Heterogeneity in State Solar and Wind Deployments:
Trade-offs between Technology-neutral and Technology-specific Renewable Energy Policies

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Introduction

- Transitions of electricity generation from fossil fuels to renewable technologies are essential in mitigating greenhouse gas (GHG) emissions.
- Large heterogeneities exist among U.S. states regarding solar and wind energy development and natural endowment.
- Renewable Portfolio Standards (RPS), so far the dominant local instruments in fostering renewable development and reducing GHG emissions from the grid power.
- To promote solar deployment, some states have designed and implemented RPS Solar Carve-Out (SRPS), which is built upon RPS.
- The RPS allows electricity suppliers to select renewable energy from a broad range of technologies and sources, while SRPS directly mandates solar electricity generation.
- **Objective:** Investigate the differential impacts of technology-neutral (RPS) and technology-specific (SRPS) renewable energy policies on different types of renewable energy sources in electricity generation.

Theoretical Framework

Theoretical setup:

- A representative electricity supplier in state i provides electricity to satisfy in-state electricity demand Q_i (perfectly inelastic).
- Three types of electricity: solar ($q_{i,1}$), wind ($q_{i,2}$), and non-renewable ($q_{i,3}$):
- $C_{i,1}$, $C_{i,2}$, and $C_{i,3}$ (generation costs) are continuous, twice-differentiable, strictly increasing and convex; $C'_{i,1}(q) > C'_{i,2}(q) > C'_{i,3}(q)$.
- Electricity supplier i is regulated by SRPS and RPS, which mandate a minimum proportion of Q_i, $\alpha_{i,1} \in [0,1]$ and $\alpha_i \in [0,1]$, $\alpha_{i,1} \leq \alpha_i$, from solar energy, and eligible renewable energy sources, respectively.
- The trading of electricity, solar renewable energy credit (SREC), and renewable energy credit (REC) (z_i , $y_{i,1}$, $y_{i,2}$) is allowed across states at market-clearing price P, θ_1 and θ_2, respectively.

Individual supplier's decision problem:

$$\min_{\{q_{i,1},\, q_{i,2},\, q_{i,3},\, z_i,\, y_{i,1},\, y_{i,2}\}} C_{i,1}(q_{i,1}) + C_{i,2}(q_{i,2}) + C_{i,3}(q_{i,3}) + Pz_i + \theta_1 y_{i,1} + \theta_2 y_{i,2}$$

$$\text{subject to: } q_{i,1} + q_{i,2} + q_{i,3} + z_i \geq Q_i;\ \ q_{i,1} + y_{i,1} \geq \alpha_{i,1} Q_i$$

$$q_{i,1} + q_{i,2} + y_{i,1} + y_{i,2} \geq \alpha_i Q_i;\ \ q_{i,1}, q_{i,2}, q_{i,3} \geq 0$$

Hypothesis 1: The adoption of SRPS or a more stringent SRPS target in one state induces a higher share of solar electricity but a lower share of wind electricity in total electricity generation in that state.

Hypothesis 2: The adoption of RPS or a more stringent RPS target in one state induces a higher share of wind electricity but a non-decreasing share of solar electricity in total electricity generation in that state.

Hypothesis 3: As SRPS or RPS becomes more stringent in one state, trading of SREC and REC increases in that state.

Empirical Model

Two-way fixed effects model with two treatment variables and staggered timing of treatments:

$$Y_{it} = \alpha + \delta_1 \mathrm{RPS}_{it} + \delta_2 \mathrm{RPS}_{it} \times \mathrm{SRPS}_{it} + \delta_3 \mathrm{RPS}_{it} \times \mathrm{RPS\_target}_{it} + \delta_4 \mathrm{RPS}_{it} \times \mathrm{SRPS}_{it} \times \mathrm{SRPS\_target}_{it} + X_{it}'\gamma + \kappa_1 OCC_{it} + \kappa_2 PDS_{it} + \tau_t + \mu_i + \lambda_n t + \upsilon_{it},$$

- Y_{it}: the share of solar or wind electricity in total electricity generation;
- RPS_{it}/SRPS_{it}: dummy policy indicators (0/1);
- $\mathrm{RPS\_target}_{it}$/$\mathrm{SRPS\_target}_{it}$: continuous policy variable in % of electricity required;
- OCC_{it}: other climate change policies, a proxy for preferences for green policies;
- PDS_{it}: the penetration rate of distributed solar, a proxy for preferences specifically for utility-scale solar;
- X_{it}: a set of control variables;
- τ_t, μ_i, and $\lambda_n t$: indexes of state fixed-effect, year fixed-effect, and region-specific linear time trend;
- υ_{it}: error term.

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Data

- U.S. state-level data from 2001 to 2019.
- Policy data: Lawrence Berkeley National Laboratory (LBNL) and the Database of State Incentives for Renewables & Efficiency (DSIRE).
- Electricity generation data: the U.S. Energy Information Administration (EIA).
- Control and proxy variables: the State Climate Policy Dashboard, LBNL, the U.S. National Renewable Energy Laboratory (NREL), and EIA.

Results

Table 1. Effects of RPS and SRPS on State-level Solar/Wind Deployment

	Dependent variable:					
	Solar electricity share			Wind electricity share		
	(1)	(2)	(3)	(4)	(5)	(6)
RPS	-0.126	-0.155	-0.129	0.520	0.516	0.554
	(0.145)	(0.141)	(0.142)	(0.567)	(0.564)	(0.573)
RPS × SRPS	0.756***	0.652***	0.263	-2.208***	-2.020***	-1.962***
	(0.177)	(0.195)	(0.173)	(0.499)	(0.499)	(0.477)
RPS × RPS target			0.040***			-0.016
			(0.014)			(0.065)
RPS × SRPS × SRPS target			0.290**			0.031
			(0.112)			(0.220)
Other green policies		0.272***	0.245***		-0.259***	-0.250***
		(0.054)	(0.058)		(0.076)	(0.081)
Penetration rate of distributed solar		0.016**	0.016**		-0.041**	-0.042**
		(0.007)	(0.007)		(0.017)	(0.018)
Solar credit multiplier	-0.083	-0.025	-0.035			
	(0.062)	(0.057)	(0.056)			
Log(Solar cost/Unit solar potential)	-1.523***	-0.528**	-0.423*			
	(0.290)	(0.246)	(0.243)			
L.External demand of SREC	0.023	-0.004	-0.008			
	(0.046)	(0.038)	(0.036)			
Wind credit multiplier				0.240	0.061	0.045
				(0.515)	(0.507)	(0.506)
Log(Wind cost/Unit wind potential)				-9.668***	-11.648***	-11.713***
				(0.975)	(1.176)	(1.236)
L.External demand of REC				-0.109***	-0.112***	-0.113***
				(0.016)	(0.016)	(0.016)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
State and year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Regional linear trend	Yes	Yes	Yes	Yes	Yes	Yes
Observations	950	950	950	931	931	931
R^2	0.514	0.626	0.644	0.764	0.772	0.772

Table 3. Effects of RPS and SRPS on State-level Solar/Wind Deployment by Periods

	Year ≤ 2010				Year > 2010			
	Solar	Solar	Wind	Wind	Solar	Solar	Wind	Wind
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
RPS	-0.026**	-0.022***	0.533***	0.573***	3.685***	3.498***	11.896***	13.079***
	(0.011)	(0.008)	(0.202)	(0.200)	(0.529)	(0.381)	(1.038)	(1.621)
RPS × SRPS	0.048**	0.028**	-0.751**	-0.630*	0.554*	-0.083	-1.632**	0.054
	(0.023)	(0.013)	(0.313)	(0.346)	(0.328)	(0.271)	(0.828)	(1.122)
RPS × RPS target		0.004**		-0.091***		0.022**		-0.085**
		(0.002)		(0.033)		(0.010)		(0.036)
RPS × SRPS × SRPS target		0.116		-0.099		0.517***		-0.463**
		(0.072)		(0.657)		(0.147)		(0.208)
Proxy variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State and year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Regional linear trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	500	500	490	490	450	450	441	441
R^2	0.723	0.755	0.743	0.748	0.813	0.827	0.932	0.933

Table 2. Effects of RPS and SRPS on State-level SREC/REC Trading

	Dependent variable:			
	Proportion of SREC traded		Proportion of REC traded	
	(1)	(2)	(3)	(4)
RPS	-0.111	-0.098	-0.775	-0.158
	(0.131)	(0.133)	(0.921)	(0.950)
RPS × SRPS	0.501***	0.278*	-2.363***	-2.233***
	(0.178)	(0.156)	(0.800)	(0.709)
RPS × RPS target		0.023**		-0.167*
		(0.011)		(0.086)
RPS × SRPS × SRPS target		0.163*		1.021***
		(0.094)		(0.380)
Proxy variables	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes
State and year fixed effects	Yes	Yes	Yes	Yes
Regional linear trend	Yes	Yes	Yes	Yes
Observations	950	950	931	931
R^2	0.610	0.617	0.659	0.668

Note: Robust standard errors in parentheses, ∗ $p < 0.1$, ∗∗ $p < 0.05$, ∗∗∗ $p < 0.01$.

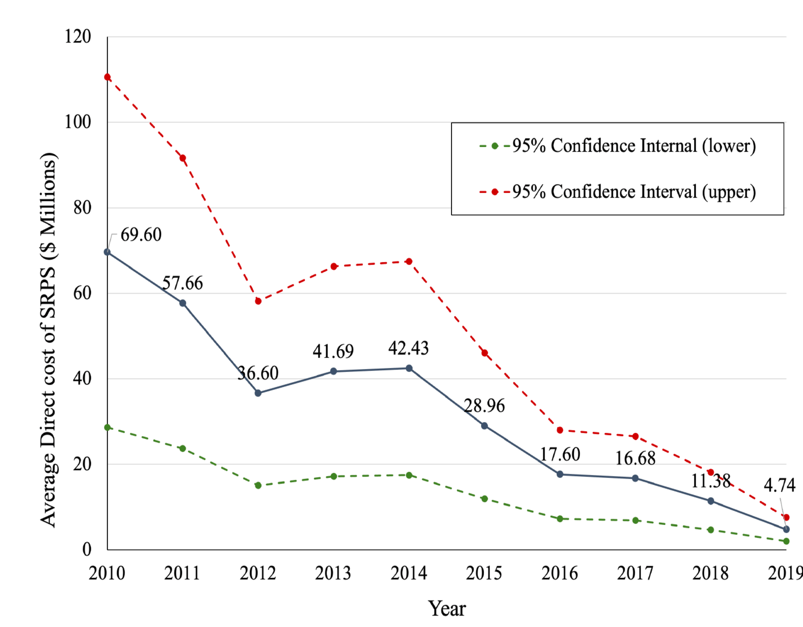

Figure 1. The Cost of Implementing a Solar Carve-Out within RPS

Conclusions

- Technology-specific SRPS has been effective in promoting the development of solar energy in the United States.
- Technology-neutral RPS is shown to have imbalanced effects on the development of renewable technologies.
- RPS and SRPS imply significant trade-offs between solar and wind development. In particular, SRPS promoted solar at the expense of wind, the relatively lower-cost energy source, and thus higher costs of electricity generation.
- Along with the impacts of policies, our results also provide quantitative estimates of the crucial cost-reduction role of technology advancement in facilitating the deployment of solar and wind energies.
- The adoption of SRPS or a more stringent SRPS target induced more extensive SREC trading, implying that SREC trading is an important tool for utilities to comply with SRPS mandates.

Discussions

- The trade-offs between technology-neutral and technology-specific policies depend on the relative cost competitiveness of the technologies and the relative competitiveness can evolve over time with technology advancement.
- In fact, the cost of solar has fallen dramatically in the last 20 years or so, increasing its competitiveness among renewables. This implies that, even though a solar carve-out has been effective in promoting solar in our study period, a technology-neutral policy may also have the potential to facilitate solar deployment nowadays.
- Policymakers should be attentive to changes in the cost structure of renewable technologies when making renewable energy policies.

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