Powering Change: Chile's Energy Transition

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PUC-Chile

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Motivation

- To global limit warming (to 1.5°C), requires substantial reductions in green house emissions
- Electricity generation sector:
  - Accounts for 30–40% of global CO_2 emissions
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- **This paper:** What factors drive the energy transition in Chile?

Outline

1. Chile's Energy Generation Transition
2. Market Forces Spurring Energy Transition
3. Policy Interventions
4. Discussion

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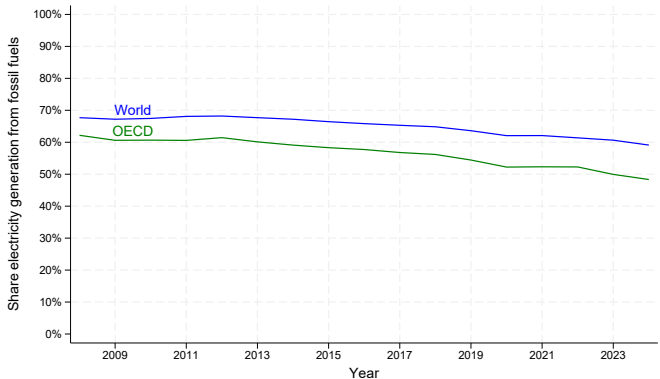

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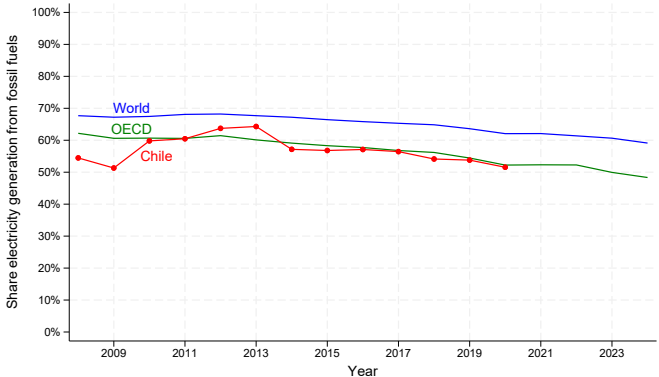

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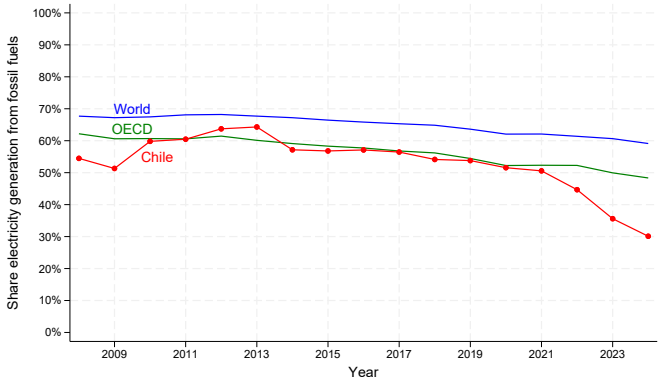

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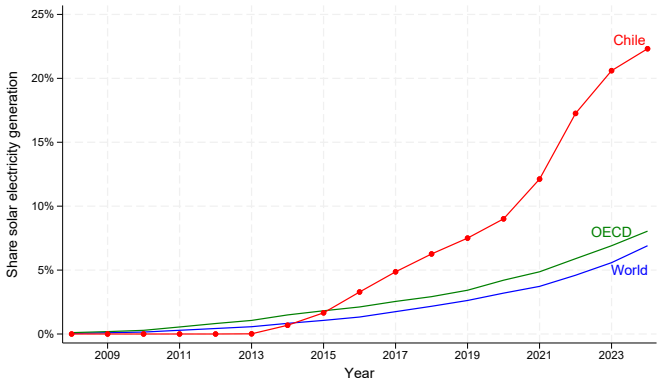
- Chile reduced its fossil share by 20 percentage points in the last four years ▸ CO_2 per kWh

Electricity Generation from Solar



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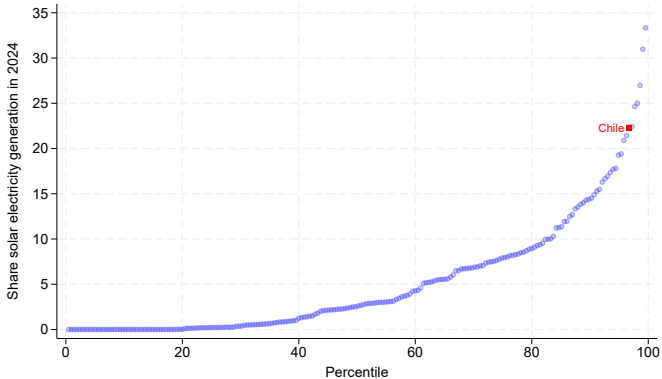
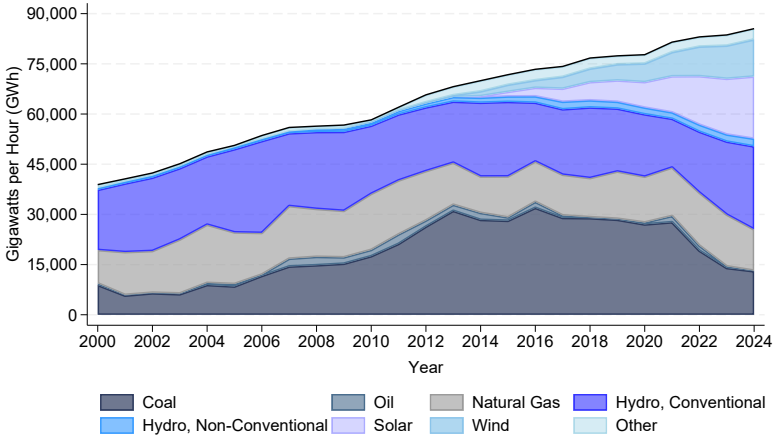


- Since 2015, Chile's solar generation increased tenfold: from 2% to 22%. ▸ Wind ▸ Hydro
- By 2024,
  - Chile is the 7th country with the highest reliance on solar, worldwide
  - Generates 22 percentage points more (10x) than the median country

Energy Generation Mix



- The recent expansion of solar and wind generation is displacing coal and natural gas

New Capacity

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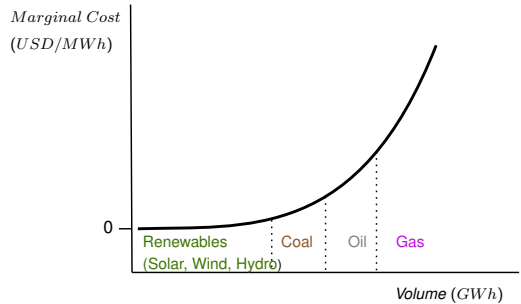

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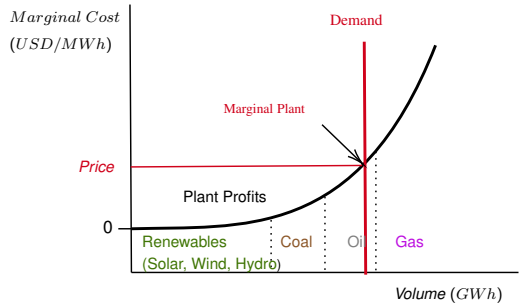

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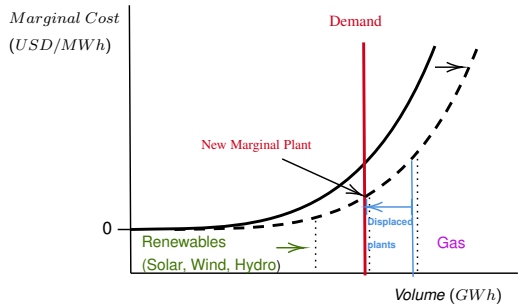

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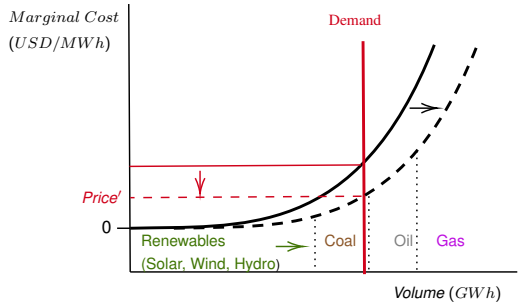
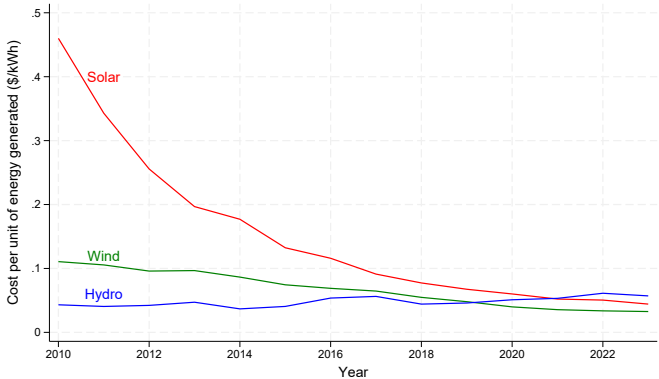


- Once installed, renewable electricity sources enjoy a cost advantage

  → However, investment decisions weigh (one-time) installation costs with (long-term) revenues

Cost of Renewable Technologies



- Since 2010, the global average levelized cost of solar electricity (LCOE) has fallen by 90%
  - 86% drop in installation cost, and a 17% increase in capacity factor
- As a result, installation of utility-scale solar is 56% cheaper than (weighted average) fossil fuel

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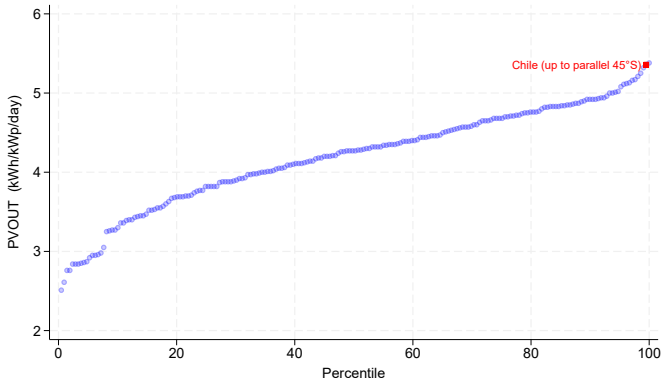

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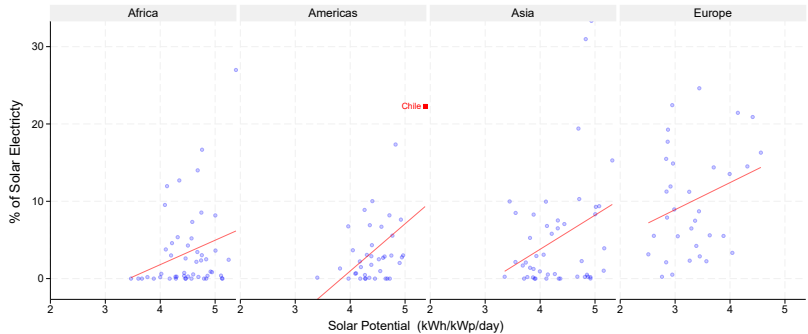

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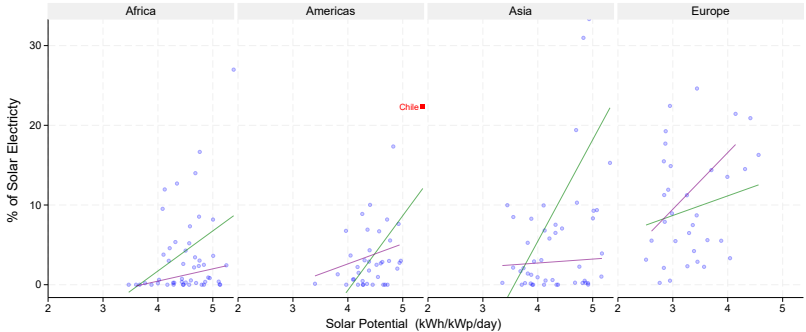

- Chile's solar generation outperforms its (linear) prediction,
  - even among countries without domestic fossil-fuel production (green linear fit)

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  - Receive electricity from utilities that purchase it through long-term contracts with generators
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- In 2015, Chile implemented a reform to auction design:
  - Electricity contracts were divided into specific time blocks (e.g., daytime, nighttime).
  - The length of contracts was increased from 15 to 20 years.
  - The period between the auction award and the supply was extended from 3 to 5 years.

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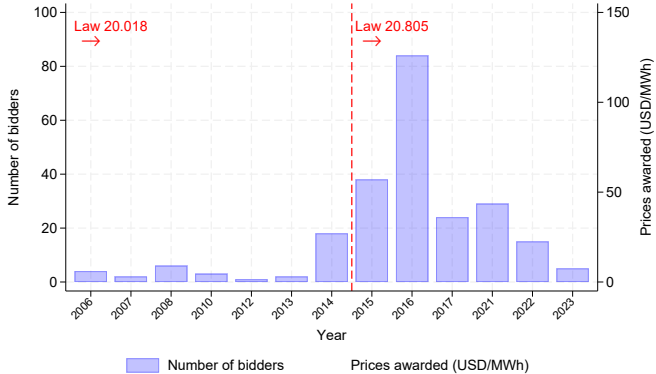

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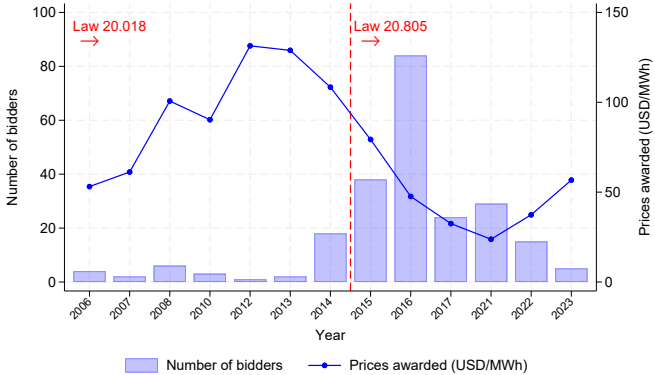

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Auction Design for Regulated Customers

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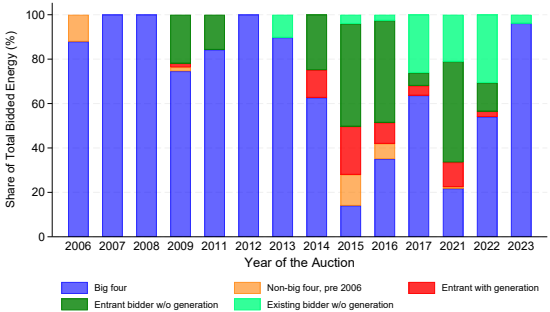
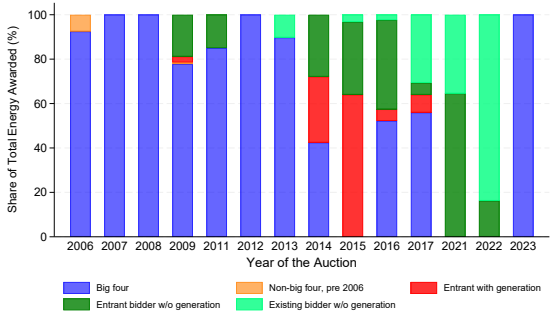


(b) Awarded Firms



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NCRE Quotas

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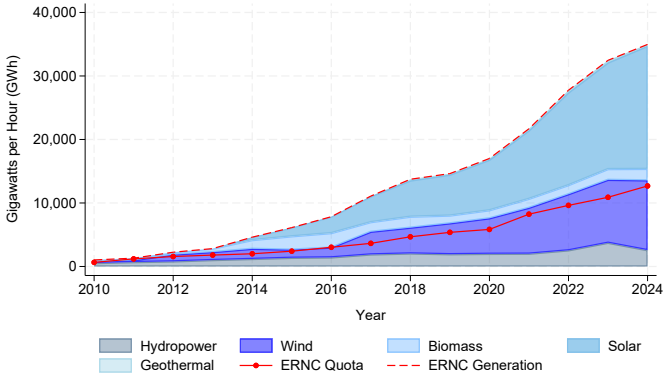
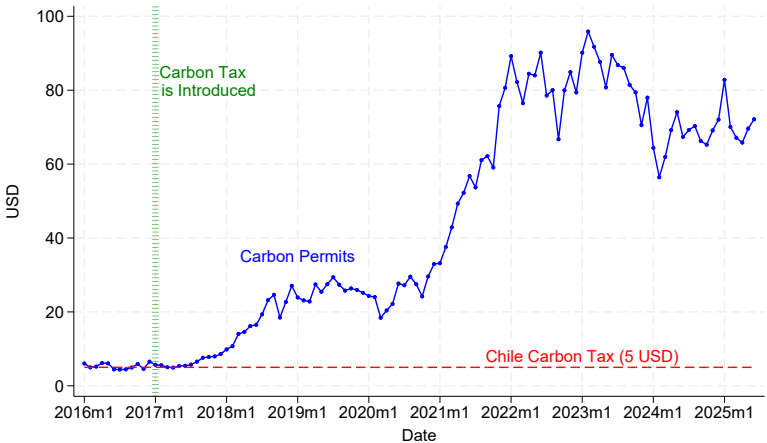


Figure: Compliance with NCRE Quotas

The CO_2 Tax

Figure: EU ETS Carbon Prices vs Chile's Carbon Tax (USD)



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- Three reactions:
  - Command and control logic $\Longrightarrow$ A price instrument would have been better
  - Gas-fired power plants not included
  - Many of the retired plants already in decline

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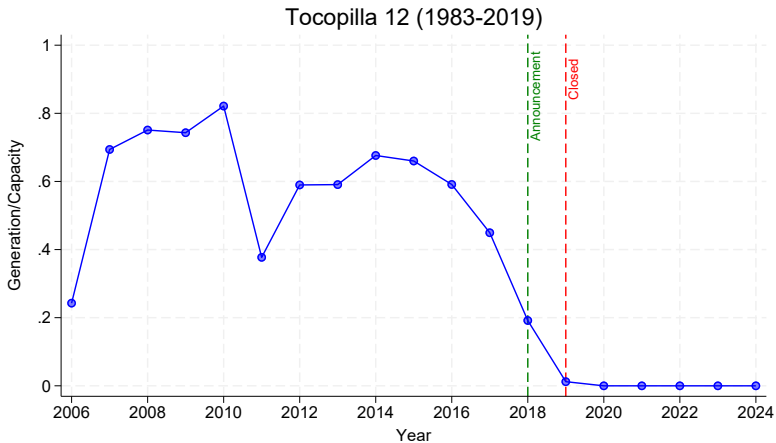
Figure: Capacity Factor of Coal Plants Phased Out by 2024



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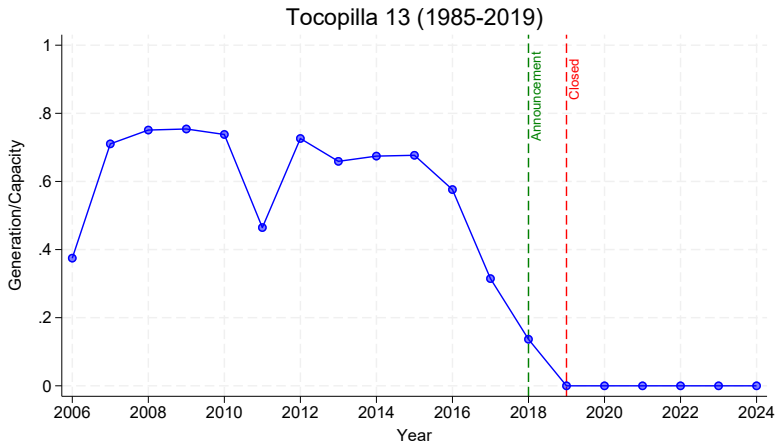

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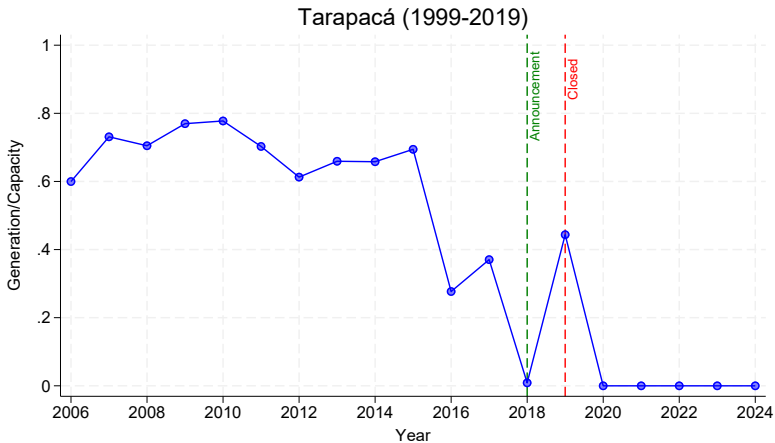

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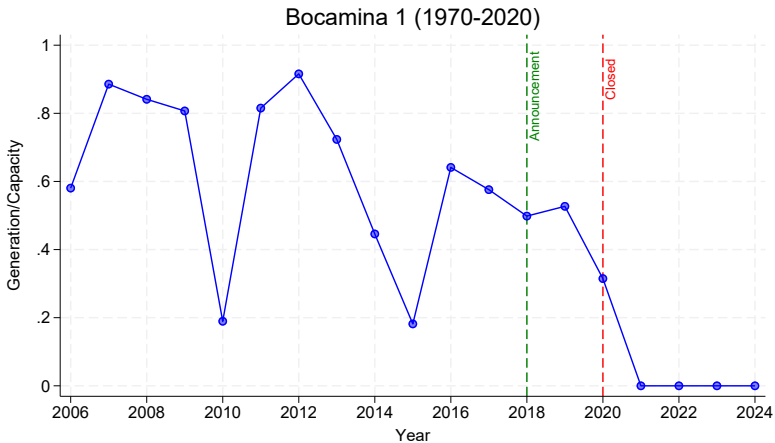

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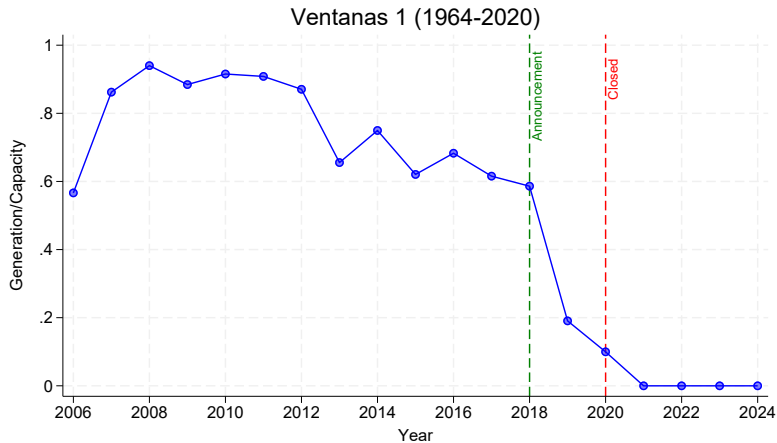

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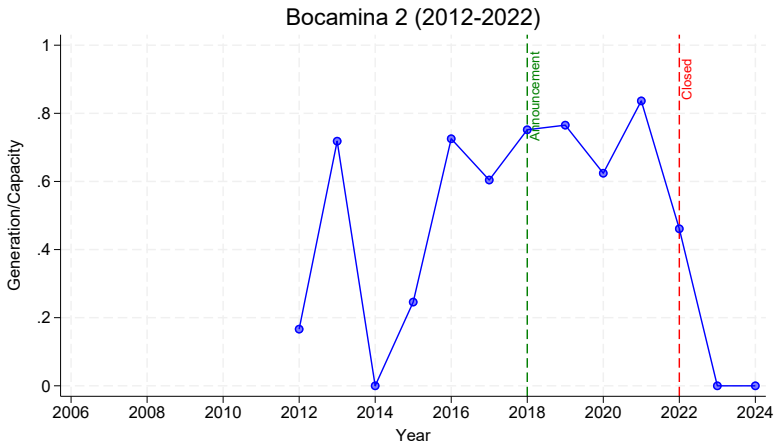

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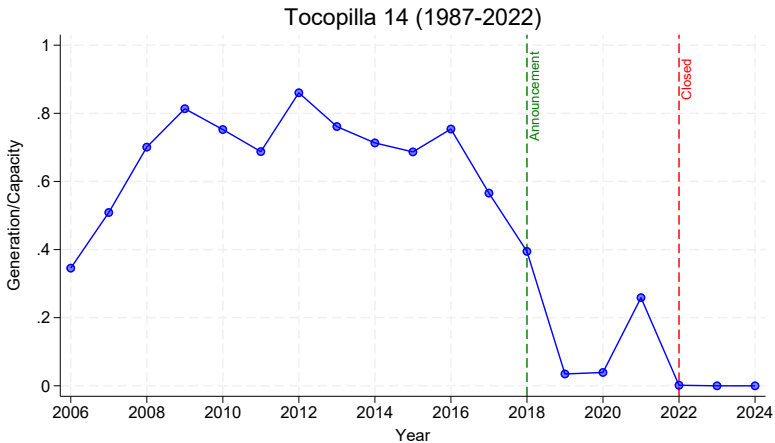

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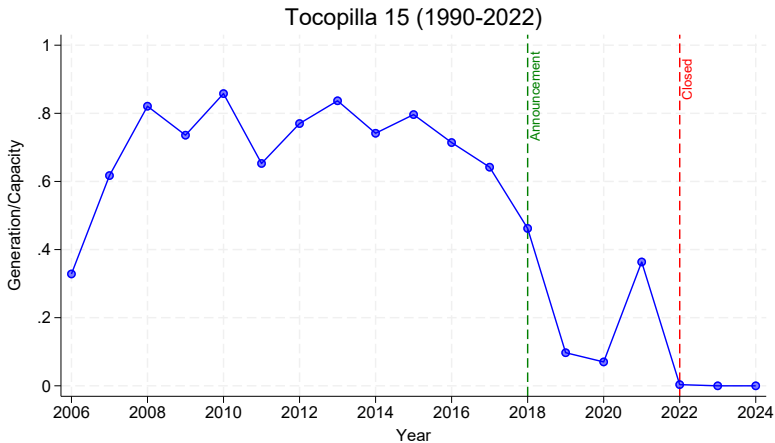

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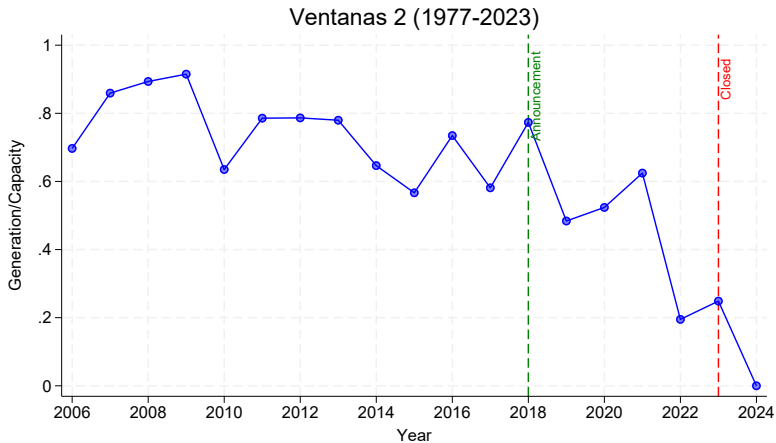

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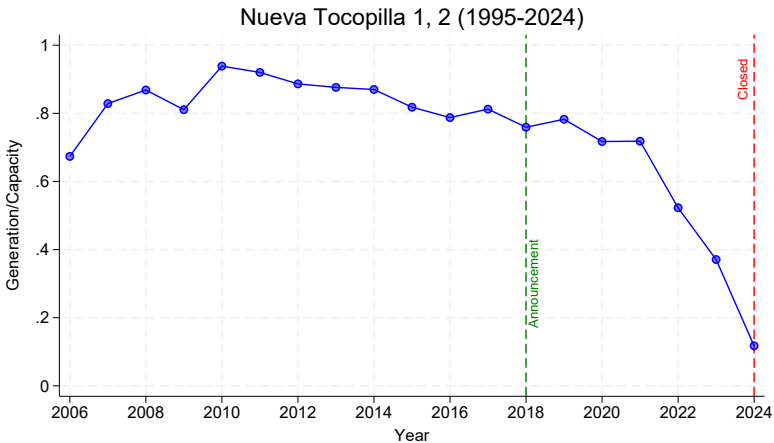
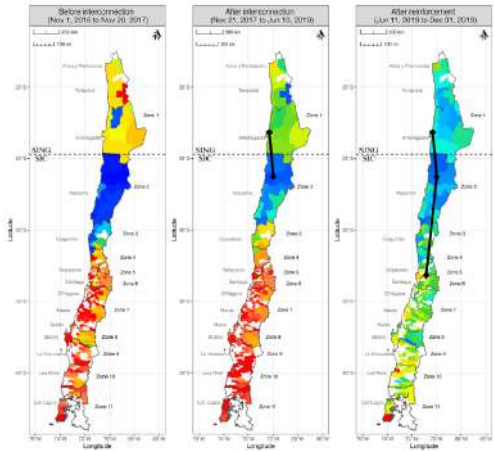


Transmission Investments

- Gonzales et al. (2023) study two recent transmission investments:
  1. Interconnection line between Atacama and Antofagasta in 2017,
  2. Reinforcement line between Atacama and Santiago in 2019.



Transmission Investments

- The perfect market integration observed in 2020 has not remained over the years. Transmission lines are becoming increasingly congested, resulting in significant price differences.

▸ Price Levels

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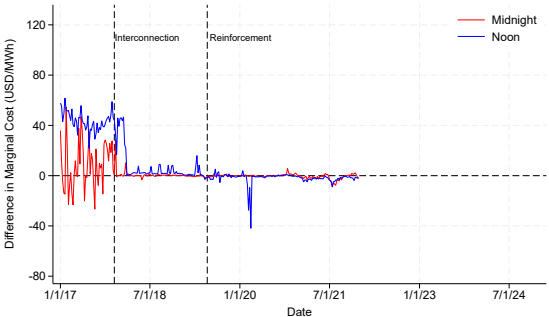

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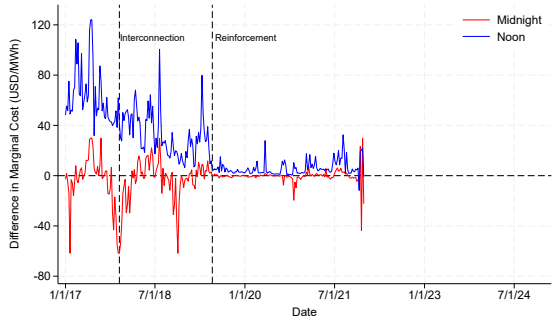

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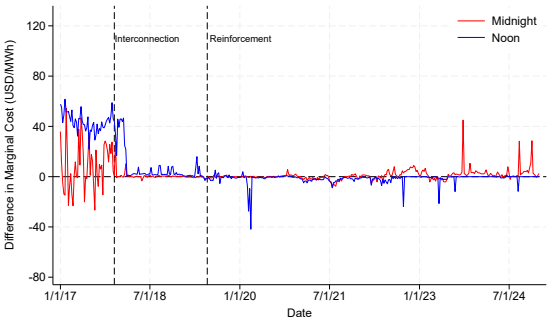

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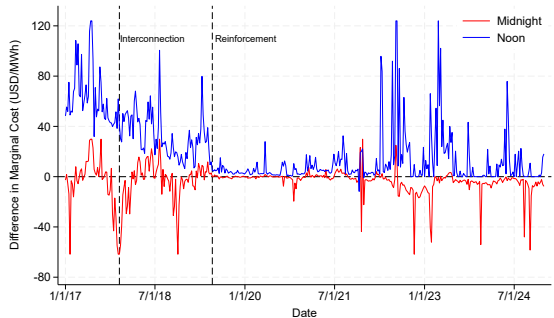

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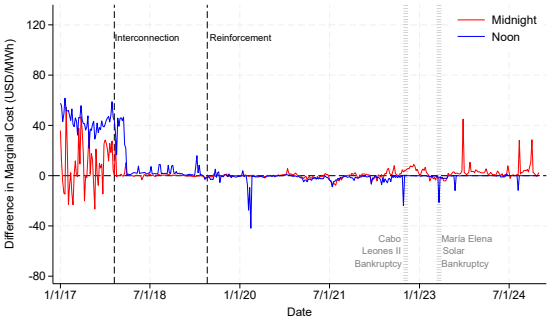

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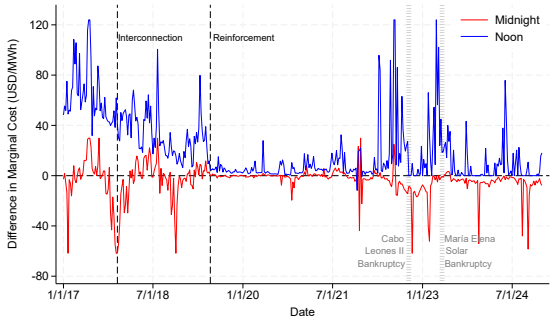
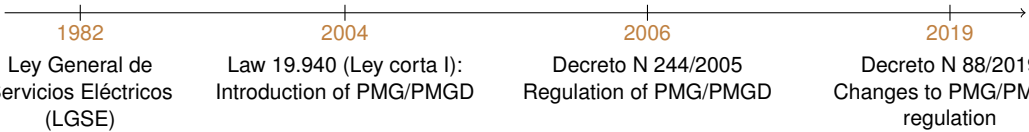


“Subsidies” for Small Generation Plants (PMGD)

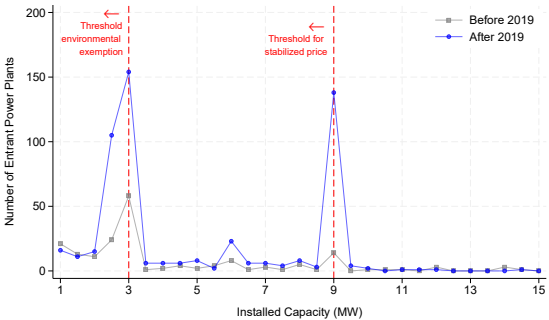


- **2004:** Introduction of “price stabilization mechanism” for generation units of less than 9 MW.
- **2006:** Small Means of Distributed Generation (PMGD) and Small Means of Generation (PMG) can choose (every 4 years) whether to sell in the spot market or at a stabilized price
- **2019:** Stabilized price is split into six time blocks

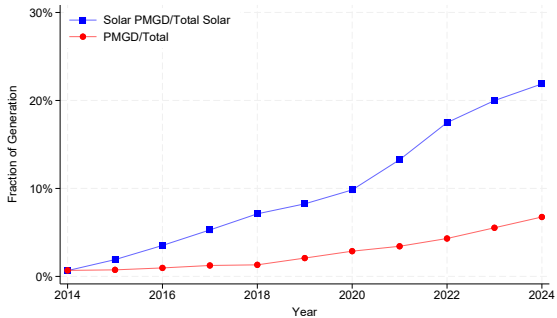
“Subsidies” for Small Generation Plants (PMGD)

- The 2019 reform had a great impact on PGMD investment.
- The participation of PMGD in total generation has steadily increased since 2014.

(a) Entry of Power Plants Between 1 and 15 MW

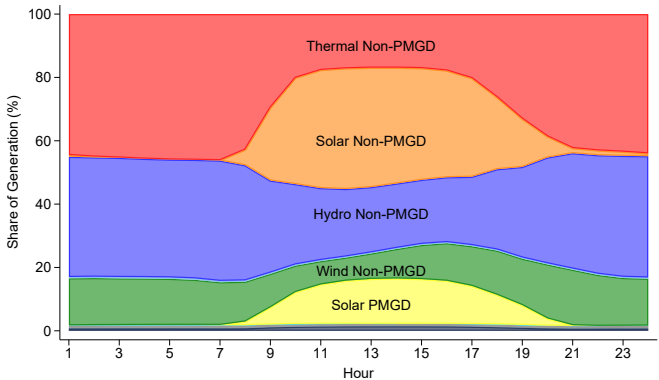


(b) Participation of PMGD in Generation



“Subsidies” for Small Generation Plants (PMGD)

Figure: Hour Generation by Technology and Plant in 2024



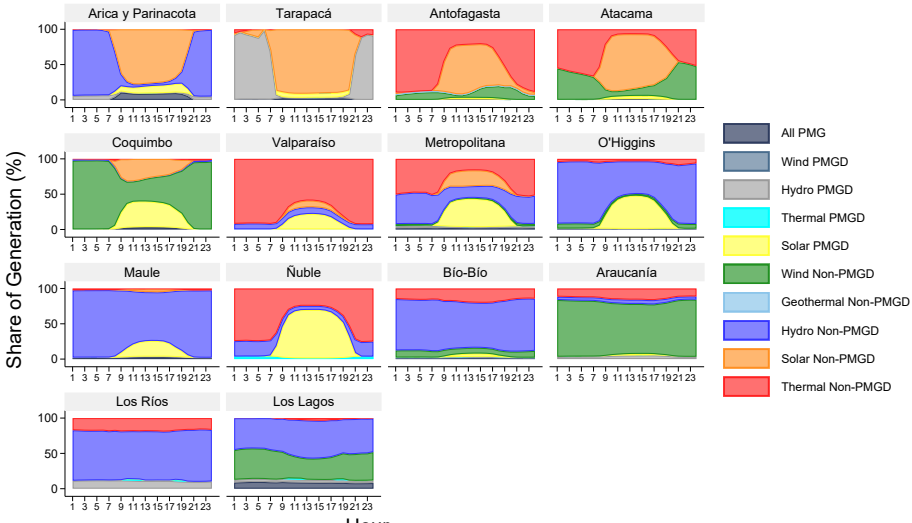
“Subsidies” for Small Generation Plants (PMGD)

- Evaluating the impact of PMGD “subsidy”:
  - Displacing clean generation $\implies$ implicit price tends to infinity.
  - Displacing dirty generation $\implies$ Is it the implicit price around levels observed in international markets? ($\approx$80 USD/ton CO_2).
- Our preliminary estimation the implicit prices of the PMGD “subsidy”, at the region-year level:

$$\text{Implicit Price} = \frac{\Delta\text{Subsidy After 1\% } \uparrow \text{ PMGD Generation}}{\Delta CO_2 \text{ Emissions From Displaced Generation}} \tag{1}$$

- Today, the stabilized price is almost by construction a subsidy (because of entry); not sure how to compute the proper counterfactual.

“Subsidies” for Small Generation Plants (PMGD)



“Subsidies” for Small Generation Plants (PMGD)

Table: Implicit Price Estimation (USD/ton CO_2)

Region	2021	2022	2023	2024
Arica and Parinacota	–	–	3,723.45	190,500.25
Tarapacá	83.03	118.23	542.37	1,025.46
Antofagasta	58.47	125.41	368.37	359.40
Atacama	27.72	108.23	333.56	382.32
Coquimbo	700.01	1,163.08	40,404.06	15,264.61
Valparaíso	-2.17	18.99	91.23	100.87
Metropolitan Region	-22.29	9.34	199.14	301.44
O’Higgins	-90.93	21.69	413.50	1,914.07
Maule	-512.77	-355.84	3,670.72	11,655.90
Ñuble	-80.81	-26.96	336.40	659.61
Bío-Bío	-41.30	-61.67	99.46	176.57
Araucanía	-1,462.28	-2,650.27	22.06	264.67
Los Ríos	-554.56	-1,163.30	-2,576.65	-5,292.76
Los Lagos	-486.82	-1,452.49	-1,057.35	-245.39
All Regions	-37.98	-16.04	222.70	325.20

Outline

1. Chile's Energy Generation Transition
2. Market Forces Spurring Energy TransitionMarket
3. Policy Interventions
4. Discussion

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Discussion

- The goal of these notes has been twofold:
  - shed light on factors contributing to the rapid growth of renewable energy in Chile over the past decade
  - share some ideas on how to improve existing policies
- Given Chile's decarbonization goals and projected growth in electricity demand, designing effective policies to support the expansion of renewable energy remains a central challenge in the years ahead.
- We did not cover many other important issues (the role of storage, auction design, pay for ancillary services, etc.). We plan to explore some of them in future research

Thank you.

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CO_2 Emission per Unit of Electricity

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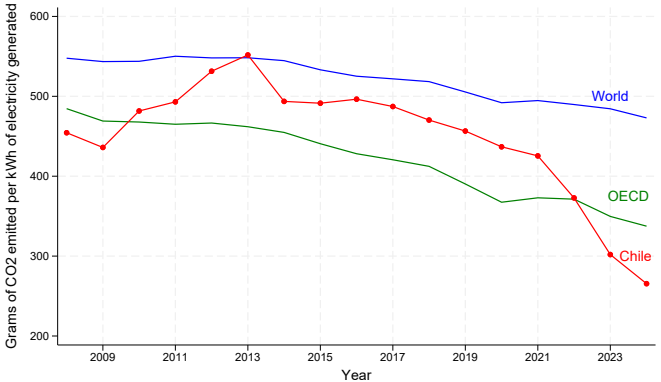

- In the last four years, Chile reduced by almost 40% the levels of emissions per unit of electricity

CO_2 Emission per Unit of Electricity

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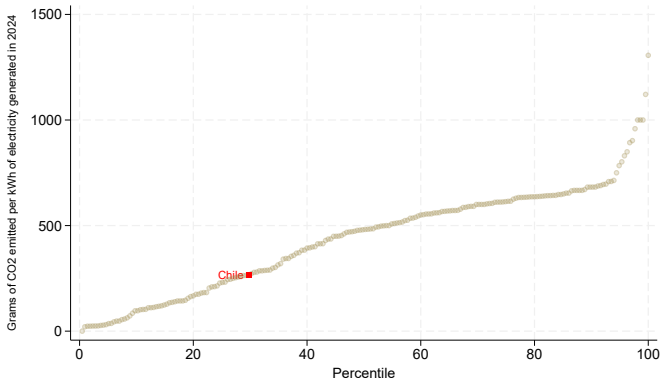

- In the last four years, Chile reduced by almost 40% the levels of emissions per unit of electricity

Electricity Generation from Wind

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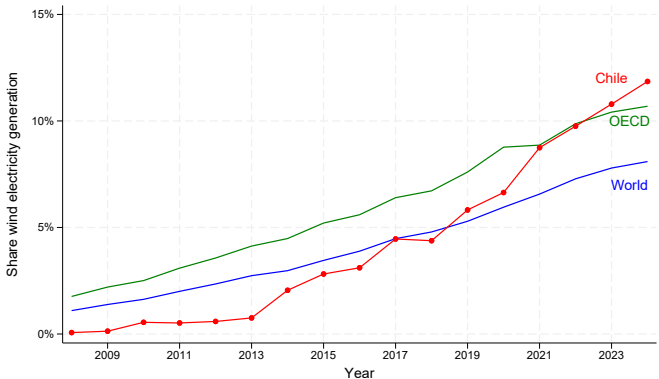

- Between 2013 and 2024, Chile's wind generation increased from 1% to 11%.

Electricity Generation from Wind

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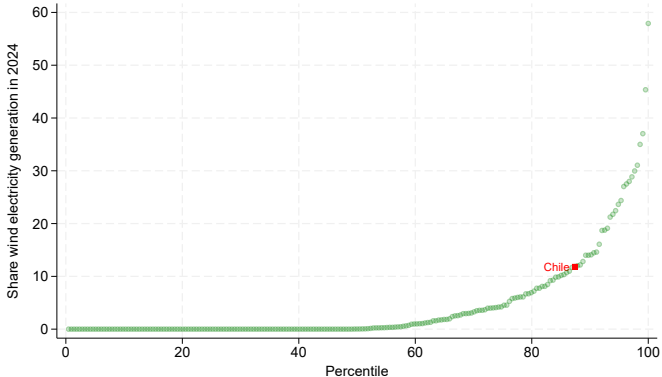

- Between 2013 and 2024, Chile's wind generation increased from 1% to 11%.
- Chile is the 28th country with the highest reliance on wind, worldwide (Denmark leads with 60%)

Electricity Generation from Hydropower

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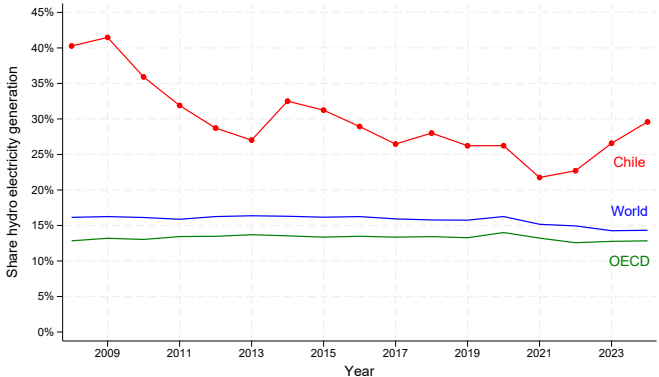

- Between 2013 and 2024, Chile’s hydro generation remained flat at around 25-30%.

Electricity Generation from Hydropower

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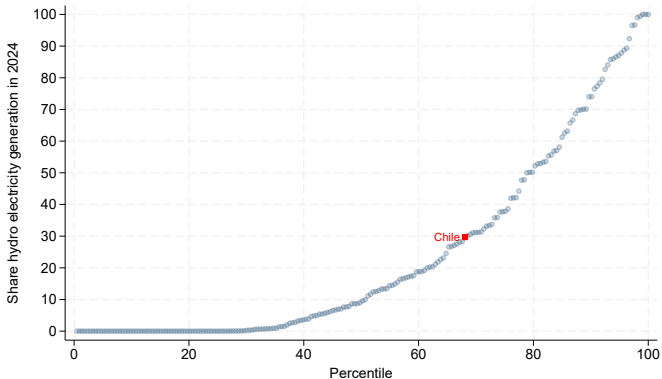

- Between 2013 and 2024, Chile's hydro generation remained flat at around 25-30%.
- Chile is the 68th country with the highest reliance on hydro, worldwide

New Generation Capacity

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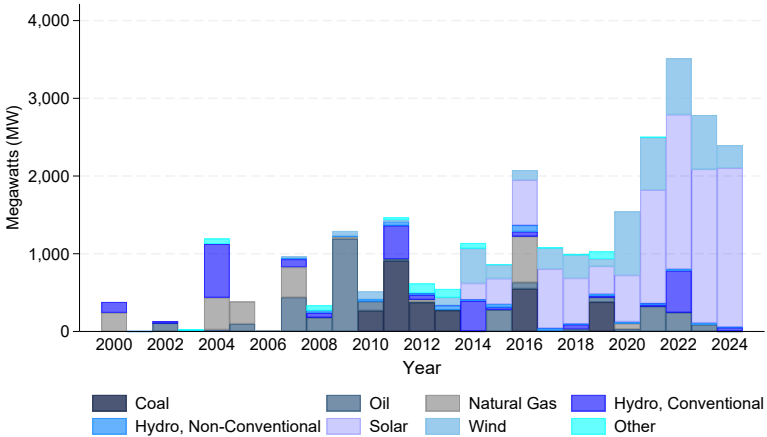

- Since 2026, almost all new investments are renewables (solar, wind, and hydro)

Transmission Investments

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Figure: Spot Price Comparison: Santiago vs. Atacama, Daytime and Nighttime