Decarbonizing Power

Challenges for expanding renewable energies

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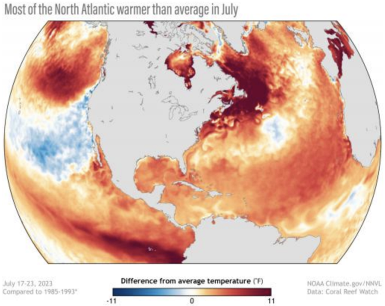
A worrisome reminder



Exceptional heat and rain, wildfires and floods mark summer of extremes

Tags: Public health Climate Climate change

3 Published 3 August 2023

There is an urgent need to decarbonize our economies

The power sector's key role

Decarbonazing power is critical to addressing climate change

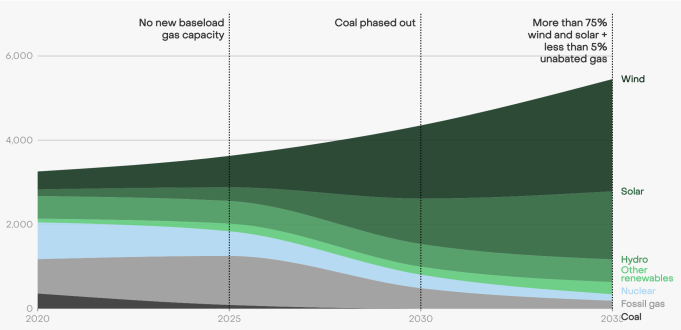


Figure: 1.5C pathways to clean power by 2035 in Europe

Decarbonazing power requires massively investing in renewables

Source: Ember

Roadmap

Challenges for expanding renewable energies

1. Re-designing electricity market arrangements
2. Addressing intermittency: energy storage, demand response, market integration
3. Promoting electrification
4. Reinforcing the transmission and distribution networks
5. Overcoming social opposition

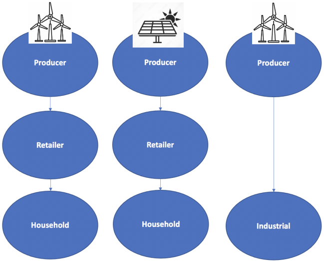
Re-designing electricity market arrangements

Re-designing electricity market arrangements

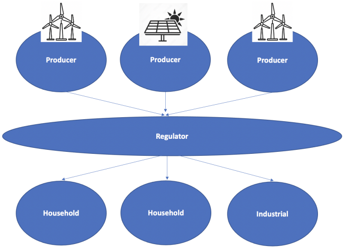
"[Renewables' expansion] raises profound questions about whether the current market designs can be adapted to provide **good long-term price signals to support investment in an efficient portfolio** *of generating capacity and storage consistent with* **public policy goals**.*"*
(Joskow, 2021)

- Current markets were designed for fossil-fuel technologies
- The expansion of renewables calls shifting the focus:
    - Productive efficiency $\rightarrow$ Investment efficiency
    - Short-run contracting $\rightarrow$ Long-run contracting

Long-term contracting in electricity markets



(a) Bilateral contracting (PPAs)



(b) Auctions (CfDs)

Research and policy questions:

- How should long-run contracts be designed and allocated?
  (Fabra and Montero, EJ 2023; Newbery, 2021)
- Who should the counterparty be?
  (Ryan, 2023; Fabra, EneEco 2023)

Are technology-neutral auctions optimal?

Fabra and Montero (EJ, 2023): Technology-neutral *vs.* technology-specific procurement

The choice of technology-neutral versus technology-specific auctions faces regulators with a **rent-efficiency trade-off**

1. A technology-neutral approach is good for **cost efficiency**
2. A technology-specific approach is good for **reducing rents**

The **optimal mechanism** involves departures from technology-neutral auctions

Modelling renewable auctions

Fabra and Montero (EJ, 2023): Technology-neutral *vs.* technology-specific procurement

Technologies and firms:

- Renewable energy is produced with technologies $t = 1, 2$
- Continuum of (risk-neutral) **price-taking** suppliers of each t

Costs:

- Aggregate cost function, for $t = 1, 2$:

$$C_t(q_t) = (c_t + \theta_t) q_t + \frac{C''}{2} q_t^2$$

- Cost parameters: $c_2 - c_1 \equiv \Delta c > 0$
- Shocks: $E[\theta_t] = 0$, $E[\theta_t^2] = \sigma > 0$ and $E[\theta_1 \theta_2] = \rho\sigma$

Social Benefits:

- $B(Q)$, where $Q = q_1 + q_2$, with $B' > 0$ and $B'' < 0$

The regulator's problem

The principal maximizes (expected) **social welfare**:

$$\max W = E\left[B\left(Q\right) - \sum_{t=1,2} C_t\left(q_t, \theta_t\right) - \lambda T(q_1, q_2, \theta_1, \theta_2)\right]$$

- λ: **shadow cost of public funds**
- $T(q_1, q_2, \theta_1, \theta_2)$: Total payment from procuring $q_1 + q_2 = Q$

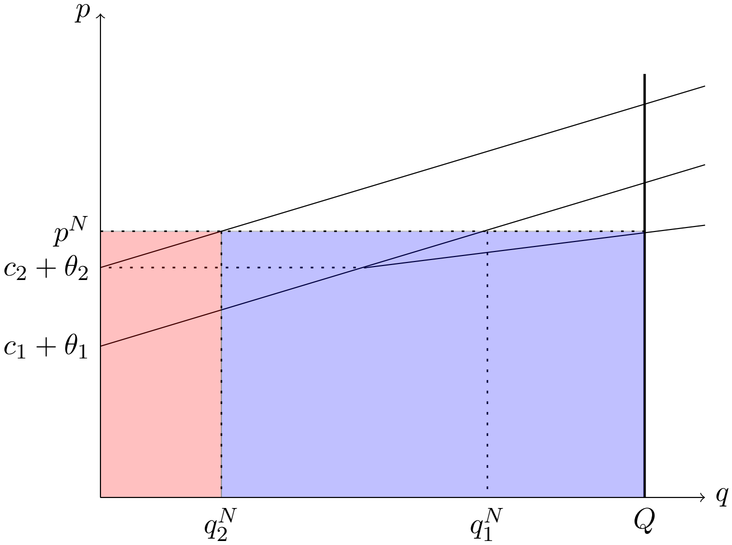
Regulators use simple mechanisms

In practice, regulators typically decide ex-ante between two approaches:

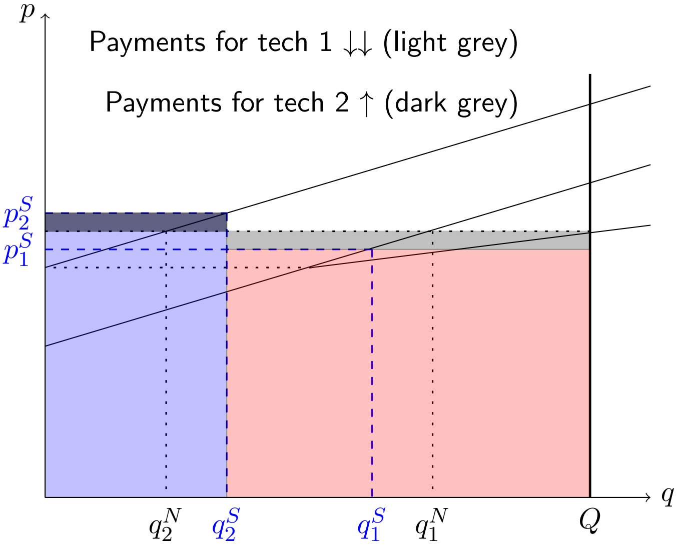
1. **Technology-neutral**: $Q^N \to p(Q^N)$ and (q_1^N, q_2^N)
2. **Technology-specific**: q_1^S and $q_2^S \to p_1(q_1^S)$ and $p_2(q_2^S)$

How do these mechanisms compare in terms of costs and rents?
How do they compare with the optimal mechanism?

Graphical Representation: Technology-Neutrality



Graphical Representation: Technology-Specific



What is the optimal mechanism?

- The regulator announces technology-specific demands:

$$P_t^d(q_1, q_2) = \frac{B'(q_1 + q_2) - \lambda C'' q_t}{1 + \lambda}$$

- Firms bid according to technology-specific supply schedules:

$$P_t^s(q_t) = C_t'(q_t; \theta_t)$$

A hybrid: technology-neutral + technology-specific approach:

1. Both technologies compete within the same mechanism
2. But they are not treated equally:
    - Costs and prices are not equalized across technologies
    - The cost-efficient allocation is distorted to minimize rents

Who should the counterparty of the long-run contracts be?

Ryan (2023): Holding Up Green Energy: Counterparty Risk in the Indian Solar Market

Counterparty risk increases auction prices, which sharply reduces investment, because demand for green energy is elastic

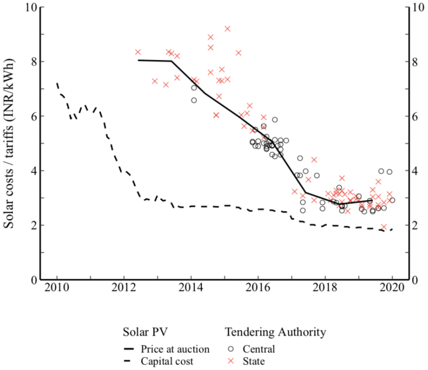


Figure: Solar auction clearing prices by intermediation; Indian solar auctions

Who should be the counterparty of the long-run contracts?

The supply curves for higher-risk counterparties shift sharply inwards relative to what would be offered to the central government

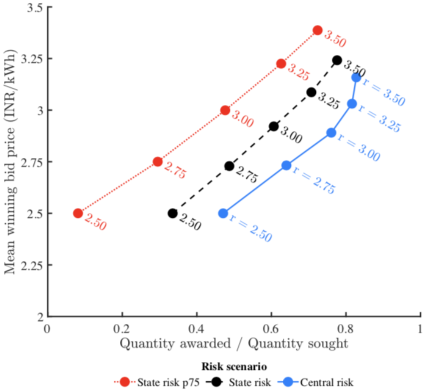


Figure: Counterfactual procurement by risk under uniform ceiling prices

Addressing renewables intermittency: energy storage, demand response, and market integration

Energy storage, demand response, market integration

- With fossil fuels, supply can follow demand
- With renewables, storage, demand response, and market integration become critical

Research and policy questions:

- Efficient incentives to invest in and operate storage facilities?
  (Andres-Cerezo and Fabra, RJE 2023)
- Are storage and renewables complements or substitutes?
  (Andres-Cerezo and Fabra, 2023; Butters, Dorsey, and Gowrisankaran, 2023)
- Is demand elastic enough to counteract renewables intermittency?
  (Fabra et al., AER P&P 2021; Allcott, REE 2011)
- Enhancing demand response through information? Automation?
  (Jessoe and Rapson, AER 20014; Bollinger and Hartmann, MS 2020)
- Effects of market integration?
  (Gonsales et al, Etca 2023; Yang, JEMM 2022; Ryan, AEJ:M 2021; Cicala, AER 2022)

Does storage promote renewable investments?

Andrés-Cerezo and Fabra (2023): Renewables and storage: friends of foes?

Energy storage can play a **fundamental** role:

- By providing energy when renewables are not available
- By reducing generation costs and emissions
- By promoting investments in renewables?

Investments in renewables promote investments in storage, and vice-versa, **unless** renewable availability is procyclical (e.g., solar) and its capacity is sufficiently small

Modelling demand and renewables

Demand $D(t) = \theta - b \sin t$ and renewables $q_R(t) = \frac{1}{2}\left(1 - \alpha \sin t\right) K_R$

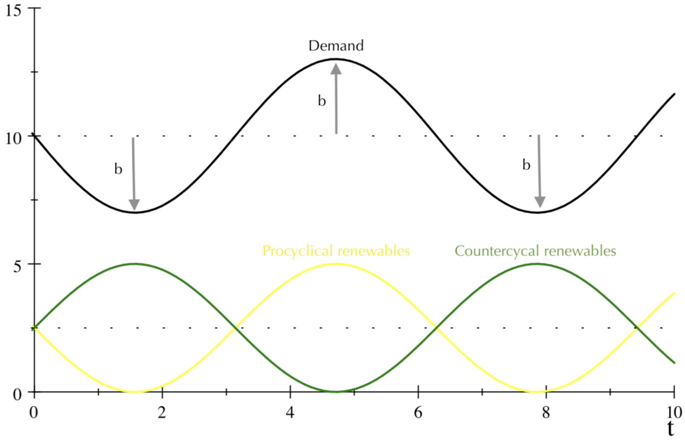
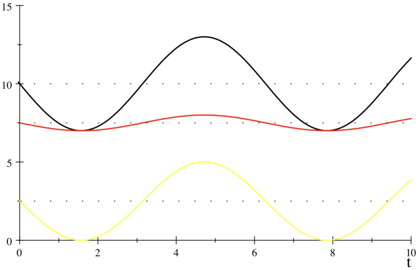


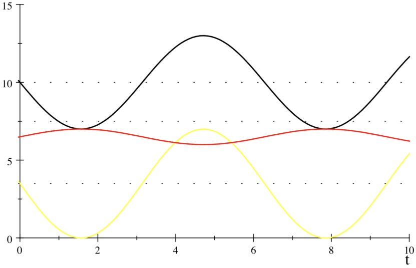
Figure: Demand (black), procyclical renewables (yellow) and countercyclical renewables renewables (green)

Prices with procyclical renewables (e.g., solar)

For low (high) K_R, prices are procyclical (countercyclical) and an increase in K_R flattens (amplifies) price differences across time



(a) Low K_R

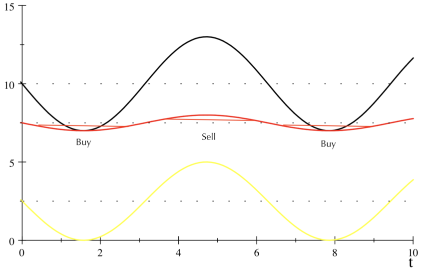


(b) High K_R

Figure: Demand (black), prices (red), and renewables (yellow)

Storage decisions with procyclical renewables

For low (high) K_R, storage buys when storage production is low (high) and sells when it is high (low)



(a) Low K_R (b) High K_R

Figure: Demand (black), prices (red), and renewables (yellow)

When are renewables hurt by storage?

Procyclical renewables and low K_R

Renewables are hurt from increasing storage because prices go down (up) when renewables sell more (less).

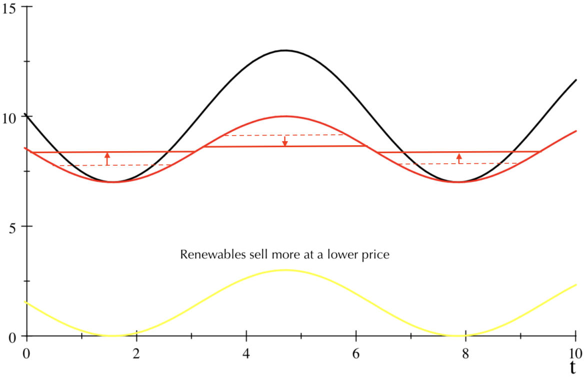


Figure: Impact of increasing storage capacity on renewable profits

When is storage is hurt by renewables?

Procyclical renewables and low K_R

Storage is hurt from increasing renewables because prices go down relatively more when storage sells than when it buys.

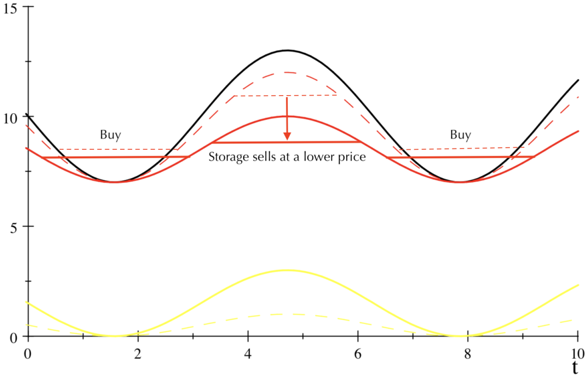
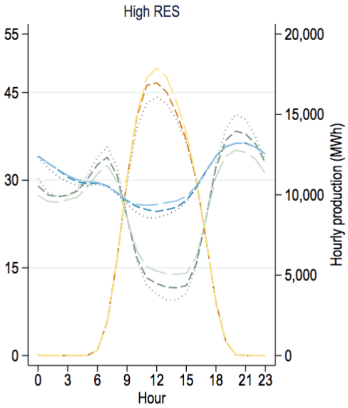


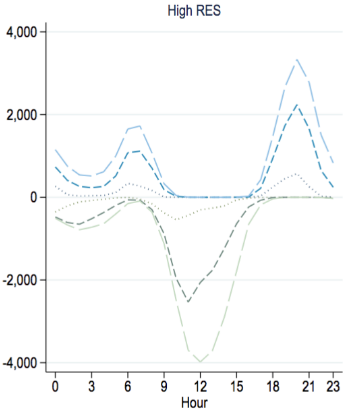
Figure: Impact of increasing renewable capacity on storage profits

Simulations

Renewable production, market prices, and storage decisions



(a) Prices and renewable production



(b) Storage

Figure: Renewable production, prices and storage decisions across the day

Simulations

Renewables and storage: friends or foes?

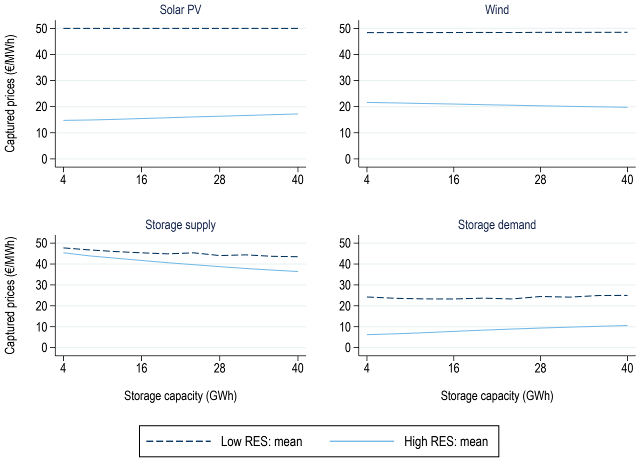


Figure: Price impacts of increasing renewables and storage

Promoting electrification: the role of electricity prices

Promoting electrification: the role of electricity prices

- Boosting demand would increase renewables profitability through price effects and reduction in curtailment
- For consumers to be willing to invest in electrification, electricity prices need to go down

Research and policy questions:

- What are the price-depressing effects of renewables?
  (Fabra and Llobet, EJ 2023; Acemoglu et al, EneJ 2017)
- How does this depend on the design of their support schemes?
  (Fabra and Imelda, AEJ:EP 2023)
- How does it depend on the ownership structure?
  (Fabra and Llobet, 2023)
- What are the effects of carbon pricing in electricity markets? Is carbon pricing optimal?
  (Fabra and Reguant, AER 2013; Borenstein and Kellogg, 2023; Liski and Vehviläinen, JAERE 2020)

What are the price-depressing effects of renewables?

Fabra and Llobet, EJ 2023: Auctions with Privately Known Capacities: Understanding Competition Among Renewables

Fundamental difference between renewables relative to conventional technologies: known (zero) marginal costs but privately-known capacities

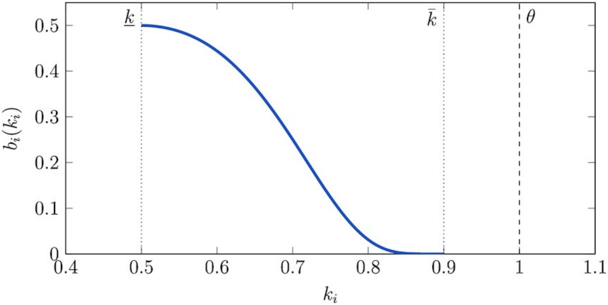


Figure: Bayesian Nash equilibrium: bid offer as a function of capacity

This figure shows the equilibrium bid as a function of k_i when $k_i U[0.5, 0.9]$, with demand $\theta = 1$ and a price cap $P = 0.5$

Reinforcing networks, and allocating fixed costs efficiently and equitably

Reinforcing networks, and allocating fixed costs

- Existing networks were not built to accommodate renewables
  - Renewable are often far from consumption → reinforce transmission
  - Some consumers have become producers → reinforce distribution
- Network costs are often recovered through volumetric charges
  - Self-consumption does not contribute to network costs

Research and policy questions:

- What is the value of transmission lines?

  (Gonzales, Ito, and Reguant, Etca 2023)
- How to define efficient and equitable electricity tariffs?

  (Cahana, Fabra, Reguant, Wang, 2023)
- And for rooftop solar?

  (De Groote and Verboven, AER 2019; Feger, Pavanini, and Radulescu, RES 2022)

What is the value of market integration?

Gonzales, Ito, and Reguant (Etca, 2023): The Investment Effects of Market Integration: Evidence from Renewable Energy Expansion in Chile

Market integration generates gains from trade and further cost reductions as it promotes investments in solar energy

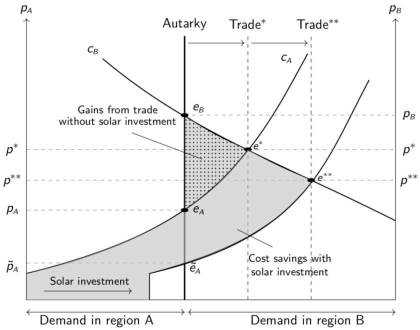


Figure: Impacts of Market Integration with and without Investment Effects

The importance of market integration

Market integration contributes to price convergence

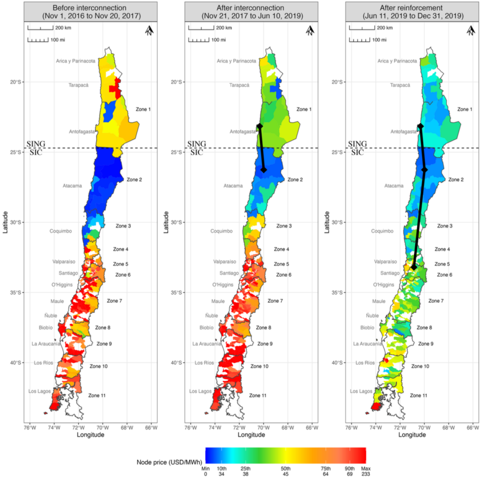


Figure: Market Integration and Spatial Variation in Electricity Prices

Market integration promotes investments in renewables

Market integration increased solar generation by around 180%, even before the interconnection was completed

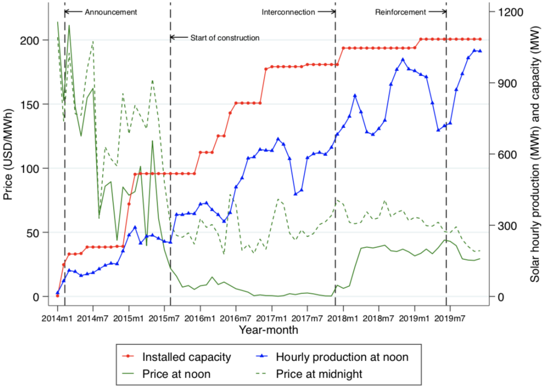


Figure: Impacts of Market Integration on Solar Expansion

Overcoming local opposition to renewables expansion

Overcoming social opposition to renewables expansion

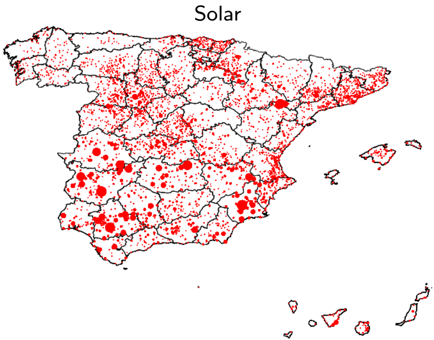
- Renewables create global environmental and socio-economic benefits (employment, industry,...) (Curtis et al., 2023; Popp et al, 2021)
- But some of the municipalities where investments occur oppose the investments (NIMBYism)

Research and policy questions:

- Do local citizens support renewable investments?
  (Germeshausen, Heim and Wagner, 2023; Jarvis, 2021)
- What are the perceived local costs?
  (Gibbons, JEEM 2015; Haan and Simmler, JPubE 2018)
- What are the local socio-economic benefits?
  (Fabra, Gutierrez, Lacuesta, Ramos, 2023)

Do the local benefits compensate for the local costs of renewable investments?

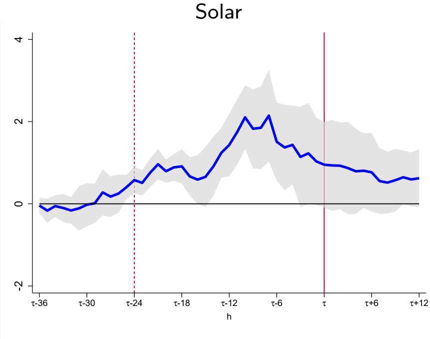
Fabra, Gutierrez, Lacuesta, Ramos (2023): Do Renewables create local jobs?

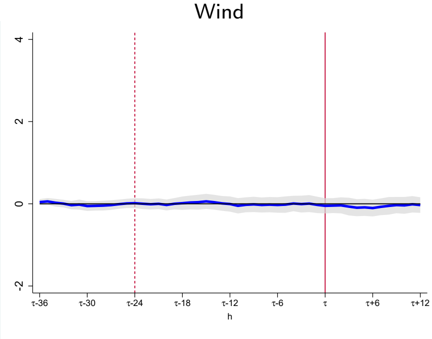


We exploit the variation of solar and wind investments across time and space to identify their effects on employment and unemployment

Local employment effects of renewable investments

Solar investments increase local employment during construction and maintenance, while wind investments have no impact





These figures show the effects of investing 1 MW on employment by firms located in the municipalities where the investment occurred in February 2006-January 2018, h months before or after the start-up date (marked with a vertical red line). Standard errors are clustered at the municipality level.

Conclusions

- Massive investments in renewables, storage and networks are required to decarbonize the power sector
- Multiple challenges for expanding renewables:
  - Market design issues
  - Competition issues
  - Socio-economic issues

These issues bring exciting research opportunities

Our research can greatly contribute to the achievement of environmental goals efficiently and equitably

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Thank You!

Questions? Comments?

More info at nfabra.uc3m.es and energyecolab.uc3m.es

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References

- Acemoglu, D., A. Kakhbod and A. Ozdaglar, "Competition in Electricity Markets with Renewable Energy Sources," The Energy Journal (2017). Volume 38.
- Allcott, H. (2011). Rethinking real-time electricity pricing. Resource and Energy Economics, 33(4), 820–842.
- Andrés-Cerezo, D. and N. Fabra (2023). "Storing power: Market structure matters". The RAND Journal of Economics, 54, 3–53.
- Andrés-Cerezo, D. and N. Fabra (2023). "Renewable Energy and Storage: Friends or Foes?". Mimeo.
- Butters, R. Andrew, J. Dorsey, and G. Gowrisankaran (2023). "Soaking Up the Sun: Battery Investment, Renewable Energy, and Market Equilibrium". Mimeo.

References (cont.)

- Bollinger, B. K., and Hartmann, W. R. (2020). "Information vs. Automation and implications for dynamic pricing." Management Science, 66(1), 290–314.
- Cahana, M., Fabra, N., Reguant, M. and Wang, J. (2023). "The Distributional Impacts of Real-Time Pricing," CEPR Discussion Papers 17200.
- Cicala, S. (2022). "Imperfect markets versus imperfect regulation in US electricity generation." American Economic Review, 112(2): 409–41.
- De Groote, O., and F. Verboven (2019). "Subsidies and Time Discounting in New Technology Adoption: Evidence from Solar Photovoltaic Systems," American Economic Review, 109 (6), 2137-2172.
- Fabra, N., and M. Reguant (2014). "Pass-Through of Emissions Costs in Electricity Markets." American Economic Review, 104(9): 2872–99.

References (cont.)

- Fabra, N., Rapson, D., Mar, R., and Wang, J. (2021). "Estimating the elasticity to real-time pricing: evidence from the Spanish electricity market," AEA Papers and Proceedings(111), 425–429.
- Fabra, N., and Imelda (2023) "Market Power and Price Discrimination: Learning from Changes in Renewables Regulation," American Economic Journal: Economic Policy (forthcoming).
- Fabra, N., and G. Llobet (2023) "Auctions with Unknown Capacities: Understanding Competition among Renewables," The Economic Journal, 133 (651), 1106-1146.
- Fabra, N., and J.P. Montero (2023) "Technology-Neutral vs. Technology-Specific Procurement," The Economic Journal, 133 (650), 669-705.
- Fabra, N. (2023) "Reforming European Electricity Markets: Lessons from the energy crisis," Energy Economics, forthcoming.

References (cont.)

- Fabra, N., E. Gutiérrez, A. Lacuesta, and R. Ramos (2023). "Do Renewables Create Local Jobs?" CEPR Discussion Paper 17206.
- Feger, F., N. Pavanini, and D. Radulescu (2022). "Welfare and Redistribution in Residential Electricity Markets with Solar Power." The Review of Economic Studies, 89(6): 3267–3302.
- Gonzales, Luis E., Koichiro Ito, and Mar Reguant (2023). "The Dynamic Impact of Market Integration: Evidence from Renewable Energy Expansion in Chile". Econometrica, forthcoming.
- Jessoe, K., and Rapson, D. (2014). "Knowledge is (Less) Power: Experimental Evidence from Residential Energy Use". American Economic Review, 104(4), 1417–1438.
- Joskow, P. (2019). "Challenges for wholesale electricity markets with intermittent renewable generation at scale: the US experience," Oxford Review of Economic Policy 35(2), 291– 331.

References (cont.)

- Newbery, D. (2021) "Designing efficient Renewable Electricity Support Schemes," Tech. rep. Energy Policy Research Group, University of Cambridge.
- Ryan, N. (2021) "Holding Up Green Energy," NBER Working Paper 29154.
- Yang, Y. (2022). "Electricity interconnection with intermittent renewables." Journal of Environmental Economics and Management, 113.