

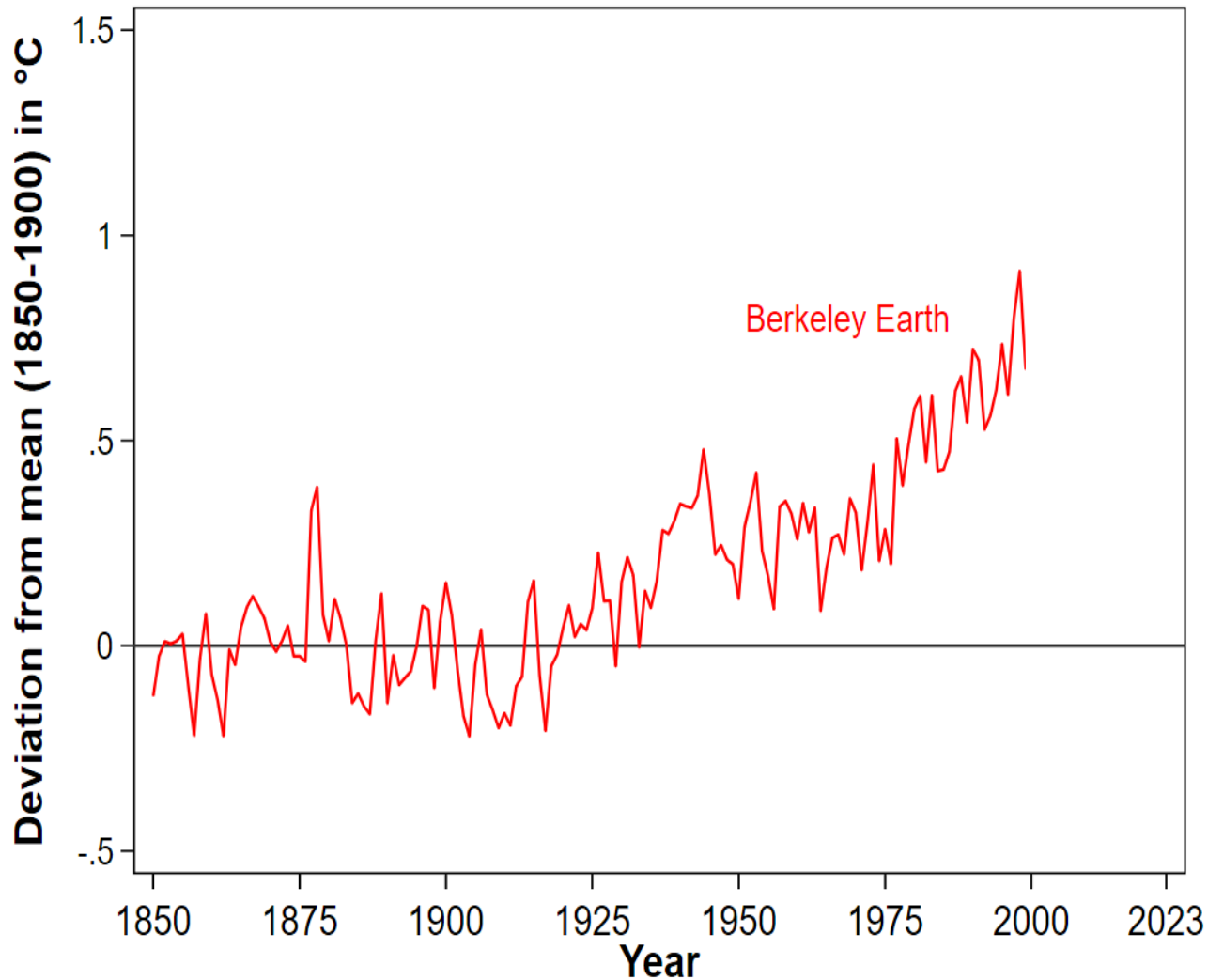
Clean Growth

Costas Arkolakis
Yale

Conor Walsh
Columbia, Minneapolis Fed

World Bank, March 2024

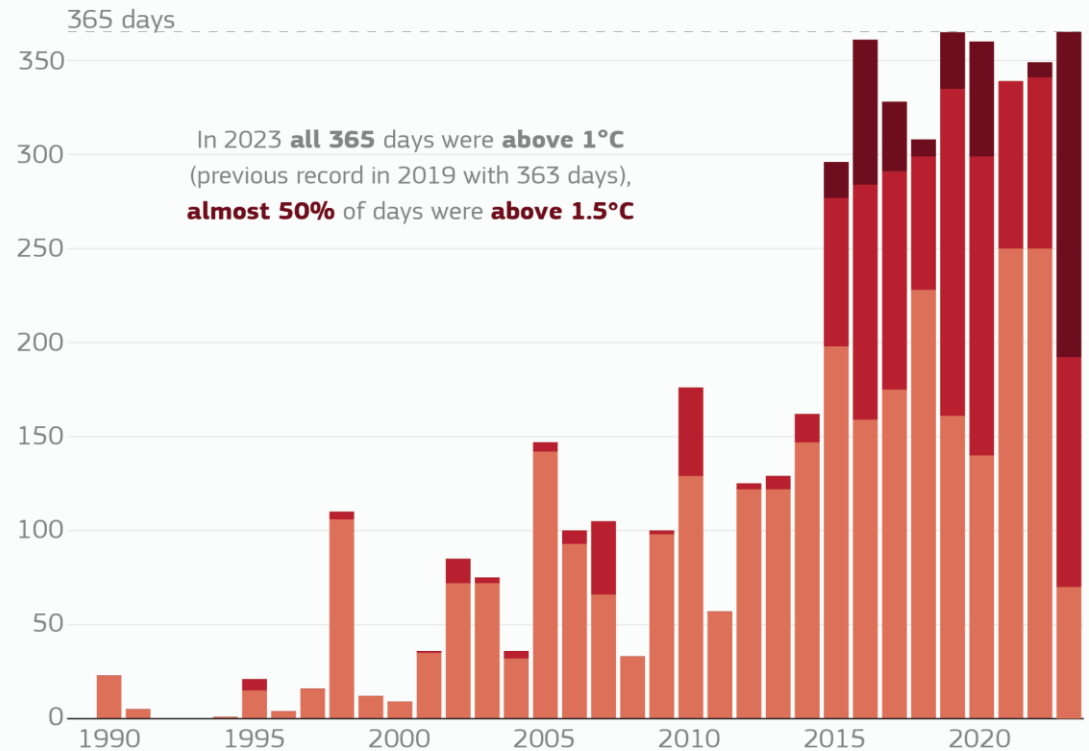
Some (Really) Bad News



RECORD NUMBER OF DAYS ABOVE 1.5°C IN 2023

Number of days with temperature increase above pre-industrial level (1850-1900) within the following ranges:

■ 1 to 1.25°C ■ 1.25 to 1.5°C ■ 1.5°C or more



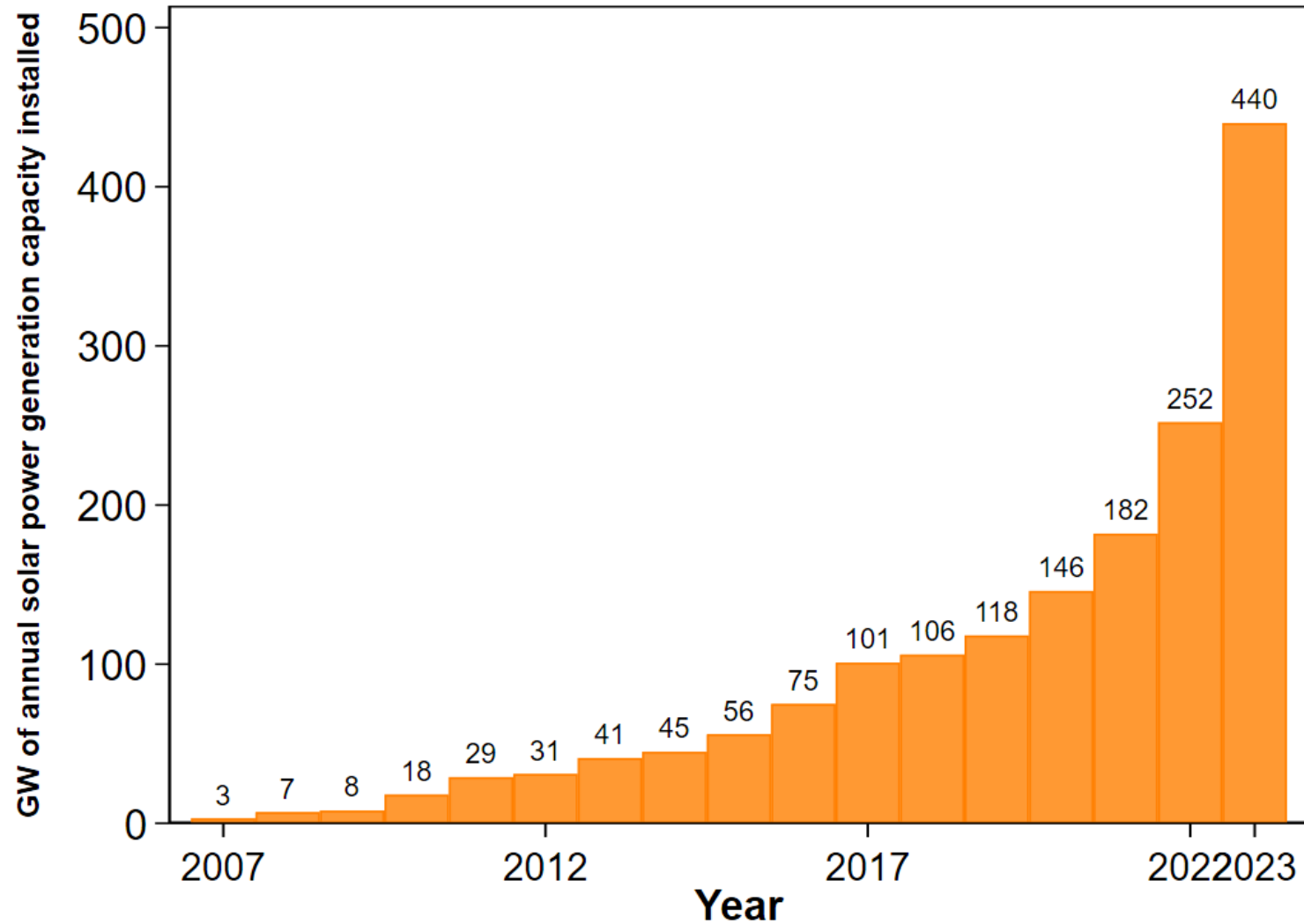
Data: ERA5 • Credit: C3S/ECMWF



PROGRAMME OF
THE EUROPEAN UNION

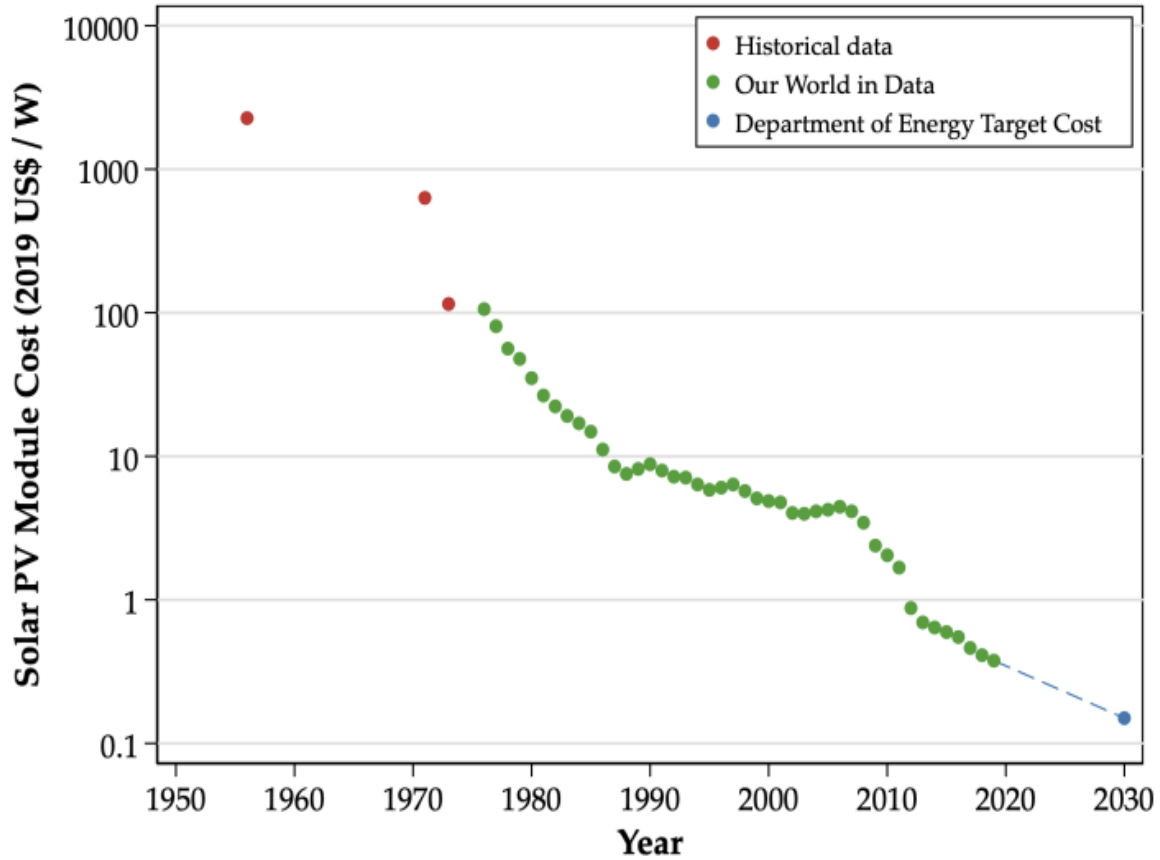


Some Stellar News for Renewable Energy

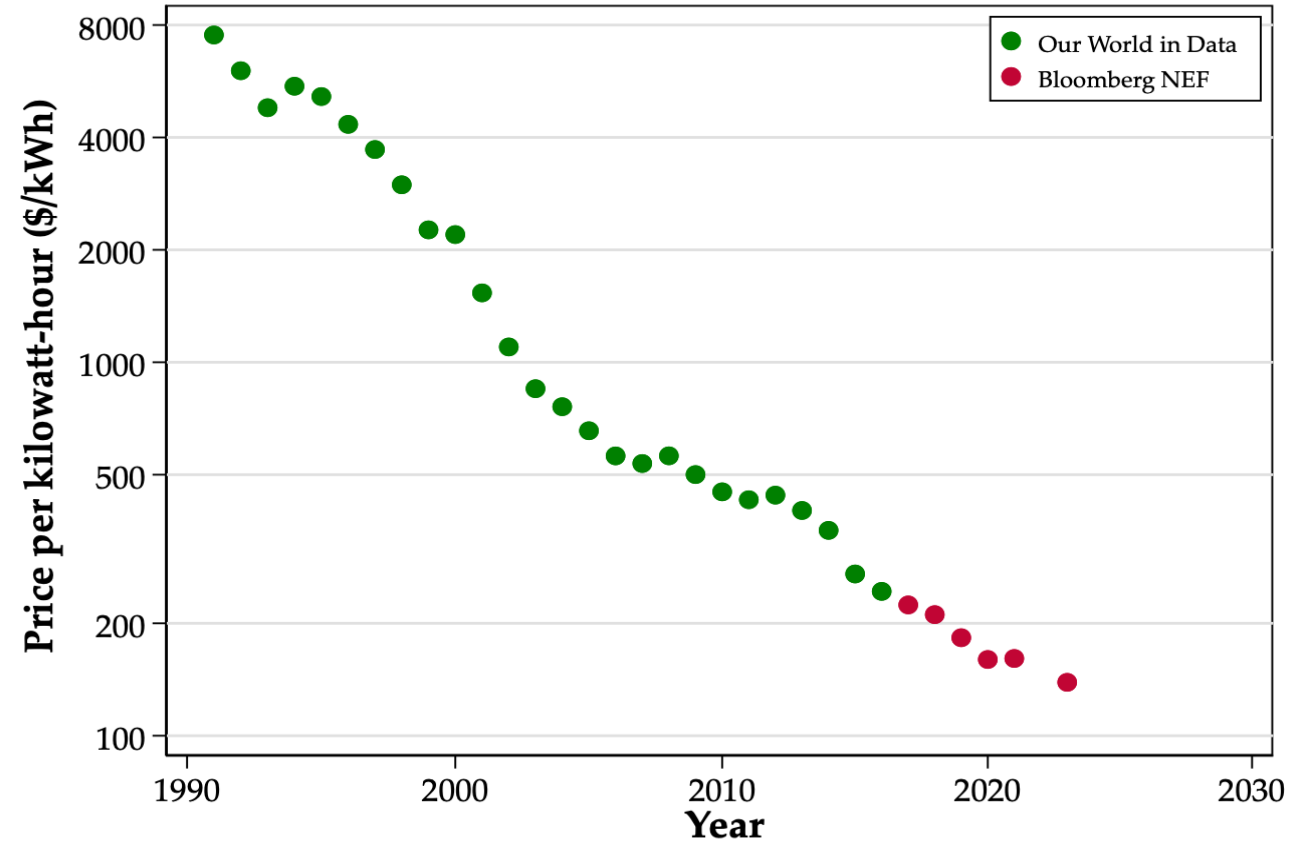


A Technological Revolution Decades in the Making

Solar Costs



(Lithium-ion) Batteries



Goal: Integrated Assessment w/ Energy Markets

- Study implications of **energy** transition
 - Model energy markets, transmission, renewables
 - Model spatial element -follow Quantitative Spatial Literature-
 - Model investment in energy resources –renewables: modular/fossil: resource extraction-
 - Model interplay of all these forces through integrated modeling in General Equilibrium
- New predictions for
 - Renewable investment and fossil fuel extraction in the long run
 - Electricity prices across countries
 - Welfare implications of energy transition and policies across countries, regions

Two Main Questions

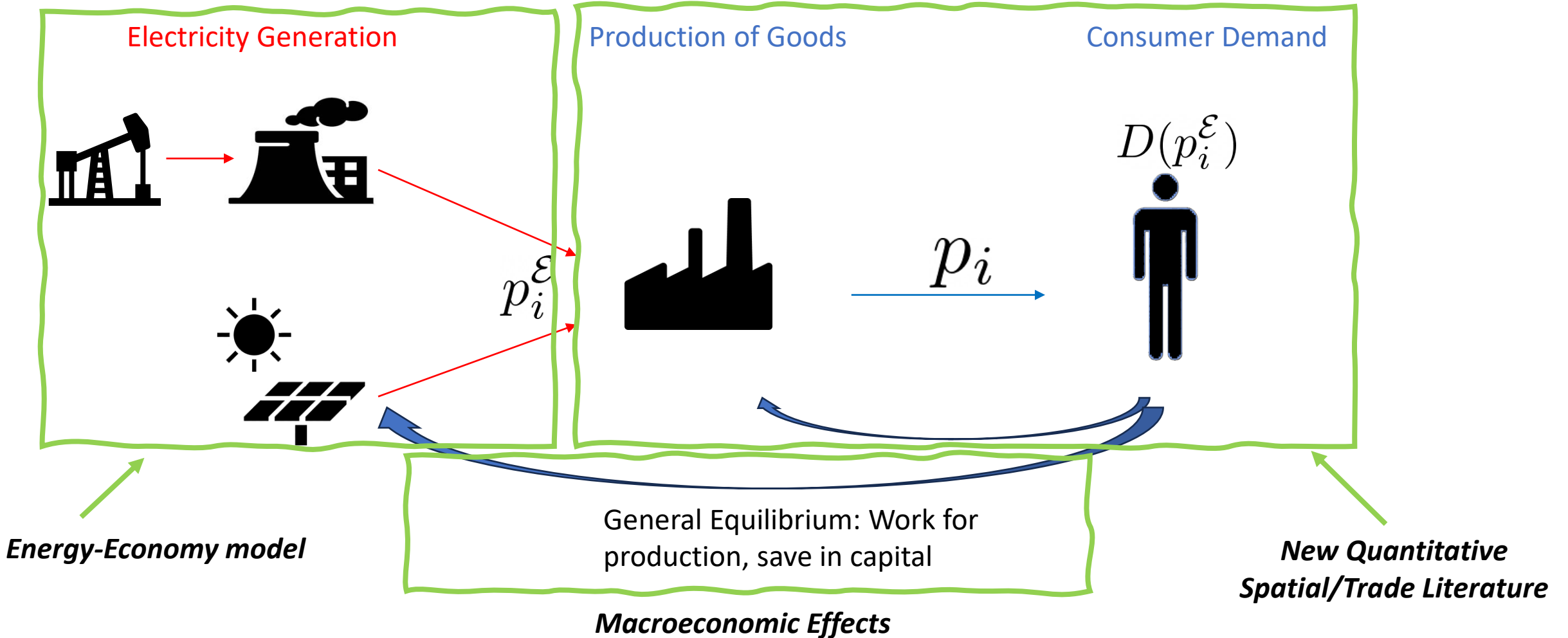
1. Who are the winners and losers of this technological revolution
 - a. What is the impact on electricity markets: renewable share, prices etc
 - b. Welfare gains: welfare improvement, income effects etc

2. What is the role for policy?
 - a. Subsidies to renewables (e.g. Inflation Reduction Act)
 - b. Investments in the grid (e.g. Infrastructure Investment and Jobs Act)

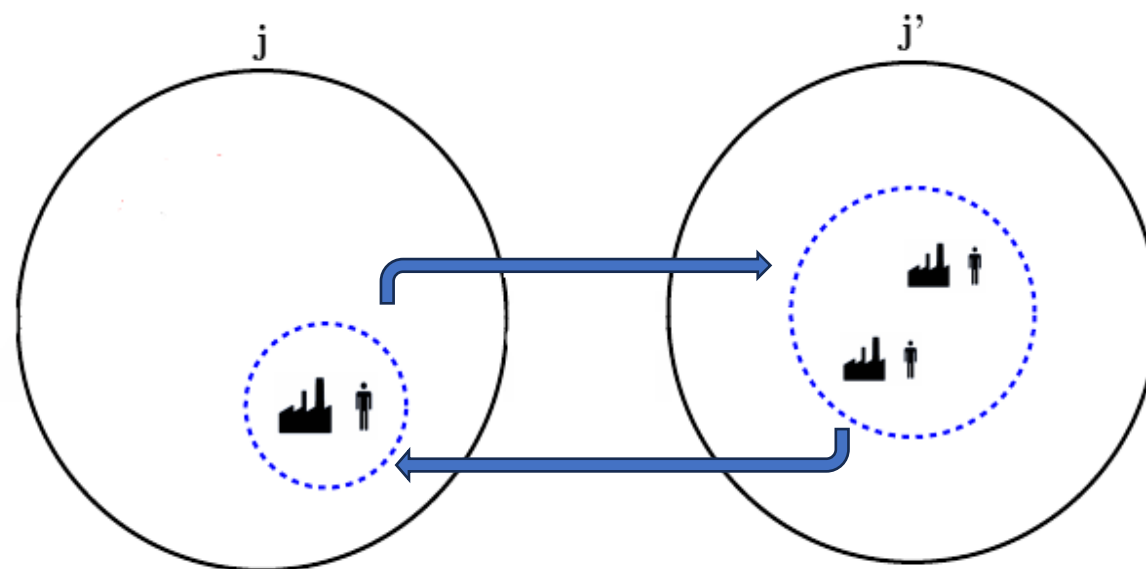
The Economy:

Energy, Production, Consumption

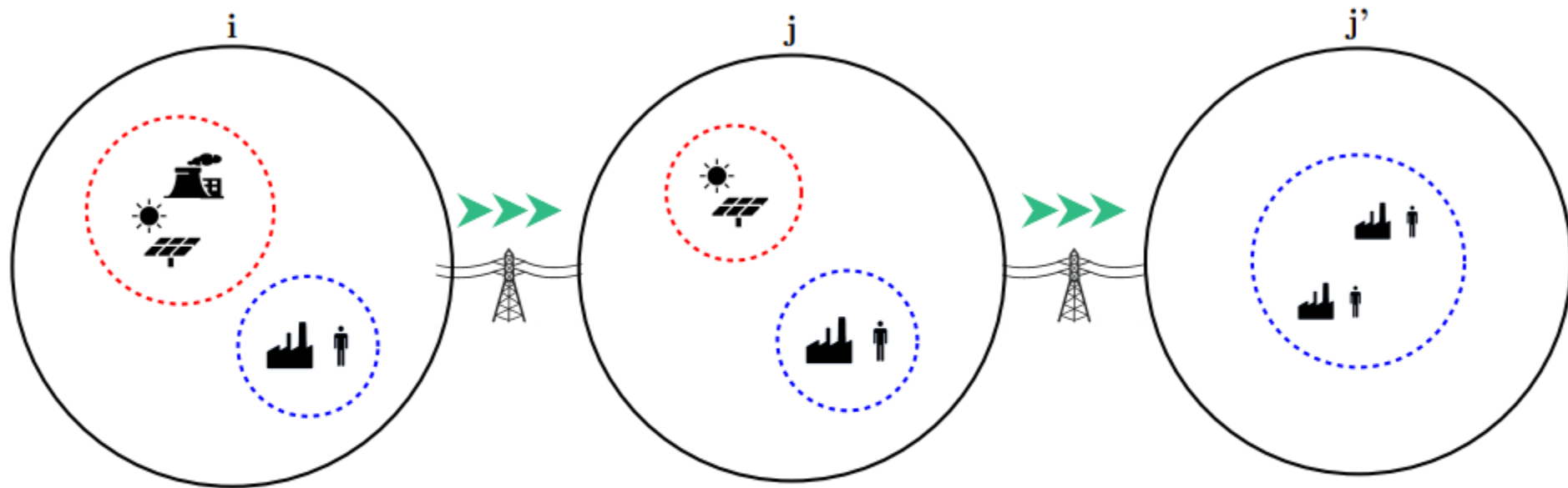
The Economy: Energy, Production, Consumption



Trade in Goods (Gross)



Trade in Electricity (Net)



The Economy:

Electricity Generation and Electricity Markets

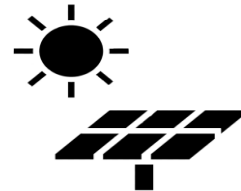
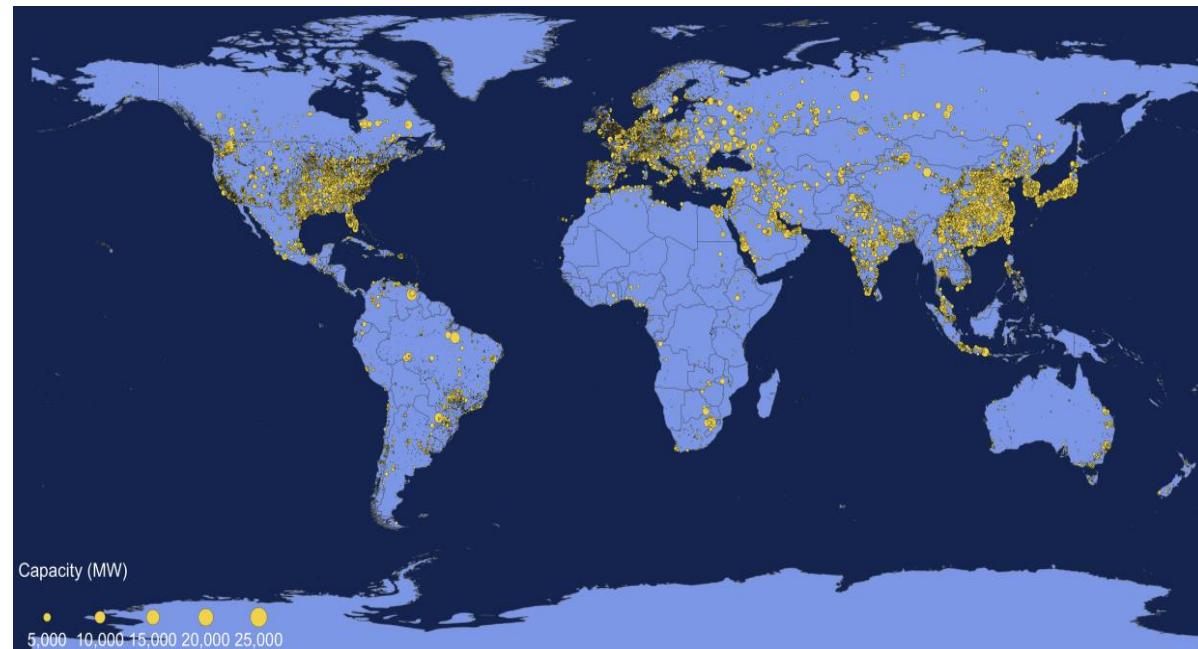
Electricity Generation Technologies



Traditional Energy Sector

- Install capacity in region i , $K_i^{\mathcal{F}}$

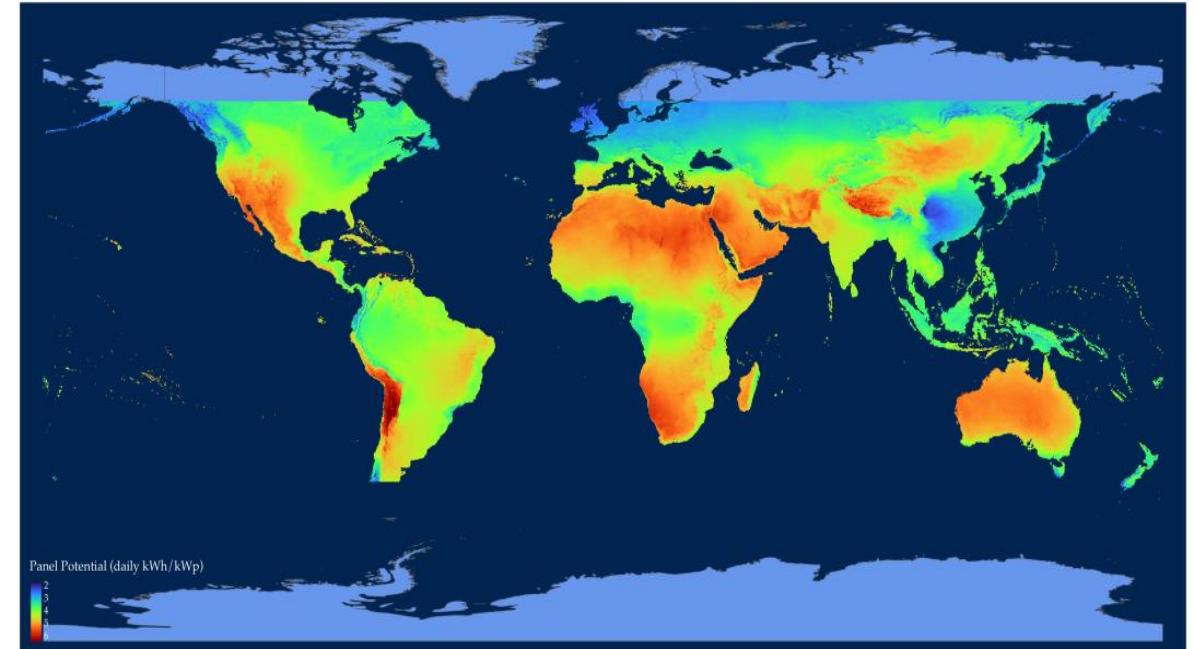
Global Installed Traditional Energy Sector Capacity



Renewable Energy Sector

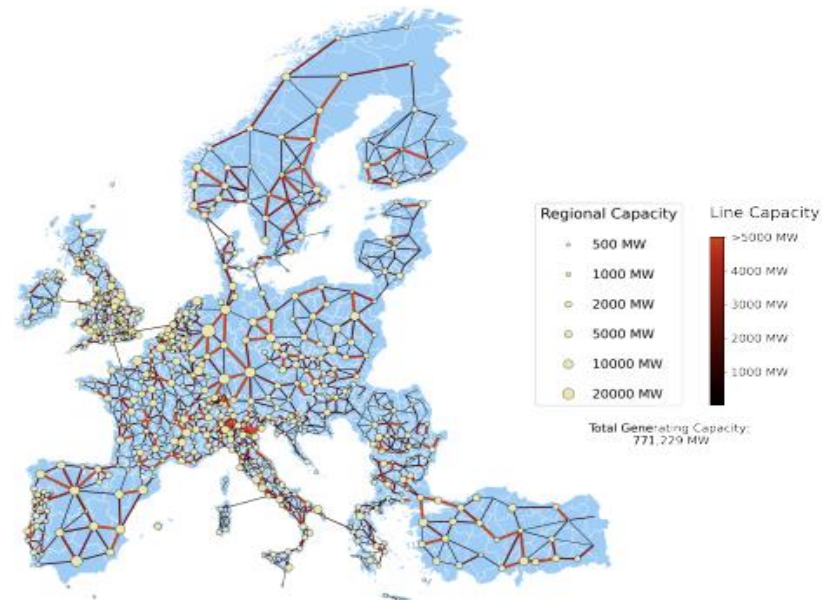
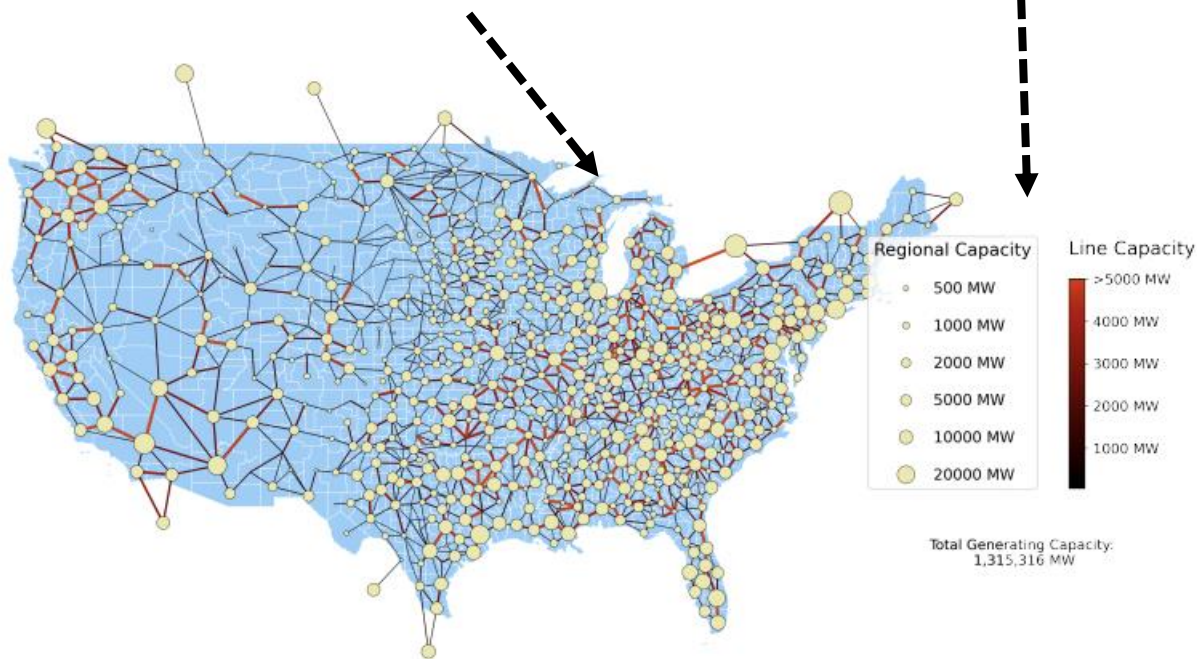
- Installed capacity in region i , $K_i^{\mathcal{R}}$, $\mathcal{R} = \{S, W\}$
- Wind or Solar, Efficiency $\theta_i^{\mathcal{R}}$

Global Variation in Solar Efficiency

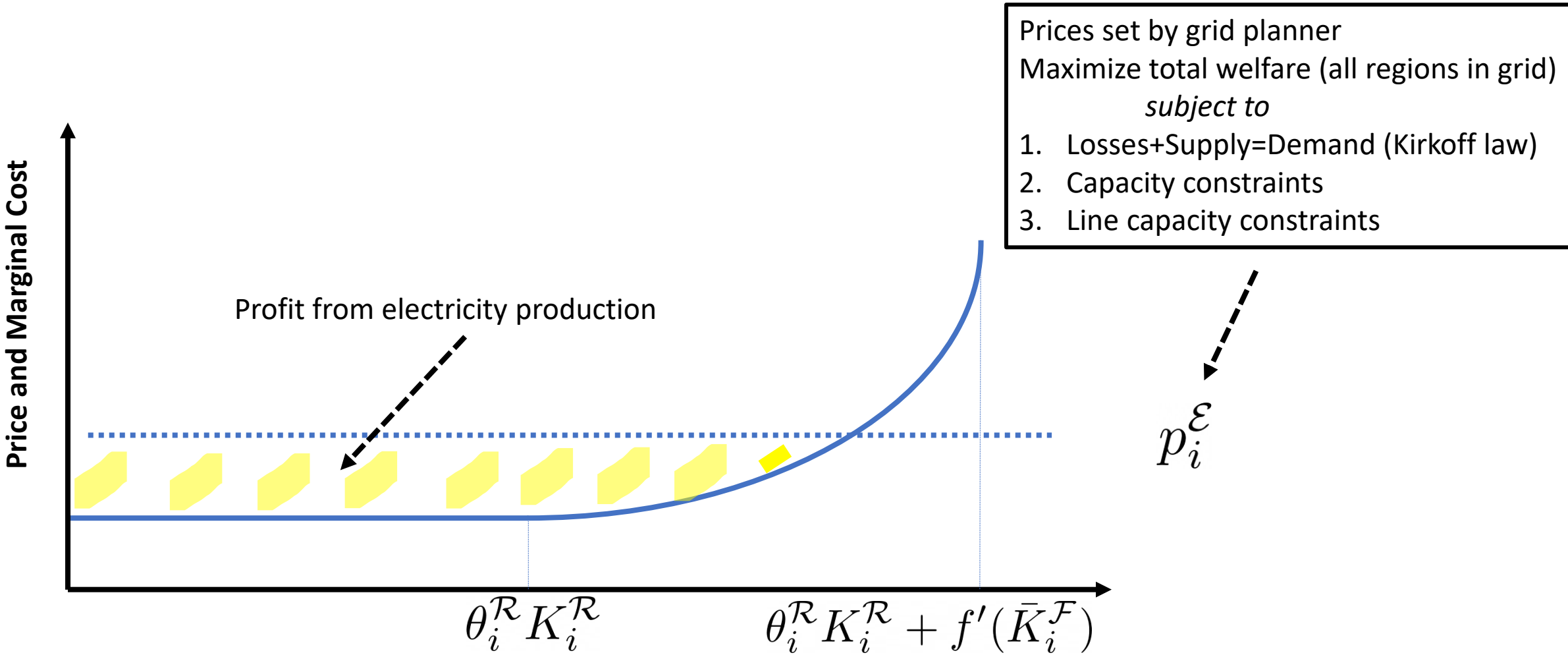


Electricity Transmission Technology

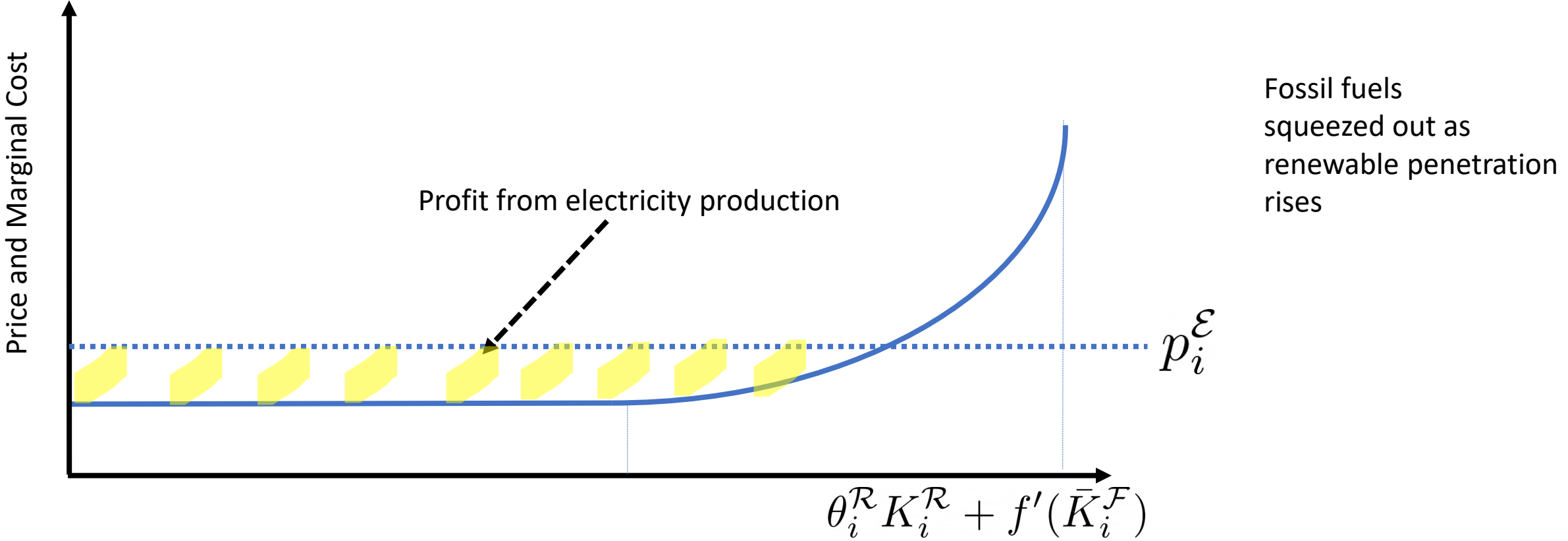
- Electricity in a region i , generated by traditional and renewable assets
 - Net supply of each region is $P_i = Y_i^{\mathcal{E}} - D(p_i^{\mathcal{E}})$
- Losses, λ , determined by physical constraints in transmission network
 - Matrix of links, resistance (inv of capacity) of lines, and net supply in each link



Electricity Markets: Merit Order Dispatch



Electricity Markets: Merit Order Dispatch



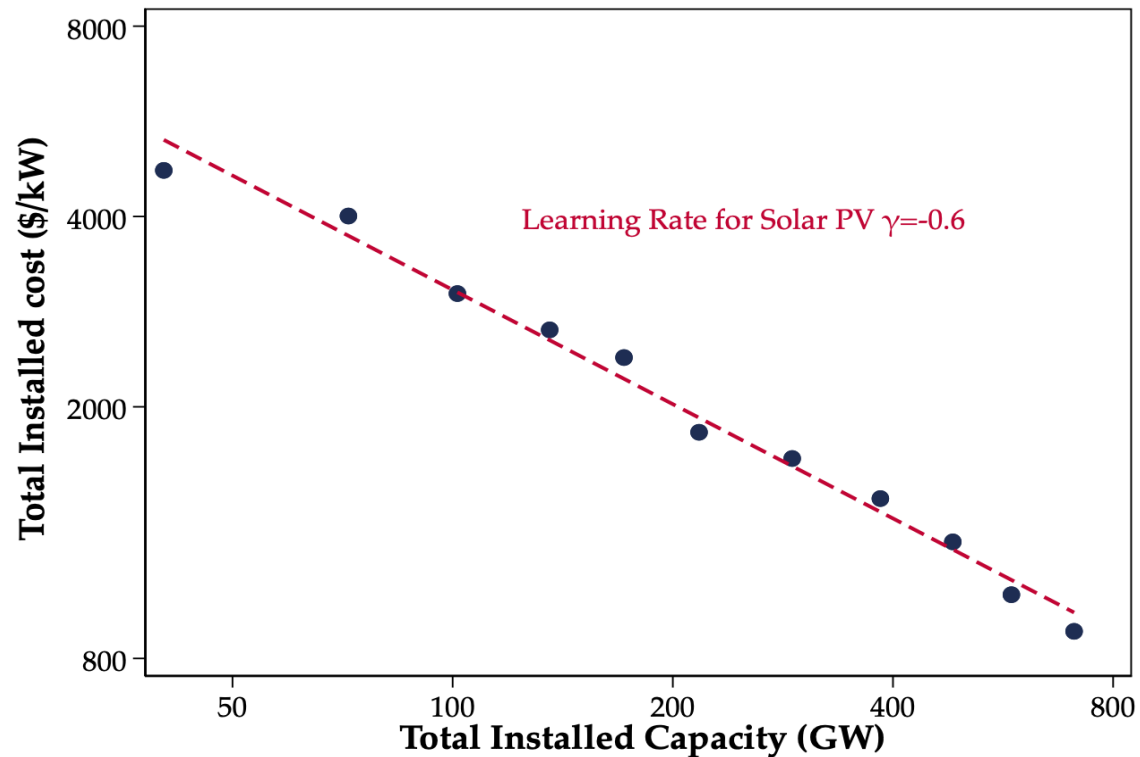
Renewable Investment and Fossil Extraction

- **Renewable investment**

- Is modular
- Has (close to) zero marginal cost
- Is subject to learning by doing (*lbd*)

- Solve value function in Walsh '21

- Add *lbd* scale effects

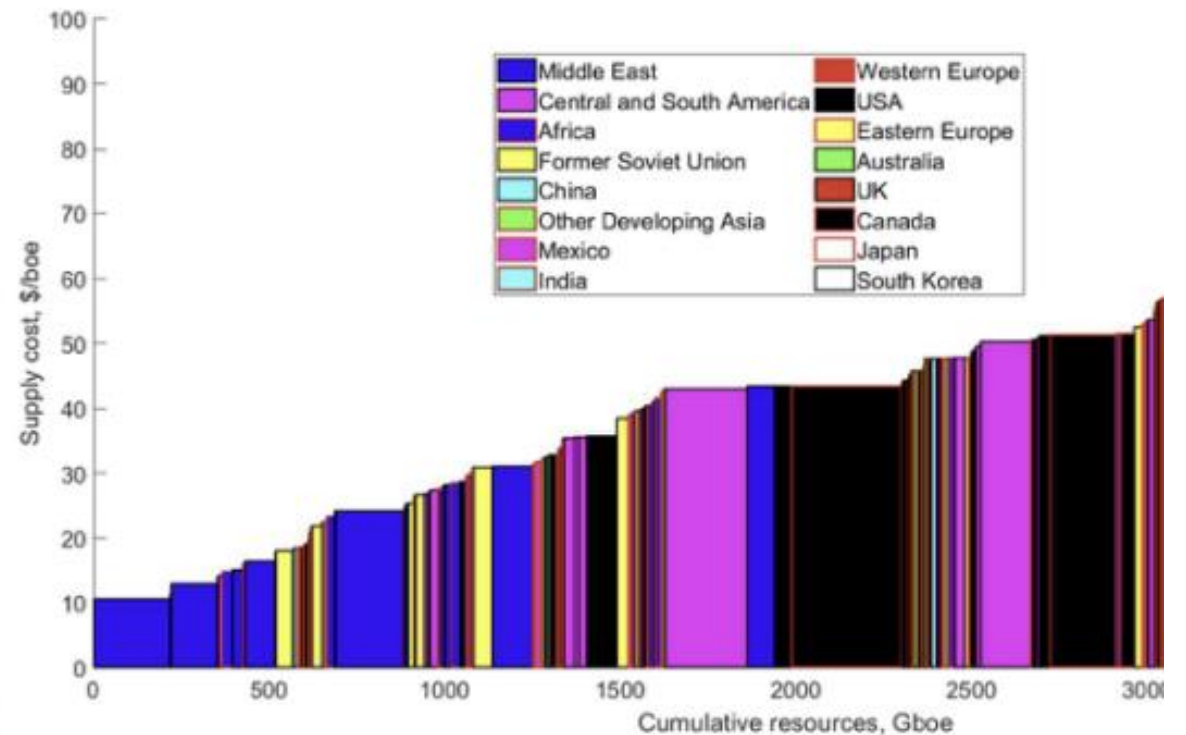


- **Fossil Extraction**

- Not modular
- Has increasing marginal costs
- Little *lbd* (some technol. progress)

- Hotelling '31 resource extraction

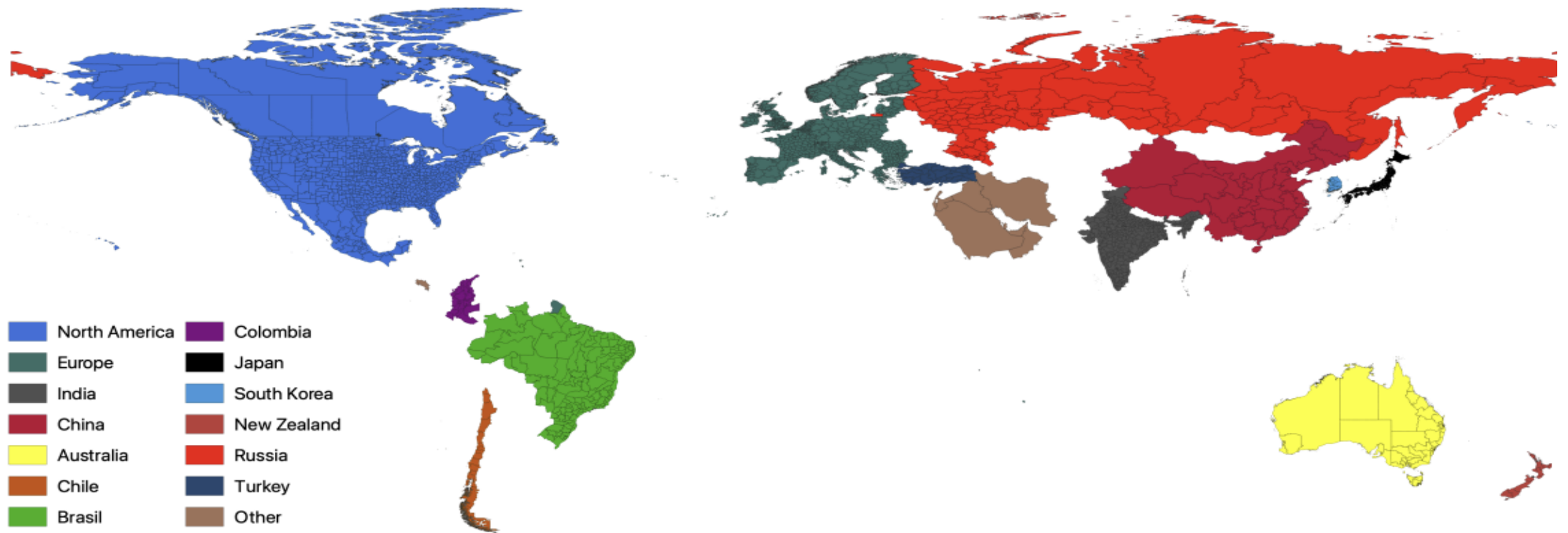
- Extraction costs **key** for wealth effects



Predictions and Counterfactual Policies

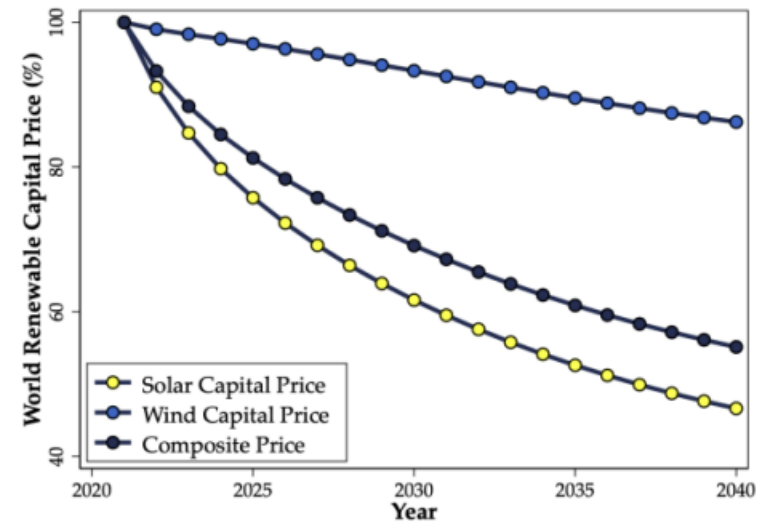
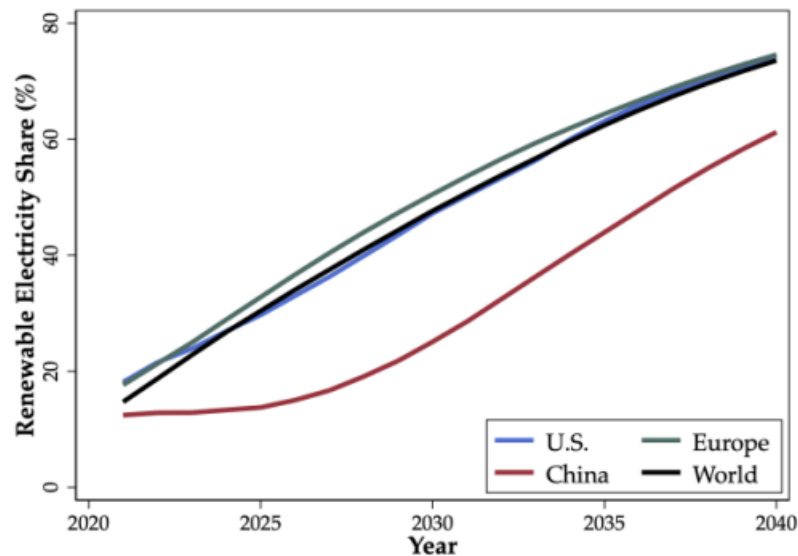
The Regional-Global Data

- Compile, combine, harmonize regional datasets (e.g. commuting zone)
 - 56 countries, 2531 regions



Clean Growth Across the Globe

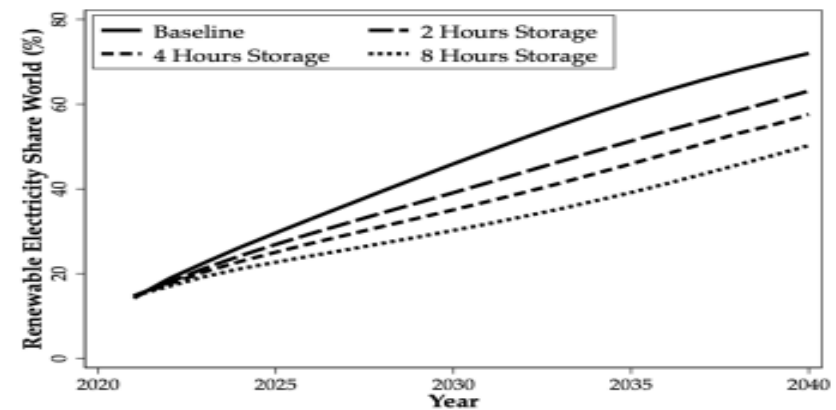
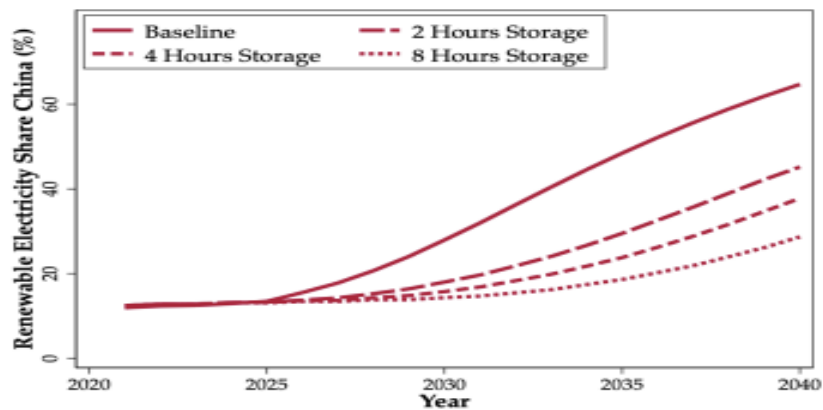
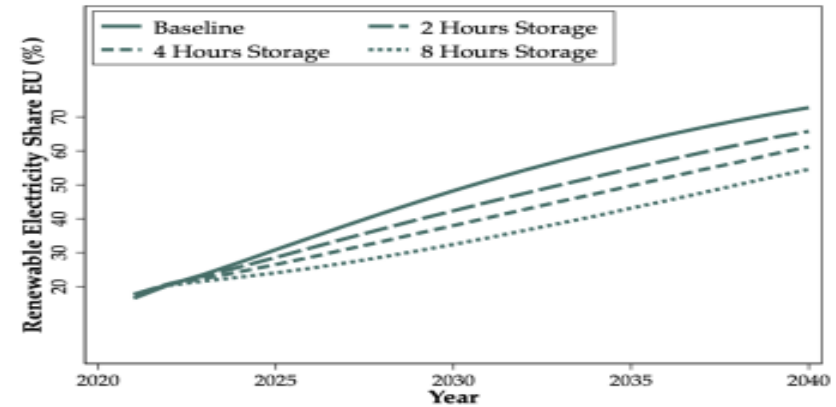
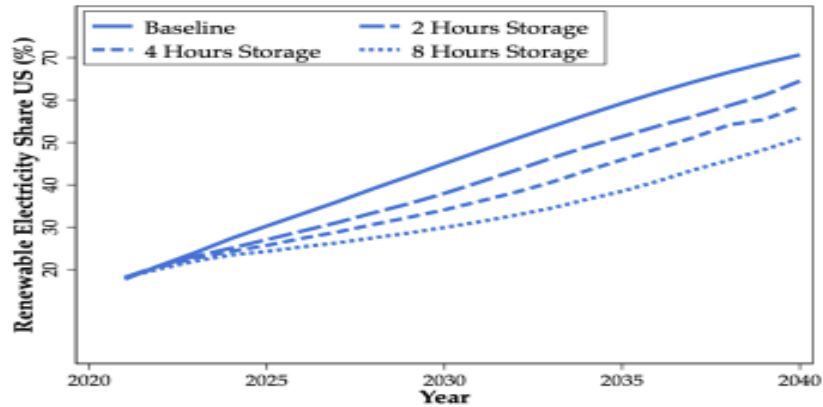
- Renewables dominate
 - Countries with ample fossil resources experience slower transition
 - Prices fall globally



The left panel shows the share of electricity coming from renewables in each country or region in the baseline scenario. This right panel shows the model's projection for the world capital prices in the baseline scenario, normalized to 100 in 2021.

Clean Growth with Storage

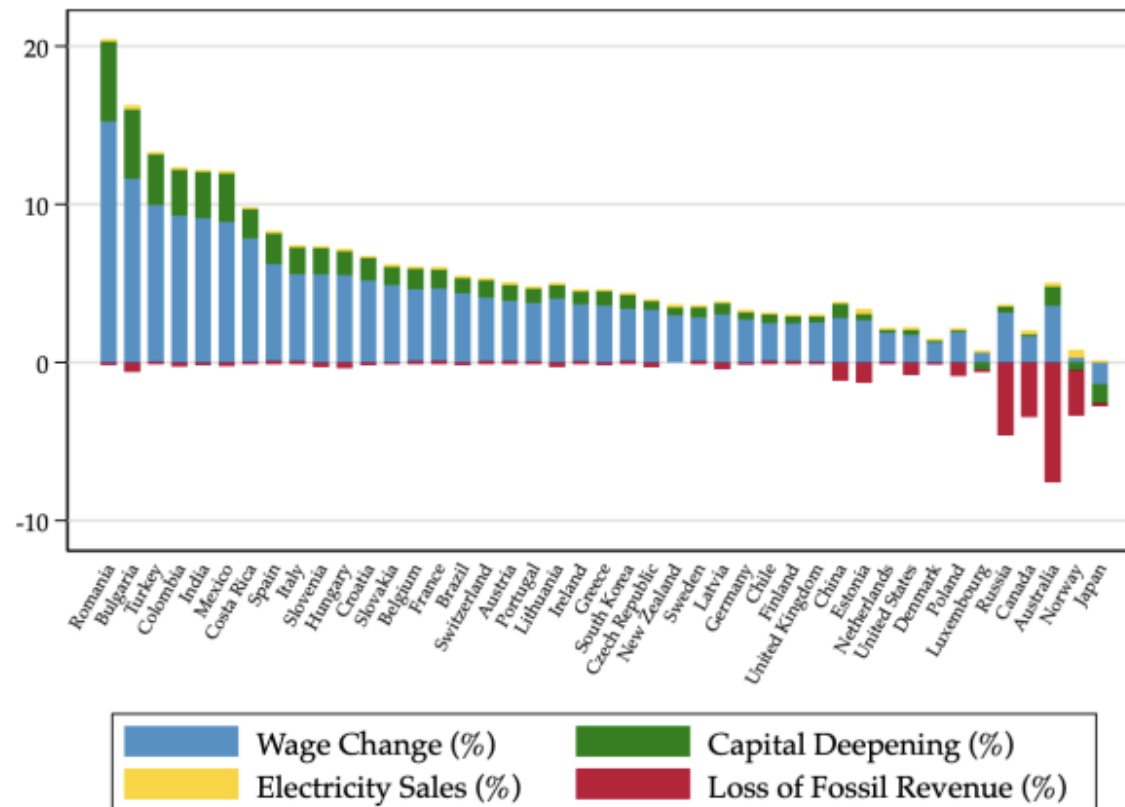
- Requiring storage slows down adoption but not considerably
 - Partial offsetting by strong learning by doing in storage



Notes: This figure plots the share of electricity by country coming from renewable sources in four different scenarios: the baseline, without any storage requirements, and then 3 scenarios of storage pairing with renewable capital.

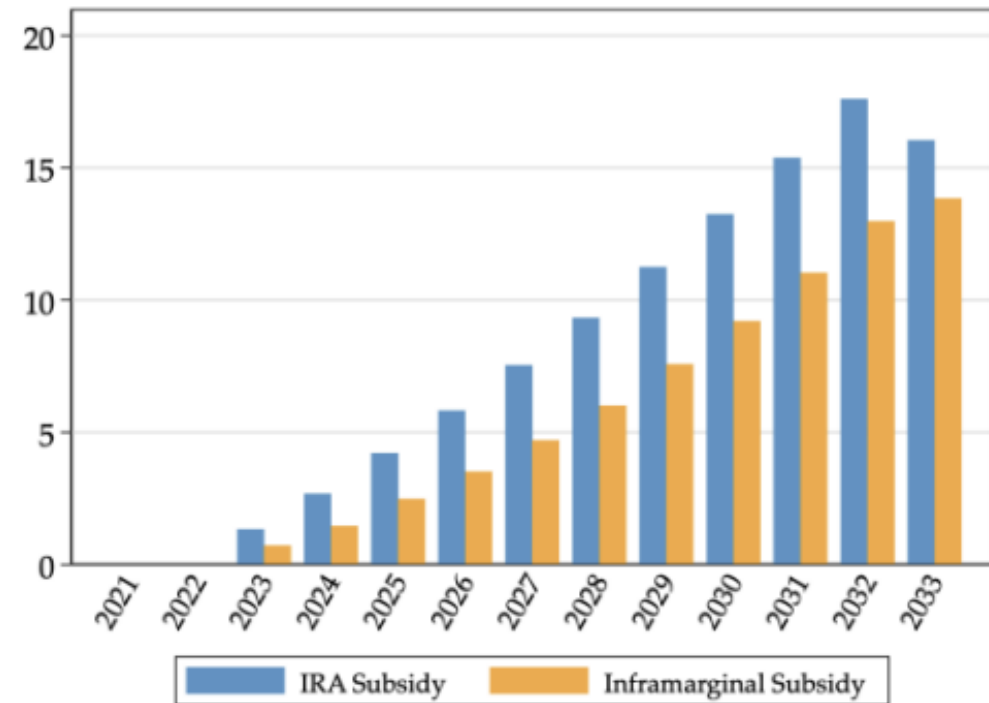
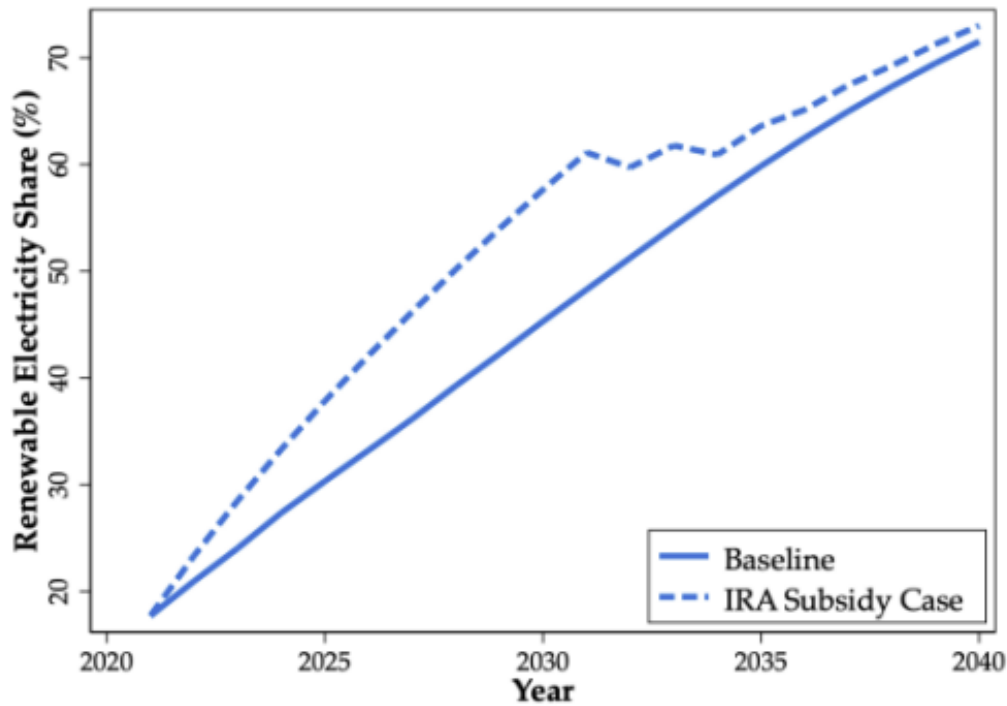
Winners and Losers Across the Globe

- Countries with connected grid, developing countries win
 - Countries specializing in exporting fossil fuels experience negative wealth effects



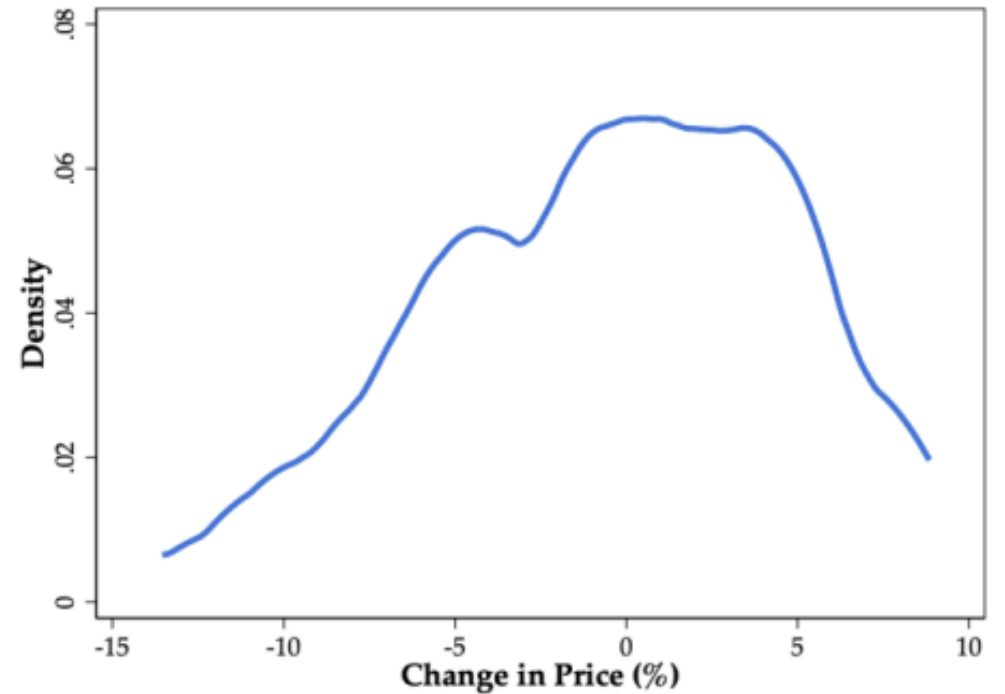
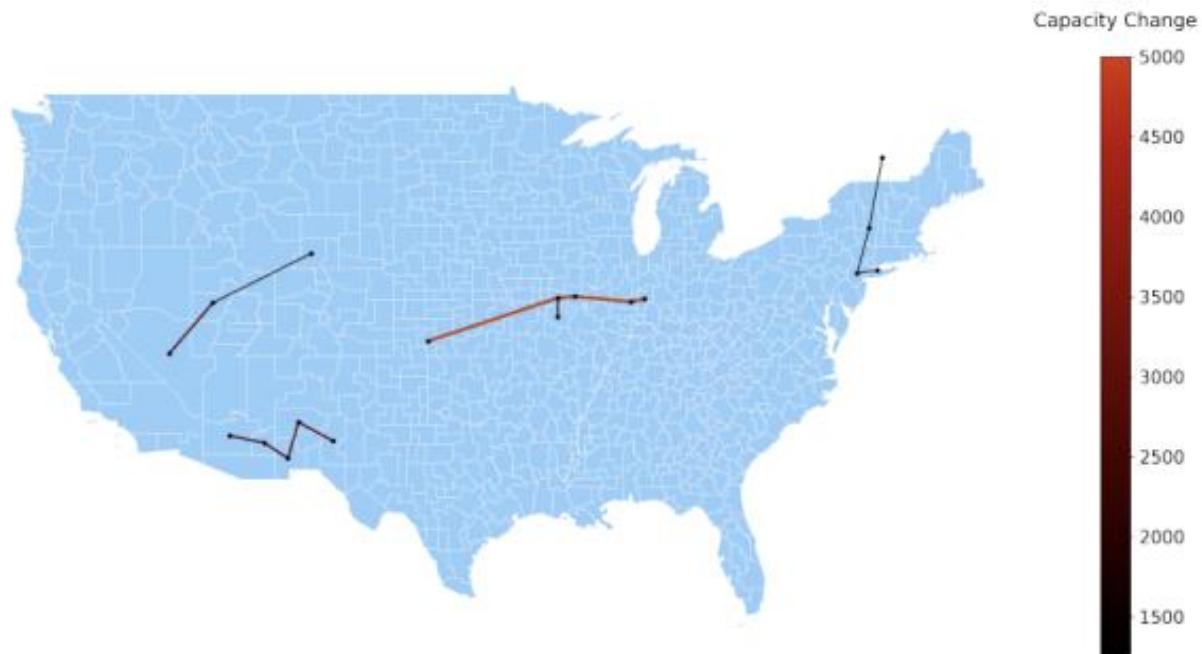
Inflation Reduction Act

- Signed into law Aug '22. Provides (retains) tax credit to renewable energy
 - \$5 in our counterfactual (\$5-26). Phases out in 2033



Infrastructure & Jobs Act

- Model specific lines under completion. Add them to our network
 - Estimated cost of \$10 billion. Generate \$1.5 billion annual net benefit. Effects not uniform



Conclusions

- Age of renewables has begun!
 - Lower capital costs spur adoption, which further lower capital costs
 - Virtuous cycle likely to push down power prices
- Policies promoting renewables/grid can have significant economic effects
- **Fossil era:** *energy scarcity*
 - **Renewable era:** energy abundance?