price and quantity of a good, generation data is used in place of price data without much loss to the theoretical analysis. Further problems exist with data that the EIA does not disclose for the purpose of keeping confidential generation information of individual firms. These observations that are not released are missing for the wind, geothermal, other renewables, price of coal, and price of natural gas. However, they make note that some amount of energy is produced by a firm. If a number is released, then clearly at least two firms are producing energy. Because of the missing data, these observations are dropped from the analysis without much loss to the data set.

Econometric Model for Estimating Wind Generation

The supply of wind energy generated is a function of several factors, including price of electricity, prices of substitutes, size of the market, and public policy. The data collected is dynamic panel data, which implies a simple OLS model will be biased and inconsistent due to autocorrelation between observations. An Arellano-Bond model accounts for the dynamics of the data while still allowing for economic interpretation of changes in variables (Arellano and Bond 1991). The Arellano-Bond model corrects for autocorrelation between observations in the panel by differencing the variables and including a lagged difference of the dependent variable. This GMM approach accounts for the dynamic process in the data as well as considering each state as a panel. This type of model also accounts for panel-specific correlations, so variations due to group characteristics are considered in the structure of the model. The equation used to examine the interactions, between RPS programs and renewable energy sources, is shown in the wind model (equation 3).

$$(3) \quad \Delta Wind_{it}=\beta_0+\beta_1 L.\Delta Wind_{it-1} +\beta_2\Delta Price_{it}+\beta_3\Delta Solar_{it}+ \beta_4\Delta Geothermal_{it} + \beta_5\Delta Other\ Renewables_{it} + \beta_6\Delta Price\ of\ Coal_{it} +\beta_7\Delta Price\ of\ Natural\ Gas_{it} +\beta_8\Delta Total\ Capacity_{it} +\beta_9 RPS_{it} +\beta_{10} EPACT_{it} +\beta_{11} Wind\ Potential_{it} +\Delta\varepsilon_{it}$$

This model captures the impact of RPS programs on wind generation. By including the first differences to account for dynamics, equation 3 analyzes the effect *RPS* has on the change in wind from one year to the next. The estimated coefficient for this parameter is expected to be positive. Including *Other Renewables, Price of Coal,* and *Price of Natural Gas* controls for other substitutes in the market, while *Total Capacity* controls for the size of the market. *EPACT* and *Wind Potential* control for other policy and technology impacts.

Furthermore, this model examines the interaction between different renewable sources. Specifically, it analyzes the effect of changes in *Solar* and *Geothermal* on changes in wind generation. Because of its small share in the electricity market, other sources of energy both renewable and non-renewable can have a large impact on wind energy. These sources are in competition with wind suppliers and should be considered substitute goods. Thus, wind energy generation is a function of renewable and non-renewable source generation. All renewable energy variables are expected to be competitors in the renewable energy sector. Thus, the sign of their coefficients are expected to be negative, because of the substitutability from one to another. Sources that provide cheaper energy with a lower cost of initial investment or technology development will be more competitive in the industry.

Examining the renewable energy market, it is possible that the amount of wind produced affects solar and geothermal generation. Because of this possible endogeneity, predictions for solar and geothermal estimates are derived from equations 4 and 5.

$$(4) \quad \Delta Solar_{it}=\alpha_0+ \alpha_1 L.\Delta Solar_{it-1} + \alpha_2 \Delta Price_{it} + \alpha_3 \Delta Price\ of\ Coal_{it} + \alpha_4 \Delta Price\ of\ Natural\ Gas_{it} + \alpha_5 RPS_{it} + \alpha_6 Solar\ Potential_{it} +\Delta\varepsilon_{it}$$

$$(5) \quad \Delta Geothermal_{it}=\delta_0+\delta_1 L.\Delta Geothermal_{it-1} +\delta_2 \Delta Price_{it} +\delta_3 \Delta Price\ of\ Coal_{it} +\delta_4 \Delta Price\ of\ Natural\ Gas_{it} +\delta_5 RPS_{it} +\delta_6 Geothermal\ Potential_{it} +\Delta\varepsilon_{it}$$

Again, an Arellano-Bond model is used because of the dynamic panel data. These predictions are then used as instrumental variables for *Solar* and *Geothermal*. This two step process accounts for the endogeneity between the renewable sources.

Results for Wind Energy Production

This study examines the effects of RPS programs on wind generation as well as the interaction between renewable energy sources. Table 6 shows the parameter estimates for the first step of the estimation process. These parameters are then used to gather predictions and use them as instrumental variables in the

Table 7 shows the results for the wind model (equation 3) estimated using the two-step Arellano-Bond model. Endogenous variables are instrumented for by using predicted values, which are estimated by exogenous variables from equations 4 and 5.

Table 6. Parameter estimates for equations 4 and 5 used to calculate instrumental variables for *Solar* and *Geothermal*

ΔSolar			***ΔGeothermal***		
Number of observations		548	Number of observations		522
Number of groups		50	Number of groups		50
	Wald chi2(7)	555.91		Wald chi2(7)	92.89
	Coef.	**Std. Err.**		**Coef.**	**Std. Err.**
L.ΔSolar	0.6876***	0.036987	***L.ΔGeothermal***	-0.2318***	0.038605
ΔTotal Capacity	1.704***	0.582142	***ΔTotal Capacity***	-1.08204	4.535193
ΔPrice of Coal	-133.49***	44.00156	***ΔPrice of Coal***	-217.518	220.272
ΔPrice of Natural Gas	-4.612	4.165907	***ΔPrice of Natural Gas***	-45.490**	20.49119
ΔPrice	896.938	2674.526	***ΔPrice***	-104435.8***	13400.27
RPS	-2266.85	1763.585	***RPS***	228.451	9230.906
Solar Potential	-1933.957***	615.9989	***Geothermal Potential***	603.388	3963.65
Constant	-151.176	596.0608	***Constant***	-12221.09***	3081.979

*,**,*** represent 10%, 5%, and 1% significance levels, respectively.

The estimated coefficient for changes *Price* is negative, but not statistically significant which contradicts the hypothesis above. As price increases, there is more opportunity for profit, and wind energy will increase its production. The results do not indicate that positive changes in prices will affect the change in wind generation in a positive way. Due to wind's small market share, this result may signal that wind is not yet affected by price, or that technological developments have changed the cost of production.

The positive coefficients for *Solar -IV*, and *Geothermal-IV* are again not as expected but the positive coefficient provide some evidence that renewable energy sources are not yet in competition with each other due to the infancy of RPS programs.

However, further research may extend this interaction by examining how restricting the various RPS programs are for the electricity markets in each state.

Table 7. Arenallo-Bond model for wind with solar and geothermal as instrumented variables

Parameter Estimates for *ΔWind*		
	Coef.	**Std. Err.**
L.ΔWind	0.5564299***	0.041353
ΔPrice	-12189.9	12156.04
ΔSolar – IV	0.9351254***	0.354418
ΔGeothermal –IV	0.119637	0.079897
ΔOther Renewables	0.000557	0.001661
ΔPrice of Coal	58.44274	176.2233
ΔPrice of Natural Gas	-0.4011	18.21237
ΔTotal Capacity	35.64297***	4.394471
RPS	25632.08***	7330.551
EPACT	7747.608	6668.633
Wind Potential	12322.63***	4707.381
Constant	-24909.8***	7547.947
Number of observations	386	
Number of groups	50	
Wald chi-squared(11)	953.86	

*,**,*** represent 10%, 5%, and 1% significance levels, respectively.

RPS programs are an effective method to increasing generation and reliance on wind energy. However, RPS programs may encourage the use of other renewable sources, while discouraging the use of solar and photovoltaic energy. These results indicate that having a RPS program induces an annual increase in wind generation of over 25,000 megawatt hours. Results for *Price of Coal*, *Price of Natural Gas,* and *EPACT* are not statistically significant. Thus, no conclusions are drawn from these parameters. The estimated coefficient for *Total Capacity* is positive and statistically significant as predicted. As market size increases the amount of wind generated increases, all else constant.

The *RPS* coefficient is positive and statistically significant. This result supports the hypothesis suggesting that RPS programs are an effective method to increasing generation and reliance on wind energy. Results indicate that having a RPS program increases the changes in wind generation from year t to year $t+1$ by over 25,000 megawatt hours. *Wind Potential* is also statistically significant indicating that areas with higher potential generate more electricity from wind than areas with low or no potential.

Conclusion

Environmental awareness has increased in the United States over the last decades. This awareness is evident in the number of governmental policies at the federal, state, and local levels aimed at protecting the air, water, and land we use. The Renewable Portfolio Standard program has become common among state governments because it encourages reliance on renewable energy to generate electricity. These programs use competition and market incentives promote increased production of electricity from renewable sources. This paper examines the impact of RPS programs on wind energy generation, as well as the interaction and possible competition between wind, solar, and geothermal energy sources.

This analysis finds that RPS programs do affect wind electricity generation in a positive way. Policy implications for these RPS programs include review and revision of policies to encourage sources that are both sustainable, renewable, and help to reduce environmental damage. However, more research is needed to examine the effects of RPS programs on other renewable energy sources, such as landfill gases, hydroelectric sources, and other biomass energies.

Results of this analysis also indicate that solar and geothermal sources are not negatively affecting wind generation. This implies that among these three renewable sources, competition is not prevalent. This may be due to the infancy of the RPS programs, or the residual effects of other government programs, such as production credits or subsidies, that do not encourage competition.

Further research includes the addition of variables that control for developments and changes in technology. Clearly, policy changes help to encourage the use of renewable energy sources, but including technology will control for any innovative techniques that could reduce the cost of producing renewable energy. Potential future research for this project would include input costs and examine their effect with RPS programs. Also, including input costs would be critical for this additional analysis.

RPS programs separate renewable and non-renewable energy markets to encourage sustainability but still maintain competition to create efficiency. Further discussion can be extended by examining this separation and possibility in encouraging other "green" initiatives in such areas as recycling vs. waste disposal, public vs. private transportation, and fuel efficient vs. low efficient vehicles.

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