A Meta-Analysis of State Renewable Energy Policies*

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Abstract

The American states have adopted a wide range of policies designed to promote renewable energy, but there have conflicting claims regarding their effectiveness. Using a meta-regression analysis, we assess the performance of these policies in fostering electricity generation from renewable sources. Our results indicate that several types of policies are associated with significant increases in renewable energy generation and/or capacity. There is, however, substantial heterogeneity in the effects of different types of policies, with renewable energy regulations producing the largest effects. Our analysis also suggests that effect estimates in the existing literature are driven in part by differences in the geographic area examined, and provide some evidence suggestive of publication bias in this literature.

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1 Introduction

In stark contrast to most other industrialized nations, the United States has relied on a decentralized, subnationally-driven approach to promoting renewable energy. State policies are the cornerstone of this approach. Motivated by the need to reduce greenhouse gas emissions, modernize electrical generation, or pursue a strategy of energy-based economic development, since the 1990s the American states have employed a wide range of policy instruments designed to encourage the electric power industry to generate electricity from renewable sources, such as wind, solar, hydropower, geothermal, and biomass. This policy activism has lead to hopes that that these "laboratories of democracy" will be able to generate substantial movement toward renewable fuel sources in the absence of policy leadership from Washington, DC (Basseches et al. 2022; Carley 2011; Fowler 2018; Rabe 2008).

Yet the effect of green policies on renewable energy generation remains in doubt. Various scholars have expressed skepticism about the ability of such policy instruments to generate substantial new electricity generation from renewable energy sectors (Böhringer et al. 2013; Frondel et al. 2010; Lesser 2010; Michaels 2008). Moreover, the existing empirical literature on the subject comes to contradictory conclusions. Although some studies find that renewable energy policies have a positive effect effect on the share of renewables in a state's electricity generation fuel mix (Carley and Nicholson-Crotty 2018; Kilinc-Ata 2016; Menz and Vachon 2006; Pastor 2020; Yi and Feiock 2014; Yin and Powers 2010), other studies find that these policies have little, if any, discernible impact (Bowen and Lacombe 2017; Carley 2009; Shrimali and Kniefel 2011; Upton and Snyder 2017; Wiser et al. 2007). These studies address a broad array of energy policies using a variety of methodologies, making it difficult to discern a clear pattern in terms of which policy instrument, if any, is more or less effective. In short, the existing state of knowledge on this issue is fragmentary, at times contradictory, and seemingly inconclusive.

In this paper, we seek to shed light on this question by conducting a meta-analysis, an empirically based synthetic review of the existing literature. Our analysis addresses two broad questions. First, what effects do a wide variety of policies employed by the U.S. states have on renewable energy generation? Second, what accounts for variation in the effect estimates produced in existing studies? Our findings regarding these questions have significant implications for both policy analysts and policymakers, which we discuss in the conclusion.

Data and Methodology

Criteria for inclusion

This meta-analysis assesses program evaluation studies that estimate the effect of American state clean energy policies on renewable energy generation. In order to be considered relevant for the purpose of the analysis, a study was required to meet several criteria. First, the outcome variable of interest must be renewable energy capacity or generation.[1] Second, the analysis must include one or more measures of American state clean energy policy (such as renewable portfolio standards or other forms of renewable energy regulation) as independent variables.[2] Third, in order to facilitate meaningful comparison across studies, the original study must conduct a statistical analysis on ex-post data with a hypothesis test against a null hypothesis. This criterion excludes ex ante simulation scenarios, analytic models, and the like. Finally, the paper must have been published in English.

[1]Capacity and generation are alternative measures the concept of renewable energy deployment. Capacity refers to the the maximum net generating ability of power plants and other installations that use renewable energy sources to produce electricity, and is often measured in megawatts. Generation refers to the overall amount of power produced from renewable sources, and is often measured in megawatt-hours. The two measures are highly correlated.

[2]In most cases, these variables were the primary variables of interest, but a couple of original studies treated them as controls.

Search process

We searched several electronic databases (Academic Search Premier, GreenFile, Google Scholar, and Web of Science) for published and unpublished articles that met these criteria. The initial search was conducted as part of a broader project examining the effects of clean energy policies, which employed a set of policy-related search terms (both general terms such as "clean energy policy" and "renewable energy policy." as well as specific tools such as "renewable portfolio standards" and "energy efficiency standards") and a set of general outcome related terms such as "effectiveness", and "evaluation." [3] A second, more focused search was used to supplement the original search using the terms "renewable energy generation", and"renewable energy capacity", along with the original policy-related terms. Finally, a reference genealogy search was conducted for each relevant study obtained, which examined the studies it cited in the references (sometimes called ancestor search) and a Google Scholar search of studies that cited it (sometimes called a descendant search).

The search process was completed in July 2021. In total, our search identified 27 studies that assess the effects of climate policies at general indicators of renewable energy generation or capacity, and an additional 19 that focus solely on specific renewable sources, such as wind or solar. For this analysis we confine ourselves to the former, though we intend to extend our analysis to include the latter in a future iteration of this paper. In addition, this analysis drops a few studies due to some coding issues, but we plan include them in a future iteration. In total, this analysis examines 19 studies, which are listed in the appendix.

Effect sizes

These studies often assessed the effects of multiple policy tools and contained multiple models, producing a large number of effect estimates. Overall we coded 565 usable effect sizes from our original studies. We omitted effect estimates produced from nonlinear specifica-

[3] In previous papers emanating from this project, we have examined the effects of clean energy policies on green jobs (Woods et al. 2022) and carbon emissions.

tions, such as variables that were included in quadratic terms or multiplicative interaction terms. Such variables do not produce a single "effect size" but rather the effect varies over the range of the relevant policy variable. This makes including them problematic, and we follow other analysts in excluding them (Gunby et al. 2017; Xue et al. 2020).

The original studies reported regression-based effects sizes in a variety of ways, which must be standardized for the purposes of meta-analysis. As with many meta-analyses in the social sciences, we chose an r-based measure, which is rooted in Pearson's product-moment correlation coefficient (r). Pearson's r is bounded between -1 and 1, with 0 indicating no relationship and 1 indicating a perfect linear relationship. In this study, positive effects indicate that the clean energy policy tool in question had a positive effect on jobs in the renewable energy sector, and negative effects indicate that it had a negative effect on these jobs.

There are two problems with an r-based measure: it is censored and heteroskedastic. Following the advice of Ringquist (2013) we accordingly transformed our measures using the Fisher transformation into Z, where $Z = 0.5ln[(1+r)/(1-r)]$. Z has a known variance that does not depend on its value ($Var(Z) = 1/n-3)$), and is unbounded. In practice, this transformation generally has little impact on the results if $Z < |.040|$ as is the case in most public policy research.

Covariates

In addition to presenting average effect sizes (weighted by the standard error), we also conduct an analysis that employs effect-level covariates to analyze why these effect sizes vary. One of our core objectives is to evaluate the impact that different policies have on renewable energy generation, so several of our covariates represent differences in policy tools. We are also interested in ascertaining the extent to which differences in the results reported in the original studies are driven by methodological choices. Our analyses, therefore, also contain variables representing the original study's policy tool operationalization, characteristics of the outcome measures, and steps taken to account for endogeneity.[4]

Policy tool

States employ a wide variety of policies to achieve their clean energy objectives, and renewable energy studies have assessed many of them. In order to classify these policies in a coherent way, we coded them as being one of three types. The first type is renewable portfolio standards, which require utilities to supply a minimum percentage of electricity from renewable sources by a specified time. These standards have been adopted by 29 states and the District of Columbia.

A second type of are other forms of renewable energy regulation. These policies include mandatory green power options, which require electricity suppliers to offer consumers the option to purchase electricity generated from renewable sources (which they must either produce themselves or buy from another supplier), and green power purchasing, which commits state agencies to procuring a certain percentage of their electricity from renewable sources. The category also include interconnection standards and net metering. Interconnection standards dictate a set of specific regulations governing how distributed renewable generation technologies may be connected to the grid. They are often adopted in conjunction with net metering, which allows consumers to sell electricity to and buy electricity from the grid as needed, reducing the transaction costs associated with distributed generation. Other regulatory policies are also included, including indexes of multiple forms of renewable energy regulation.

The final policy included is public benefit funds, which allocate financial resources (usually generated by fees on customer utility bills) toward energy efficiency and renewable energy

[4]In addition to these variables, we also coded a small number of additional methodological features of the original studies, including whether the outcome was measured in absolute or relative terms, whether the relevant policy variable was lagged, and the number of policy instruments that were included in the model. Preliminary analyses suggested that these variables were not significant predictors of effect size heterogeneity, and for reasons of parsimony they are not included in the analyses reported here.

programs ranging from consumer education and low-income assistance to renewable energy research and development. Public benefit funds may be used for renewable energy or energy efficiency purposes, and are included as a separate variable in these analyses.

The vast majority of our effects could be coded as falling into one of these categories. There were a few, however, that looked at alternative policies that fall outside these categories. These include financial incentives (e.g., subsidies and tax breaks) for renewable energy, and energy efficiency policies. There were too few of them to include in this analysis, but we hope to have enough of them to include in a future iteration of this study.

We employ a set of dichotomous variables to represent each of the three types of policies included in our analysis. Renewable energy regulation is a broad category, and policies were coded as falling in that category if the original analysis employed either (1) a variable representing an individual policy that falls within that category, or (2) a variable that was operationalized as an index of individual policies that fall within that category. This coding rubric is designed to maximize agreement with the coding employed in the original studies.

The original studies operationalized the policy tools discussed in the previous subsection in a variety of ways. In order to capture these differences, we employ a dummy variables indicating cases where the variable is simply a dichotomous indicator representing whether a particular policy was in effect in the state in a given year, as opposed to an index or other measure designed to represent the scope, duration, or stringency of an individual policy.

Geographic scope of the outcome measure

Although the policy tools examined are implemented at the state level, the outcome measure employed in the original studies was sometimes measured at a regional level encompassing both a state and its surrounding neighbors. This distinction has been found to be important in meta-analyses of other effects of clean energy policies (Woods et al. 2022) The analyses therefore include dummy variable representing whether the outcome was measured at the state level.

Accounting for endogeneity

Endogeneity can threaten the ability of researchers to draw valid inferences from their empirical models. This is a potentially significant issue for studies of renewable energy, because unobserved factors that cause an expansion of the clean energy sector could also have motivated states to adopt clean energy policies in the first place. Our meta-regression models include a dichotomous variable that represents whether the original research took steps to address this issue, via lagging the relevant policy variable, employing a fixed effects model, or utilizing an instrumental variables or Heckman-style two step approach. It was, of course, possible for more than one of these approaches to be included in the same model, but for our purposes the variable was simply coded as one if any step was taken to address endogeneity.

Peer reviewed publication

A key issue in many meta-analyses is whether published studies overestimate policy effects due to the tendency of null findings to remain unpublished. To test for publication bias, we include a dummy variable in the meta-regression analysis to examine whether peer reviewed studies produce systematically larger effect estimates. The dummy variable is coded one if the publication has undergone peer review.

Intercoder reliability assessment

The data from each of the original studies was collected by two of this study's authors working independently. We assessed the level of intercoder reliability in the recording of information needed to calculate effect sizes (such as coefficients, p-values, and the direction of the effect), and the coding of the covariates included in the meta-regression models. The two coders were in agreement in 87% of the cases, a rate considered good using typical rules of thumb. Most discrepancies were due to typographical or transcription errors.

Results

Descriptive statistics

Descriptive statistics for the variables employed in the subsequent analyses can be observed in Table 2. All of the variables except the effect sizes are dichotomous variables.

Table 1: Descriptive statistics

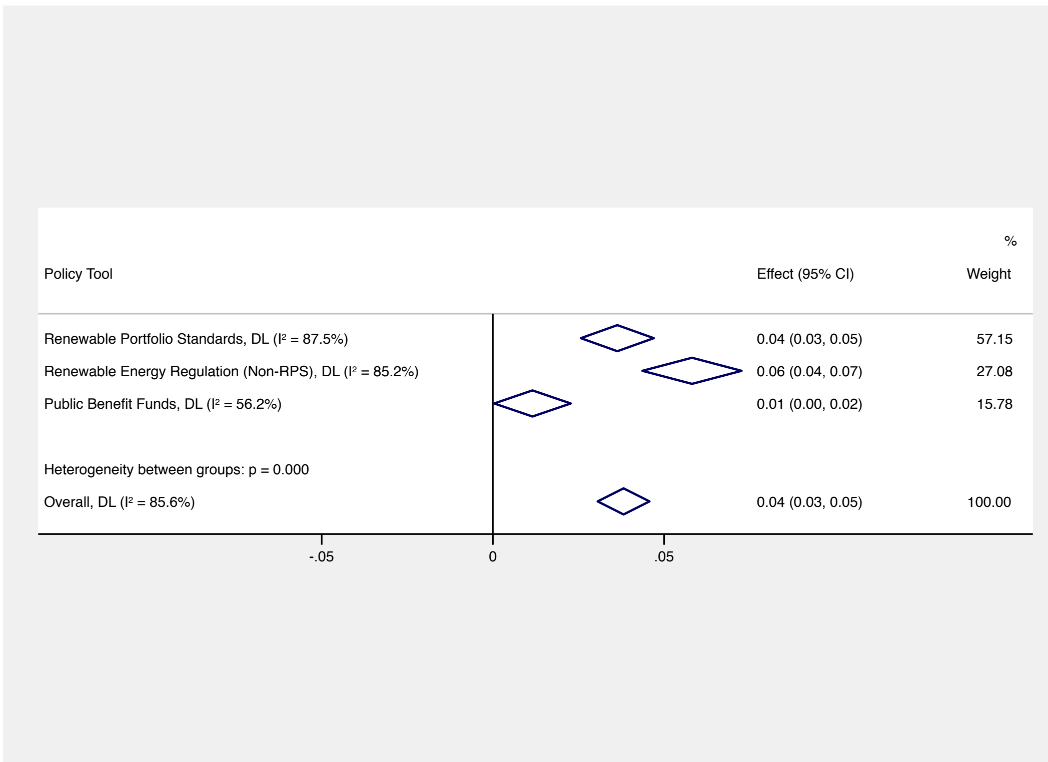
	N	Mean	Std. Dev.
Effect size	565	.038	.121
Renewable portfolio standards	565	.502	.500
Renewable energy regulations (non-RPS)	565	.241	.428
Public benefit funds	565	.135	.342
Policy is operationalized with a dummy variable	565	.678	.468
Dependent variable is measured at the state level	565	.913	.280
Analysis accounts for endogeneity	565	.938	.240
Study is peer-reviewed	565	.511	.500

Forest plot

Forest plots facilitate comparisons of the average effect sizes. A typical approach involves combining all the effects reported in each study into a single study-level effect estimate, which are presented graphically. Here, however, we take a somewhat different approach. Collectively, the original studies examine a wide variety of policy tools, but as indicated in Table 1, the studies vary in terms of which policies they assess. Because our primary interest is in the effect of these policies on renewable energy, we present the average effect estimates for each policy (or combination of policies) rather than for each study. This approach, which utilizes the same statistical technique as that commonly used to generate average study-level effect sizes, is similar to that taken in other recent meta-analysis studies that examine multiple types of policies (Juárez et al. 2019; Khanna et al. 2021; Vooren et al. 2019).

Figure 1 presents the forest plot. Each diamond represents a weighted average effect estimate (center) and its associated 95 percent confidence interval (points) for the policy tools discussed above, calculated across the studies that estimate these effects.[5] The figure indicates that the estimated effects for all three policy tools is statistically distinguishable from zero, indicating that they do produce increases in renewable energy generation and capacity, with non-RPS renewable energy regulations producing the largest increases. Both RPS and other types of regulatory approaches generate substantially larger estimated effects than public benefit funds.

Figure 1: Forest Plot of Average Effect Sizes, by Policy Tool



Note: The triangles represent 95% confidence intervals, with the point estimates at the center.

The average effect size across all policies about .04. Although this would be typically considered a weak relatioship for Pearson's r, it is larger than the estimated effect of several other types of public sector interventions that have been estimated using a similar meta-

[5]Since the renewable energy regulations category(non-RPS) includes some RPS policies that were incorporated into indexes in the original studies, the average effect size of .012 may be slightly inflated from what it may have been if it included non-RPS regulatory policies exclusively.

analysis methodology. Indeed, as pointed out by Gerrish (2016), the mean effect size of most policy interventions—such as effects of education vouchers on school performance (.009), the effect of performance management (.03) and public service motivation (.025) on organizational performance, and the effect of poverty decentralization policies on economic well being (-.01) and negative behaviors (.003)– appears to be quite small. Our effect estimates is comparable to the effect estimates produced by these other studies.

The forest plot also reports the I^2 statistic, which is measure of the amount of heterogeneity of the estimate, which is explained by factors other than random sampling (Higgins and Thompson 2002). The I^2 statistic is 85.6%, which would be very high for studies employing randomized control trials but is moderate for meta-analyses in the social sciences, for which an I^2 statistic value of over 90% would not be unusual (Ringquist 2013).

Meta-regression analysis

In order to examine these effects more closely, we conduct a set of meta-regression analyses. Meta-regression allows us to properly weight the average relationship between state clean energy policies and renewable energy outcomes, incorporating both the efficiency (from sample size) and the magnitude of the effect estimates in the original studies. It also allows us to condition the average effect size on a set of covariates. To do so we regress the r based effect, Fisher's Z, on the independent variables discussed earlier.

A particular concern in meta-regression analysis is the problem of observational non-independence. Each original study produces multiple effects using the same data, but these effects are not independent. There are two ways of dealing with this problem. The first is to collapse all the effects within a study to a effect, either by choosing a single effect estimate or computing a weighted average. However, because independent variables and modeling techniques vary significantly within our original studies, this approach throws away much of the methodological variation we are interested in assessing. Moreover, one of our core goals is to examine the effects of individual policy tools, and collapsing the effects of multiple policies into a single effect would obscure any differences between them.

The second approach, taken here, is to retain the individual effect estimates, addressing the issue of observational non-independence via a modeling technique that accounts for it. Specifically, we use clustered robust variance estimation (CRVE) to assess our effects. The CRVE method allows us to retain the individual effect estimates, addressing the issue of observational non-independence issue via a clustered robust parameter variance–covariance matrix suggested by White's (1980) heteroscedasticity-consistent covariance matrix. This method is suggested by Ringquist (2013) and is employed in other recent social science meta-analyses (Gerrish 2016).

We must also account for the fact that meta-analysis of data generated in non-experimental settings generally produces a distribution effects that are different for reasons other than sampling error alone. In this context a random effects model is generally preferred to a fixed effects model, which allows us to estimate the heterogeneity of the effect tau^2.[6] Tau^2 is an estimate of the distribution around a true effect, and is included in the effects' weights. A Q-test of fixed versus random effects confirms that random effects is the appropriate framework, meaning that effects come from a distribution of effects that are different by more than sampling error alone ($p < .001$).

Meta regression results

Table 3 presents the results of meta-regression analyses assessing the factors associated with differences in the effect estimates produced in the original studies. For policy tools, the omitted reference category is public benefit funds, which had the lowest estimated effect size in Figure 1. The results of the first model indicate that when controlling for various aspects of the methodologies employed in the original studies renewable energy regulations other

[6]While it is similar to the terminology employed in panel data analysis, fixed vs. random effects has a different meaning in this context, and has more in common with hierarchical linear models.

than RPS policies produce increases in renewable energy capacity and generation that are significantly greater than those produced by public benefit funds. There is no statistically significant distinction, however, between the effects of renewable portfolio standards and public benefit funds.

Table 2: Meta regression: Impact of renewable portfolio standards on renewable energy generation/capacity

	Coeff.	Std. Error
Renewable Portfolio Standards	0.009	(0.015)
Renewable energy regulation (Non-RPS)	0.035*	(0.013)
Policy is operationalized with a dummy variable	−0.005	(0.013)
Dependent variable is measured at the state level	0.0451*	(0.015)
Analysis accounts for endogeneity	−0.067	(0.027)
Study is peer-reviewed	0.006**	(0.008)
Constant	0.047**	(0.034)
Observations	564	
R^2	0.129	

Note: Robust standard errors, clustered by study.
$^{**}p < 0.05$, $^{*}p < 0.1$

The results also indicate that studies that measure green jobs at the state level generate larger effect estimates than those that measure them at the regional level. In addition, there are systematic differences between the effect estimates produced in peer-reviewed versus non peer-reviewed studies. The effect estimates in peer-reviewed studies are significantly larger, which may be evidence of publication bias. The results provide no evidence that measurement choices regarding the core independent variable or the use of techniques designed to control for endogeneity make a difference.

Conclusion and Policy Implications

Clean energy transitions are an important concern for scholars and policymakers, but the academic literature has produced conflicting findings regarding the renewable energy generation potential of renewable energy policies. Our meta-analysis allows us to combine the estimates produced in the original studies to produce a more precise interpretation of effects of clean energy policies, both overall and by individual policy type. It also allows us to examine why original studies produce different results, by assessing the extent to which these differences are driven by different methodological choices.

For policymakers, our analyses produce two important takeaway points. First, the available evidence indicates that green policies are systematically associated with increased renewable energy generation and capacity.. This suggests that, broadly speaking, a portfolio of renewable energy policies may indeed produce results. Second, the evidence suggests there is substantial heterogeneity in the magnitude and statistical significance of the effects across policies. In particular, the evidence regarding the renewable energy promotion effects of policy tools varies substantially across types of policies.

Scholars will be interested in these substantive results as well, but an additional key takeaway from our analysis pertains to the importance of measurement choices. Variables representing measurement of the dependent variable were significant. These results suggest that analysts should carefully consider measurement choices in designing their study. In particular, researchers should contemplate the most appropriate breadth and geographic scope of their measure of renewable energy generation. In addition, our results suggest that publication bias may be an issue in this area, as published studies report significantly stronger effects than unpublished ones. Attention to these areas will help scholars develop a more refined understanding of the effects of energy policies, as well as a stronger evidence base on which to base future policy decisions.

In future iterations of this project, we will look to expand upon the analyses presented here in a variety of ways. First, we have nine additional studies of general renewable energy generation that our search identified that we will add the effects of. At present these effects have mostly been coded, but were omitted from this analysis due to some unresolved questions about some of the coding. Second, we will seek to add the the effects of studies that look specifically at wind and solar generation. These are the two largest individual sources of renewable energy, and we have identified several studies that analyze these sources specifically. Doing so will allow us to examine possible heterogeneity of policy effects across different renewables. Finally, we plan to incorporate a more fine-grained analysis of various policy tools, and further investigate methodological choices that may impact study results, including a whether the original study included theoretically important independent variables. The final product, we believe, may have significant implications for both scholars and policymakers

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A Appendix: Studies Included in Meta-Analysis

1. Bowen and Lacombe (2017)
2. Carley (2009)
3. Carley and Nicholson-Crotty (2018)
4. Cochran (2015)
5. Delmas and Montes-Sancho (2011)
6. Demidov (2019)
7. Fischlein and Smith (2013)
8. Fullerton and Ta (2019)
9. Greenstone and Nath (2020)
10. Haas (2017)
11. Iselin (2014)
12. Jang (2018)
13. Kilinc-Ata (2016)
14. Koo (2013)
15. Park (2015)
16. Pastor (2020)
17. Shrimali and Kniefel (2011)
18. Upton and Snyder (2017)

19. Yin and Powers (2010)