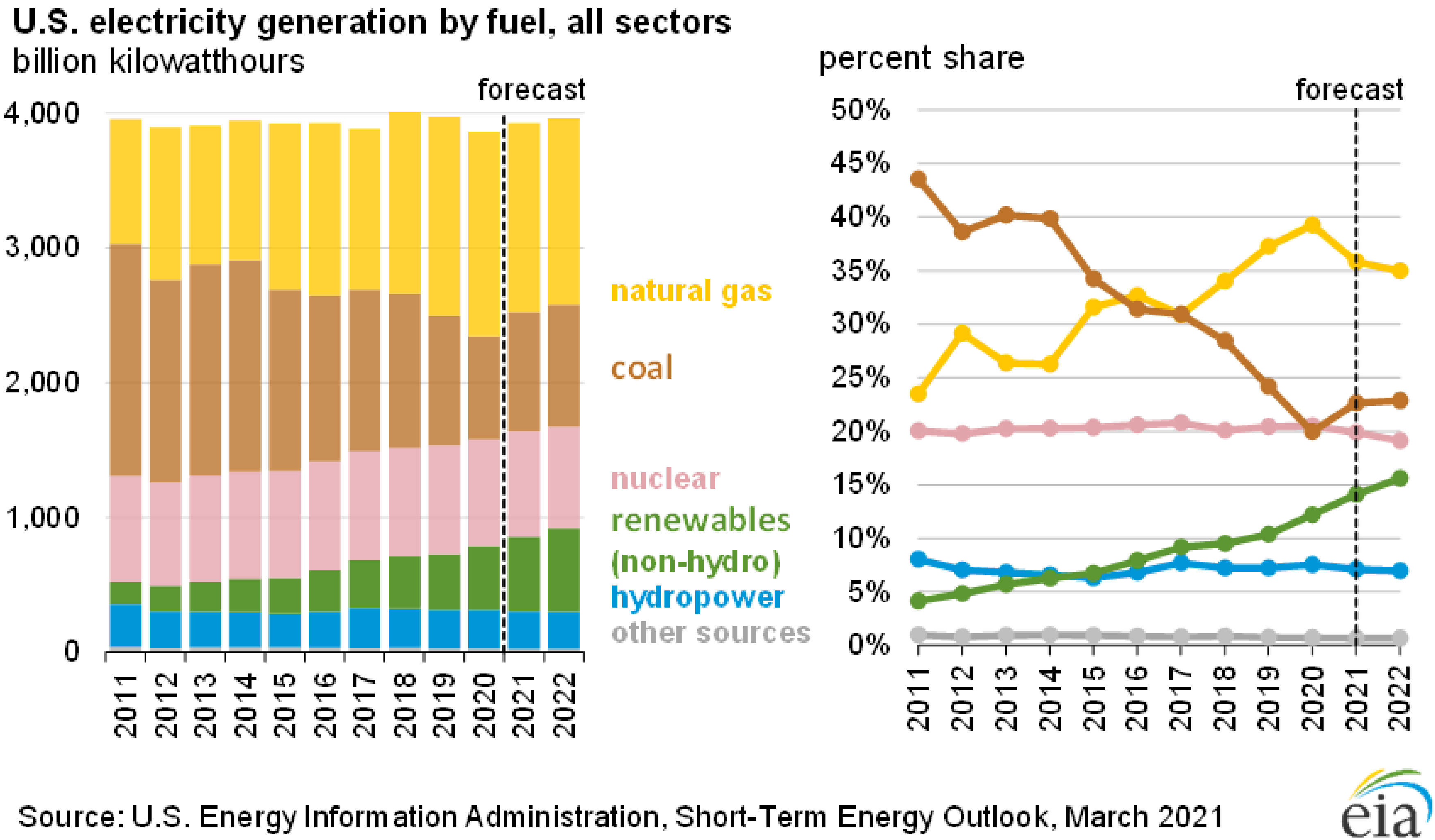
Renewable Energy

Professor Richard Sweeney, Econ 3391

Outline (*shortened)

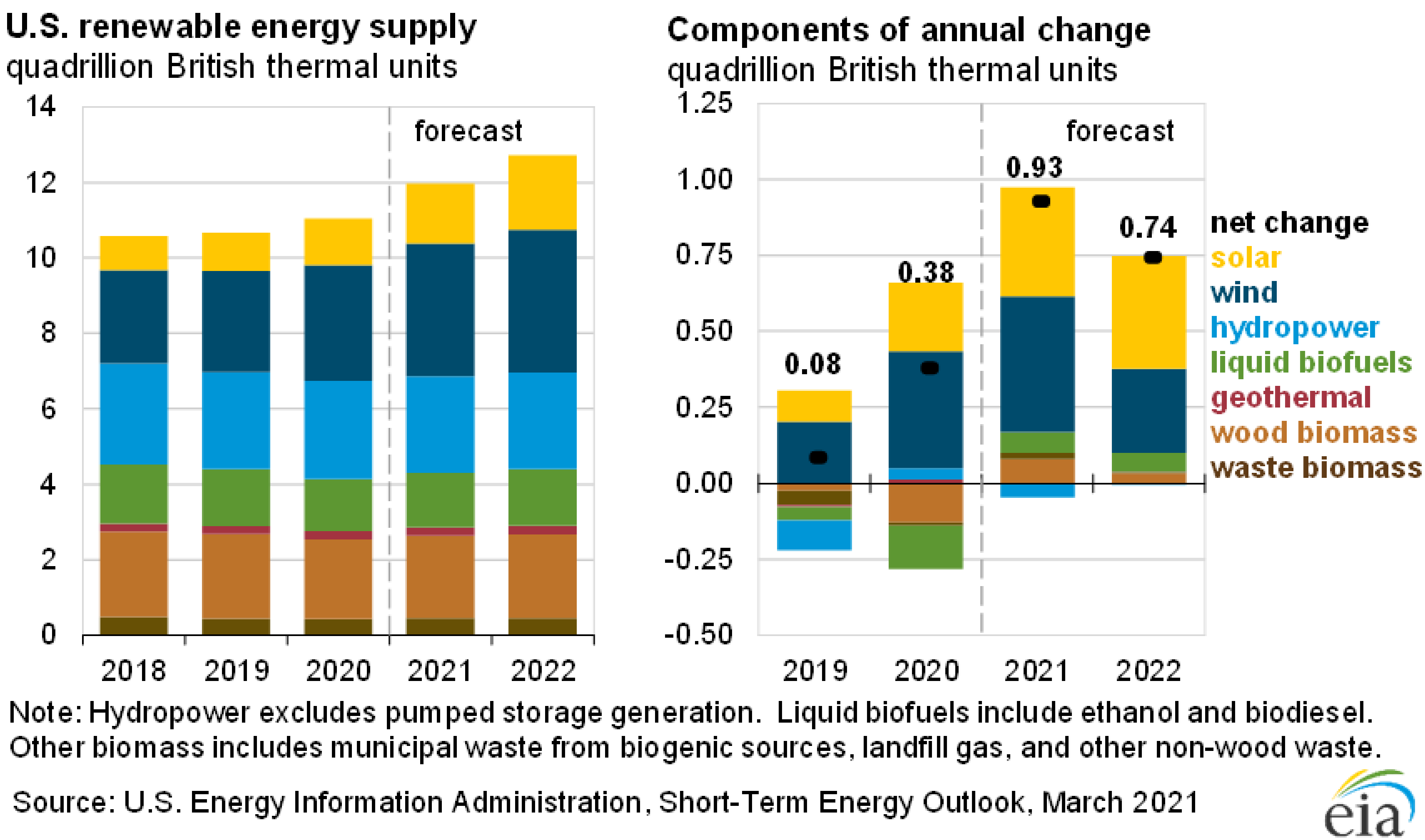
- Background
- Policies *
- Subsidies vs taxes
- Input vs output subsidies (wind)
- The costs (?) of solar?

State of renewables in the US



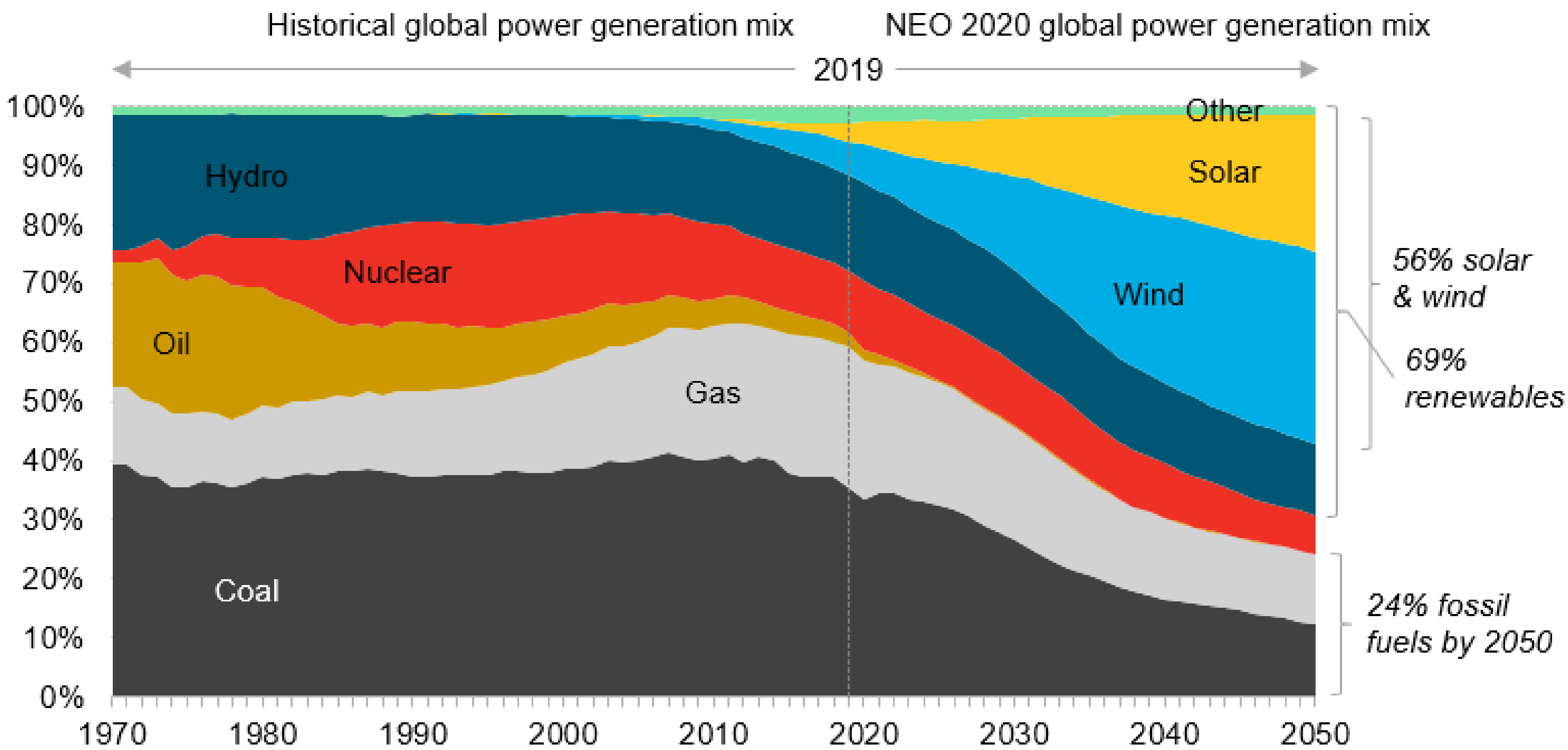
Source: https://www.eia.gov/outlooks/steo/report/electricity.php

State of renewables in the US



Source: https://www.eia.gov/outlooks/steo/report/electricity.php

Global Power Mix



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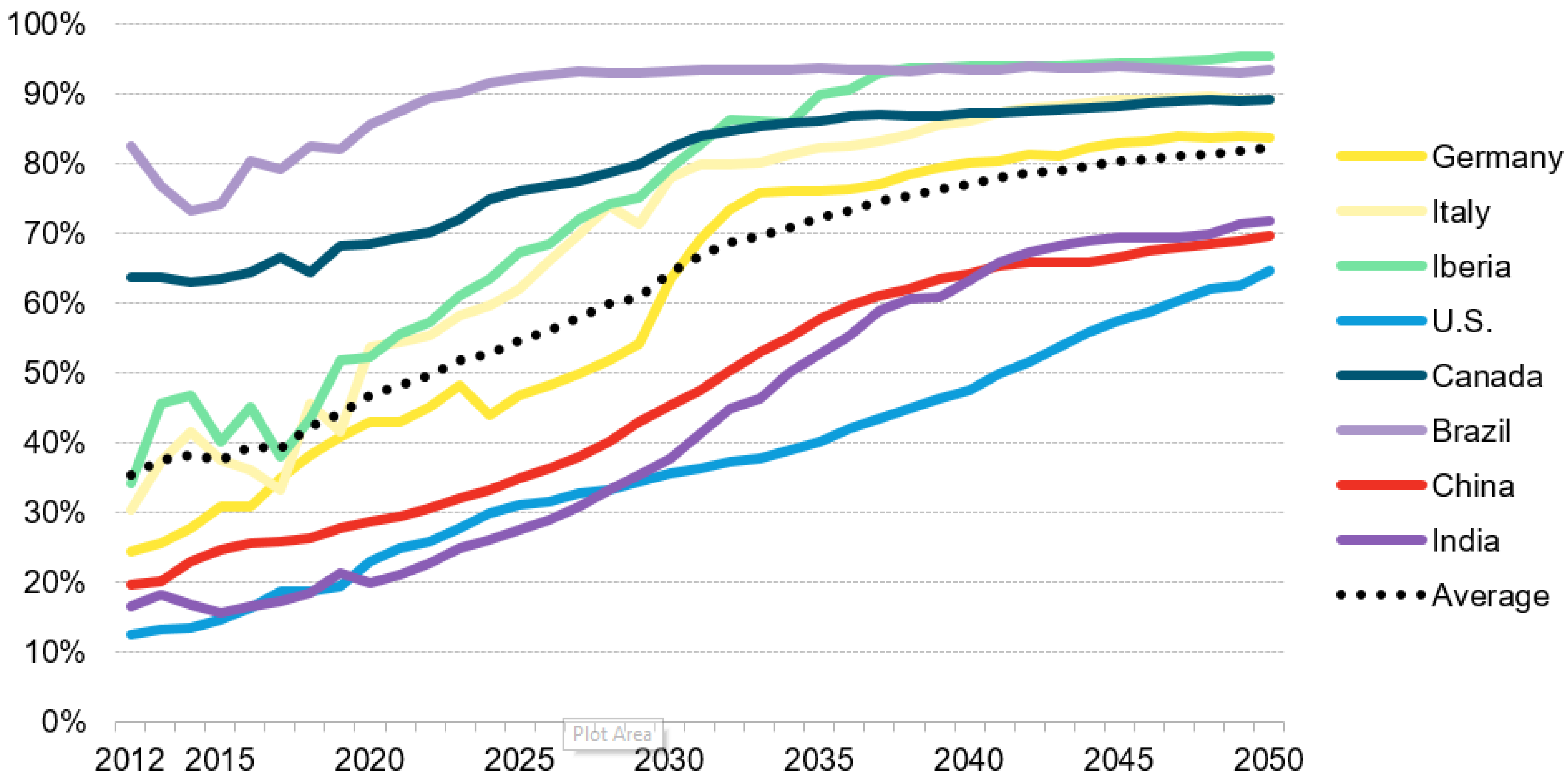
US lags most in % renewables



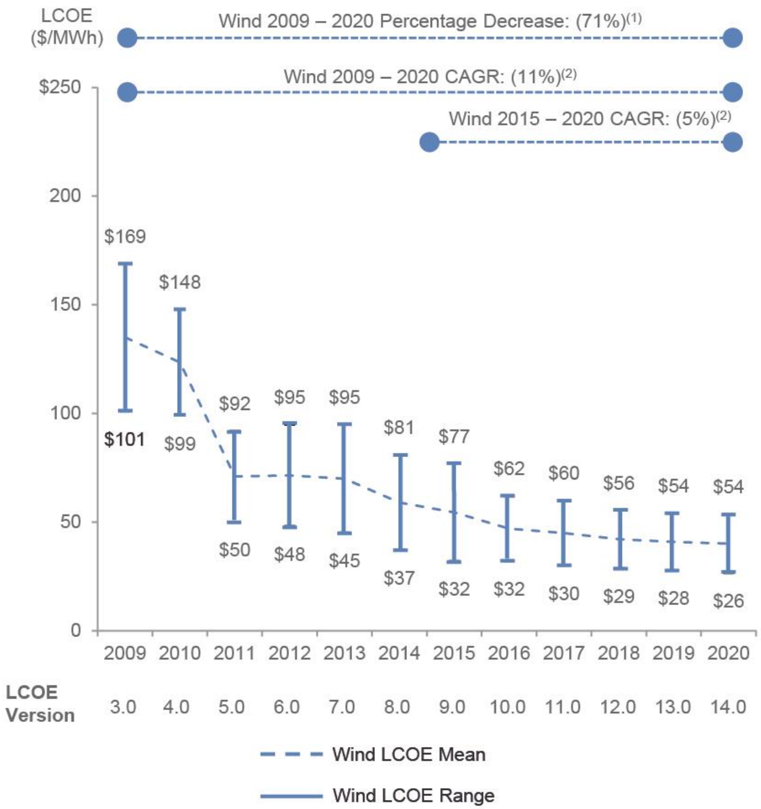
Source: BNEF

Costs have come down a lot over time

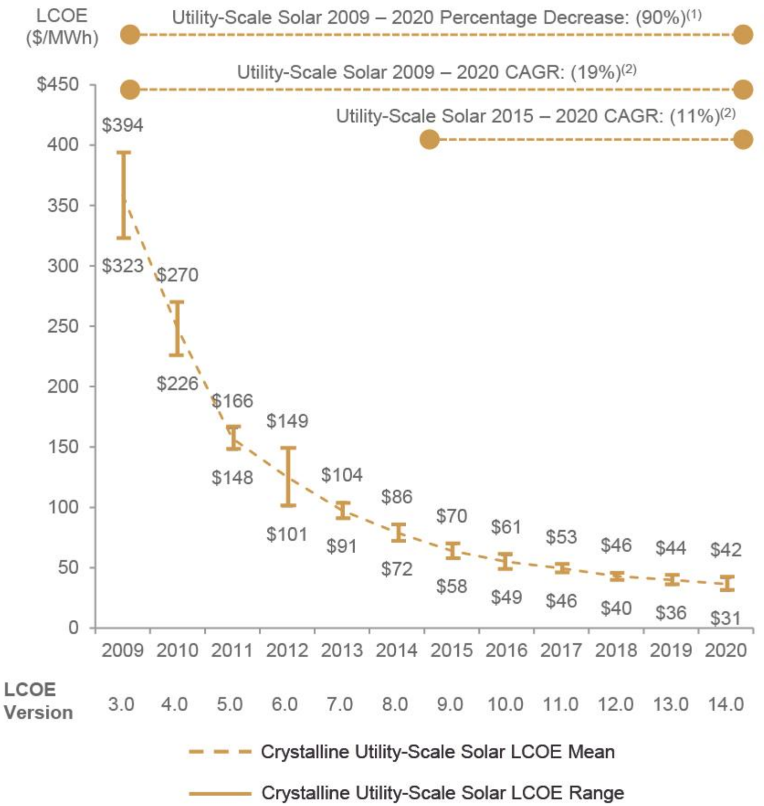
Levelized Cost of Energy Comparison—Historical Renewable Energy LCOE Declines

In light of material declines in the pricing of system components and improvements in efficiency, among other factors, wind and utility-scale solar PV have exhibited dramatic LCOE declines; however, as these industries have matured, the rates of decline have diminished

Unsubsidized Wind LCOE



Unsubsidized Solar PV LCOE



Source: Lazard estimates.

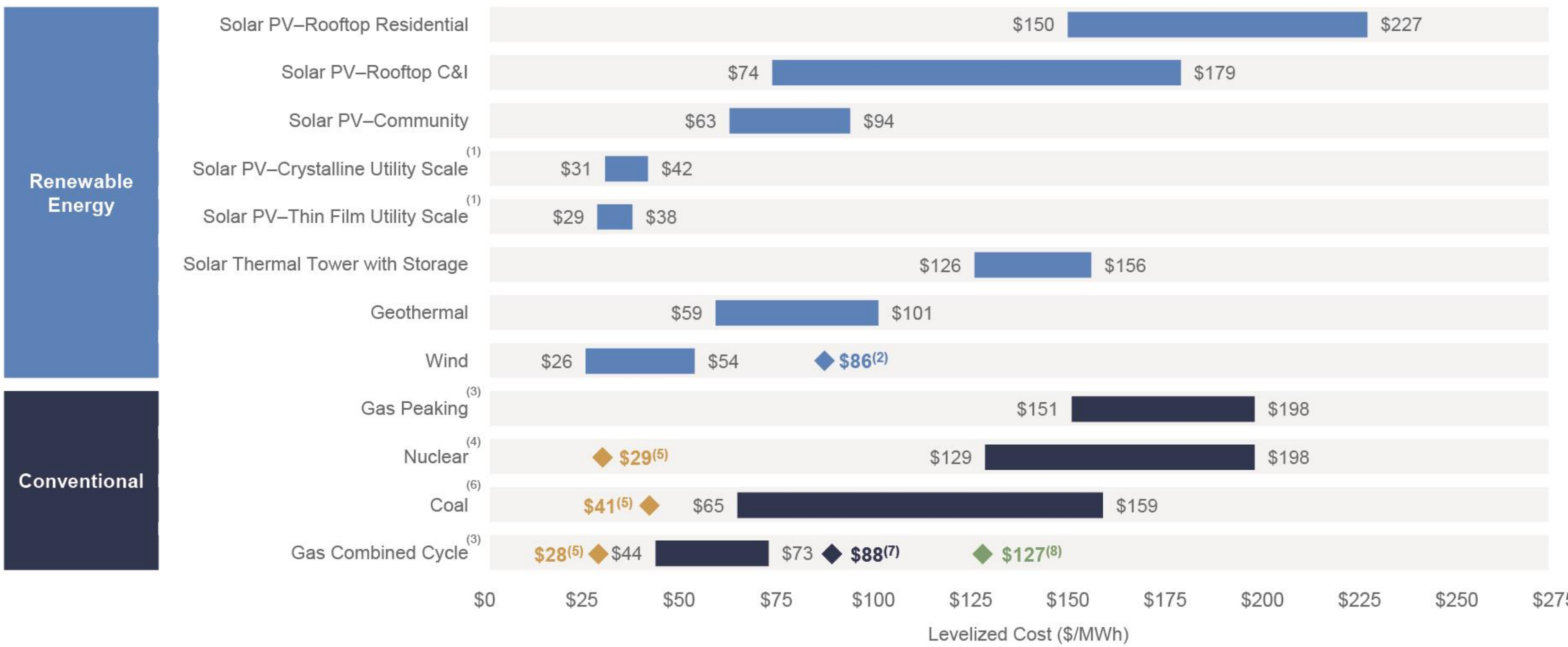
(1) Represents the average percentage decrease of the high end and low end of the LCOE range.

(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.

Unsubsidized costs cheaper than new conventional; not quite marginal existing

Levelized Cost of Energy Comparison—Unsubsidized Analysis

Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances



Source: *Lazard estimates.*

Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital sensitivities. These results are not intended to represent any particular geography. Please see page titled "Solar PV versus Gas Peaking and Wind versus CCGT—Global Markets" for regional sensitivities to selected technologies.

(1) Unless otherwise indicated herein, the low case represents a single-axis tracking system and the high case represents a fixed-tilt system.
(2) Represents the estimated implied midpoint of the LCOE of offshore wind, assuming a capital cost range of approximately $2,600 – $3,675/kW.
(3) The fuel cost assumption for Lazard's global, unsubsidized analysis for gas-fired generation resources is $3.45/MMBTU.
(4) Unless otherwise indicated, the analysis herein does not reflect decommissioning costs, ongoing maintenance-related capital expenditures or the potential economic impacts of federal loan guarantees or other subsidies.
(5) Represents the midpoint of the marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equivalent to its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper- and lower-quartile estimates derived from Lazard's research. Please see page titled "Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation" for additional details.
(6) High end incorporates 90% carbon capture and storage. Does not include cost of transportation and storage.
(7) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Blue" hydrogen, (i.e., hydrogen produced from a steam-methane reformer, using natural gas as a feedstock, and sequestering the resulting CO_2 in a nearby saline aquifer). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is $5.20/MMBTU.
(8) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "Green" hydrogen, (i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is $10.05/MMBTU.

Source: Lazard

Some policy questions

- How effective has policy been and encouraging adoption?
  - How much of this cost decline was *caused* by policy?

History of US climate policy

1970s: Federal energy efficiency policy targets appliances, autos and buildings
- initially motivated by energy price spikes (OPEC), but main motivation today is climate change

1992: Senate approves U.N. Framework Convention on Climate Change
- Renewable energy production tax credit (PTC) added to 1992 Energy Policy Act (by Sen. Chuck Grassley (R-IA))

1997: Senate pre-empts Kyoto Protocol (Byrd-Hagel)
- Clinton admin negotiates anyways
- Bush admin formally declares non-entry

2003-2007: Several **bipartisan** bills in the Senate
- notable McCain-Lieberman cap-and-trade bill
- Congress mandates emissions reporting (GHGRP)

US climate policy under Obama admin

2009: American Clean Energy and Security Act (aka "Waxman-Markey") narrowly passes House

- set cap on total US emissions 2012-2050
- Senate fails to pass a related measure

2014: Clean Power Plan proposed

- Obama admin decided to use executive authority
- Note: Some feel this action was *required* by *Massachusetts vs EPA (2007)*, where SC ruled EPA required to regulate CO2 under the Clean Air Act

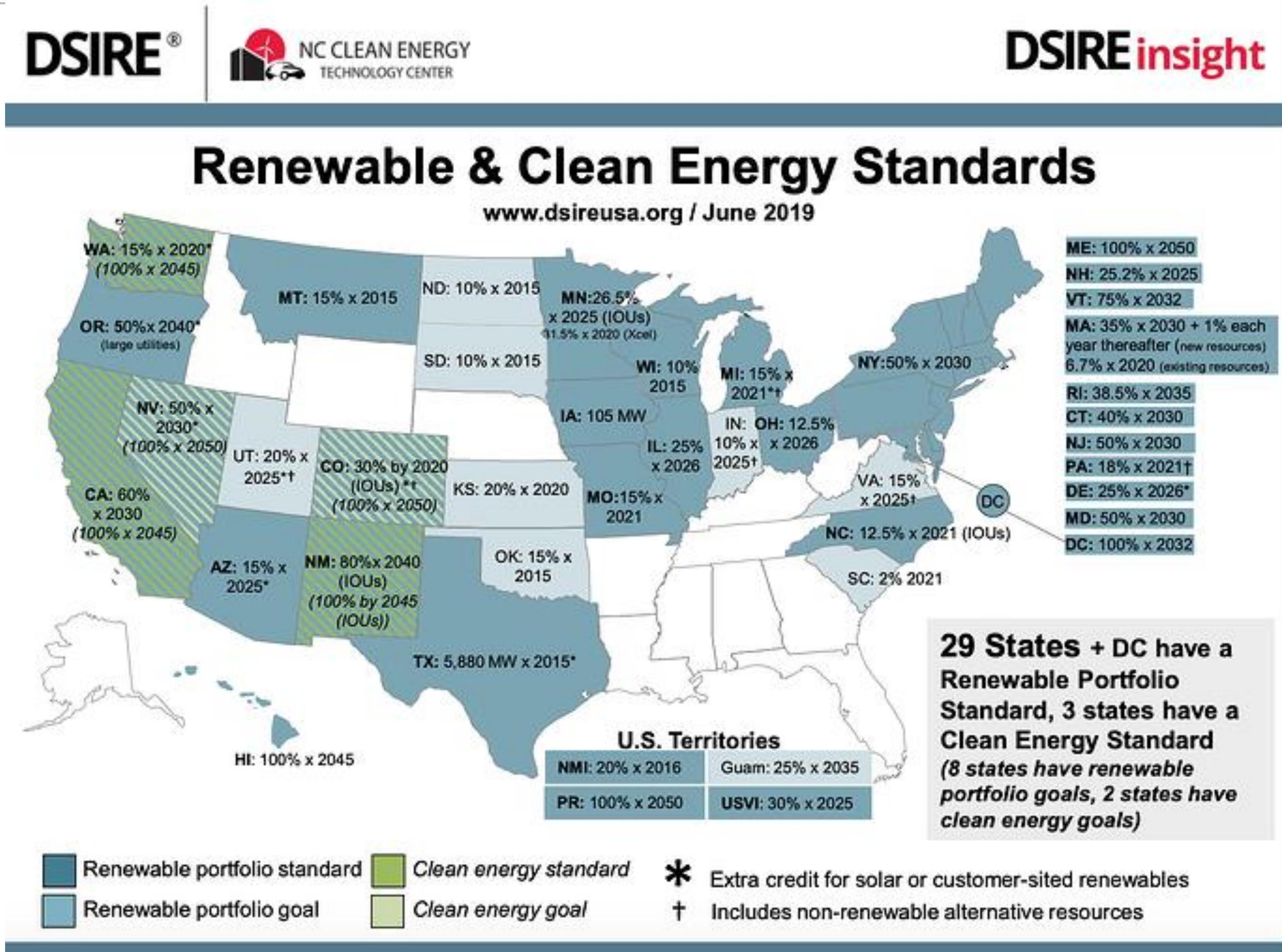
2016: Obama admin pledges US action in Paris, with CPP as the centerpiece

Much of this halted, reversed under the Trump administration

Trump Reversed Course on Most Fronts

- Clean Power Plan Scrapped
- New CAFÉ standards suspended
- US formally exited Paris Agreement

Subnational initiatives pushed forward



Biden signs Inflation Reduction Act into law

By Maegan Vazquez and Donald Judd, CNN
Updated 10:29 PM EDT, Tue August 16, 2022

Mandel Ngan/AFP/Getty Images

US President Joe Biden speaks during a signing ceremony for H.R. 5376, the Inflation Reduction Act of 2022, in the State Dining Room of the White House in Washington, DC, on August 16, 2022. (Photo by MANDEL NGAN / AFP) (Photo by MANDEL NGAN/AFP via Getty Images)

Key climate provisions in the Inflation Reduction Act?

Clean electricity	Cost in billions
New tax credits for emissions-free electricity sources and storage Including wind, solar, geothermal, advanced nuclear, etc.	$62.7
Extending existing tax credits for wind and solar power	$51.1
Tax credit for existing nuclear reactors To prevent them from closing	$30.0
Extend energy credit Through 2024	$14.0
Clean energy rebates and grants for residential buildings Rebates for installing heat pumps and retrofitting homes	$9.0
Financing for energy infrastructure Updates and expands lending programs to make energy generation and transmission more efficient	$6.8
Tax credit for carbon capture and storage	$3.2

What are the key climate provisions in the Inflation Reduction Act?

- **Individual clean energy incentives**

	Cost in billions
Green energy credits for individuals Extends and increases tax credits for energy-efficient properties	$36.9

- **Clean fuel and vehicles**

	Cost in billions
Tax credits for new and used electric cars Incentives for purchasing emissions-free vehicles, with income limits, and for installing alternative fueling equipment.	$14.2
Clean hydrogen production	$13.2
Fuel tax credits Creates new credits for low-carbon car and airplane fuels, and extends credits for biodiesel and other renewable fuels	$8.6
Financing for clean energy vehicles Loans and grants for the production of hybrid, electric and hydrogen fuel cell cars	$2.9

- **Air pollution**

	Cost in billions
"Green bank" for energy investments For investments in clean energy projects, particularly in poor communities	$20.0
Other air pollution reduction Includes funding for monitoring and reducing pollution, and grants for disadvantaged neighborhoods	$14.8

Some econ questions about subsidies

- How *cost effective* has policy been?
  - Was policy well designed or wasteful?
- Subsidies vs taxes
- How to design subsidies

How to promote renewable energy?

How to promote renewable energy?

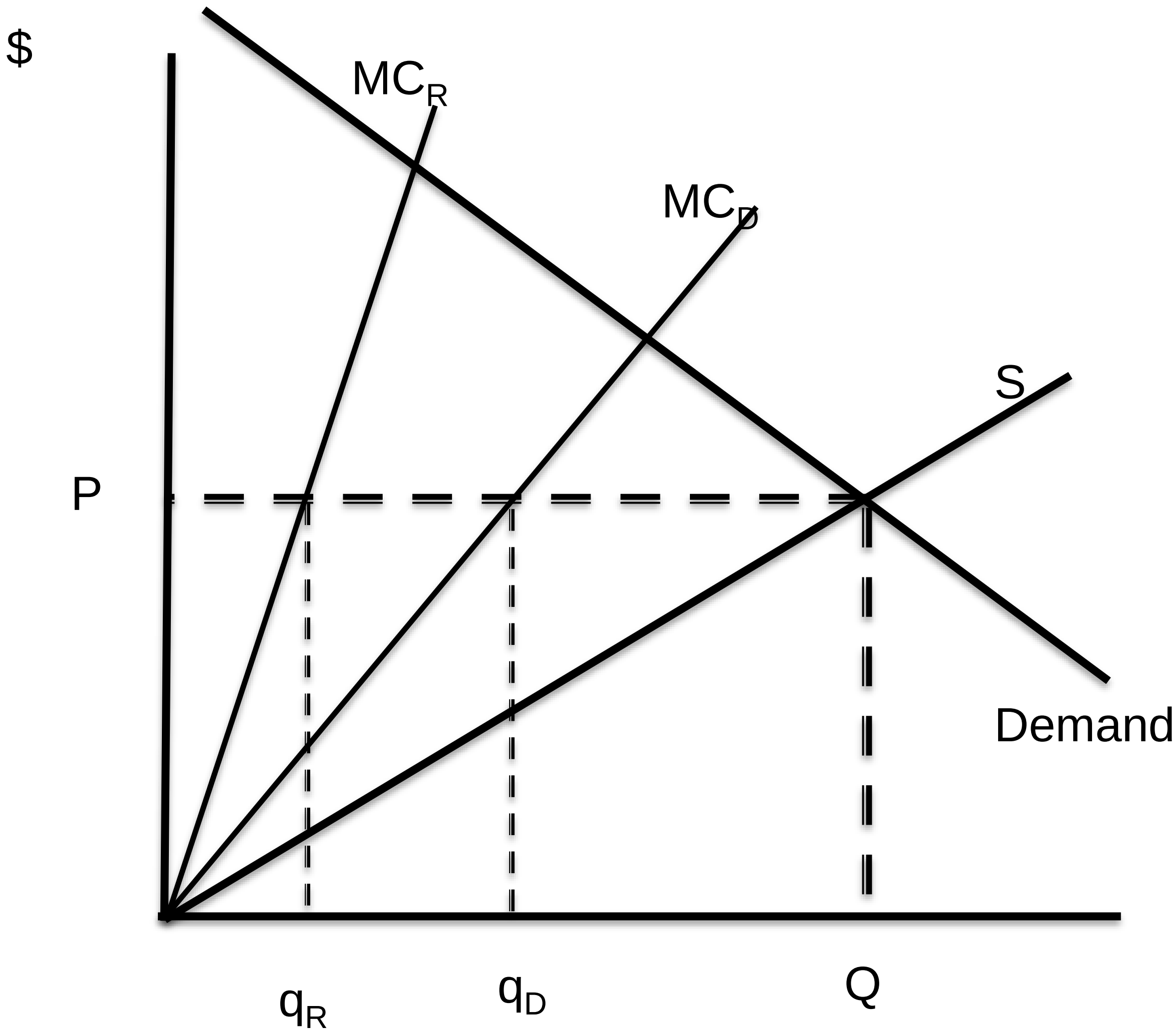
- Best policy would be to place a price on emissions equal to their social cost.
  - **Few countries do this.**
- Instead, many countries prefer to **subsidize clean energy**
  - Many countries around the world use **feed-in tariffs**
  - US has federal tax credits (going back to 1992)
- How do these "second best" policies compare?
- Is it just as good to subsidize renewables as it is to tax coal?

Thinking about the efficient outcome

- Over half of our electricity production comes from fossil fuels
- These generators emit carbon-dioxide. And, in most states, there is no fee associated with these emissions.

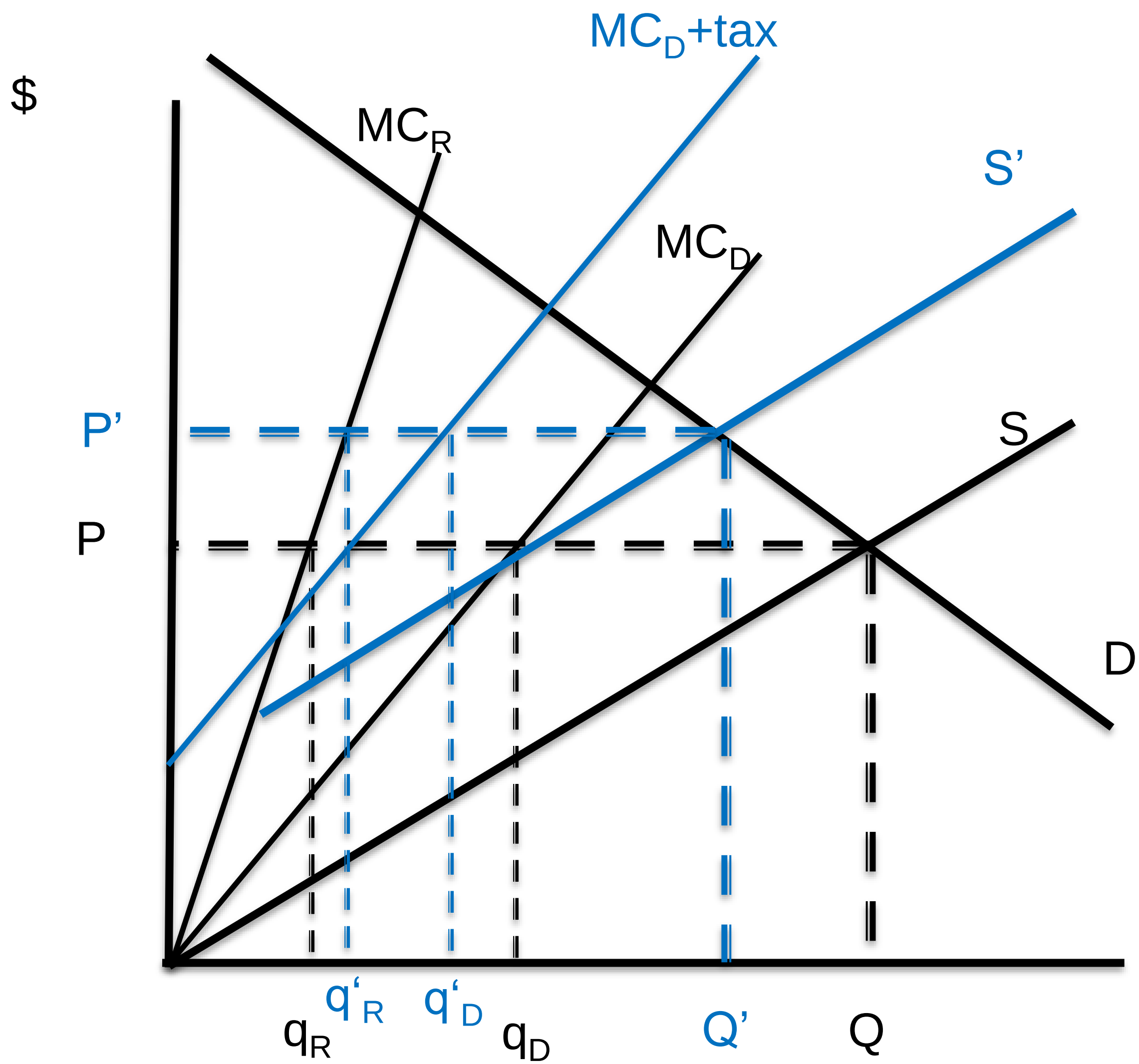
- Relative to the socially efficient levels, do you think US electricity prices are too high or too low?
- What about consumption? Are we consuming too much or too little electricity?

Taxes vs subsidies



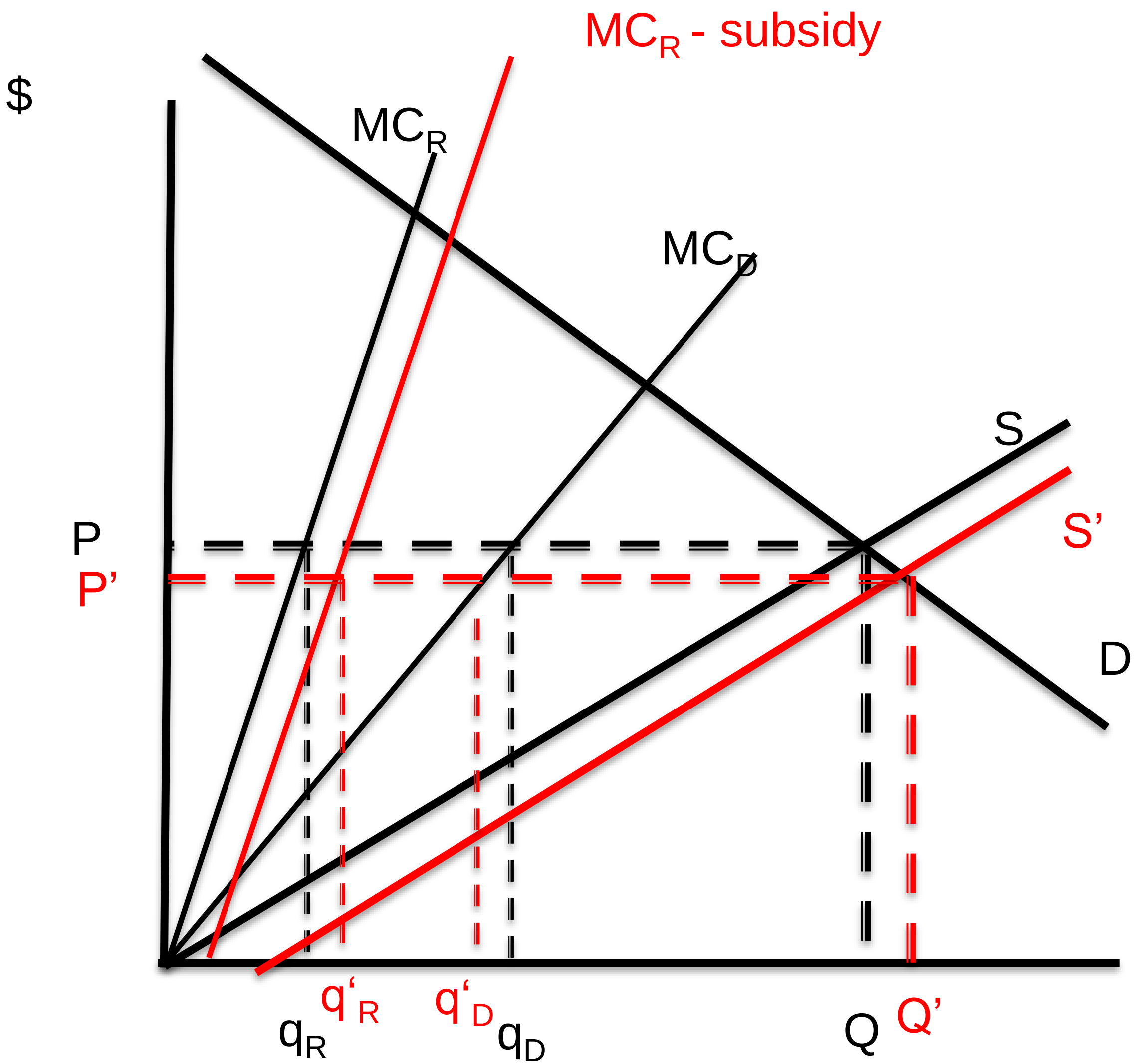
- Two sources of electricity, renewable (R), and dirty (D)
- Horizontal sum to get the aggregate supply curve
- This intersects with downward sloping demand to determine price P
- Which in turn determines how much each technology produces

How does a tax on carbon affect energy consumption?



- Now imagine we tax coal at it's social cost.
- This shifts it's supply curve up
- This shifts the aggregate supply curve out
- Which gives us new prices and quantities
  - Higher MC reduces coal supply
  - The higher price increases renewable supply
  - But total consumption declines
- Note this raises tax revenue = q'D * tax

What if we try to achieve the same outcome by subsidizing renewables?



- Let's pick a subsidy that gives the same q'R at the old price
- This shifts the aggregate supply curve **down**
- So total quantity Q must go up (people use more energy)
- Which in turn means that coal supply is higher than with the tax (but still lower than the baseline)
- Note that unlike the tax, we also have to **spend** subsidy cost q'R * subsidy
    - Opposite of the double dividend

Taxes vs subsidies summary

- Market failure due to coal externality
- When we internalize this externality, we use less coal. Some coal users switch to substitutes

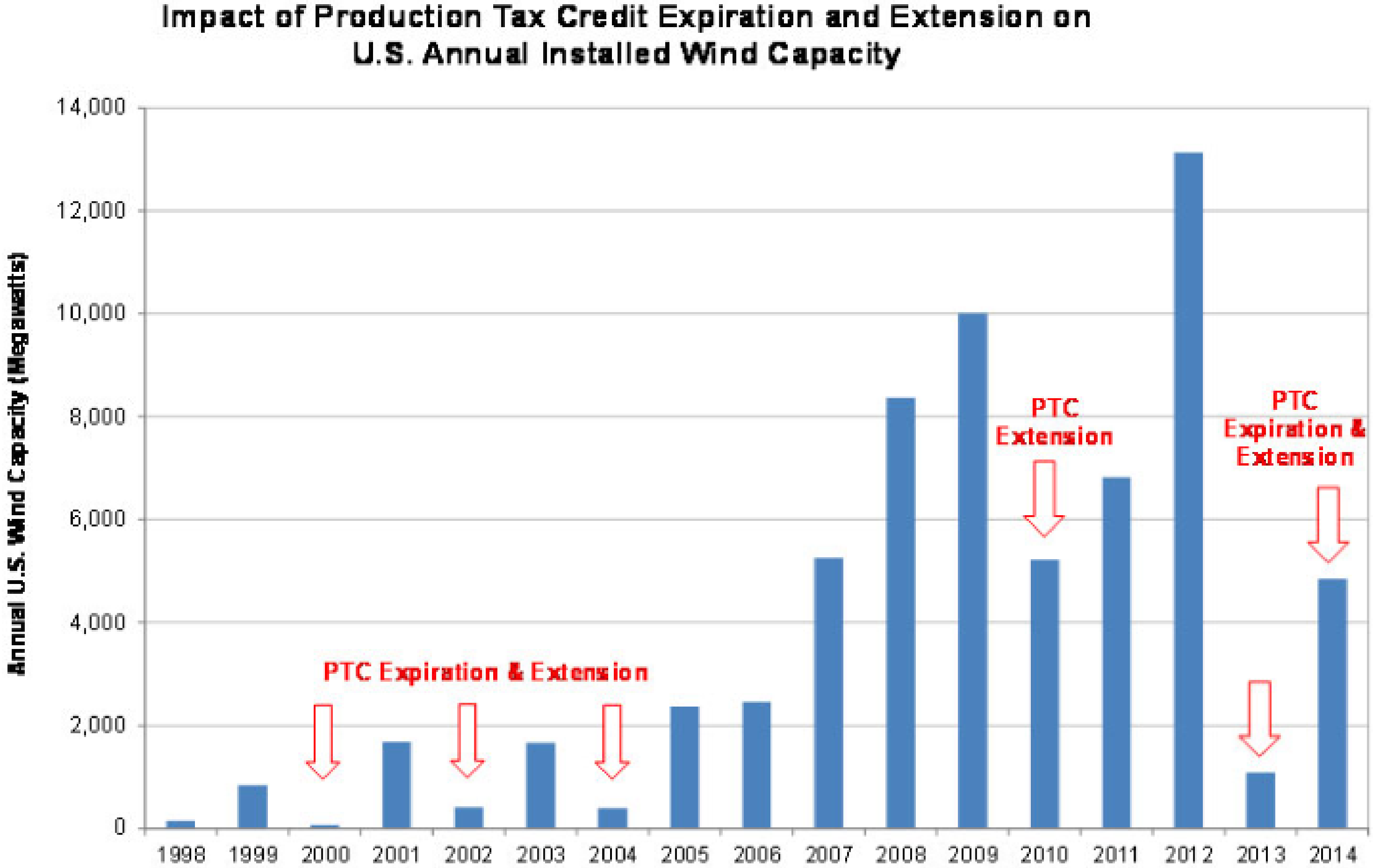
- Politically, it is appealing to try to just jump to this outcome by subsidizing clean energy
- But this actually *subsidizes* energy (with no corresponding externality justification)
  - Coal consumption will go down, but will still be above the social optimum
  - Plus we have to raise tax revenue to pay for the subsidy. This has DWL

What should we be subsidizing?

Production tax credits

- Originally enacted as part of the Energy Policy Act of 1992
- Provides wind operators a $23 tax credit for each MWh generated during first 10 years of operation
- How does a tax credit work?
- Why do we use tax credits instead of subsidies?
    - political?

Congress has allowed the PTC to lapse 6 times



How should we think about the impact of these lapses?
How much more wind would we have if the PTC had never lapsed?

Alternative to the PTC: Capital subsidies

- 2009 ARRA introduced a new subsidy type that targeted wind investment rather than electricity output
  - 1603 grant program
- Initially proposed in January 2009 during ARRA negotiations
  - Motivated by concern over limited tax equity
- Cash payment for 30% of capital costs
- Firms choose PTC or §1603 grant

- Is this shift from output subsidies to input subsidies good public policy?

Investment versus Output Subsidies: Implications of Alternative Wind Power Incentives

Joseph Aldy[1] Todd Gerarden[2] Richard Sweeney[3]

[1]Harvard Kennedy School

[2]Cornell Dyson

[3]Boston College

Broader Motivation

- Government often has choice between subsidizing inputs or outputs
  - LIHTC vs. Section 8 housing vouchers
  - Subsidize fertilizer or farmland vs. crop prices
  - R&D grants/tax credits vs. innovation prizes
  - Renewable capacity vs. renewable generation
- Policy objective is typically related to output
- What happens when we use capital subsidies to encourage output?
  - Intensive margin: Less production?
  - Extensive margin: More investment?
- Empirically rarely observe competing subsidies in same setting
  - 1603 was novel in that there was a simultaneous choice

Research Question

Are wind farms less productive if they receive an investment subsidy rather than an output subsidy?

Methods

- Use natural experiment introduced by ARRA
- Instrumental variables approach (fuzzy RD)
- Matching + "difference-in-differences"

Results

- Wind farms selecting the investment subsidy are 10-12% less productive than they would have been (under the PTC)
- Back of the envelope calculation suggests US paid 17% more per unit of wind output under 1603

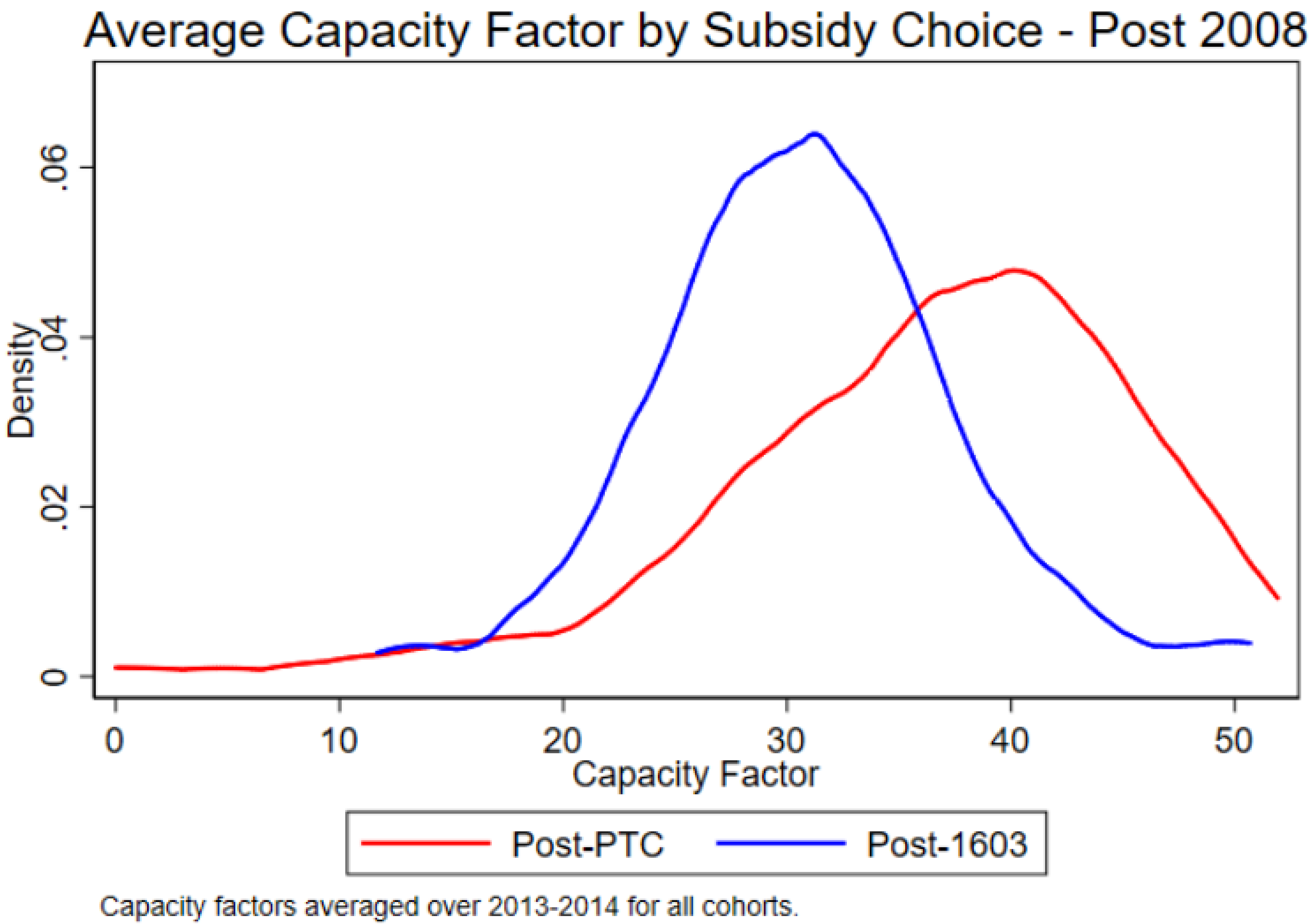
Economics of Wind Power

- Large initial capital investment
  - Siting, financing, procurement, etc.
  - Long lead times – average time in MISO queue > 3 years
- Once online, generation each period is a function of wind speeds
- ... and managerial / operational decisions
  - Is the wind turbine available?
    - downtime after failure
  - State of operational efficiency
    - maintenance frequency and quality
  - McKinsey (2008) - "improved O&M could account for a nearly 20% increase in the equity IRR"
- Marginal effort can increase performance

Data

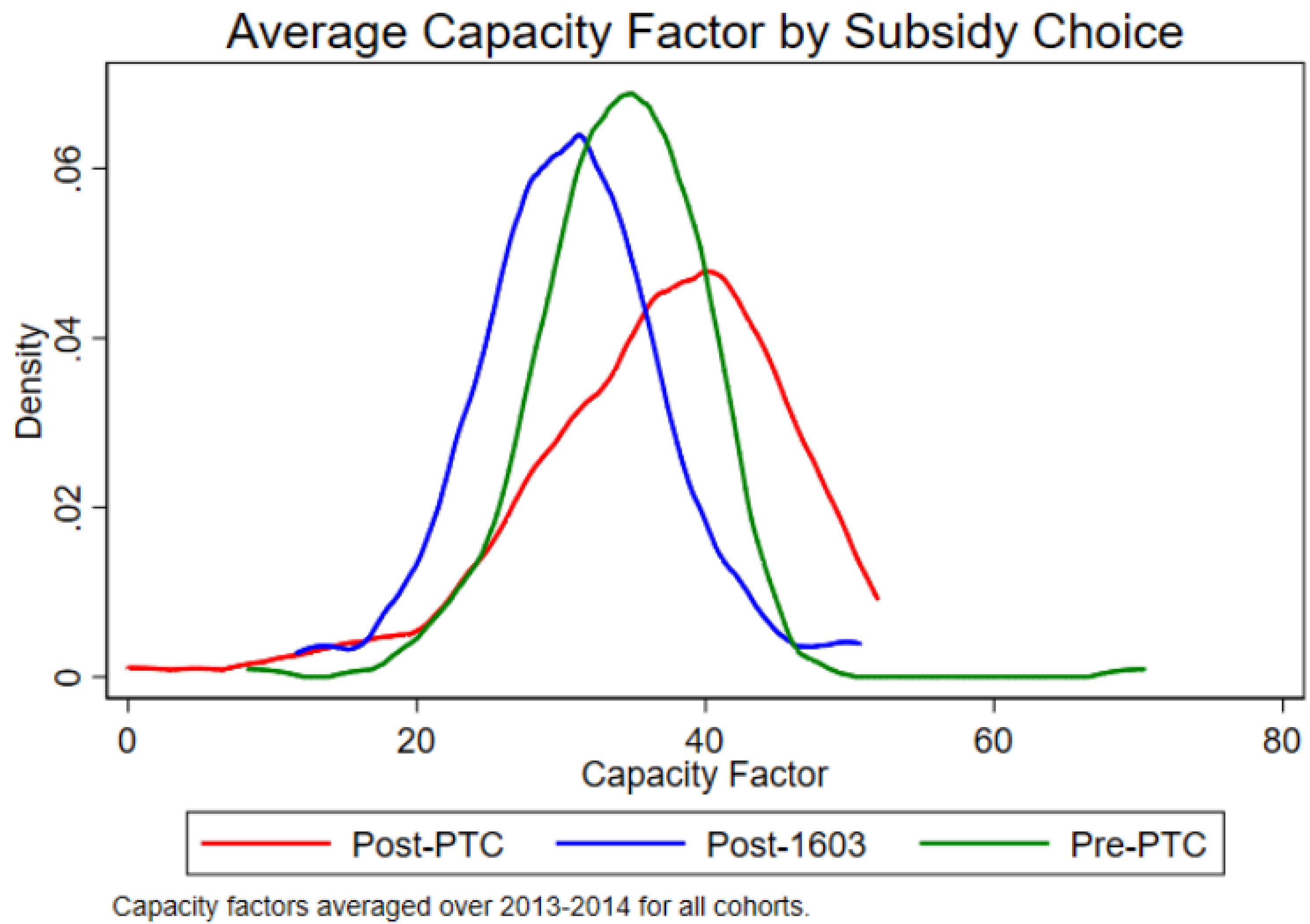
- **EIA Form 860:** plant characteristics
- **EIA Form 923:** monthly generation
- **Department of Treasury:** §1603 cash grant information
- **3TIER:** hourly windspeeds by location
- **American Wind Energy Association:** turbine info and offtake type

Empirical change: Subsidy is *selected* (naïve comparison biased)



Number of plants: 111 Post PTC, 205 Post 1603

Empirical change: Subsidy is *selected* (naïve comparison biased)



Number of plants: 258 Pre-PTC, 111 Post PTC, 205 Post 1603

Comparison of Post-ARRA Projects by Subsidy Choice

Projects entering 2009-2012

	PTC	1603	Difference	p-value
Nameplate Capacity (MW)	102.27	92.03	10.24	0.30
Turbine Size (MW)	1.84	1.91	-0.07	0.20
Design Wind Speed (MPH)	17.81	17.33	0.48	0.27
Regulated	0.23	0.03	0.20	0.00
IPP	0.68	0.89	-0.21	0.00
PPA	0.67	0.86	-0.19	0.00
Potential Capacity Factor	39.59	34.83	4.76	0.00
Capacity Factor	36.76	30.61	6.15	0.00
New Wind Farms	107	192		

Simple model in paper shows that with convex effort costs, selection depends on the *ratio* of expected output to capital costs.

Empirical Model

$$q_{it} = \delta D_i + \beta X_{it} + \nu_t + \epsilon_{it}$$

- q is capacity factor = (generation / capacity) X 100
- D indicator for §1603 grant receipt
- δ captures effect of capital subsidy
- X vector of wind farm characteristics
  - wind speed (hourly), contract type, age, etc

Empirical challenge: D_i was chosen with knowledge of ϵ_{it}

Research Design

- Ordinary Least Squares
  - Conflates selection and policy effects
- Instrumental Variables
  - Restrict sample to 2008-2009
  - Instrument for D with temporal discontinuity in §1603 eligibility
  - "Fuzzy RD" in time
- Matched "difference-in-differences"
  - Match post-ARRA plants to pre-ARRA plants
  - Compare difference within pairs across post-ARRA subsidy types

Instrumental Variables Overview

1. Restrict sample to narrow window around ARRA (2008-2009)
   - All projects planned before 1603 program was announced

2. Instrument for 1603 selection with date placed in service
   - First stage:

$$D_i = \gamma \cdot 1\left\{1603 \text{ eligible}\right\}_i + \xi X_i + \mu_i$$

   - Second stage:

$$q_{it} = \delta \hat{D}_i + \beta X_{it} + \nu_t + \epsilon_{it}$$

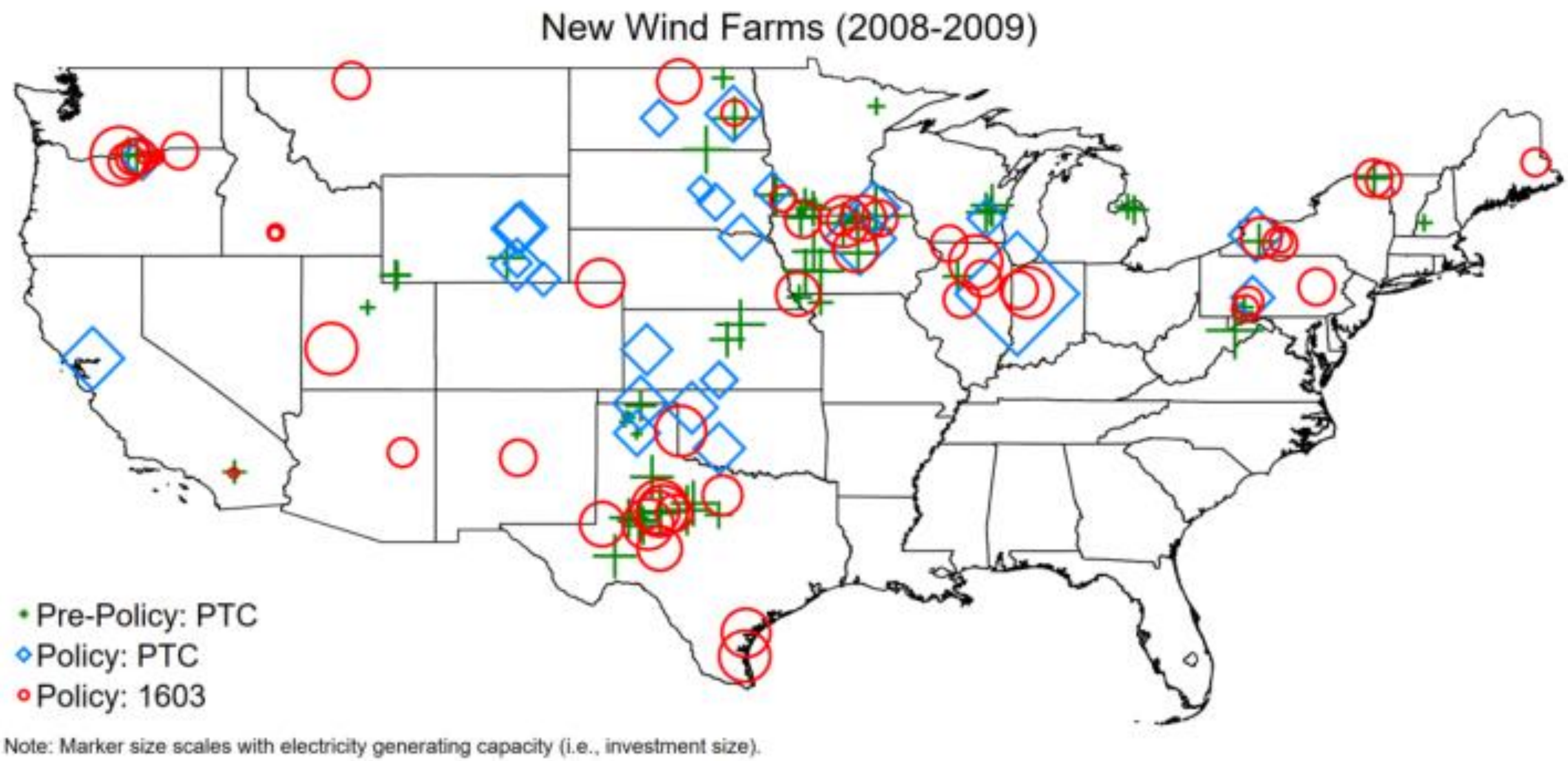
Exclusion restriction: instrument acts only through treatment

- no time trends
- RDD robustness check (but weak first stage)

IV Sample Summary Statistics

	2008	2009	Difference	p-value
Nameplate Capacity (MW)	85.97	110.73	-24.77	0.05
Turbine Size (MW)	1.82	1.81	0.00	0.95
Design Wind Speed (MPH)	18.01	17.50	0.52	0.29
Regulated	0.13	0.12	0.01	0.81
IPP	0.58	0.79	-0.21	0.01
PPA	0.75	0.74	0.01	0.85
Potential Capacity Factor	37.50	37.24	0.27	0.84
Capacity Factor	34.47	31.85	2.62	0.01
New Wind Farms	69	77		
1603 Recipients	0	51		

Many plants located in same state (state policy is captured with state FEs)



Instrumental Variables Results

	(1)	(2)	(3)	(4)
1603 Grant	-3.63***	-2.84***	-2.89**	-3.16***
	(0.90)	(0.83)	(1.24)	(1.17)
Regression Type	OLS	OLS	2SLS	2SLS
Controls	Y	Y	Y	Y
State FE	N	Y	N	Y
R-sq.	0.557	0.660	-	-
N	8752	8752	8752	8752
First-stage F-stat.			169	113

Controls: Regulated, PPA, IPP, Potential Capacity Factor, wind variance, and log capacity. Standard errors clustered at the plant level presented in parentheses.

Average 1603 Plant Capacity Factor ~ 30

Preferred estimate ~ 10% reduction

What Was the Net Impact of the 1603 Program?

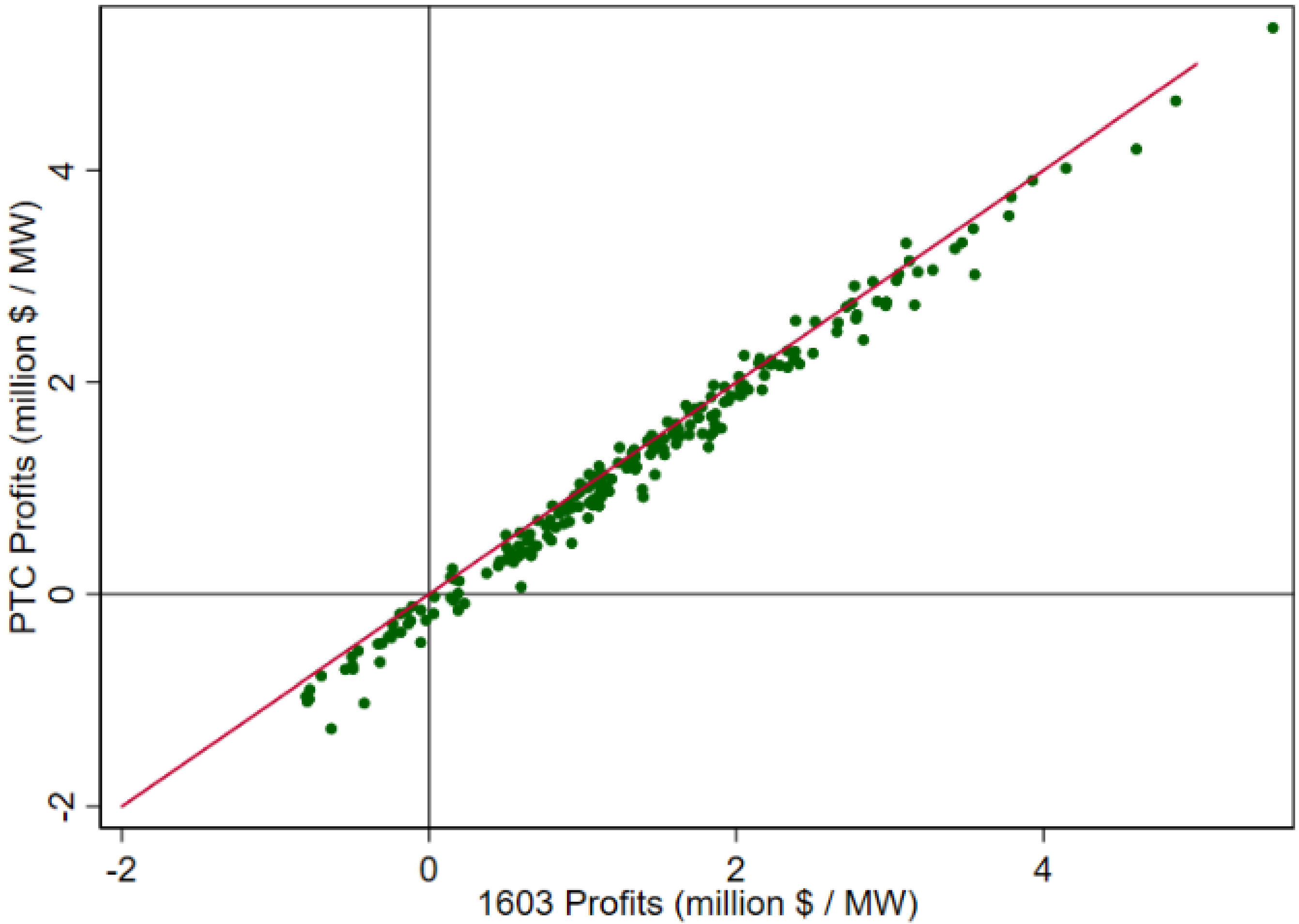
- 1603 plants produced less ***conditional on operating***
- However, the program may have encouraged entry
- We do two things to evaluate whether this was the case:
  1. look for extensive margin selection in the time series
  2. check if 1603 plants appear profitable under PTC counterfactual

Steps for Estimating Profits Under Each Subsidy

- Predict lifetime output (25 years) Details
- Counterfactual capacity factor 3.3pp higher for first 10 years
- Resale Prices from EIA and AWEA PPA information
  - Monthly average REC prices from Marex Spectrom
  - Operating costs assumed 9 $/MWh
- (real) Discount rate (5%)
  - PTC revenue deflated by assumed 8% tax equity yield
- Investment costs from 1603 grant awards

Very few plants look “marginal” to the subsidy

Figure 5: PTC Profits vs 1603 Profits for 1603 Recipients



With few marginal plants, 1603 Grant cost more and generated less wind power

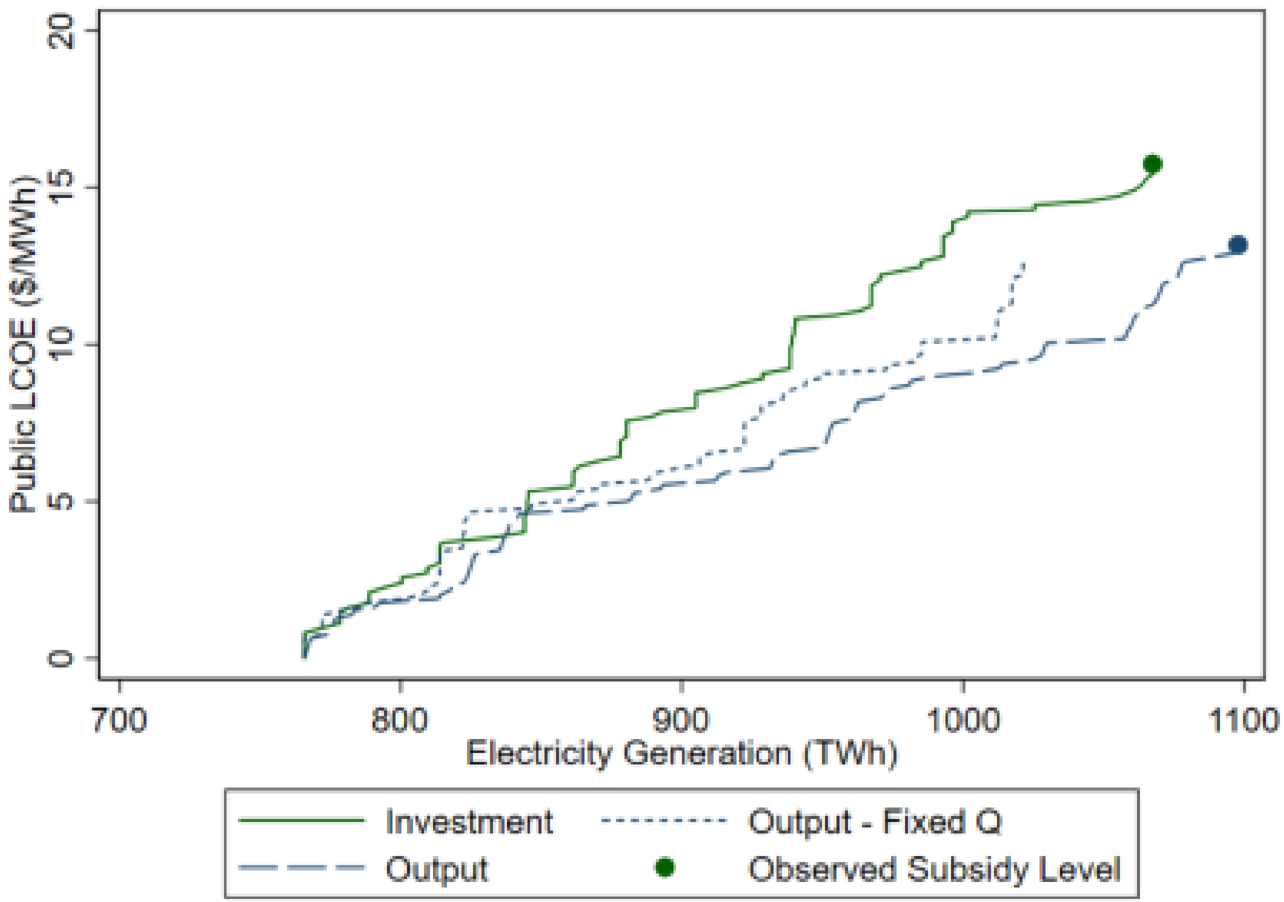
Table C.1: Estimated Subsidy by Group

Group	N	1603 Output (MMWh)	1603 Subsidy ($M)	1603 Subsidy ($/MWh)	PTC Output (MMWh)	PTC Subsidy ($M)	PTC Subsidy ($/MWh)
Always Profitable	176	562	17,564	31.24	596	17,674	29.67
Marginal	6	15	674	43.58	17	599	35.97
Never Profitable	29	103	3,488	34.00	109	3,401	31.07

Estimated electricity generation and subsidy for 1603 recipients, divided into three groups depending on their estimated profitability under the 1603 grant and the PTC. Output and Subsidy are in net present value terms, and Subsidy per MWh is constructed by taking the ratio of the sum of discounted subsidy expenditures to the sum of discounted electricity generation as in the definition of the LCOE. The first set of numbers correspond to outcomes under the subsidy they chose. The second set presents a counterfactual for the subsidy they did not choose.

What if we switched investment subsidies?

(b) All Plants



Conclusion

The efficient policy would price emissions, but policymakers reveal preference for subsidizing substitutes instead

This introduces several distortions

- investment subsidies: reduce inframarginal effort, distort input mix
- output subsidies: negative prices
- both: emissions displacement unclear

We exploit a novel policy to evaluate the implications for wind energy

Highlights generic tradeoff between program efficiency and expansion

- Imperfectly targeted investment subsidies can reduce the operational efficiency of inframarginal recipients

Subnational renewable policy

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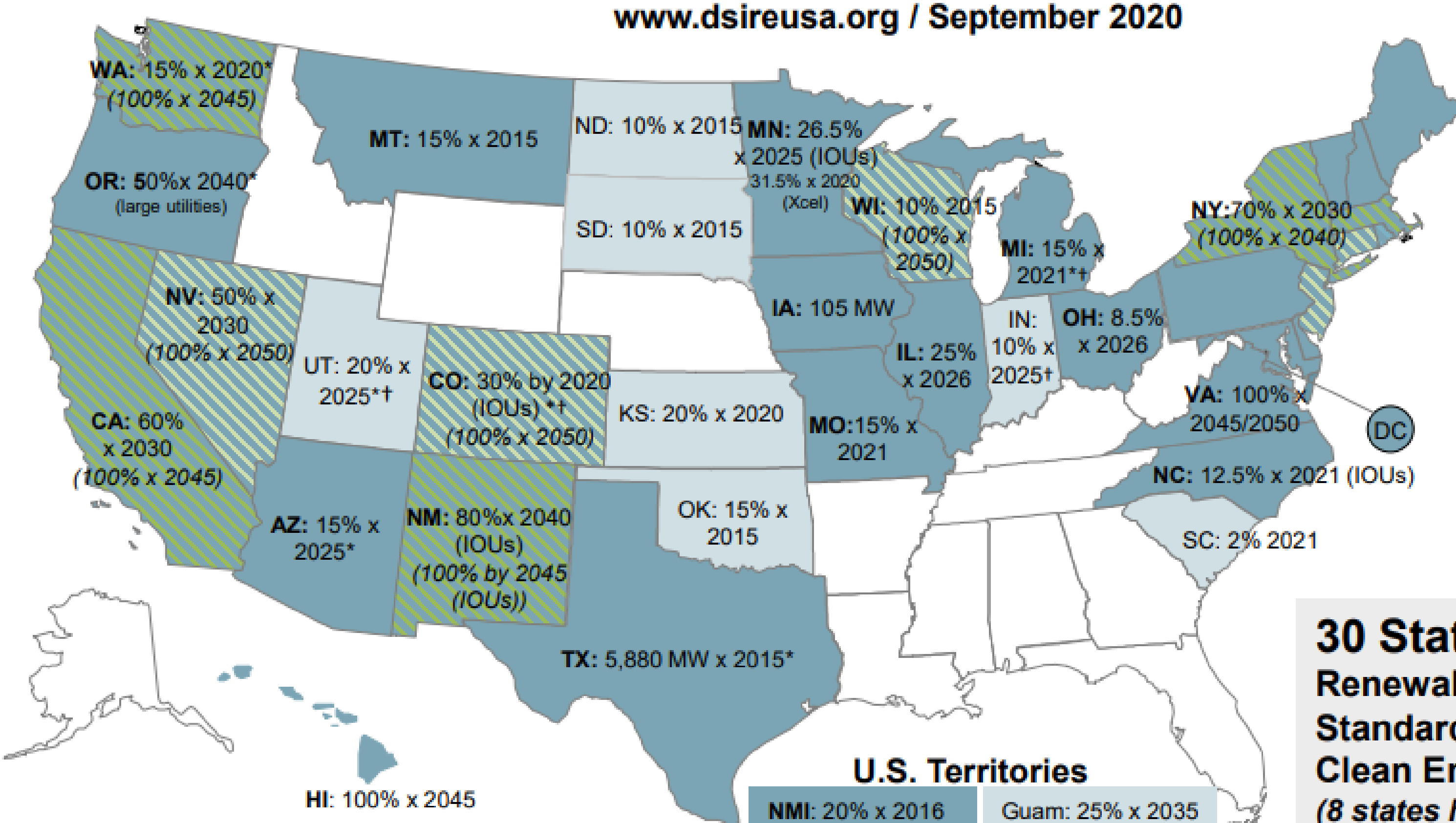


ME: 100% x 2050

NH: 25.2% x 2025

VT: 75% x 2032

MA: 35% x 2030 + 1% each year thereafter (new resources) 6.7% x 2020 (existing resources) *(80% x 2050)*

RI: 38.5% x 2035; 100% x 2030 Goal

CT: 40% x 2030; *(100% x 2040)*

NJ: 50% x 2030; *(100% x 2050)*

PA: 18% x 2021†

DE: 25% x 2026*

MD: 50% x 2030

DC: 100% x 2032

U.S. Territories

NMI: 20% x 2016	Guam: 25% x 2035
PR: 100% x 2050	**USVI:** 30% x 2025

30 States + DC have a Renewable Portfolio Standard, 5 states have a Clean Energy Standard
(8 states have renewable portfolio goals, 5 states have clean energy goals)

- Renewable portfolio standard
- Renewable portfolio goal
- *Clean energy standard*
- *Clean energy goal*

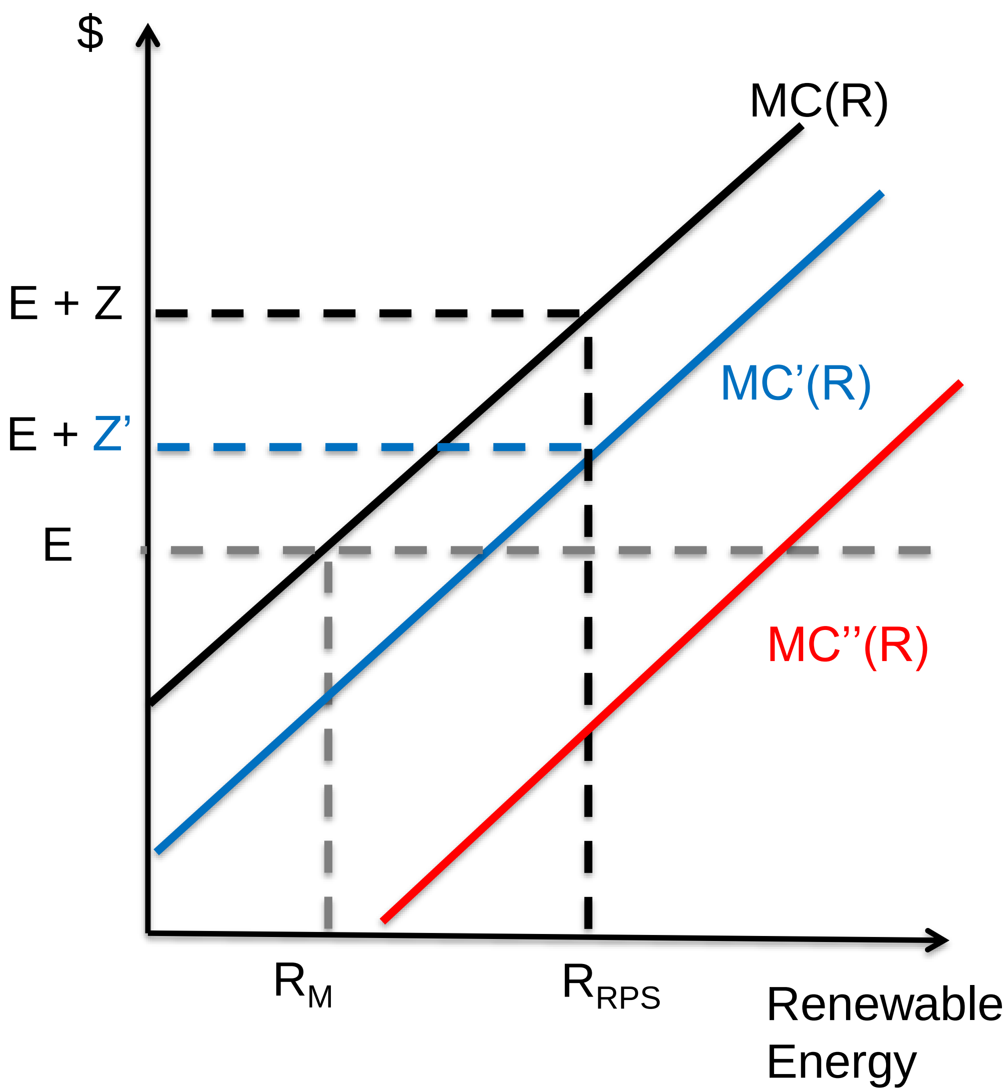
* Extra credit for solar or customer-sited renewables

† Includes non-renewable alternative resources

How renewable portfolio standards work

- An RPS is a mandate that a certain share **(s)** of electricity come from renewable sources
- An RPS of 20% mandates that R/(R+D)=s=.2
  - Where R = renewable; D = dirty generation
- Operationally:
  - Every time a renewable plant generates power it creates a credit (called a "REC")
  - Every time a dirty plant generates power it has to procure **s/(1-s)** RECs at price Z
  - Where Z floats to clear the market

How renewable portfolio standards work



- E is the price of electricity
  - Without policy, quantity of renewable energy would be R_M
- State policy mandates R >= R_{RPS}
  - To achieve goal, polluters pay permit price Z
- What happens if renewable technology improves, and costs come down?
  - If the RPS remains unchanged, the price Z will drop, by the quantity of renewables will remain unchanged.
- If costs continue to decline, so that R_rps is profitable *without* the subsidy, then the permit price goes to zero.
  - This is how you can tell if an RPS is "binding" or not

How much do these RPS policies cost?

Do Renewable Portfolio Standards Deliver Cost-Effective Carbon Abatement?*

Michael Greenstone[†]
Ishan Nath[‡]

November 12, 2021

Abstract

The most prevalent and perhaps most popular climate policies in the U.S. are Renewable Portfolio Standards (RPS) that mandate that renewable sources, such as wind and solar, produce a specified share of electricity, yet little is known about their efficiency. Using a comprehensive data set and a difference-in-differences style research design, we find that electricity prices are 11% higher seven years after RPS passage and carbon emissions are 10-25% lower. Point estimates suggest that the cost per ton of CO2 abatement ranges from \$60-\$300, though these estimates do not account for possible future cost reductions due to RPS-induced technological progress.

States adopted RPS at different times

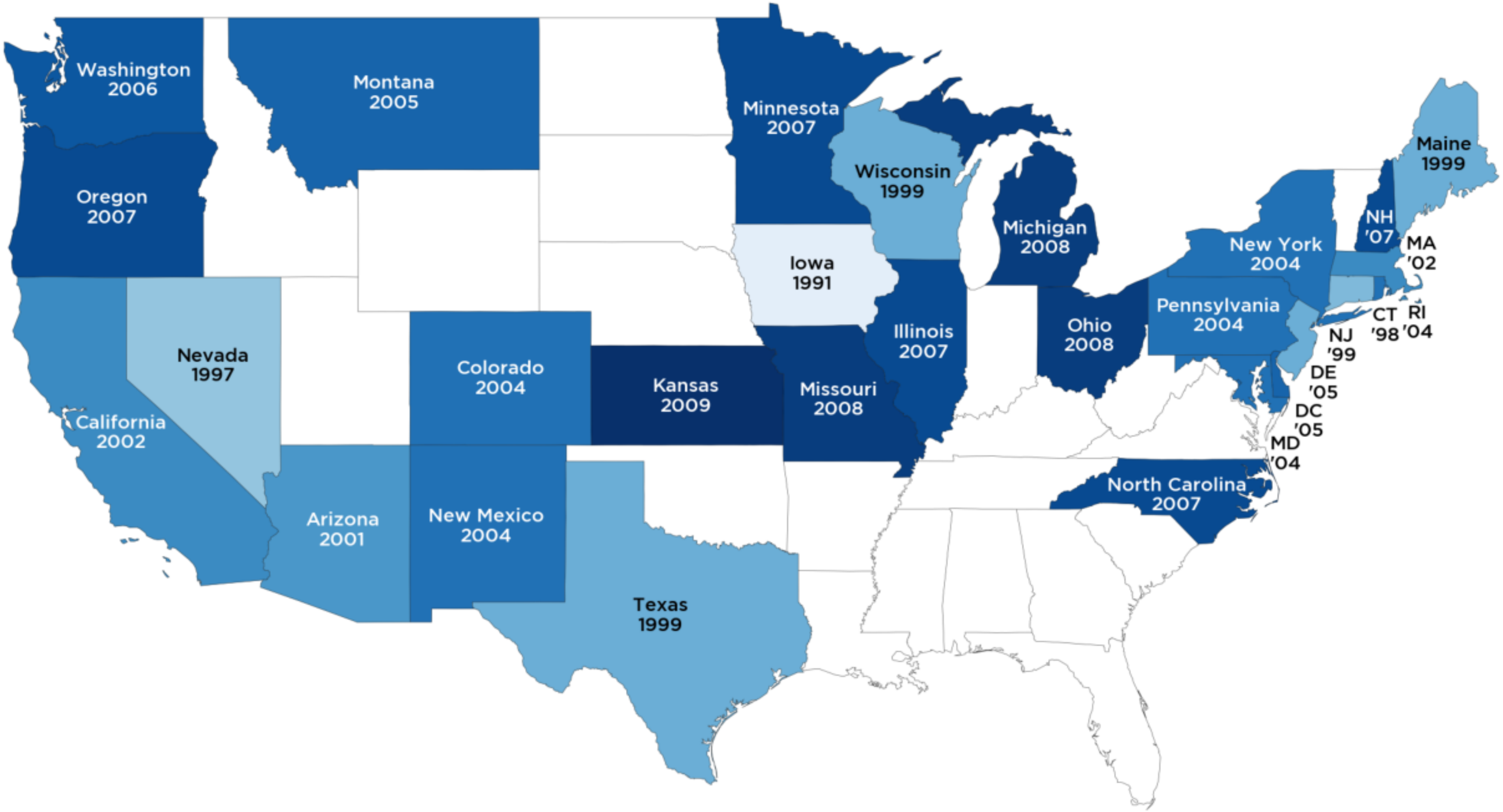
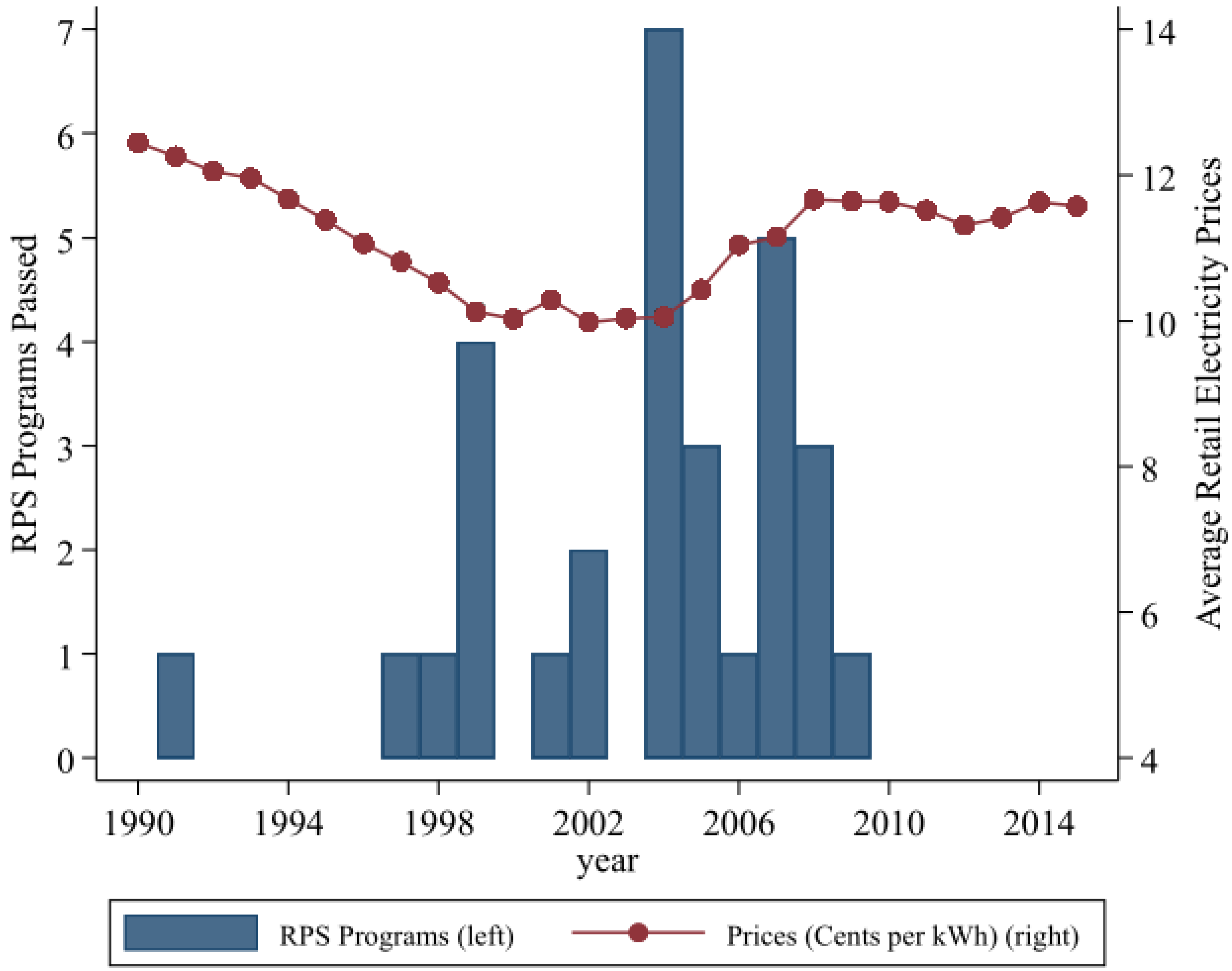
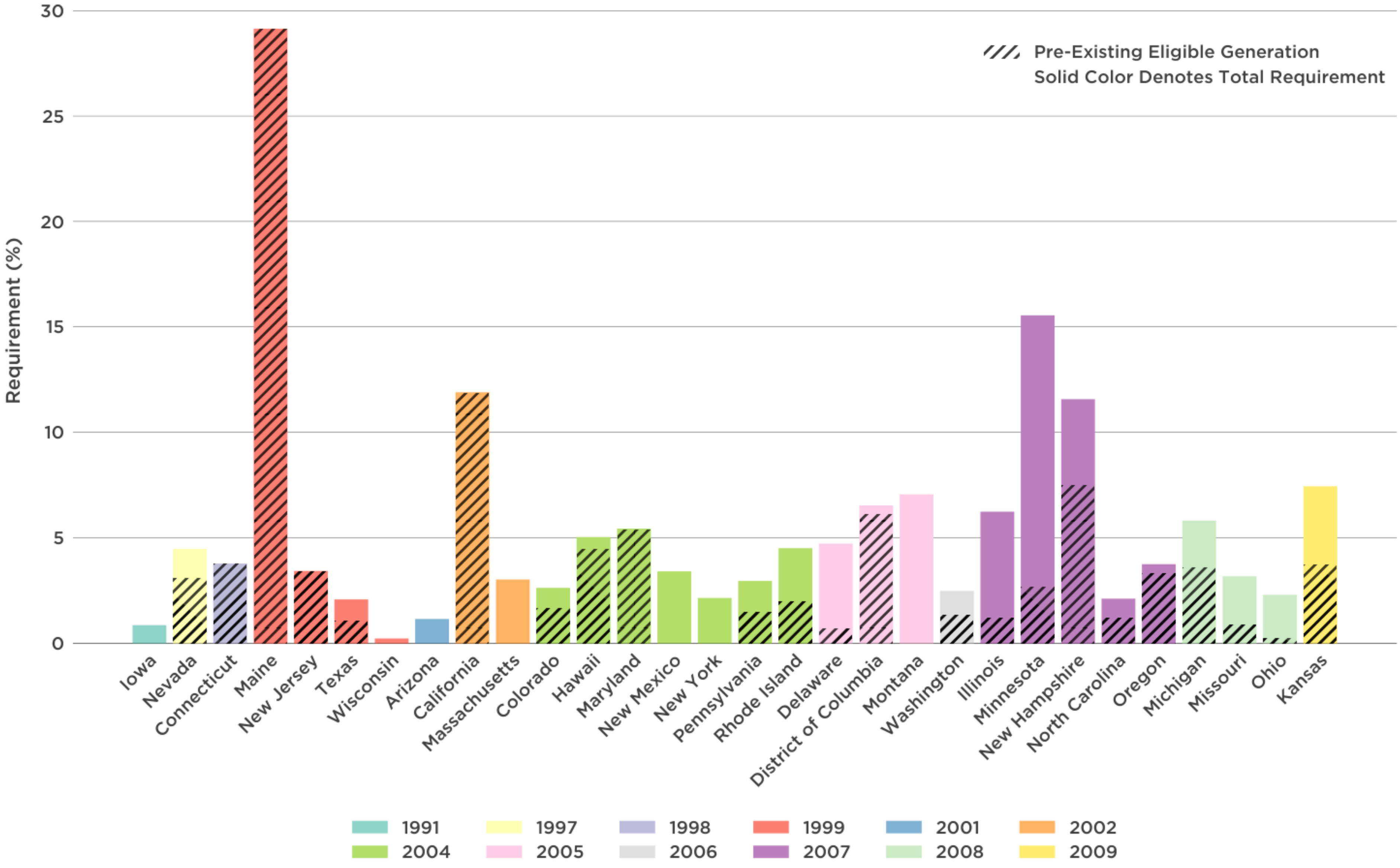


Figure 2: Number of RPS Programs Newly Passed into Law, by Year



Notes: Average national retail electricity prices are shown in constant 2019 dollars and taken from the EIA. We construct data on new RPS legislation passage from a combination of state legislative documents, state government websites, and summaries from the U.S. Department of Energy.

Figure 3: RPS Total and Net Requirements, by State



Empirical strategy

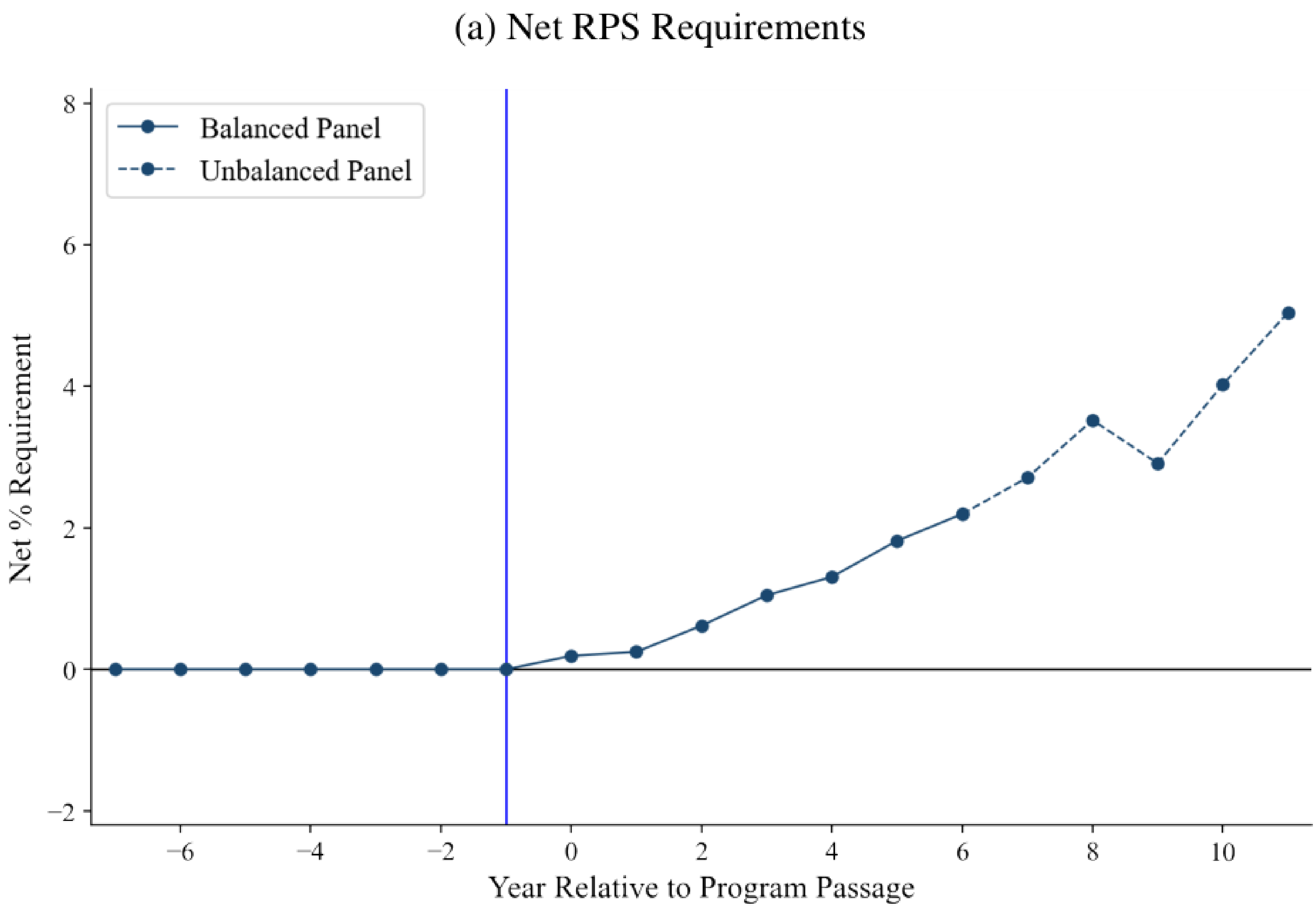
Our empirical approach begins with an event-study style equation:

$$y_{st} = \alpha + \sum_{\tau \in \{-19,\ldots,18\} \setminus \{-1\}} \sigma_\tau D_{\tau,st} + X_{st} + \gamma_s + \mu_t + \varepsilon_{st}, \tag{7}$$

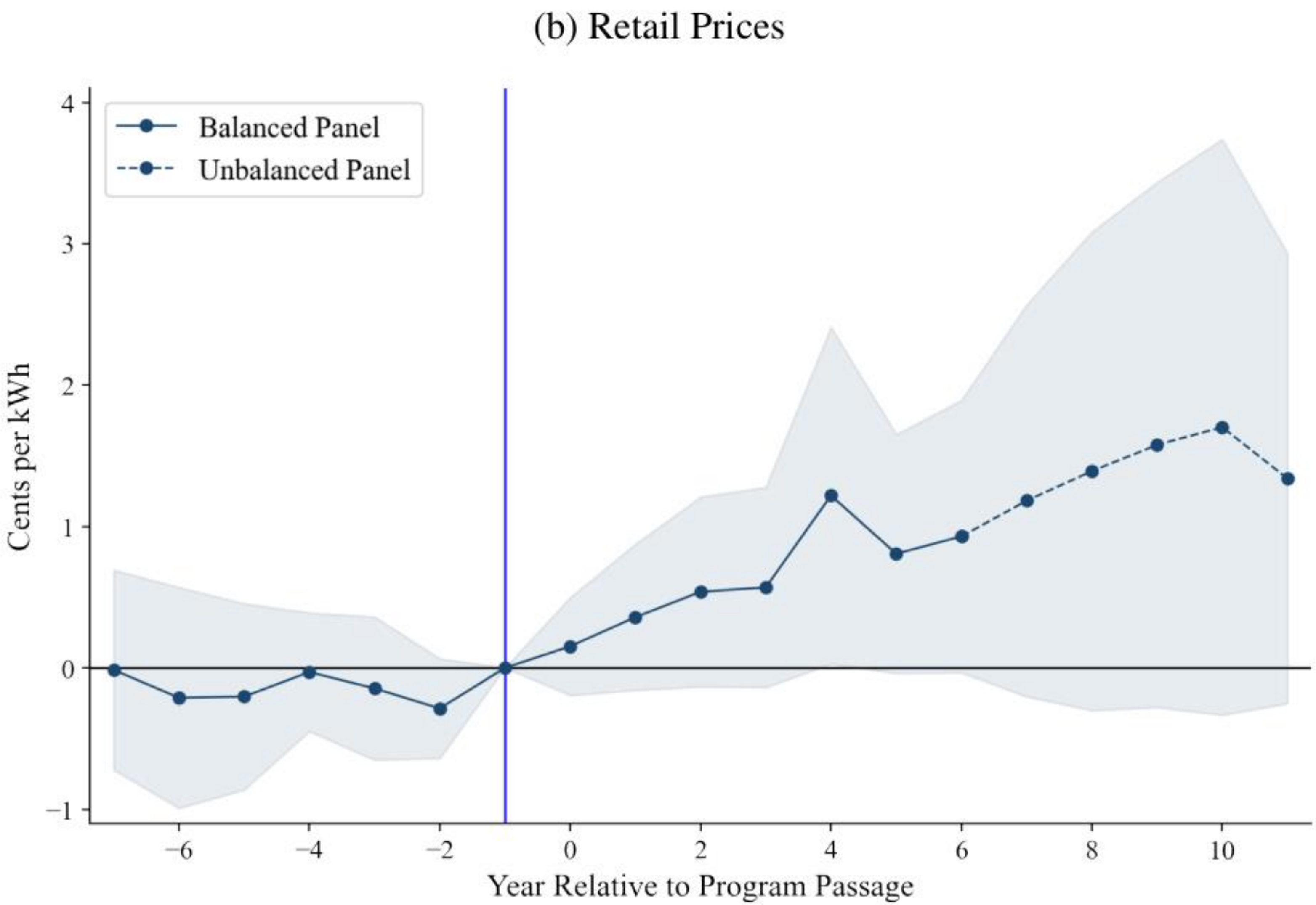
where y_{st} is an outcome of interest in state s in year t. We include state fixed effects, γ_s, to control for any permanent, unobserved differences across states. Year fixed effects, μ_t, non-parametrically control for national trends in the outcome of interest. X_{st} includes time-varying indicators for the presence of energy efficiency resource standards, restructuring, net metering programs, green power purchasing programs, public benefits funds, and NO_x trading programs, along with the continuous control variable measuring the intensity of Clean Air Act regulation. The variables $D_{\tau,st}$ are separate indicators for each year τ relative to the passage of an RPS law, where τ is normalized to equal zero in the year that the program passed; they range from -19 through 18, which covers the full range of τ values.[16] For states that never adopt an RPS program, all $D_{\tau,st}$ are set equal to zero. As non-adopters, they do not play a role in the estimation of the σ_τ's but they aid in the estimation of the year fixed effects, μ_t, as well as the constant, α.

The σ_τ's are the parameters of interest as they report the annual mean of the outcome variable in event time, after adjusting for state and year fixed effects, and the wide set of controls. An

Net increase in renewables (much smaller than gross statute)



Increase in retail prices



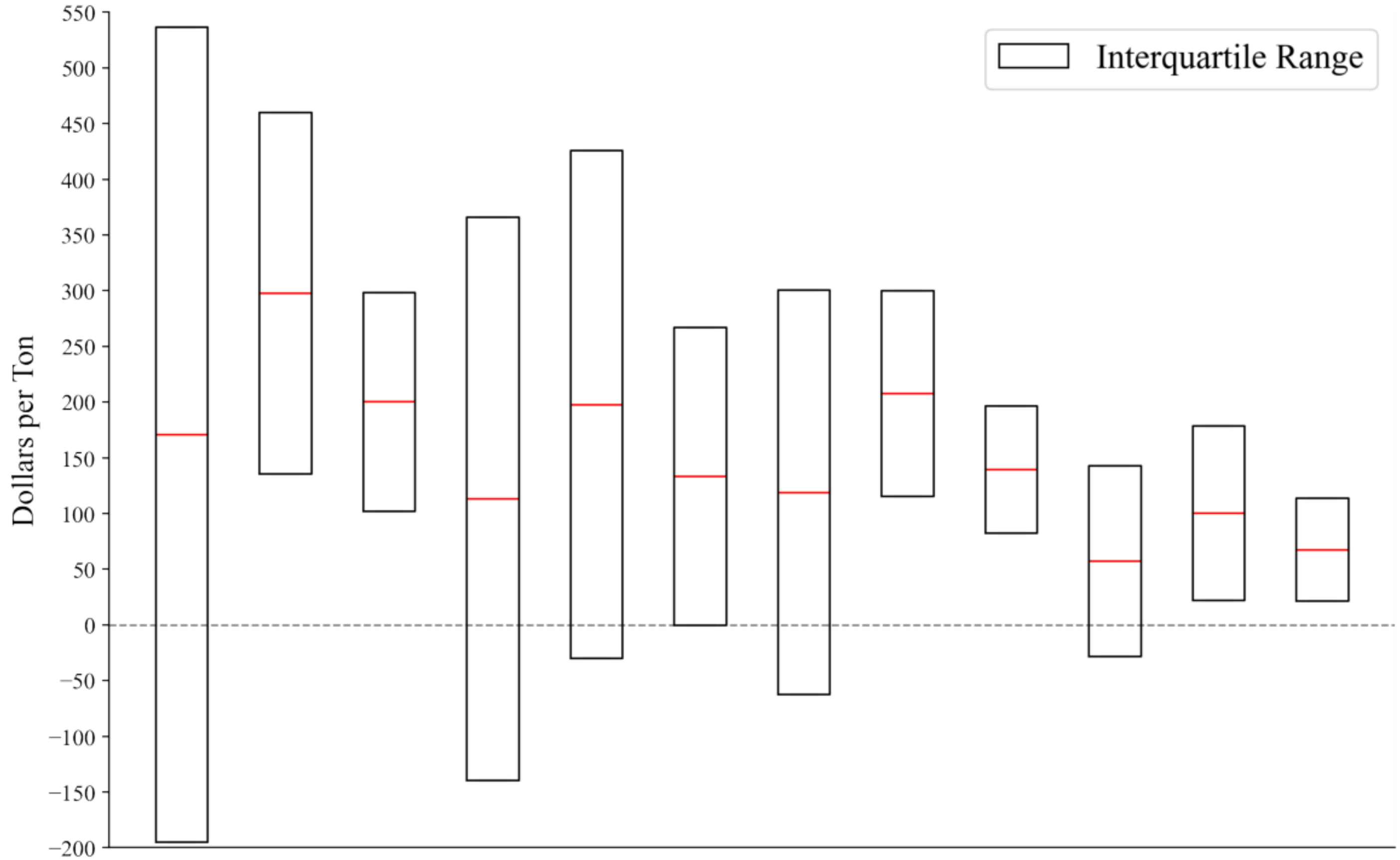
Find electricity prices are ~ 11% higher seven years after RPS passage

	Base Specification (1)	Continuous control for energy efficiency (2)	Exclude Hawaii (3)	Year-Region Fixed Effect (4)	Year-Division Fixed Effect (5)
Panel A: 7 Post-Passage Years, Balanced Sample					
Mean Shift (δ_3)	0.36	0.39*	0.28	0.49*	0.43
	(0.23)	(0.22)	(0.24)	(0.25)	(0.26)
Trend Break (β_3)	0.14*	0.16*	0.16*	0.10	0.09
	(0.09)	(0.09)	(0.09)	(0.08)	(0.08)
Effect of RPS 7 years after passage	1.22**	1.37**	1.23*	1.11**	0.99*
($6\beta_3 + \delta_3$)	(0.58)	(0.60)	(0.61)	(0.51)	(0.52)

$$
\begin{aligned}
y_{st} = {} & (\delta_0 + \beta_0 \tau_{st}) + (\delta_1 + \beta_1 \tau_{st}) * \mathbb{1}(-19 \leq \tau \leq -8)_{st} * \mathbb{1}(\text{RPS} = 1)_s \\
& + (\delta_2 + \beta_2 \tau_{st}) * \mathbb{1}(7 \leq \tau \leq 18)_{st} * \mathbb{1}(\text{RPS} = 1)_s \\
& + (\delta_3 + \beta_3 \tau_{st}) * \mathbb{1}(0 \leq \tau \leq 6)_{st} * \mathbb{1}(\text{RPS} = 1)_s \\
& + X_{st} + \gamma_s + \mu_t + \varepsilon_{st}. \qquad (8)
\end{aligned}
$$

RPS policies reduce CO2, but at a cost that probably exceeds the social cost of carbon

Figure 6: Cost per Ton of CO_2 Abatement



Price Specification												
BA Aggregation (Sales Weighted)	✓			✓			✓			✓		
BA Aggregation (State-Count Weighted)		✓			✓			✓			✓	
State			✓			✓			✓			✓

How do these state policies interact with federal subsidies?

- Federal production tax credit pays wind farms \$23/MWh
  - Almost a 50% increase in revenue

- Solar plants have 30% of their investment costs paid for by the federal investment tax credit.

- These policies are very expensive
  - Recent PTC extension scored at about \$5 billion

- Are they doing any good?

Politics

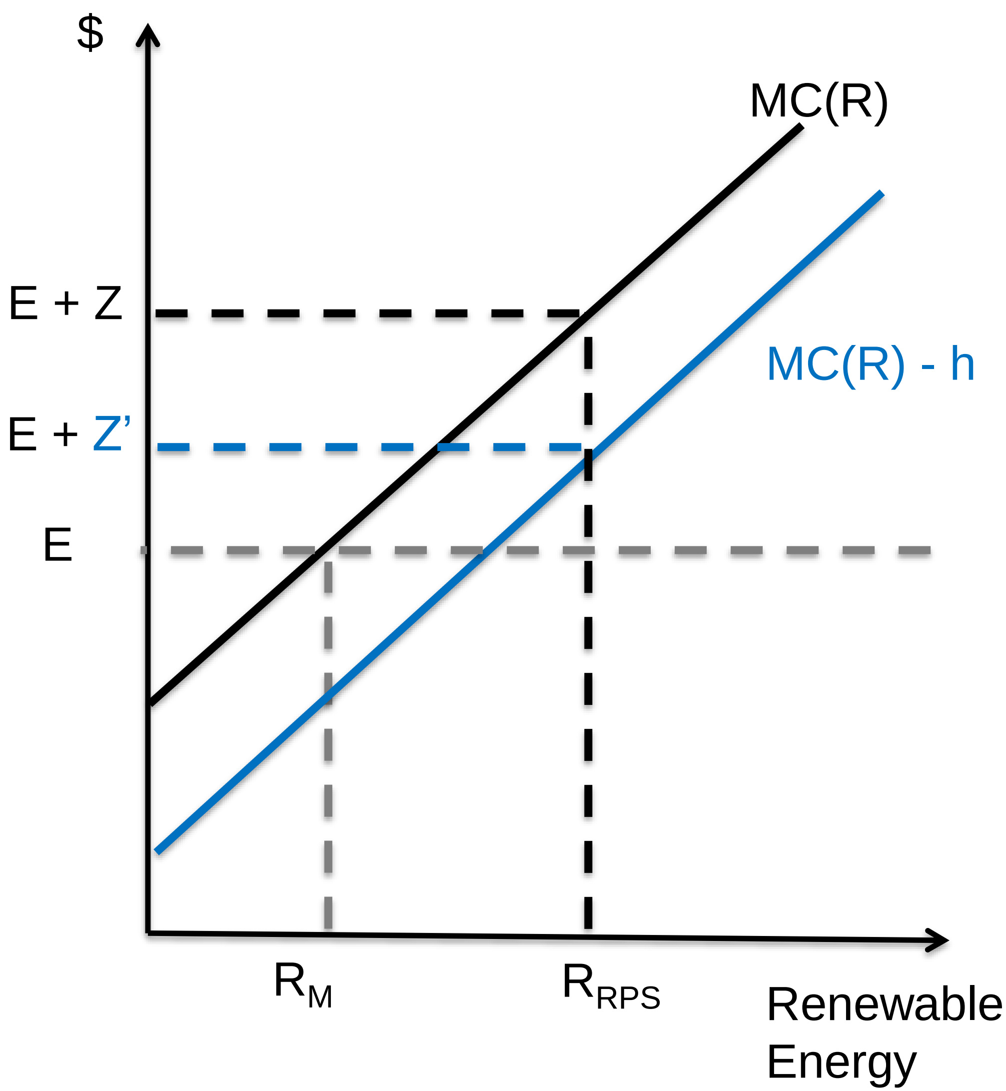
Renewable-Energy Backers Want 10-Year Tax Credits in Biden Plan

By Ari Natter
March 25, 2021, 2:00 AM EDT

- Solar power advocates lobby to be part of infrastructure deal
- White House is crafting proposal that could hit $3 trillion

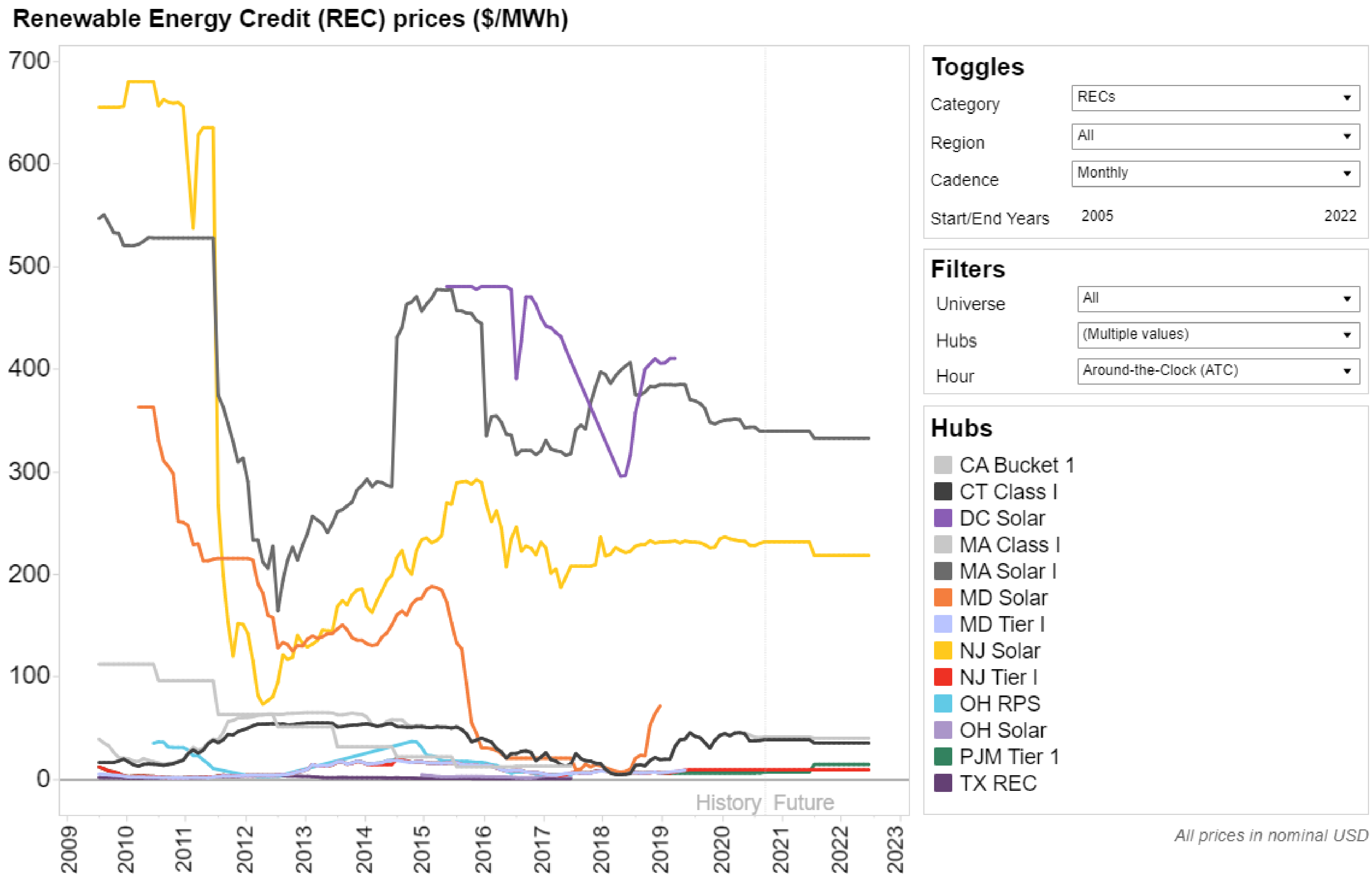
Construction workers unload a turbine blade at a wind farm in Encino, New Mexico. *Photographer: Cate Dingley/Bloomberg*

How do federal renewable subsidies affect RPS states?



- A federal subsidy reduces the marginal cost of renewable energy by **h**
- If MC – h intersects E to the left of R_{RPS} , the state policy still binds
  - Subsidy has no impact on the quantity of renewables in the state
- Only effect is to lower the permit price Z that polluters have to pay
  - So this is like a subsidy from federal taxpayers to polluters

(Current) REC prices suggest PTC marginal in some markets



What about “green” electricity packages?

Your Renewable Energy Mix Options:

Our green power program adds a small premium to your electric bill. For most households, it only adds $15-20 per month or 45-74 cents per day. Your total payments toward *New England GreenStart* and *New England Wind* are **100% federally tax-deductible**.

Your rate per kWh is determined by the renewable energy option you choose. You can select from two renewable energy options, which differ in price and content:

New England Wind℠

Biggest Impact

MIX	**100% wind power from Massachusetts wind turbines (Class I)**
RATE	**3.8 cents/kWh** in addition to your normal electric bill

New England GreenStart℠

MIX	**25% Massachusetts wind, solar and anaerobic digester gas (Class I)** **75% New England low-impact hydropower**
RATE	**2.4 cents/kWh** in addition to your normal electric bill

Other reasons for subsidies

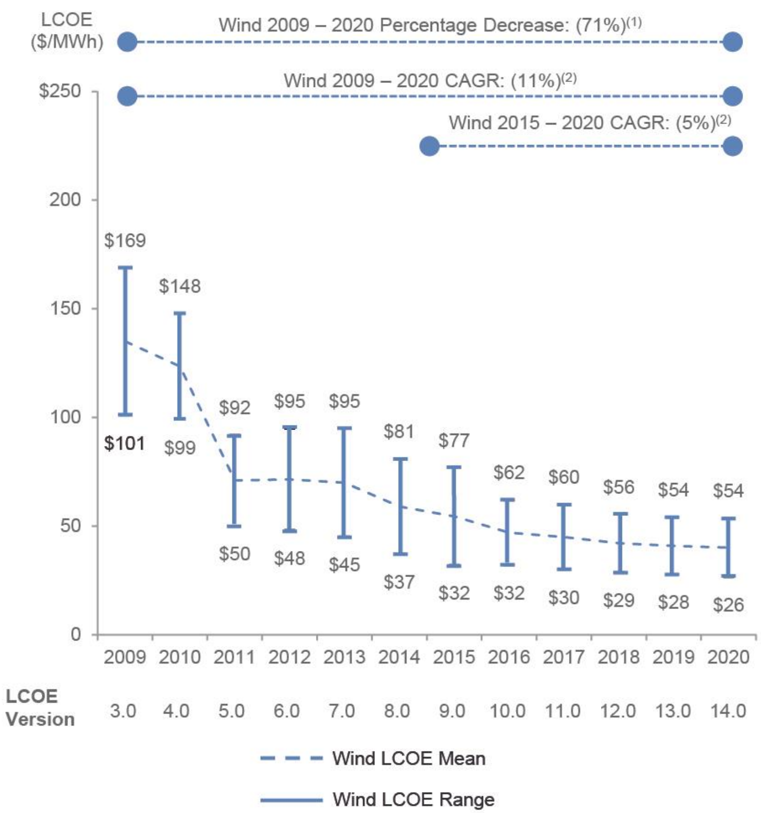
This was a VERY controversial paper

- Some critics complained about the estimation strategy or the data used
- But many argued that the exercise was fundamentally flawed.
- The authors estimated the impact of RPS policy on *current* renewable costs and emissions. What might this be missing?

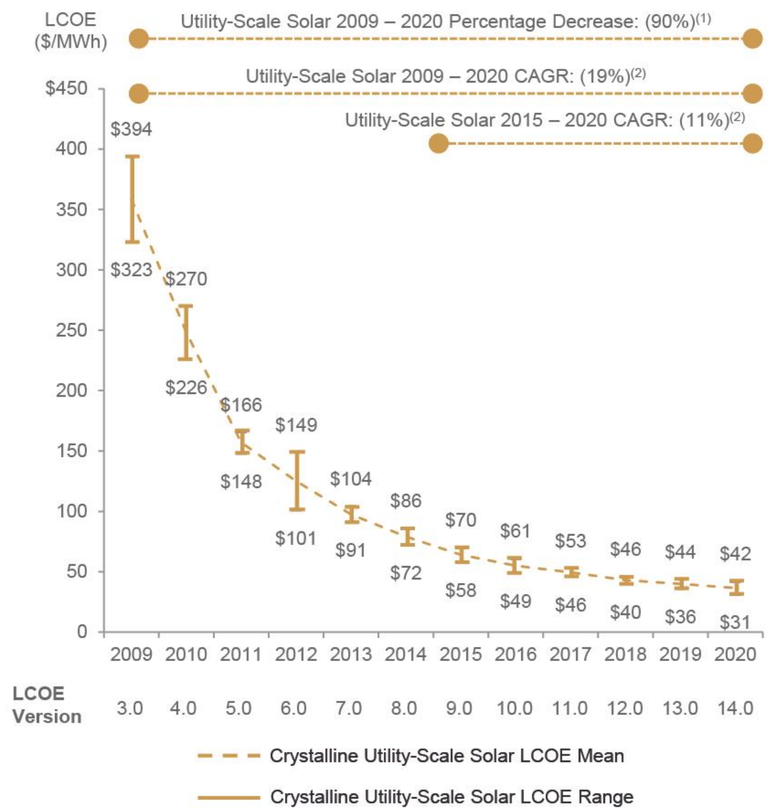
Levelized Cost of Energy Comparison—Historical Renewable Energy LCOE Declines

In light of material declines in the pricing of system components and improvements in efficiency, among other factors, wind and utility-scale solar PV have exhibited dramatic LCOE declines; however, as these industries have matured, the rates of decline have diminished

Unsubsidized Wind LCOE



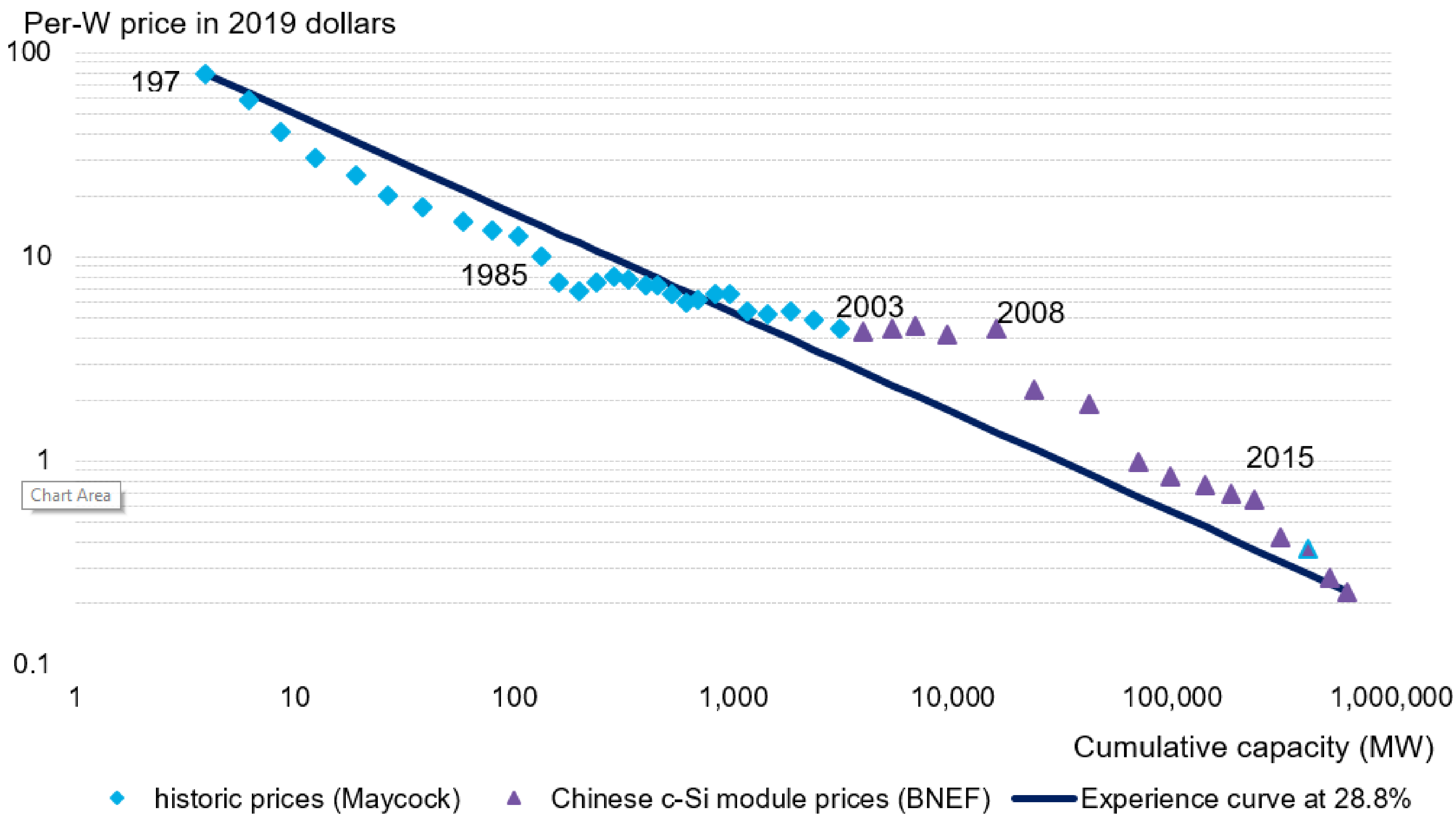
Unsubsidized Solar PV LCOE



Source: Lazard estimates.

(1) Represents the average percentage decrease of the high end and low end of the LCOE range.

(2) Represents the average compounded annual rate of decline of the high end and low end of the LCOE range.



Source: https://www.eia.gov/outlooks/steo/report/electricity.php

Learning-by-doing

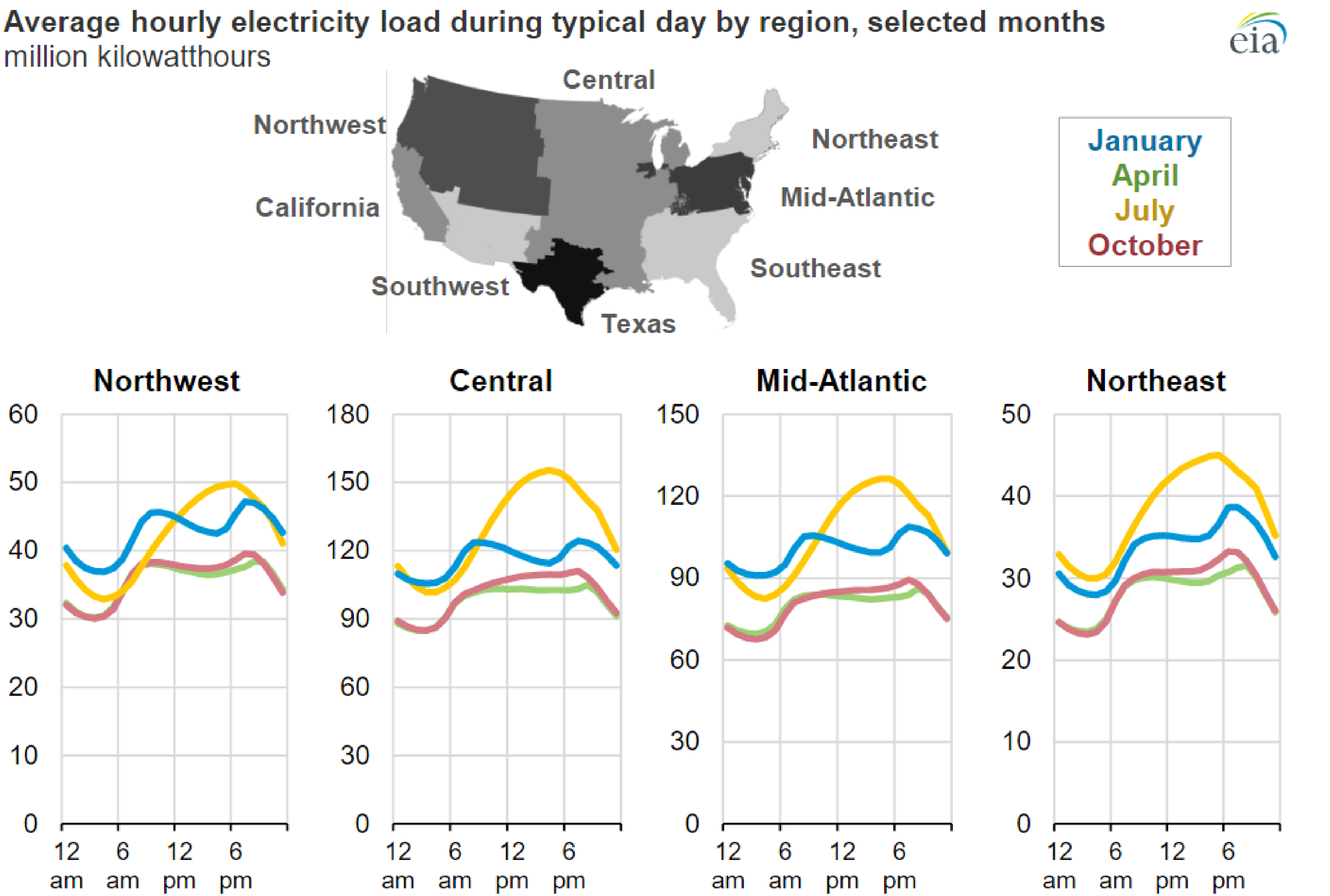
- Is surely happening. Has been documented in shipbuilding, airplanes, auto assembly plants.

- But, does that mean it should be subsidized?

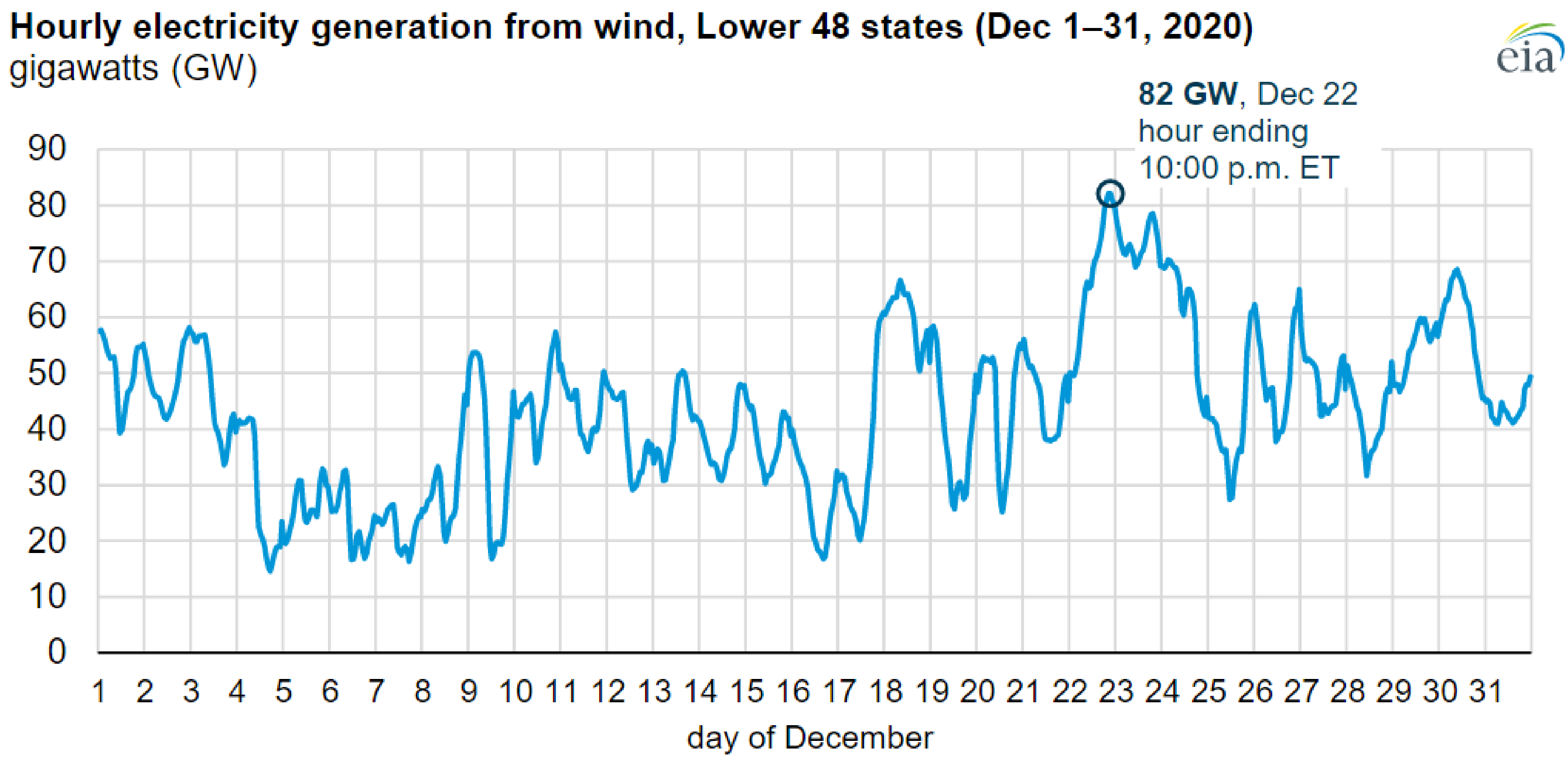
Backup

Dispatch issues

Primary constraints now are about integration with the grid



Wind is highly variable



Source: U.S. Energy Information Administration, *Hourly Electric Grid Monitor*

Solar more predictable (but not perfect); inherent variability though.

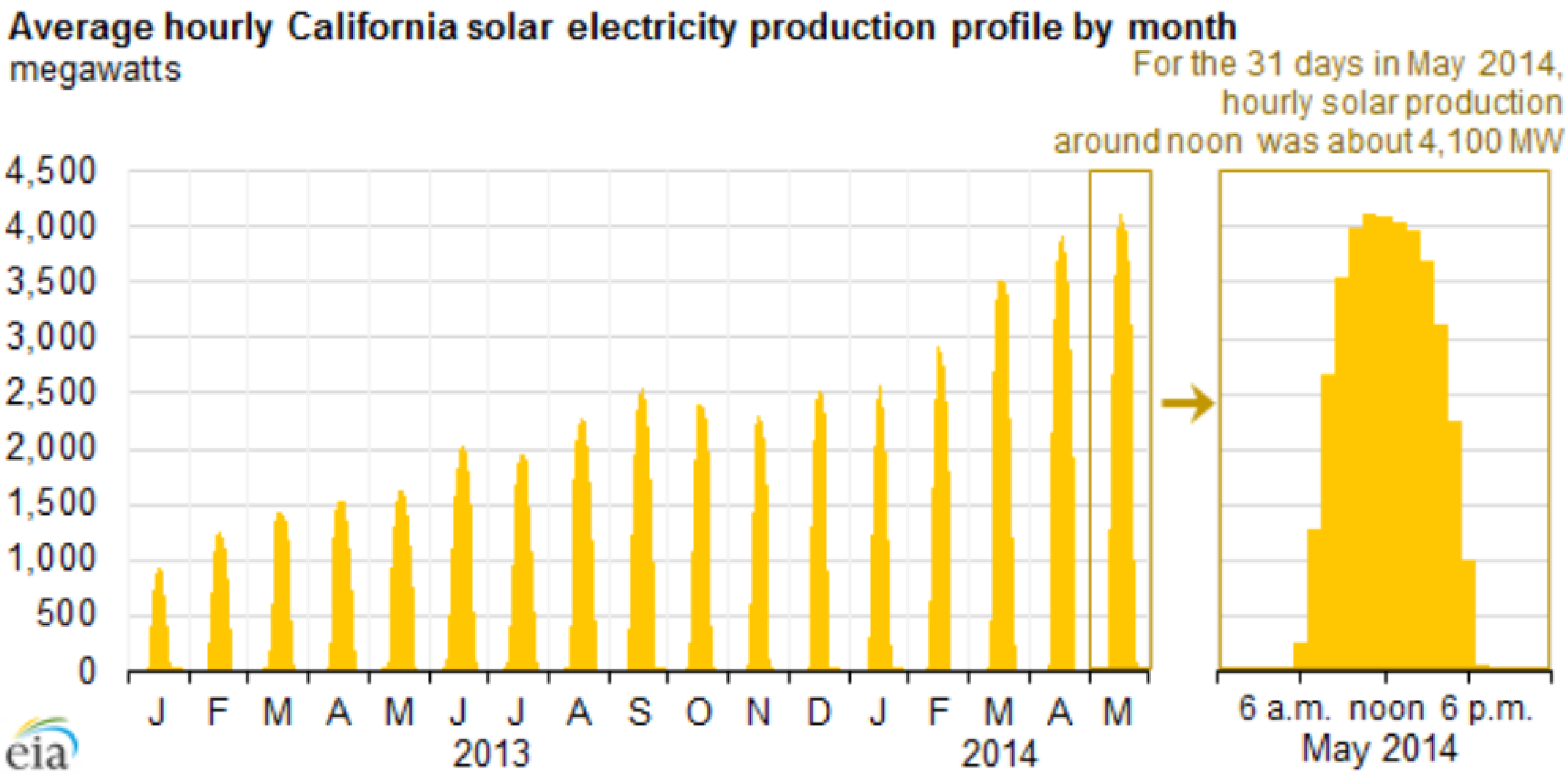
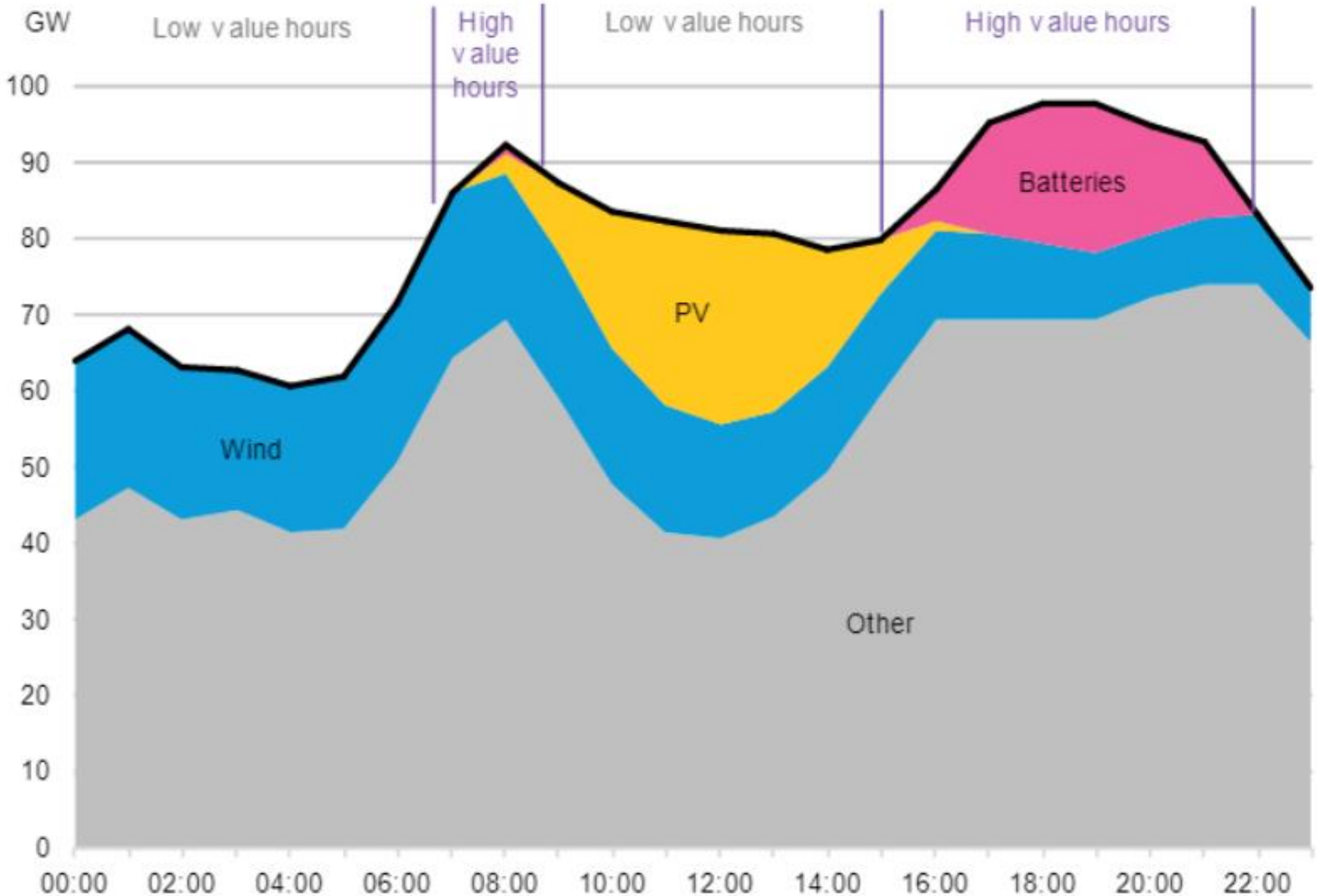


Figure 147: Batteries can make solar and wind dispatchable



Source: BloombergNEF