Economics 134 L17. Renewable energy

Will Rafey

UCLA

December 1, 2025

Announcements

1. Course evaluation!

"Please ask your students to log into MyUCLA to complete the evaluations, as instructor encouragement is one of the best ways to ensure a high response rate."

2. Extended office hours, 5–7.30pm this Wednesday

3. Final exam: Saturday, 12/6, 8am–11am
   - Broad 2160E (everyone)

Clean technology

Innovation:

- renewable energy (today)
- electric vehicles (L18)

Two externalities

Broadly, two reasons to subsidize renewable energy:

1. negative **externalities** with fossil fuel production (air pollution, climate change)
2. positive **externalities** in innovation

Related, but distinct.

Solar energy

- 2010–20: the decade of solar
- Government support
- Cost declines
- Environmental externalities

Optimal clean energy policy

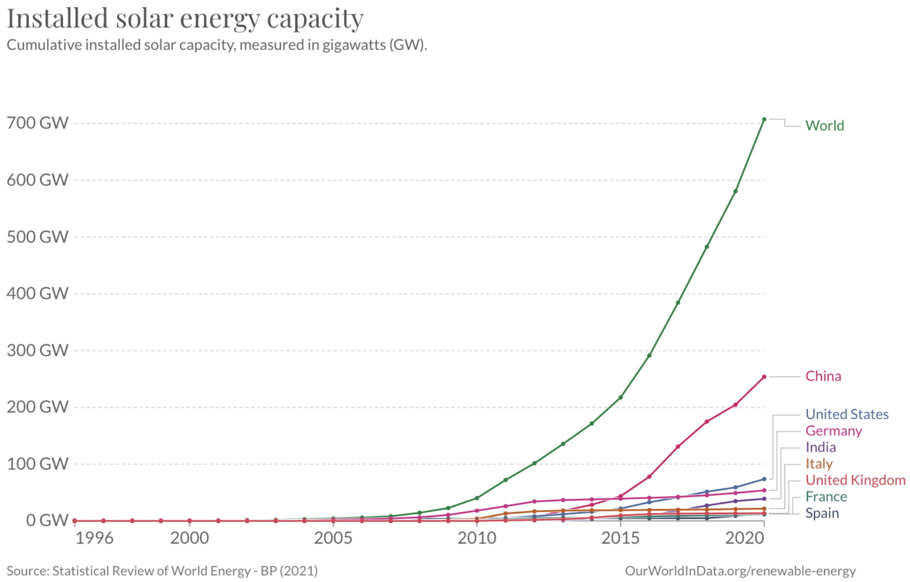
- Transition to clean technology

The rise of solar

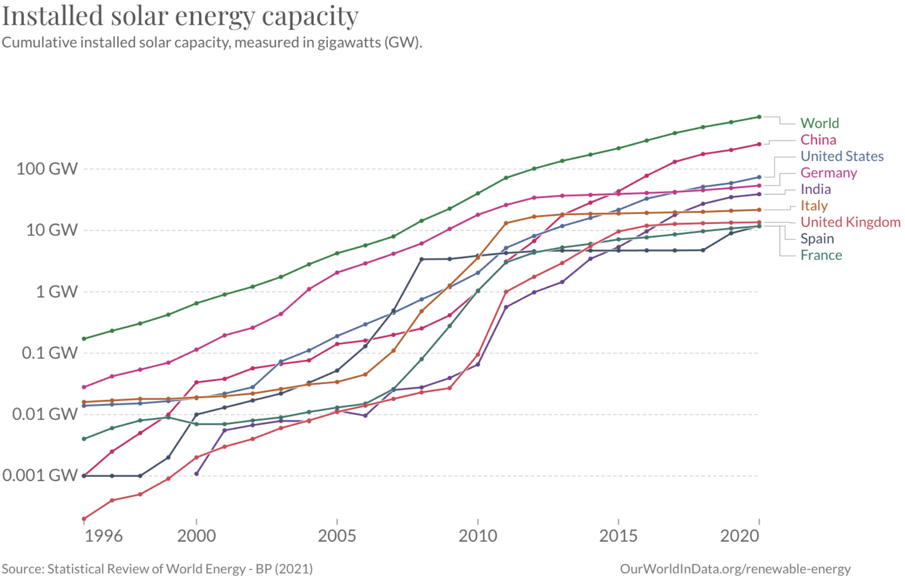
Three stylized facts from 2005–20:

1. Immense increase in solar energy installation
2. Substantial increase in government support
3. Tremendous cost declines

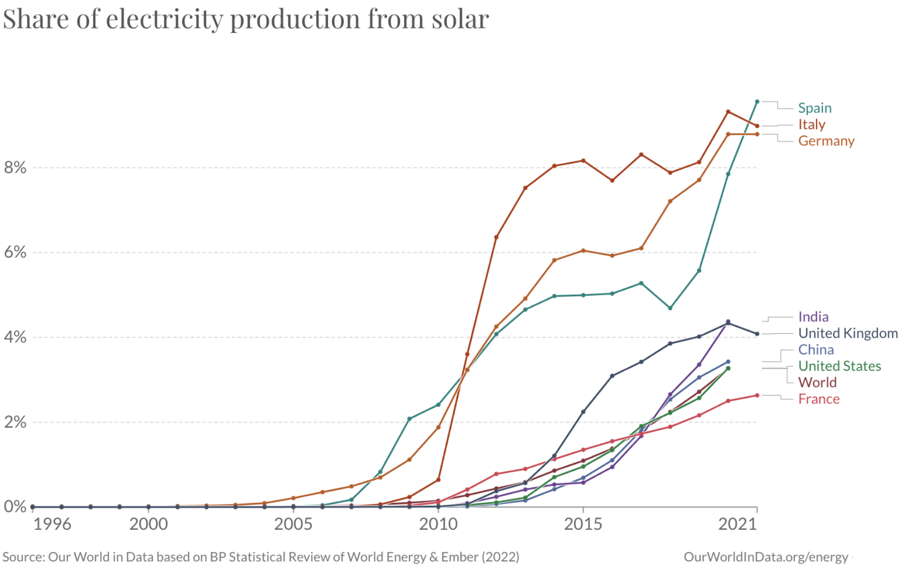
The rise of solar (levels)



The rise of solar (logs)



The rise of solar (%)

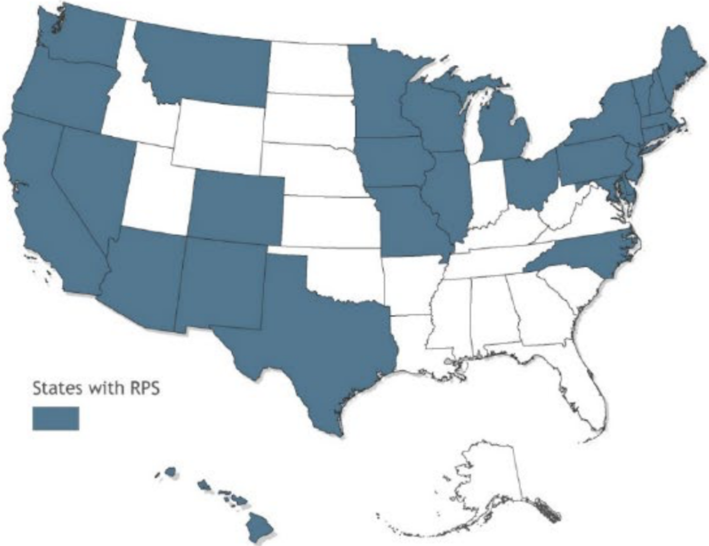


1. Renewable energy incentives in the U.S.

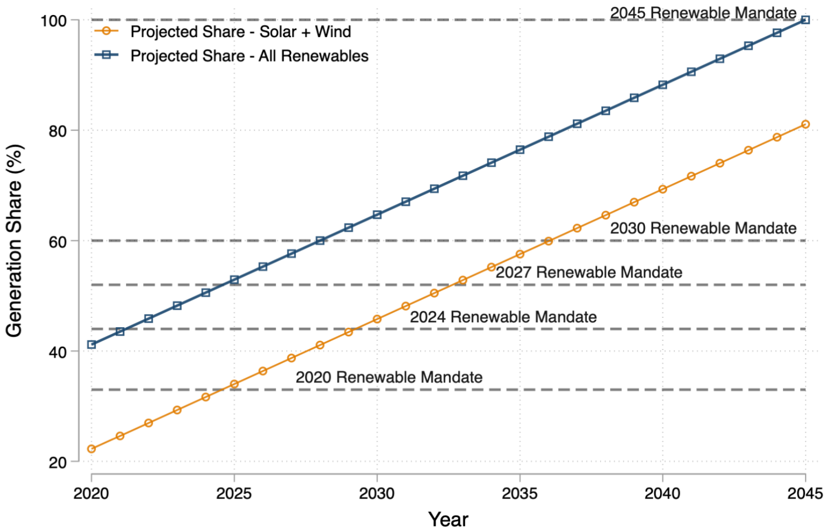
Two key sources:

- state mandates — "renewable portfolio standards"
  - 29 states
  - e.g., policy passed in 2005 specifying 20% renewable electricity by 2020
  - often implemented as a cap-and-trade (via tradeable "renewable energy credits")
- federal subsidies — mainly production, investment tax credits
  - approx \$51 billion from 2005–15
  - Inflation Reduction Act of 2022: \$370b over 2022–30 (CBO, JCT)
  - OBBB of 2025 (H.R. 1): expires after 2027 (commercial solar, 48E) and 2025 (residential solar, 25D)
    - added new supply chain restrictions

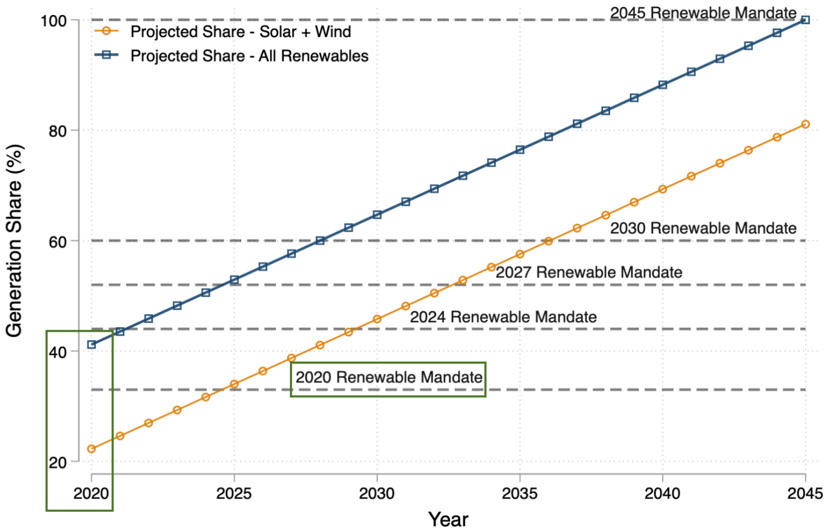
States with renewable portfolio standards



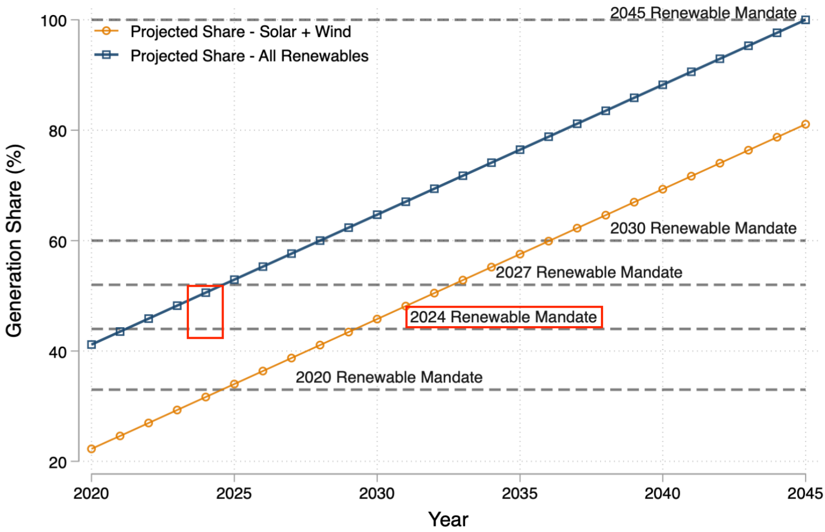
California's renewable portfolio standard



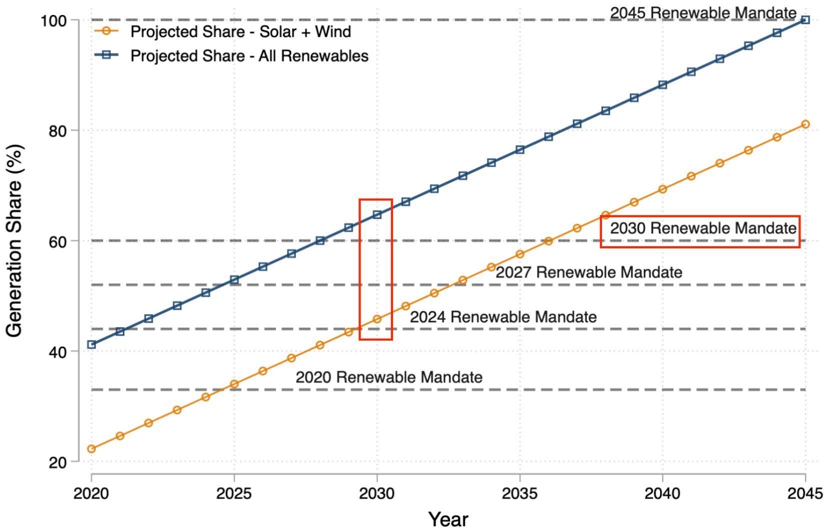
California's renewable portfolio standard



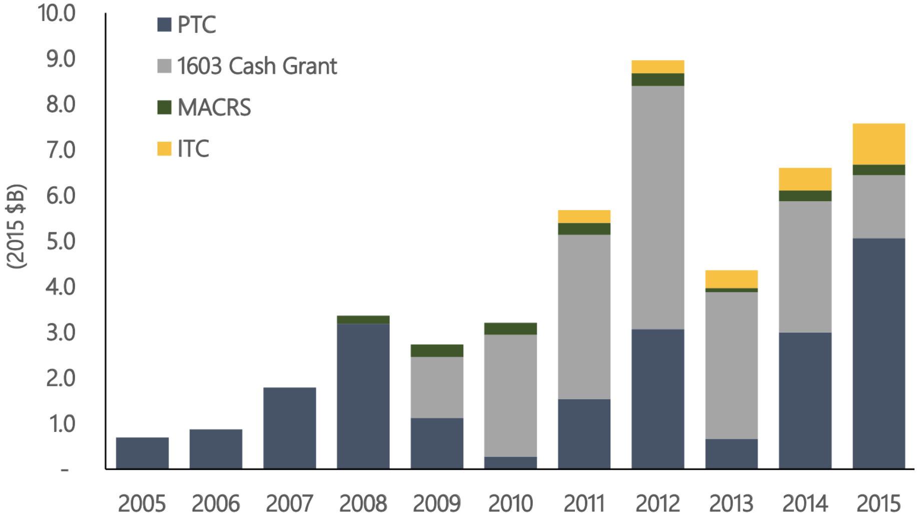
California's renewable portfolio standard



California's renewable portfolio standard

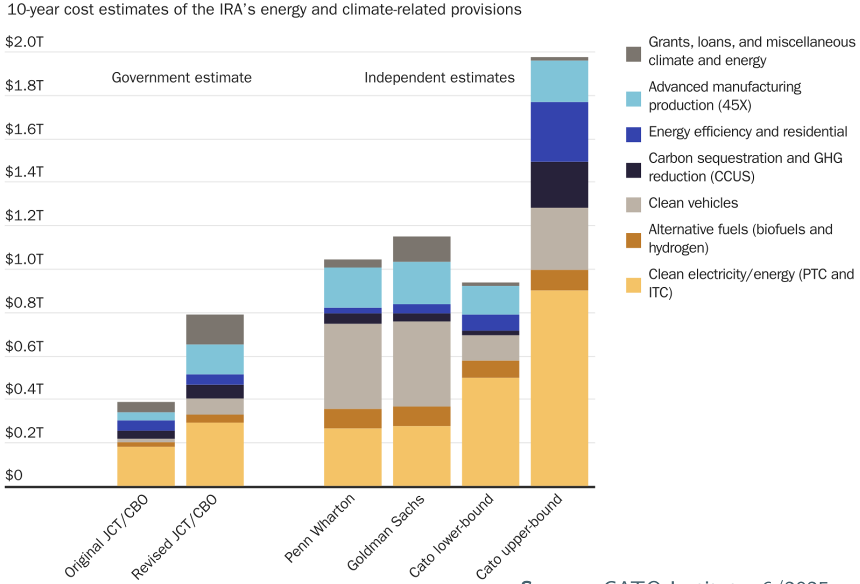


Federal subsidies, 2005–2015



Source. Kirshenberg et al. 2018, p. ES-4.

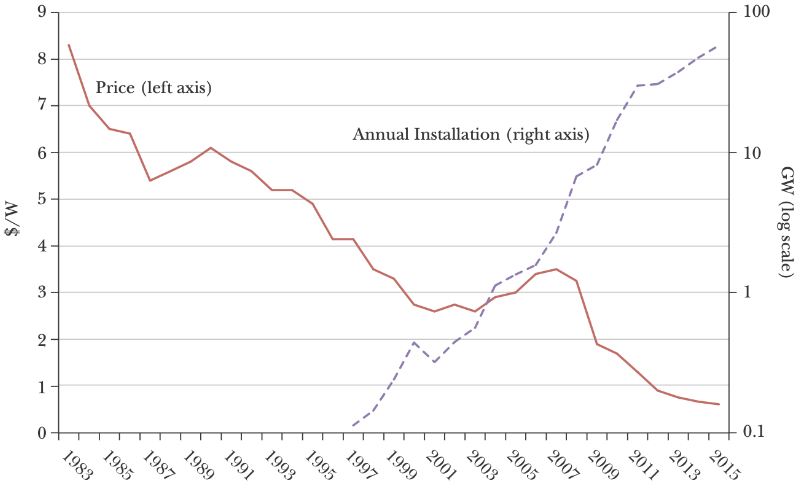
Federal subsidies, 2022–



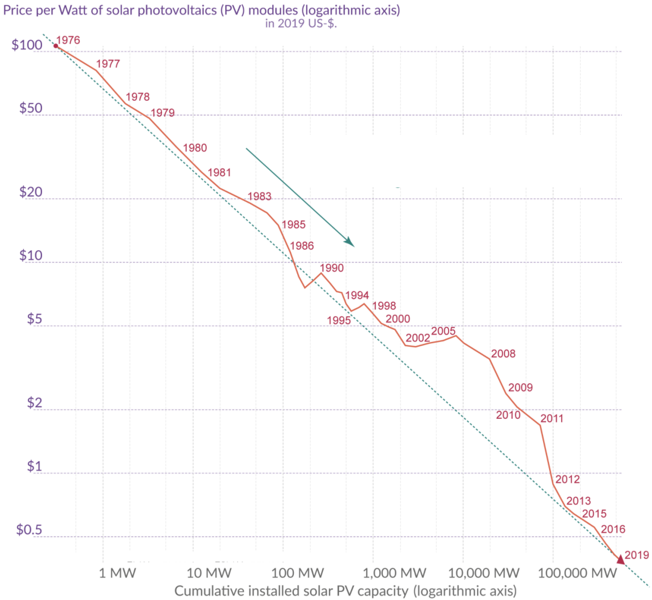
Source. CATO Institute, 6/2025, p. 6.

2. Cost declines

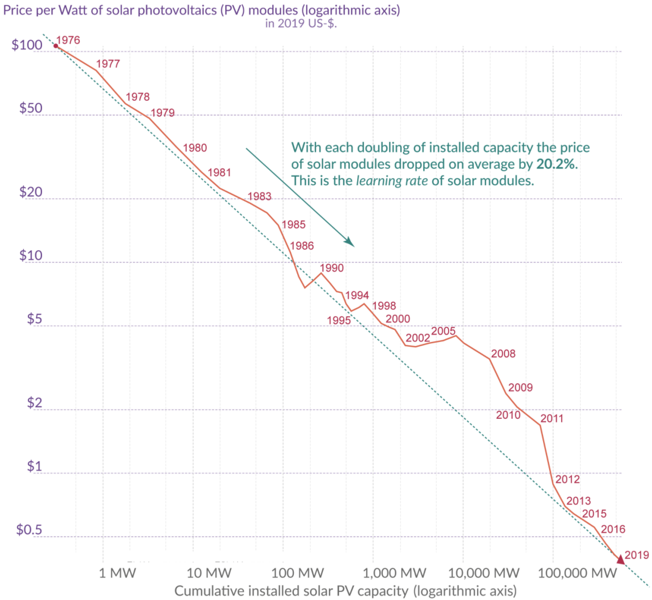
Solar Panel Price Indexes Excluding Subsidies and Cumulative Worldwide Installed Capacity, 1983–2015



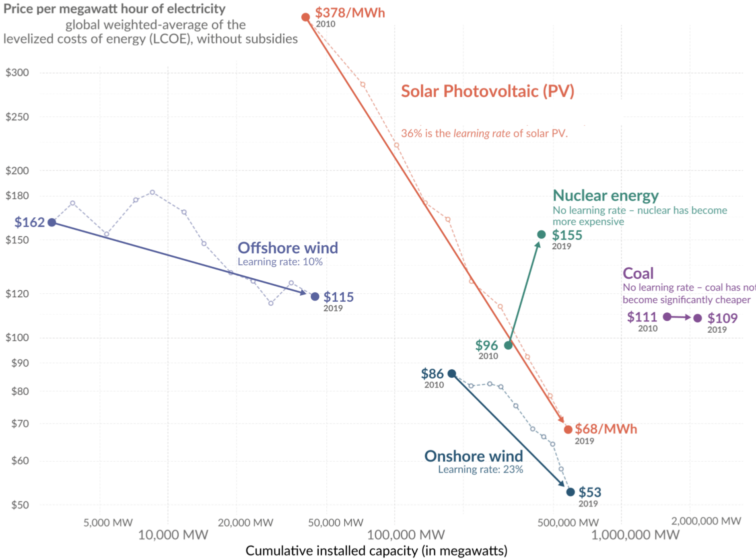
Cost declines



Cost declines

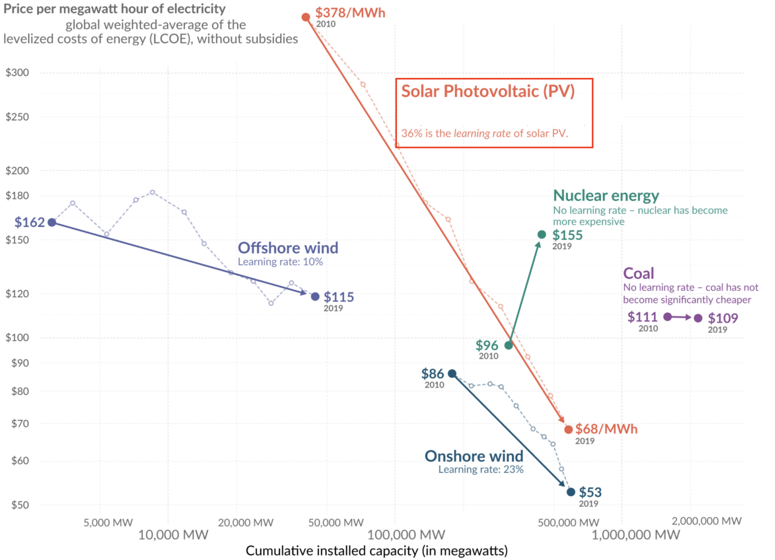


Cost declines



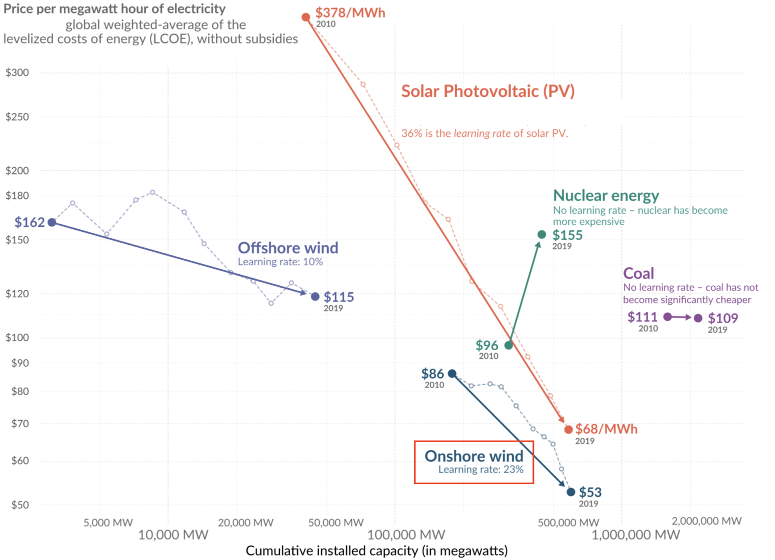
Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal – IAEA for nuclear capacity and Global Energy Monitor for coal capacity.

Cost declines



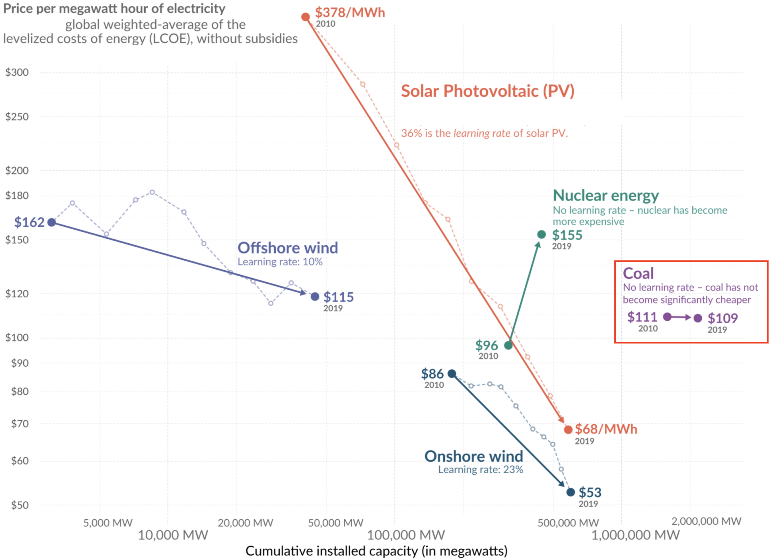
Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal – IAEA for nuclear capacity and Global Energy Monitor for coal capacity.

Cost declines



Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal – IAEA for nuclear capacity and Global Energy Monitor for coal capacity.

Cost declines



Source: IRENA 2020 for all data on renewable sources; Lazard for the price of electricity from nuclear and coal – IAEA for nuclear capacity and Global Energy Monitor for coal capacity.

Discussion

Appears to be significant declines in cost.

1. As always, correlation $\neq$ causation:
   - many confounding variables (e.g., silicon price decline)
   - the past may not guide the future
2. Channel unclear: economies of scale v. learning-by-doing
   - **economies of scale**—likely internalized by the firm
   - **learning-by-doing**—maybe internalized by firm, but could create spillovers (externalities) across firms

   $\hookrightarrow$ very different policy implications, as we will see

3. Externalities

Renewable energy does not generate carbon emissions

Complicated by two factors:

1. taxing/subsidizing energy, in general, may **affect** aggregate energy demand ("rebound" effect)
   - subsidy (e.g., tax credit) should increase demand
   - mandate (e.g., RPS) should decrease demand
2. avoided carbon emissions depend on the **counterfactual** electricity generation source $\hookrightarrow$

Regional variation in displaced emissions, U.S.

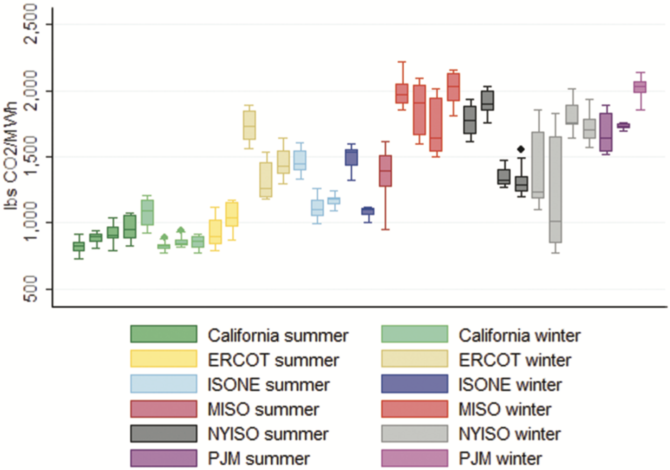


Figure 3. Seasonal marginal operating emissions rates. This figure illustrates the range of hour-specific estimates of the marginal operating emissions rate.

Source. Callaway, Fowlie, and McCormick 2018, p. 57.

Regional variation in displaced emissions, U.S.

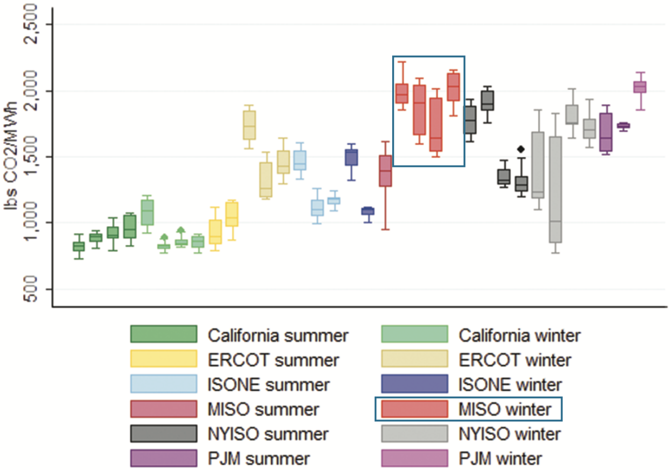


Figure 3. Seasonal marginal operating emissions rates. This figure illustrates the range of hour-specific estimates of the marginal operating emissions rate.

Source. Callaway, Fowlie, and McCormick 2018, p. 57.

Regional variation in displaced emissions, U.S.

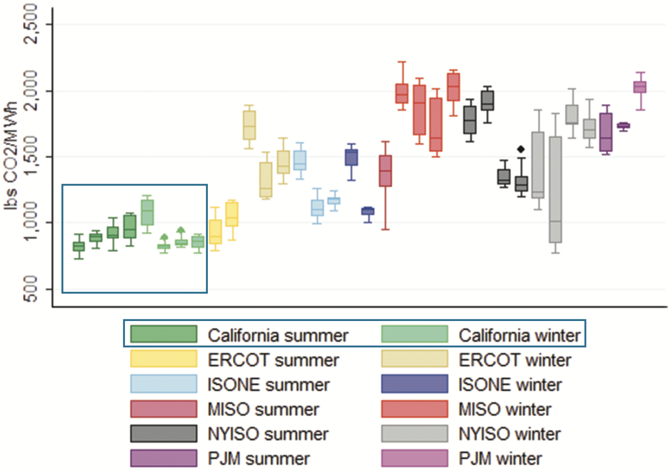


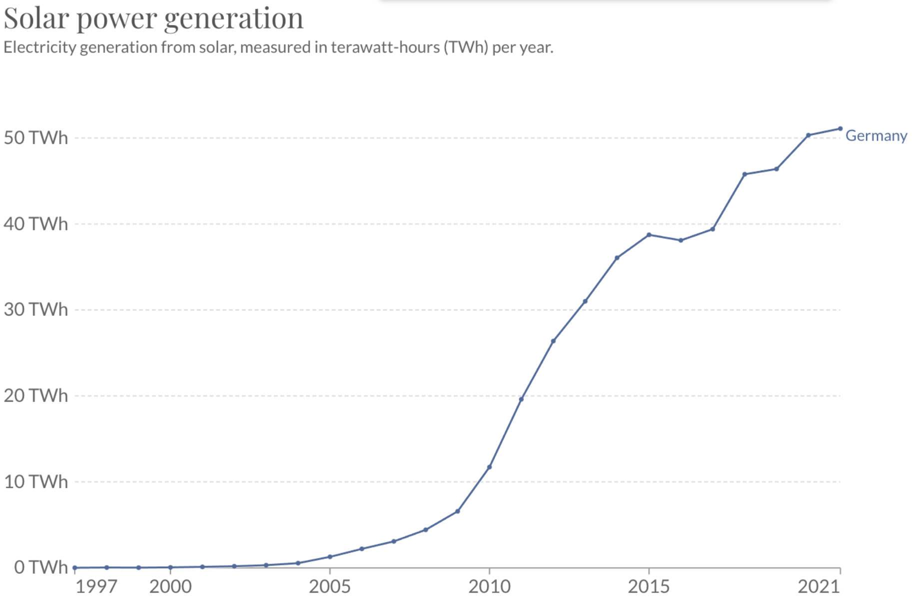
Figure 3. Seasonal marginal operating emissions rates. This figure illustrates the range of hour-specific estimates of the marginal operating emissions rate.

Source. Callaway, Fowlie, and McCormick 2018, p. 57.

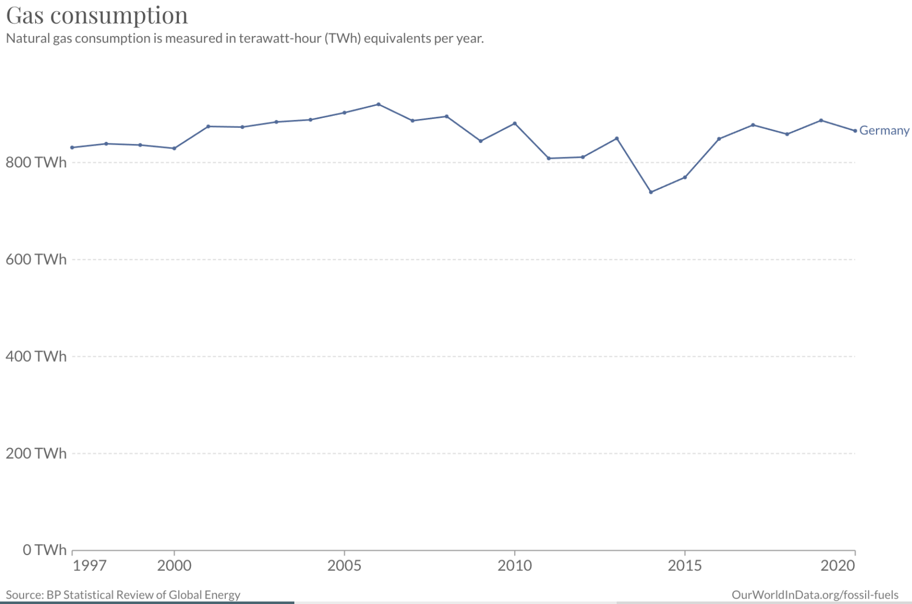
Detour: Germany

What did Germany displace with all of its solar?

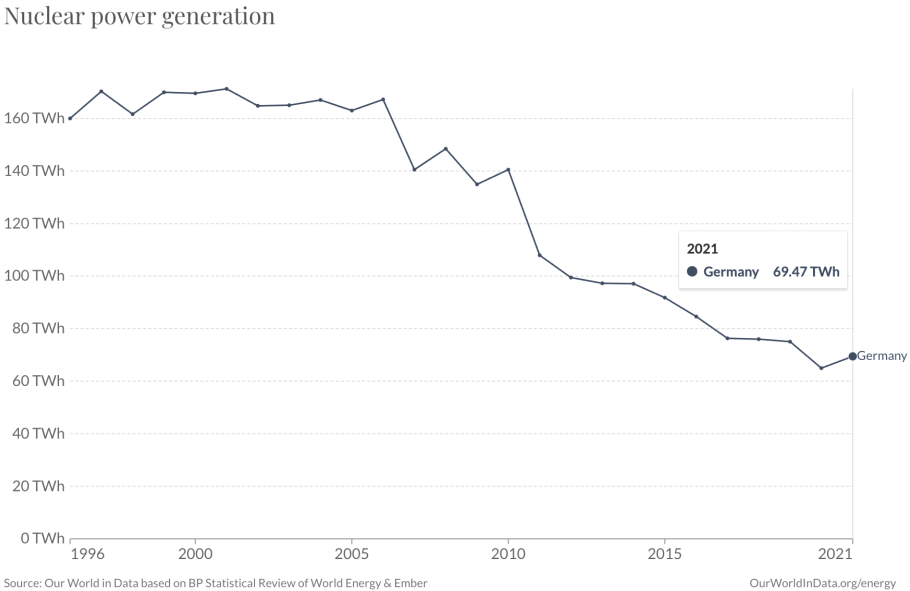
Detour: Germany



Detour: Germany



Detour: Germany



Solar energy
- 2010–20: the decade of solar
- Government support
- Cost declines
- Environmental externalities

Optimal clean energy policy
- Transition to clean technology

Clean technology

Suppose there are two types of technologies:

- dirty, which produces an externality in proportion to inputs, k_d
- clean, which produces no externality

Both types have a production function $f(k)$, and incur k in input costs.

Dirty firm. Profits for the dirty firm, given a tax τ on the externality, are given by

$$f(k_d) - k_d - \tau k_d.$$

Let $k_d^*(\tau)$ solve $f'(k_d^*) - 1 - \tau = 0$ (maximize profits). Then

$$\pi_d^*(\tau) = f(k_d^*) - k_d^* - \tau k_d^*$$

are the dirty firm's equilibrium profits for a given tax τ.

Clean technology

Clean firm. Profits for the clean firm are independent of the tax, but may involve some subsidy $S > 0$. They are given by

$$\pi_c^*(S) = f(k_c) - k_c + S$$

Transition to clean technology. Suppose that all firms are initially dirty, but each firm can switch to clean for a fixed adoption cost $\mathcal{C} > 0$.

Denote the fraction of clean firms by $q \in [0, 1]$.

Equilibrium clean technology adoption. For some interior $q \in (0, 1)$, firms must be indifferent between clean or dirty:

$$\pi_c^*(S) - \pi_d^*(\tau) - \mathcal{C} = 0.$$

Clean technology: Optimal policy

Case I. Optimal tax. What is the first-best level of k_d?

Welfare is

$$W = \underbrace{q\left[f(k_c) - k_c\right] + (1-q)\left[f(k_d) - k_d\right]}_{\text{net output}} - \underbrace{D((1-q)k_d)}_{\text{damages}} - \underbrace{q\mathcal{C}}_{\text{cost}}$$

Maximize W via

$$0 = \frac{\partial W}{\partial k_d} = (1-q)(f'(k_d) - 1) - (1-q)D'(\cdot)$$

and, dividing by $1-q$, we obtain

$$f'(k_d^{\text{FB}}) - 1 - D'(\cdot) = 0.$$

This implies that we can attain the first-best level, k_d^{FB}, by imposing a tax τ equal to the marginal damage!

Clean technology: Optimal policy

What is the first-best level of clean technology, q^{FB}?

Again, maximize W, to obtain

$$0 = \frac{\partial W}{\partial q} = f(k_c) - k_c - [f(k_d) - k_d] + k_d D'() - \mathcal{C}$$

Note that, if $D'(\cdot) = \tau$, this gives the condition for efficient adoption as

$$\underbrace{f(k_c) - k_c}_{\pi_c^*(0)} - \underbrace{([f(k_d) - k_d] - k_d D'())}_{\pi_d^*(\tau)} - \mathcal{C} = 0.$$

But

$$\pi_c^*(0) - \pi_d^*(\tau) - \mathcal{C} = 0 \qquad (\star)$$

is **exactly** the condition for equilibrium adoption of clean technology!

No need for subsidy.

Clean technology: Subsidies only

Case II. Subsidies only. Suppose instead that we cannot directly regulate dirty production, so that $\tau = 0$.

Should we subsidize clean technology? Yes. ✓

We can attain the efficient level of clean technology with a subsidy of

$$S = k_d D'(\cdot),$$

but this will **not** reduce carbon emissions from the firms that remain dirty.

Clean technology subsidy without regulating existing dirty production is a **second-best** policy solution to the externality.

- better than nothing
- worse than the optimal tax

Remark. The case of a clean technology mandate is identical.

Next time

Last lecture—we'll finish our analysis of optimal clean tech policy + discuss electric vehicles!