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Article

Utilizing GIS to Examine the Relationship Between State Renewable Portfolio Standards and the Adoption of Renewable Energy Technologies

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Abstract: In the United States, there is no comprehensive energy policy at the federal level. To address issues as diverse as climate change, energy security, and economic development, individual states have increasingly implemented Renewable Portfolio Standards (RPSs), which mandate that utility providers include a specified amount of electricity from renewable energy sources in their total energy portfolios. Some states have included incentives for individual energy technologies in their RPS, such as solar electric (also called photovoltaic or PV technology). Here, we use GIS to visualize adoption of RPSs and electricity generation from renewable energy sources in the US and examine changes in renewable electricity and solar electric generation over time with the goal of informing future policies aimed at promoting the adoption of renewable energy technologies.

Keywords: Renewable Portfolio Standards; solar electric technology; technology adoption; GIS

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1. Introduction

In the United States, there is no comprehensive energy policy at the federal level [1]. To address issues as diverse as climate change, energy security, and economic development, individual states have increasingly implemented Renewable Portfolio Standards (RPSs), which mandate that a specific amount of the electricity provided by utility companies is produced from renewable energy sources [2]. Many authors have explored, in various ways, the emergence of RPSs as potential policy tools to efficiently and effectively promote a transition to renewable energy technology usage [3–6]. RPS mandates are often met by installing what are perceived to be the most cost-effective renewable energy systems, such as large-scale wind technologies [7,8].

However, RPSs vary widely from state to state, with large differences in the amount of energy production mandated, the renewable energy sources included, whether they apply to all utilities equally [9], and the policy provisions specified within the broader RPS goals. RPS policies can include specific provisions that favor or reward the use of particular renewable energy technologies. For example, some states include provisions in their RPSs to promote more expensive technologies (like solar electric, also called photovoltaic or PV) through either "multipliers" or "set-asides". Multipliers give additional credit for energy produced from a specified technology, literally doubling or tripling the credit utilities can apply to their mandated targets from the energy produced. Credit multipliers for solar technologies sometimes apply to both small scale and large scale solar systems, incentivizing both residential installation and construction of utility owned concentrated solar power plants. However, credits for large scale and/or utility owned solar production facilities are often more restrictive and less lucrative than multipliers applied to residential scale systems. Some states include "set-asides," provisions that literally set aside a particular percentage of the overall mandated RPS goal that must come from specific sources, specifically solar and distributed generation. When RPSs include set-asides or multipliers specifically for distributed generation, they are aiming to promote energy that is produced at the site where it is consumed [10] or to facilitate incentives for residential PV adoption or other small-scale energy technology applications [11].

Feed-in tariffs, also referred to as buy-back agreements, mandate that utility companies purchase all electricity produced by a residential small-scale generation facility (such as roof mounted PV panels or residential-scale wind systems) in excess of home consumption at a rate higher than standard residential rates. This rewards customers monetarily for the energy they produce beyond their own usage. The specific provisions of set-asides, multipliers, and feed-in tariffs are sometimes adopted as an intentional means of promoting particular value-laden aims, such as residential or small-scale renewable technology adoption, or for intentionally promoting a market for what are arguably more expensive renewable energy technologies [11].

While it may be a truism to suggest that solar technology is more feasible for use in sunny climates [12–15], many others suggest that policy mechanisms play a significant role in shaping renewable energy technology adoption at the state level [2,3,5,6,16–18]. Some scholars examine the relative merits of these policies [3,4,19]. Others debate how, and how successfully, renewable energy standards actually increase renewable energy usage [6,7,20,21].

This paper utilizes GIS to visually compare state RPS policies, the policy mechanisms included in a state's RPS, and specific forms of renewable energy technology adoption from solar energy sources.

GIS is a valuable tool for assessing renewable energy potentials, as this kind of energy production is uniquely geographically situated and contextual [22]. While GIS can be used to facilitate and support energy planning [23,24], the current study suggests it can also be used in policy assessment. Below, we present a geographic visualization using GIS and an analysis of RPS policies and changes in renewable energy technology adoption over time at the state scale to examine the ability of state-level RPSs to promote renewable energy technology adoption. Specifically, we ask whether particular RPS provisions intended to promote solar technologies correspond to state-level solar technology adoption and whether there is congruence between RPS mandates and renewable energy technology adoption within a state.

2. Methods

To create maps showing each state's renewable energy policies, production, and consumption, a vector-based map of the US was used as a basemap [25] and each state was assigned the attributes described below using ESRI ArcMap 9.3. Table 1 shows an example of the information included in the attribute table of this map for each state. The data were analyzed and presented at the state scale, because RPS policies are applied at this level and differences among RPS mechanisms within each state apply to the entire state population.

Table 1. Example table of state attributes for Renewable Portfolio Standard (RPS) provisions and energy consumed and produced from solar and renewable sources.

State	RPS	Solar Provision Code [1]	Change in Solar Production [2]	Change in Solar Consumption [3] (BTU)	Total 2011 Consumption (BTU)	Change in Renewable Production [4]	Renewable Production 2011
Alabama	None	0	0	36	173	−0.47%	7.48%
Alaska	None	0	0	7	8	3.53%	19.80%
Arizona	10%–20%	5	0.08%	4386	7914	−0.56%	8.84%
Arkansas	None	0	0	−1113	158	−1.49%	7.54%
California	>30%	2	0.21%	26055	43199	11.43%	33.03%

[1] Codes for RPS provisions for solar: 0 = No RPS; 1 = Non-binding goal (no provision); 2 = RPS with no solar provisions; 3 = Solar provision and/or distributed generation (DG) set aside OR solar multiplier; 4 = Solar provision and/or distributed generation (DG) set aside AND solar multiplier; 5 = Solar provision and/or distributed generation (DG) set aside AND/OR solar multiplier, and feed in tariff; 6 = Only feed in tariff.
[2] Change in the percent total electricity produced from solar technology from 2000 to 2011.
[3] Change electricity consumed from solar energy technology sources less than 1 megawatt (MW) from 2000 and 2011.
[4] Change in the percent of each state's energy produced by renewable technology from 2000 to 2011.

Data from the Solar Energy Industry Association was used to determine which states had an RPS or a non-binding renewable energy goal and which states had neither [26]. These goals are most often expressed as a specified percentage of a state's total electric portfolio; for states that express their goals as an amount of electricity produced, these amounts were converted to percentages of the state's total energy production, expressing these goals in a way that makes them comparable between states. Of the states with RPSs, the percentage of each state's total electricity portfolio required to come from renewable energy sources was entered as the "RPS" attribute for that state (Table 1, column 2), and these attributes were used to symbolize the map showing RPS goals (Figure 1).

Figure 1. Renewable portfolio standards in the US by goal. Data from the Solar Energy Industry Association [26].

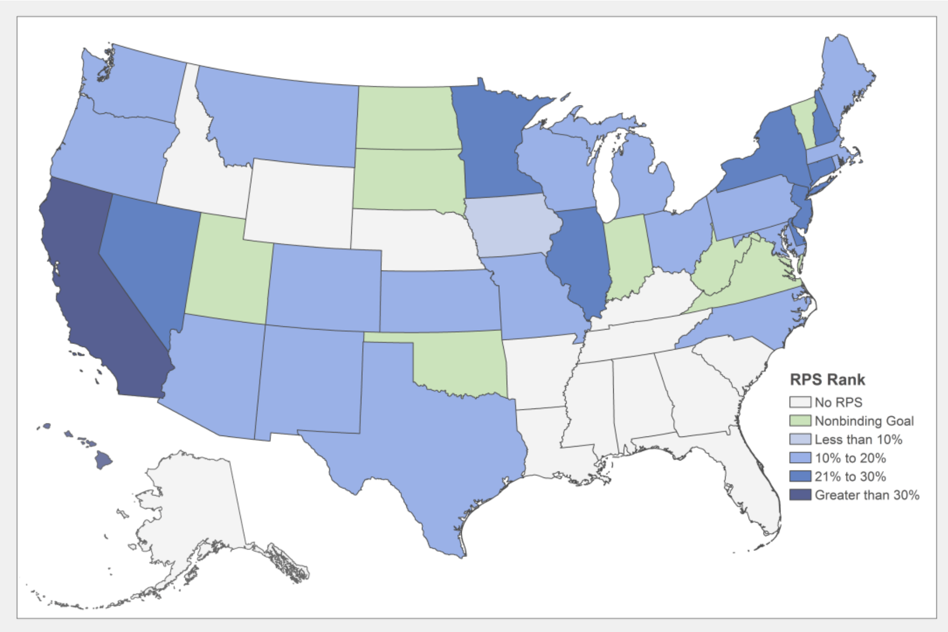
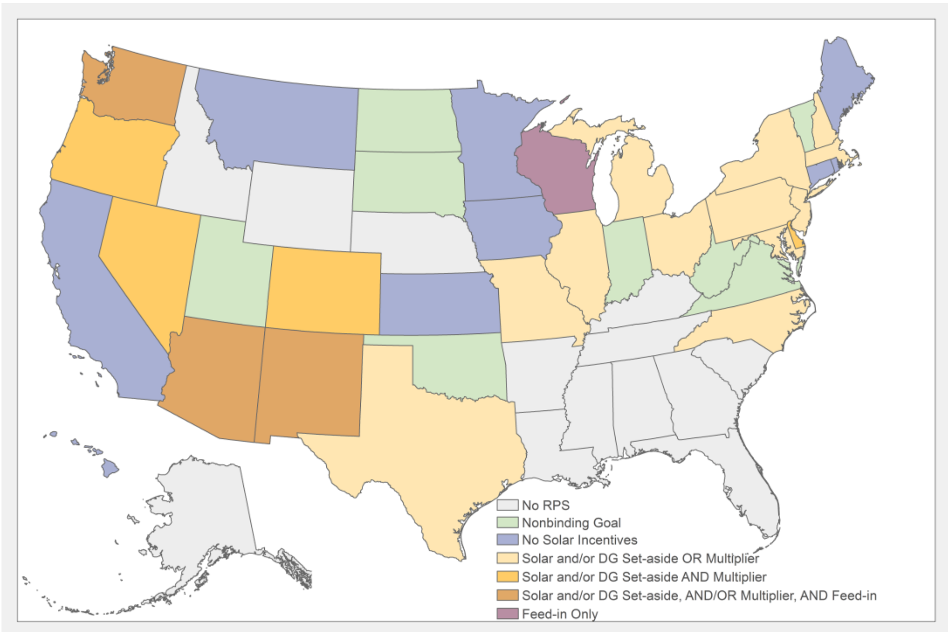


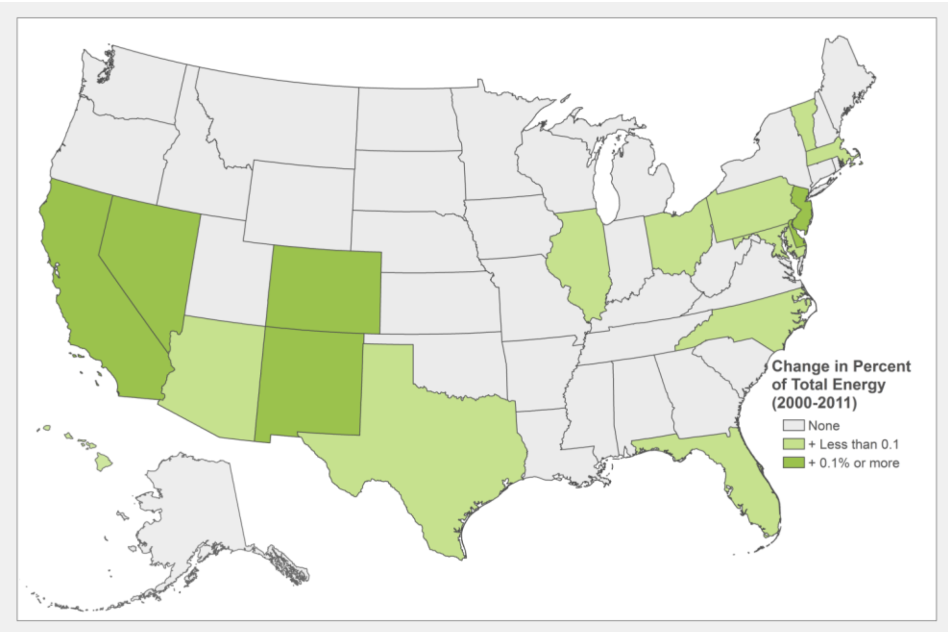
Figure 2. RPS provisions for solar and distributed energy technologies by state. Provisions for solar and distributed energy technologies include solar and/or distributed generation (DG) set asides, solar and/or DG multipliers, and feed-in tariffs. Data from the Database of State Incentives for Renewable Energy (DSIRE) [27] as well as previously published research [21,28].



The provisions of each state's RPS were also examined to determine whether they included special incentives for solar technology or distributed generation using the Database of State Incentives for Renewables and Efficiency (DSIRE) [27], a collaborative venture of the US Department of Energy and North Carolina State University, and data from previous research [21,28]. These provisions were coded and entered as the "Solar Provision Code" attribute for each state (Table 1, column 3). These attributes were used to symbolize a map showing State RPS Solar Incentives (Figure 2) and used to examine whether these policies are correlated with increased adoption.

Data from the US Energy Information Administration (EIA) was used to examine change in the production and consumption of electricity from solar energy sources in each state from 2000 to 2011 [29,30]. Solar consumption and production data combine solar electric and solar thermal energy sources. The change in production of energy from solar sources was calculated by subtracting the percent of each state's energy produced by solar technology (both solar electric and solar thermal sources) from facilities of all sizes in 2000 from the percent produced in 2011, and the resulting value was entered as the "Change in Solar Production" attribute (Table 1, column 4). These attributes were used to symbolize a map showing each state's change in electricity production using solar technology between 2000 and 2011 (Figure 3).

Figure 3. Change in percentage of total electricity produced from solar by state. This map presents the change in the percentage of a state's total energy production coming from solar energy sources from 2000 to 2011 using data from the US EIA [30].



The change in consumption of energy from solar sources was calculated by subtracting each state's "photovoltaic and solar thermal energy sources consumed by the residential, commercial, and industrial sectors, other than power generated at commercial and industrial facilities with capacity of 1 megawatt or greater" in 2000 from the consumption in 2011 (Figure 4), and the resulting value was entered as the "Change in Solar Consumption" attribute (Table 1, column 5). These attributes were used to symbolize a map showing each state's change in energy from solar technology consumed between 2000 and 2011

(Figure 4). The total consumption of energy from solar sources in 2011 was entered as the "Total 2011 Consumption" attribute (Table 1, column 6) and used to symbolize a map showing each state's total energy consumption from solar sources less than 1 MW, expressed in BTUs (Figure 5).

Figure 4. Change in energy consumption from solar by state. This map presents the change in electricity consumption sources from solar energy resources, including solar thermal and solar photovoltaic, from 2000 to 2011 using Data from the US EIA [29].

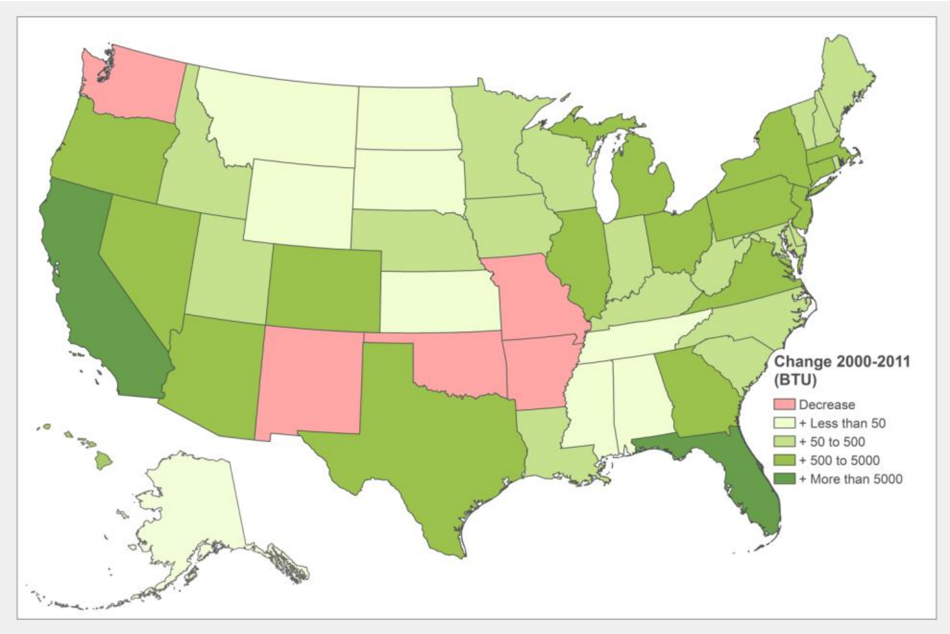
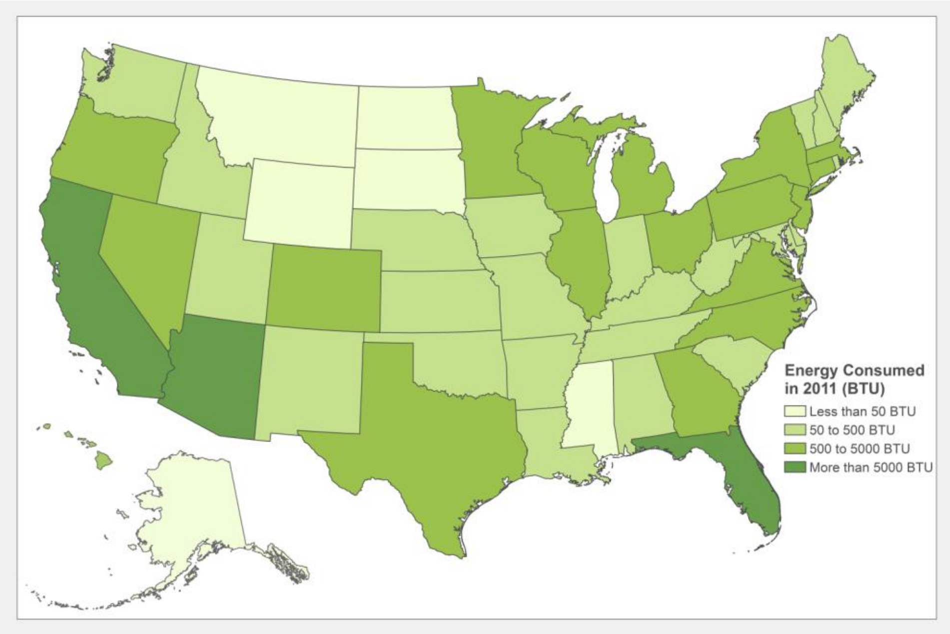


Figure 5. Total energy consumption from solar sources, 2011. This map presents a state's total energy consumption coming from solar energy sources, including solar thermal and solar photovoltaic, in 2011. These data from US EIA focus on small (1 MW or less) solar systems [29].



Unlike the production data, consumption is not shown relative to the total energy consumption by each state and only consumption of energy from solar sources generating less than 1MW are shown. Although the combination of PV and solar thermal into one data category is an unfortunate weakness in the data, the specificity of size (less than 1 MW) of the consumption data does focus on the types of solar energy promoted by the special provisions often included in a state RPS. Using this data focuses attention of the kinds of solar technology incentivized most frequently and most lucratively through RPS policy: small scale, distributed PV applications.

Data from the US EIA was also used to examine change in the production of electricity from renewable resources from 2000 to 2011 and the percent of total electricity produced from renewable sources in 2011 [30]. Renewable energy sources included conventional hydroelectric, geothermal, wood and wood derived fuels, other biomass, wind, solar thermal and photovoltaic. To calculate change in production of electricity from renewable sources, the percent of each state's energy produced by renewable technology in 2000 was subtracted from the percent produced in 2011. The change in production in each state was entered as the "Change in Renewable Production" attribute (Table 1, column 7). These attributes were used to symbolize a map showing each state's change in energy production from renewable sources between 2000 and 2011 (Figure 6). The total electricity produced from renewable energy sources in 2011 was entered as the "Renewable Production 2011" attribute (Table 1, column 8) and used to symbolize a map showing these data (Figure 7).

Figure 6. Change in percent of total electricity generation produced from renewable sources by state. Renewable energy sources included: conventional hydroelectric, geothermal, wood and wood derived fuels, other biomass, wind, solar thermal and photovoltaic. Categories classified and data provided by US EIA [30].

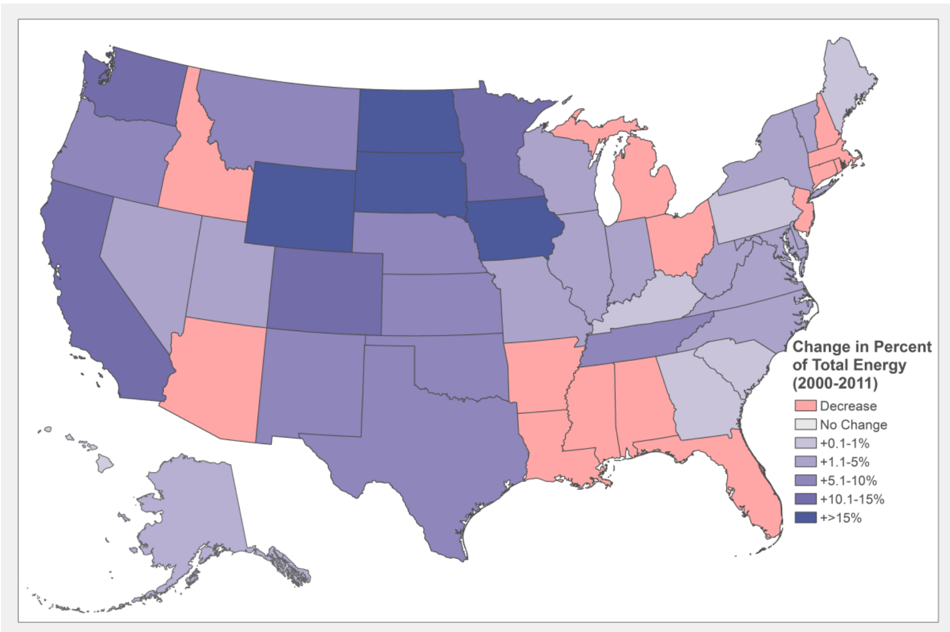
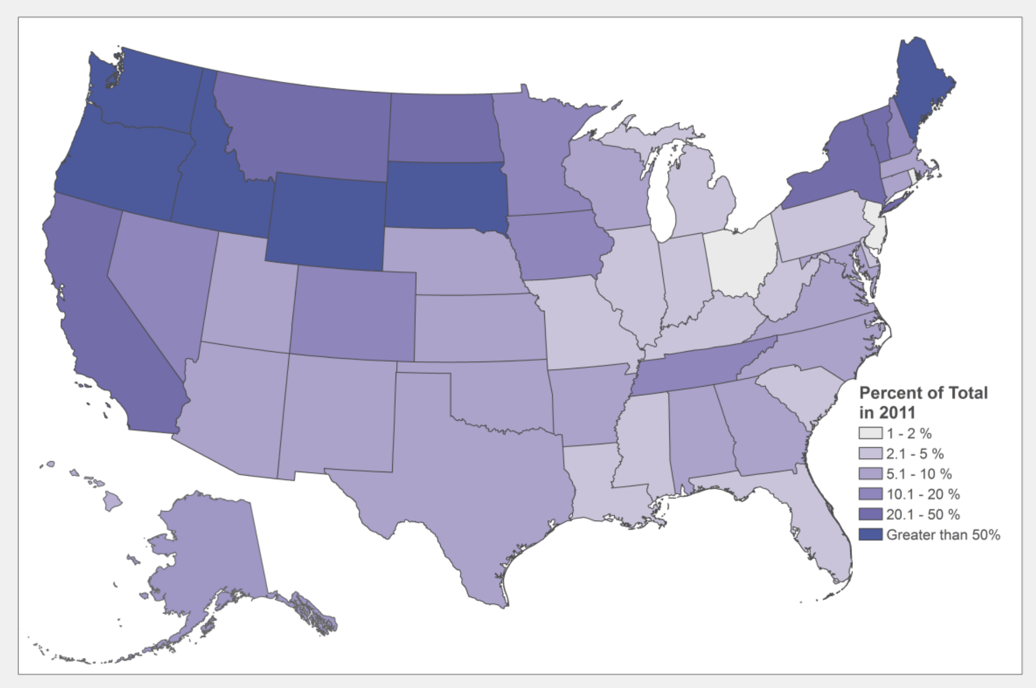


Figure 7. Percent of all electricity production from renewable sources, 2011. Renewable energy sources included: conventional hydroelectric, geothermal, wood and wood derived fuels, other biomass, wind, solar thermal and photovoltaic. Categories classified and data provided by US EIA [30].



3. Results

The amount of renewable energy resources, including solar radiation as well as the potential of wind, hydroelectric, and geothermal sources of energy, varies considerably across the US and is certainly geographically contextualized. Yet, even with widely divergent spatial variation in climate and natural resources, more than half of US states (30 out of 50 states, and the District of Columbia) have adopted a RPS mandating that electric utilities dedicate a specified percentage of their total energy portfolio to renewable energy resources. As an alternative to RPS mandates, a minority of states (5 of the remaining 20 without RPSs) have adopted non-binding goals.

Figure 1 presents a categorization of RPSs at the state level based on whether the state's policy is binding and the designated percentage of the total electricity portfolio that is required to come from renewable energy sources. As illustrated, there is considerable variation in the ambitiousness of each state's RPS. Some require less than 10% of each utility company's total portfolio be generated from renewable energy resources, while some are aiming much higher. California and Hawaii have the boldest RPS policies, with targets above 30% (33% by year 2020 and 40% by year 2030, respectively). The extent to which RPS policies and the particular technology-specific policy provisions included within RPS design actually result in increased technology adoption is analyzed, considered, and problematized below.

3.1. Do Solar Technology Provisions Correlate with Solar Technology Adoption?

Figure 2 illustrates the variation in specific RPS provisions for solar and distributed technologies, including solar and/or distributed generation (DG) set asides, solar and/or DG multipliers, and feed-in tariffs. Arizona, New Mexico, and Washington have the most generous policies in terms of promoting small-scale electricity generation through set-asides, multipliers, and a feed-in tariff.

However, examination of solar technology usage suggests that these policies do not always correspond with increased solar technology usage within the state. Figure 3 presents the change in total electricity production coming from solar energy sources from 2000 to 2011. This map illustrates the extent to which electricity produced from solar energy sources from facilities of all sizes contributes to total, overall electricity generation within a state, based on a percentage. Because solar represents a tiny fraction of total energy production in both 2000 (when many states first began implementing RPS mandates) and 2011, this map categorizes states as experiencing only three possible types of change: none, very small (less than 0.1%), or slightly larger (more than 0.1%). Many of the states that have experienced the larger increase in solar energy production as a percentage of total state energy production (such as Delaware, New Jersey, New Mexico, and Nevada) have specific provisions for incentivizing solar energy technologies in their RPSs. On the other hand, Oregon and Wisconsin both have specific provisions for solar included in their RPS but have experienced no change in solar energy production as a contribution to the state’s total energy production. New Mexico has increased its production of solar energy more than its neighbor state Arizona, even though the states have similar provisions for solar in their RPSs. In contrast, California has increased the percentage of solar energy production contributing to its total energy production without specific solar incentives in its RPS.

Electricity production from solar energy resources is certainly increasing in the United States. According to the Solar Energy Industries Association, 22 states produced more than 10 megawatts (MW) of electricity from solar energy sources in 2011, compared to only four in 2000 [31]. However, overall electricity demand has also increased. Since RPSs mandate that a designated percentage of a utility’s overall energy portfolio be produced using renewable resources, examining solar electricity’s contribution to total energy production as a percentage corresponds most appropriately to RPS mandates. As suggested by Figure 3, the contribution of solar energy as a percentage of total electricity production has not increased momentously, and increases have not consistently taken place in states with policies intended to promote solar technology adoption.

Figure 4 presents the change in energy consumed from solar energy technology, also looking at a change from 2000 to 2011. These data focus on small (1 MW or less) solar systems and examines the change in consumption between 2000 and 2011, not measured as a percentage of total state consumption. As illustrated, some states experienced increases in energy consumption from solar technology sources without a RPS (Florida) or without specific provisions for solar technology included in the state’s RPS (California).

Figure 5 presents a ranking of states based on consumption of solar energy in 2011. These data focus on small (1 MW or less) solar systems. Again, Florida stands out as a state highly ranked in consumption of energy from solar resources and without a RPS, and California stands out as highly ranked in consumption of energy from solar resources although the state’s RPS does not include provisions for solar. This map illustrates the suggested mixed support for the relationship between RPS incentives for solar and solar technology adoption. All five states in the smallest category of electricity consumption from solar resources have no RPS or (in the case of Montana) no solar incentives in their RPS. Most of the states in the second largest category (12 out of 17) have solar provisions in their RPSs. Yet two states in the second largest category have either no RPS (Georgia) or a non-binding renewable energy goal (Virginia), and two other states in the second largest category (Massachusetts and Minnesota) have no solar provisions in their RPS.

Table 2 provides a summary of data related to RPS provisions and solar energy technology usage. States with the most ambitious RPSs (aiming to produce greater than 21% of total electricity from renewable energy sources) and with special provisions for solar in their RPSs (those with solar and/or distributed generation (DG) set asides, multipliers, and feed-in tariffs as well as those with solar and/or distributed generation (DG) set asides and multipliers) are included, along with states that experienced a 0.1% or greater increase in solar production's contribution to overall energy generation, states that experienced a 50% or greater increase in solar consumption, and states that consumed more than 5,000 BTU produced from solar technology in 2011.

Table 2. Summary of RPS provisions for solar and changes in solar technology use.

RPS Goal (Figure 1)	**Special RPS Provisions (Figure 2)**	**Change in Solar Production (Figure 3)**	**Change in Solar Consumption (Figure 4)**	**Total Consumption of Solar, 2011 (Figure 5)**
1. California	1. Arizona	1. California	1. Arizona	1. Arizona
1. Hawaii	1. New Mexico	1. Colorado	1. California	1. California
2. Connecticut	1. Washington	1. Delaware	1. Florida	1. Florida
2. Delaware	2. Colorado	1. New Jersey	1. Hawaii	
2. Illinois	2. Delaware	1. New Mexico	1. New Jersey	
2. Minnesota	2. Nevada	1. Nevada		
2. New Hampshire	2. Oregon			
2. New Jersey				
2. Nevada				
2. New York				

Table 2 demonstrates that there is not consistent evidence that percentage of renewable energy production mandated by a RPS or special provisions for solar technologies within a RPS correspond with increased solar technology adoption. For example, the state of Arizona has special RPS provisions for solar and ranks highly in solar consumption. However, the solar production data captures solar energy's contribution to the state's total energy production portfolio expressed as a percentage, the measurement used for RPS compliance, and Arizona does not rank highly in solar energy production. On the other hand, California ranks highly in solar production and consumption and has an ambitious RPS, but its RPS does not include specific provisions for solar technology. Washington and Oregon both have special provisions in their RPS but have not experienced a large increase in either solar production's contribution to total energy generation or solar consumption. Washington has actually experienced a decrease in solar energy consumption. Some states (like Florida and California) are increasing their use of solar energy technologies, measured in its percent contribution to overall energy production and in the total amount of solar energy consumption, without

RPS mandates or without specific provisions within their RPS mandates, while other states have these provisions but are not experiencing an increase in solar technology use, measured as either percent contribution to overall energy production or total amount of solar energy consumed.

3.2. Do RPS Mandates Correlate with Renewable Energy Technology Adoption?

Figure 6 illustrates changes in renewable energy production's contribution to total electricity generation within each state between 2000 and 2011. Most states implemented or significantly strengthened their RPSs after 2000 [32], so focusing on this time frame reasonably corresponds to the beginning of RPS implementation. As demonstrated, three of the four states with the largest increases (greater than 15% increase) in renewable energy generation between 2000 and 2011 do not have mandatory RPS policies—Wyoming has none, while North Dakota and South Dakota have non-binding goals. The fourth state, Iowa, has an RPS that requires only 105 megawatts (MW) of renewable energy production, which is less than 10% of total current electricity generation in the state, making it one of the least ambitious RPS policies in the country. In contrast, eight of the 14 states that have experienced a decrease in the percentage of energy contributed by renewable energy sources to total electricity generation have RPS policies (see Tables 3 and 4).

Figure 7 illustrates the electricity generation from renewable energy sources as a percentage of total electricity generation in each state using 2011 data. Of the six states that produced more than 50% of their total electricity from renewable sources, only half have RPSs. In the three states with RPS policies, those mandates require a maximum of 30% renewable energy production in the total electricity portfolio.

Table 3. State RPS mandates in states with increased percentage of renewable energy generation contributing to overall energy generation.

States with Significant Increase * in Renewable Production	State's RPS Mandate Classification (None, Non-Binding, or RPS)
California	RPS
Colorado	RPS
Iowa	RPS
Minnesota	RPS
North Dakota	Non-binding
South Dakota	Non-binding
Washington	RPS
Wyoming	None
n = 8	Number with RPS: 5

* Defined here as 10% or more, and is measuring the renewable energy generation as a percentage of total electricity production in a state.

Based on the change in renewable energy production as a percentage of states' total energy production from 2000 to 2011, there is no correlation between percentage of renewable energy generation mandated by a state's RPS and increased production in renewable energy in that state on average (Table 5). In fact, states with no RPSs and states with the most ambitious RPSs showed approximately the same average increase percentage of in energy production from renewable sources contributing to total electricity generation, 6.1% and 5.9%, respectively. States with an RPS requiring less than 30% of energy to come from renewable sources actually fell below the 4.4% national average in increased percentage of energy production from renewable sources contributing to a state's total energy production.

Table 4. State RPS mandates in states with decreased * percentage of renewable energy generation contributing to overall energy generation.

States with Decrease in Renewable Production	State's RPS mandate classification (None, Non-Binding, or RPS)
Alabama	None
Arkansas	None
Arizona	RPS
Connecticut	RPS
Florida	None
Idaho	None
Louisiana	None
Massachusetts	RPS
Michigan	RPS
Mississippi	None
New Hampshire	RPS
New Jersey	RPS
Ohio	RPS
Rhode Island	RPS
n = 14	Number with RPS: 8

* Measured as renewable energy generation as a percentage of total electricity production in a state.

Table 5. Change in percent of total energy generation produced from renewable sources, 2000 to 2011.

State RPS Ranking	2000	2011	Change
No RPS	5.3%	11.5%	6.1%
Nonbinding goal	15.0%	20.1%	5.1%
Less than 10%	0.6%	4.8%	4.3%
10% to 20%	15.5%	18.5%	3.0%
21% to 30%	16.8%	20.6%	3.8%
Greater than 31%	15.1%	21.1%	5.9%
Nation Wide Average	12.7%	17.1%	4.4%

4. Discussion

Previous research has demonstrated a far greater potential for renewable energy generation than current policy targets aim to utilize [33]. Regardless of physical potential, policy is believed to shape whether or not adoption of innovative technologies, specifically renewable energy technologies, takes place [1,2,10,21]. This research visually illustrates that renewable electricity, including electricity from solar energy sources, is being generated in states without a state-level RPS. Some states are producing much more electricity from renewable sources than required by their RPS policies, and some states that are producing larger percentages of their state's total electricity needs with renewable energy sources do not have RPS mandates at all. The likely explanation is that these states (one thinks here of North Dakota and South Dakota) are developing renewable energy generation, such as wind energy production facilities, so that they can sell that electricity to neighboring states with RPS policies, such Minnesota, Iowa, or Montana (Figure 1).

RPS policies do not require that the electricity be generated within the state; they require that each utility company's total energy portfolio include the designated percentage of renewable energy resources. This may provide an argument for supporting a national RPS standard [34] as a means of acknowledging the inconsistencies between how power production is counted across states and who gets credit for that production in a RPS. While government agencies collect data on state-level production and consumption, RPS policies allow utilities to purchase renewable electricity from generation facilities located outside the state and count that toward RPS compliance. Investor owned utility companies are inter-state corporations, producing and transmitting electricity across state borders throughout geographical regions to consumers in multiple states. Making energy policy at the state level, while lauded for filling in for the mostly nonexistent energy policy at the federal level [2], does not correspond to the scale of industry organization and practice. Many utility companies have historically resisted RPS policy implementation, at least in part for this very reason; it is difficult to comply with state-level policy when you operate in multiple states. As this analysis demonstrates, any analysis of energy policy, incentives, and production that does not take geographic relationships into consideration will be skewed, given the operation of policy and practice that takes place at multiple, often inconsistent, geographic levels.

RPSs may not actually increase renewable energy production within the states that mandate them; instead, they arguably offer a means of addressing environmental concerns, such as curbing carbon emissions, to citizens in states with political climates suitable for passing RPSs. Massachusetts, for example, has a relatively ambitious RPS policy, aiming to produce 15% of the states' electricity from new renewable energy generation by 2020. However, the state's production of electricity from renewable energy resources decreased between 2000 and 2011, because overall energy production increased during the same period. This points to the difficulty of meeting RPS standards in the face of ever-increasing energy demand and their limitation as a policy mechanism, as they do not prioritize or promote energy conservation.

In other words, states with more politically liberal constituencies can pass RPSs, even if the policies do not actually increase renewable energy production in their state and thus do not address the economic considerations often raised when promoting an RPS, such as job creation and economic development within a state. Some states address this by including provisions in their RPS mandating that a designated percentage of the energy must be generated within the state. However, it is unclear whether the calculations of expected job creation or economic growth used to promote RPS passage are based on only the energy produced in state. Again, the inconsistency of scale in energy production and energy policy, where state-level policies are used to regulate inter-state industry operations, complicate any meaningful analysis of their effectiveness, and scale must be carefully considered in order to assess whether policies are having their intended outcome.

This means that states that may not have a political climate favorable toward RPS policies may nonetheless be developing renewable energy generation capacity to provide energy for states that are receiving the credit for that production toward their RPS goal. This means that states can reach RPS goals without actually investing in development of renewable energy technology within their own state. RPS policies may thus drive an increase in renewable energy production even in states without a political climate favorable to such policies. RPSs demonstrate political acceptance of a policy agenda that promotes renewable energy technologies, and they provide a means of substantiating the technical and economic feasibility of renewable energy production. Perhaps RPS policies have an indirect influence on increasing renewable energy production by making it more politically and economically palatable even in places that don't actually adopt the specific policy mechanisms of a RPS. However, this analysis suggests that RPS policies do not consistently promote renewable energy technology development within only states that have RPS policies promoting, even mandating, that a designated percentage of overall electricity generation come from renewable energy resources.

RPS policies may represent a case of geographical policy spillover, where the development of renewable energy capacity does not consistently take place in the state that adopts a RPS but instead occurs across state lines. This is consistent with US energy infrastructure, which has long involved interstate transmission of electricity. RPSs are often promoted as a means of addressing state-level concerns regarding economic development. However, they may not, as this paper illustrates, actually work to increase renewable energy production within the state. Given this geographical policy spillover, wherein RPSs may be increasing renewable energy technology adoption outside the states that actually adopt RPS mandates, the promotion of RPS policies could more realistically focus on the national and global implications of curbing carbon emissions; this may also support the case for a RPS at the federal level.

Limitations in the data may also partially explain the findings presented here. Individual states differ on what they count as a renewable energy source for the purposes of their mandate [35], but that variation is not captured here, because a choice was made to use renewable energy production data that includes all sources to standardize across states rather than to specify calculations based on each state's RPS provisions. The data used to measure total renewable energy production include all possible sources, but that may be too broadly defined to capture state level nuance and variation. Specifically, one potential issue with these data is the inclusion of hydroelectric sources of power; many RPS policies limit the amount of hydropower that can be counted toward the mandated goal. However, this state-level analysis is based on comparing states using equivalent data, which requires including all forms of renewable energy production. Similarly, data on solar energy technology usage that does not separate solar electric from solar thermal technologies may not provide the most accurate means of examining solar technology adoption for the purposes examining RPS policy. Solar thermal technologies have long been used for pool heating systems, which may partially explain the levels of solar energy consumption in Florida and California. This is an inevitable limitation given the available data, and the numbers are so miniscule in comparison to overall electricity production (from all sources, including all renewable sources) that it likely makes little difference in the overall picture presented in this analysis. A final consideration is that this analysis does not take into account the impacts of financial mechanisms, such as state-level rebates and incentives (other than feed-in tariffs) offered in conjunction with an RPS or the federal tax credits and their changes over time.

5. Conclusions

This analysis suggests that RPSs do not always lead to increased production of electricity from renewable energy sources in states that adopt them. And the inclusion of specific provisions for solar technology does not always correspond with increased solar technology adoption as a percentage of overall electricity generation or increased solar energy consumption within a state, nor does the ambitiousness of an RPS necessarily align with an increase in renewable energy technology as a percentage of a state's total electricity portfolio. RPS policies may bring publicity to a state's efforts to pursue environmental and economic sustainability through renewable energy production, but they do not appear to consistently correspond to an increased in the contribution of renewable energy to total energy generation within those states. Instead, they may represent a case of geographical policy spillover, where states without RPS policies may be indirectly impacted by the implementation of RPSs in neighboring states, leading to an increase in renewable energy production but not just in states with RPS mandates.

Since overall renewable energy production has increased in the US, this analysis is not intended to suggest that RPSs do not or have not encouraged the production of electricity from renewable energy sources. In fact, increased renewable electricity production does appear to be spatially aggregated near regions with RPS mandates (the Midwest) and does not appear to be occurring in regions with fewer RPS mandates or goals (the southeastern US) (Figure 1). The most interesting finding here is that RPSs don't necessarily result in increased generation from renewable energy sources within a state, but may increase production in other states. While this corresponds to the general trajectory of electricity generation and transmission in the United States, this policy spillover effect is inconsistent with the arguments often made in favor of RPSs related to state-level economic development.

Future research will involve a more statistically driven multivariate analysis utilizing spatial statistics to determine the factors contributing to renewable energy and solar energy technology adoption. The geographical visualizations presented here, which compare state-level policy design and state-level technology adoption data, suggest an important factor to consider in future statistical analyses: a state's proximity to a state or other states with a RPS policy. The visual illustration presented here points to the importance of spatial relationships in policy analysis, a novel insight that would not have been clear without the visual component of data presentation.

Addressing the limitations of these data, specifically with regard to energy sources and the reporting of solar electric and solar thermal energy technologies as a single category, is an important step in moving forward with this analysis. Future research to examine the contours of state policy with additional specificity, taking into consideration the specific forms of renewable energy included in each state's policy, as well as the specific financial incentives offered by each state, may more clearly elucidate the relationship between renewable energy policy and renewable energy adoption at the state level. The key is ensuring that future analyses of RPS policy implementation include a consideration of the spatial relationships important to understanding geographical policy spillover.

Conflicts of Interest

The authors declare no conflict of interest.

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