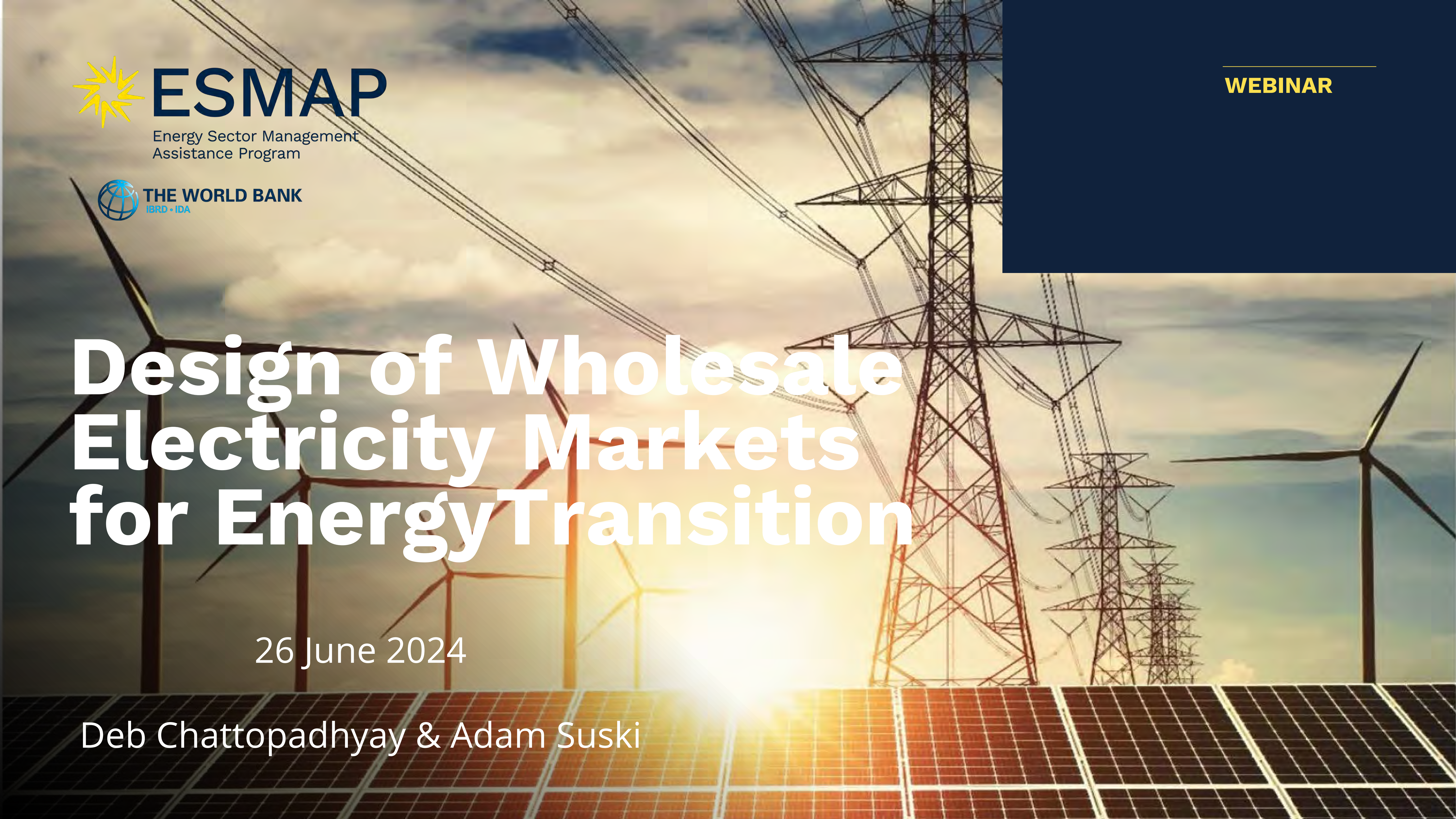


ESMAP
Energy Sector Management Assistance Program

THE WORLD BANK
IBRD • IDA

WEBINAR

Design of Wholesale Electricity Markets for EnergyTransition

26 June 2024

Deb Chattopadhyay & Adam Suski

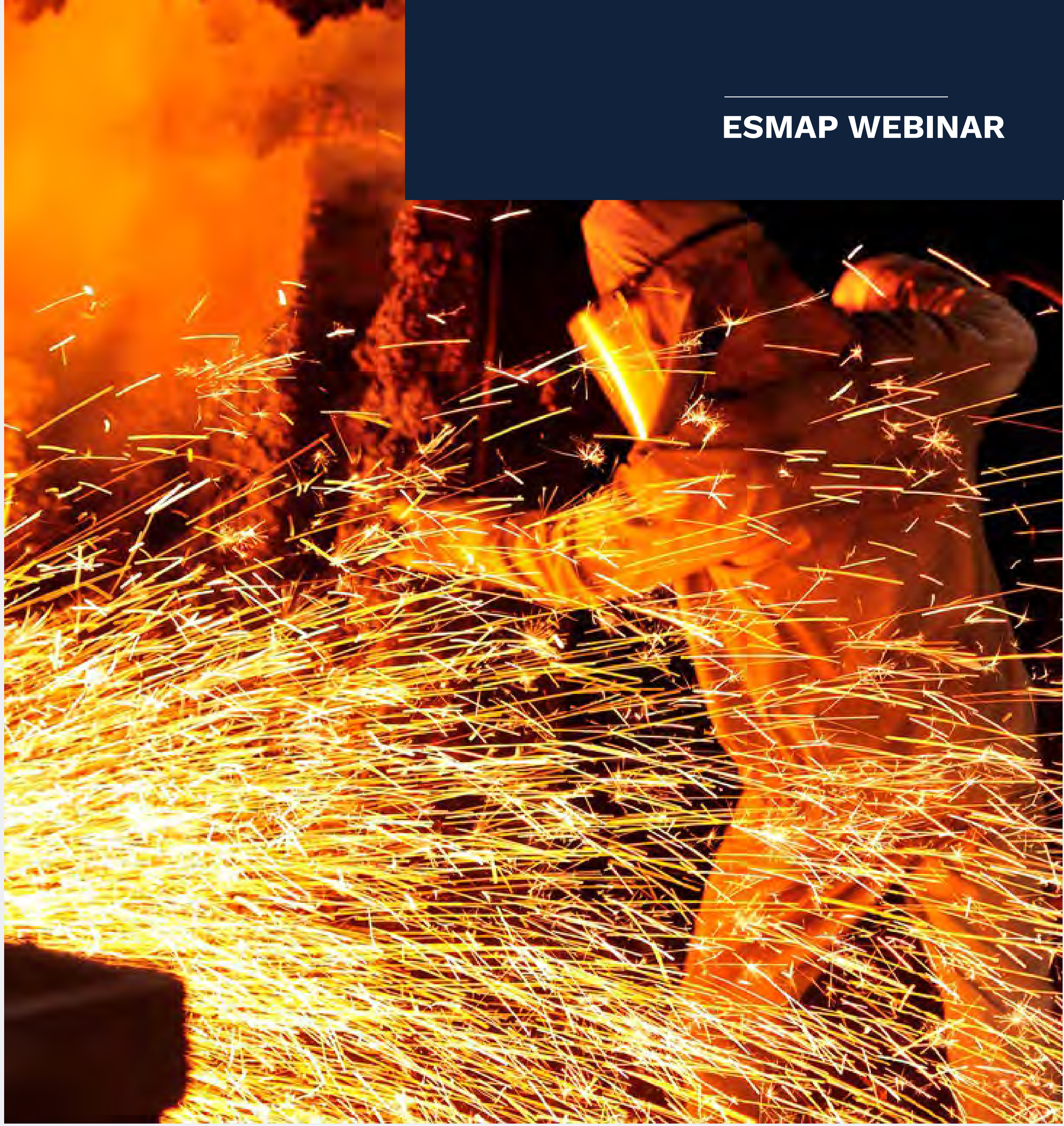
KEY QUESTIONS

1. Is design of existing wholesale electricity markets robust enough and compatible with carbon reduction policies?

2. Is the status quo good enough to deliver a decarbonized power system? OR

3. Are there adjustments needed in some of the existing features of a market or to augment the market with some mechanism? OR

4. Do we need a paradigm shift to long term contracts and/or rethink marginal cost-based pricing?



KEY QUESTION

There are important subtexts to it:

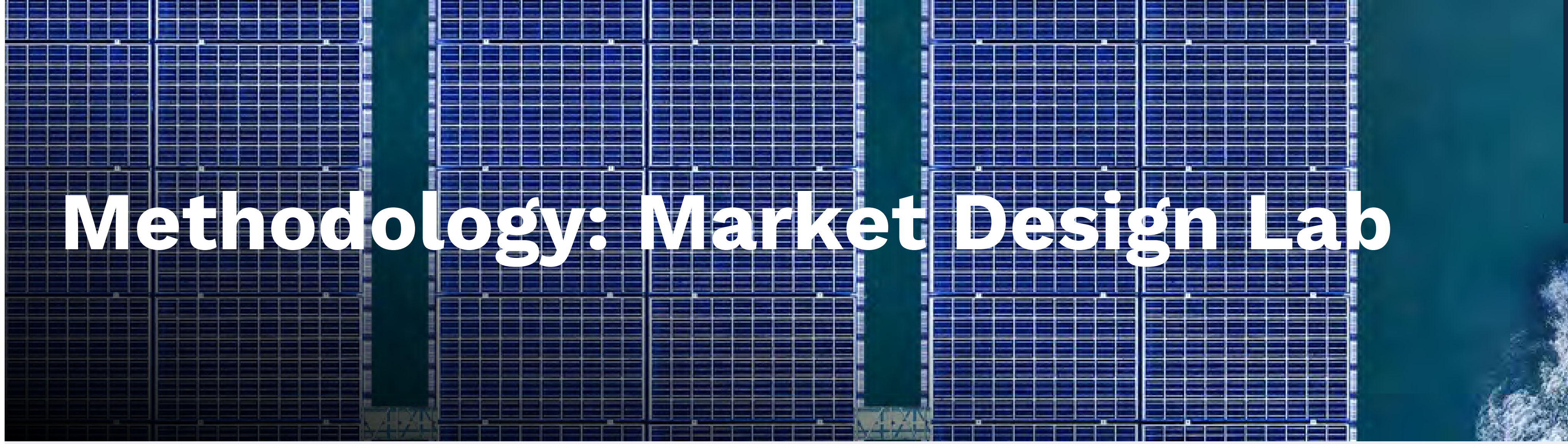
- Multiple market design options – Energy Only (EO), Energy Only with (Frequency Control) Ancillary Services (E+AS), Capacity and Energy (E+SM), Capacity, Energy and Ancillary Services (E+AS+CM), etc setting aside cost based pools
- Does one of these in fact perform better than others in a carbon constrained world? [Prices go up? Prices go up and down a lot? Excessive market power? System becomes unreliable?]
- What kind of system security risks do we need market designs to “cover”?
- [Standard (n-1)? Fast acting VRE related risks that can exceed (n-1)? Slow acting but even bigger risks like hydro or wind drought?]

What we would like to discuss today…

- A methodology to test if some of the popular market designs are vulnerable to price volatility, market power and security risks, especially under a carbon constraint

- Some results from a couple of case studies that we have conducted so far

- Hear your views on the methodology and the findings and also additional case studies that can be put to test!

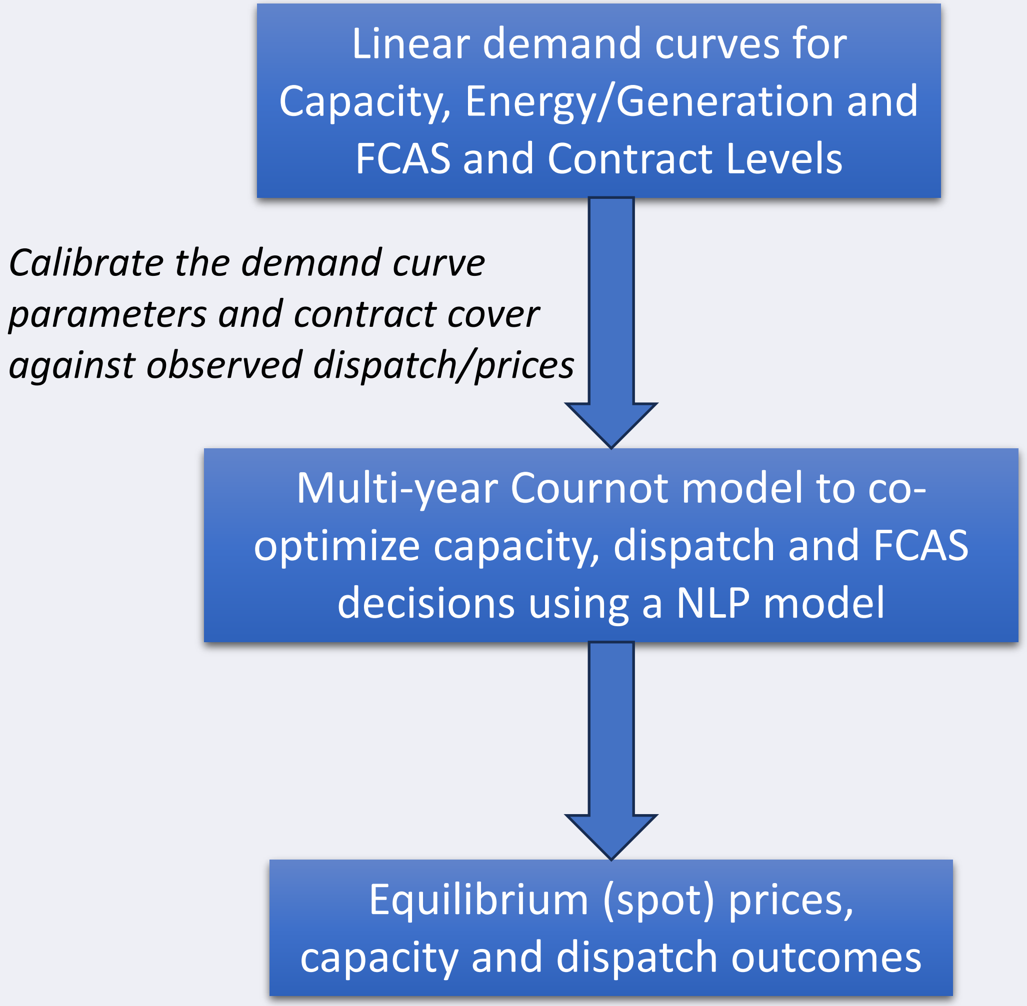


Methodology: Market Design Lab

- Modular structure to be able to add capacity and frequency control ancillary services (FCAS) markets to have 1, 2, or 3 commodities with the demand curves

- Calibration is essential to ensure prices and dispatch align with observed behavior

- Core Cournot model can be augmented with a bid preparation heuristics, market clearing engine, capacity expansion and reliability simulation models



Methodology: Cournot Model (Energy Only Market)

i	Generating company
j	Node
Ω	Association of genco and nodes
Θ	Connected pairs (j,j')
Y_j	Net injection to node j (MW)
q_i	Generation by i (MW)
$X_{i,j}$	Genco i feeding node j (MW)
$F_{j,j'}$	Physical flow from node j to node j'
α_j, β_j	Linear demand equation parameters
C_i	Marginal cost of genco i (\$/MWh)
$F_{j,j'}^{max}$	Transfer capability (MW)
X_i^{max}	Max generation capacity (MW)

Maximize,

$$\sum_j [\alpha_j - \frac{1}{2}\beta_j Y_j] Y_j - \sum_i q_i C_i - \sum_{i,j} \frac{1}{2}\beta_j X_{i,j}^2$$

S.t. ,

$$\sum_{(i,j)\in\Omega} X_{i,j} + \sum_{(j',j)\in\Theta} F_{j',j} + \sum_{(j,j')\in\Theta} F_{j,j'} = Y_j$$

$$q_i = \sum_{j=1}^{M} X_{i,j}$$

$$\sum_{j=1}^{M} X_{i,j} \le X_i^{\max}$$

$$F_{j,j'} \le F_{j,j'}^{\max}$$

$$q_i,\ X_{i,j},\ Y_j,\ F_{j,j'} \ge 0$$

Methodology: Cournot Model (Capacity & Energy)

And the model can be extended to include TWO commodities (suffix e for energy an c for capacity) to maximize the joint social welfare from both commodity markets:

$$\max_{X^e, X^c, F} \sum_{j,y,t} \left\{ Y_j^e(y,t) P_{e,j}(y,t) - \sum_i c_i^e q_i^e(y,t) \right\} - \sum_{i,j,y,t} \frac{1}{2} \beta_j(y,t) (X_{i,j}(y,t))^2 + \sum_{j,y} \left\{ Y_j^c(y) P_{c,j}(y) - \sum_i c_i^c q_i^c(y) \right\} - \sum_{i,j,y} \frac{1}{2} \bar{\beta}_j(y) (X_{i,j}^c(y))^2$$

Add FCAS as a third commodity, related joint production and FCAS constraints, carbon constraints, etc. etc.

Methodology: Analysis

- Consider alternative scenarios around carbon limits and market design scenarios (EO, E+AS, E+CM, E+AS+CM) as well as extreme scenarios such as very high/low hydro
- Look at the resultant capacity, dispatch, reserve margin and commodity prices outcomes
- Compare the performance of different market design options in terms of price, wholesale cost, emissions and reliability outcomes
- Try to find some empirical evidence as to whether one design performs substantially better than others across a range of scenarios

Case Studies

- These models were developed as part of World Bank initiatives in Ukraine and Georgia for different purposes, and currently under implementation for India

- In fact, even without energy transition issues, the analytical framework has been valuable to test the market design issues e.g.,

  is a FCAS or capacity market useful to deal with RE variability?

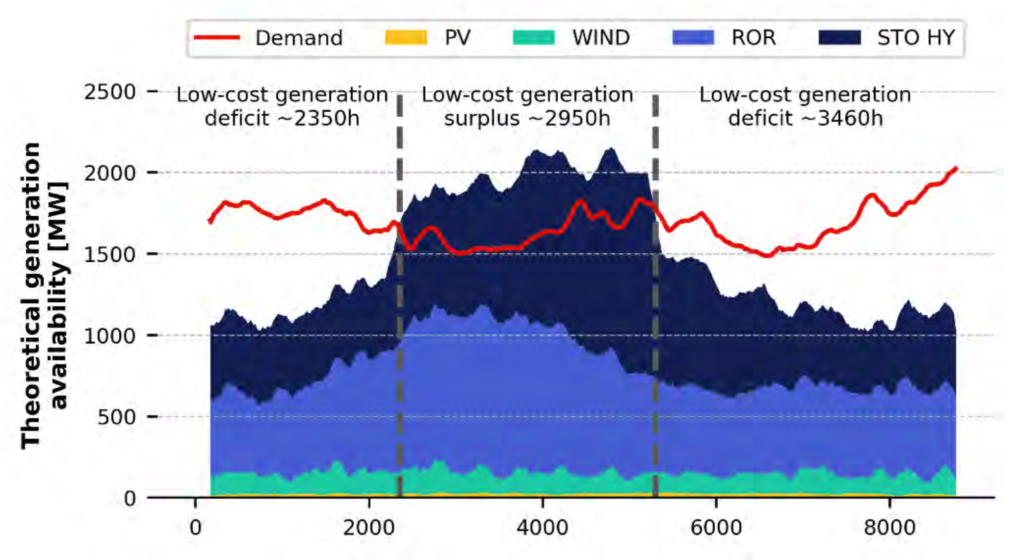
  Would storage be useful?

  Where should the price cap be set not to choke peaking investments? Would prices in an EO market be highly volatile under different hydrology regimes?

- The following slides focus on the decarbonization scenarios for three markets (Ukraine and Georgia in Eastern Europe and India)

Georgia – Key Information

- Georgia recently joined the Energy Community and is required to reform its power sector to comply with the **Third Energy Package** and achieve a deregulated electricity market structure based on the **European Union Target Model**
- Georgia is a relatively **small hydro-dominated market** with a total installed capacity of 4,596 MW, including 3,394 MW of hydropower and 1,181 MW of thermal power plants (TPP).
- **Imports account for 10%** of the supply in 2022, but this value can vary significantly with hydrological conditions.
- Georgia faces two strategic long-term challenges
  1. Improving its security of supply through diversification of import sources and increasing its capacity base;
  2. Meeting the growing demand with sustainable energy sources while keeping a high level of reliability and potentially facing extended periods of severe droughts.



Seasonal availability of low-cost renewable generation in Georgia
Source: World Bank calculations

Georgia – Two Classical Market Reform Features

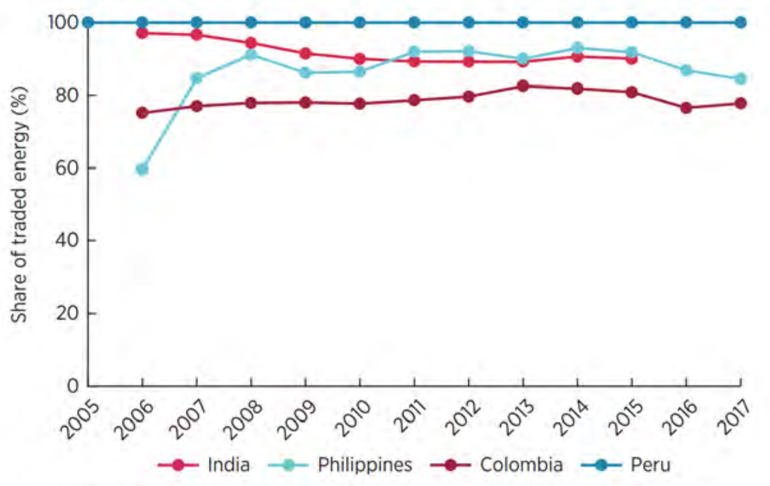
- Georgia faces two challenges that are often faced by countries launching wholesale markets:

1. The majority of the generation is now subjected to **long-term contracts**, hydropower units, and so-called public service obligations (PSOs).

In the proposed market regime: PSO | CfD full capacity → CfD part of capacity

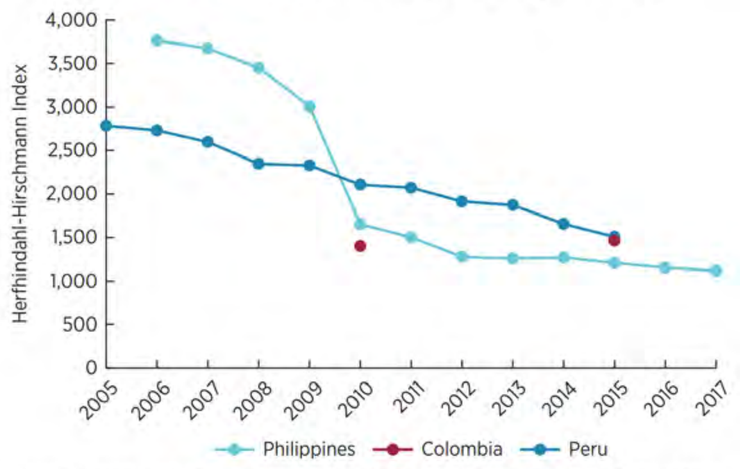
2. **Potential market power concerns** beyond 2027, especially if the system experiences a dry year.

* *Relative size of contract market as share of traded energy*



Source: World Bank elaboration based on Rethinking Power Sector Reform utility database 2015.

* *Evolution of market concentration index for generation*



Source: World Bank elaboration based on Rethinking Power Sector Reform utility database 2015.

* Adopted from V. Foster and A. Rana, Rethinking Power Sector Reform in the Developing World. Washington, DC: World Bank, 2019

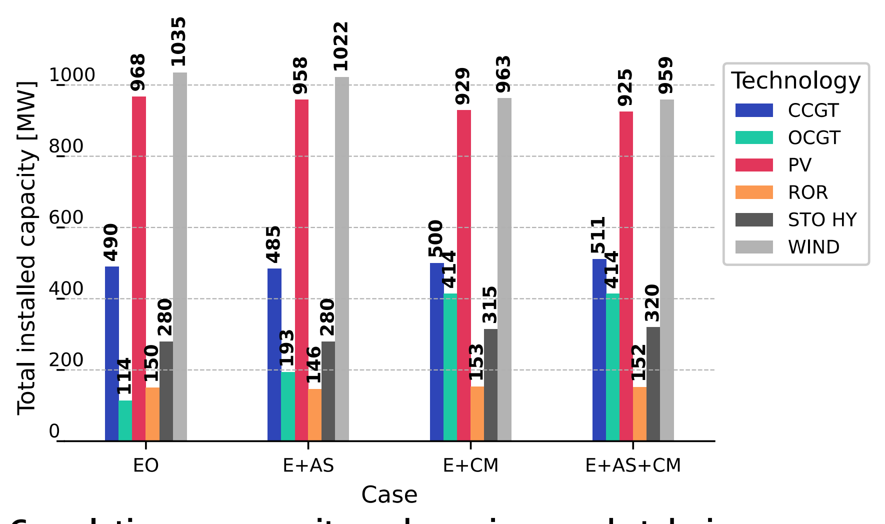
Modelled Market Design Options

We test four key market design combinations:

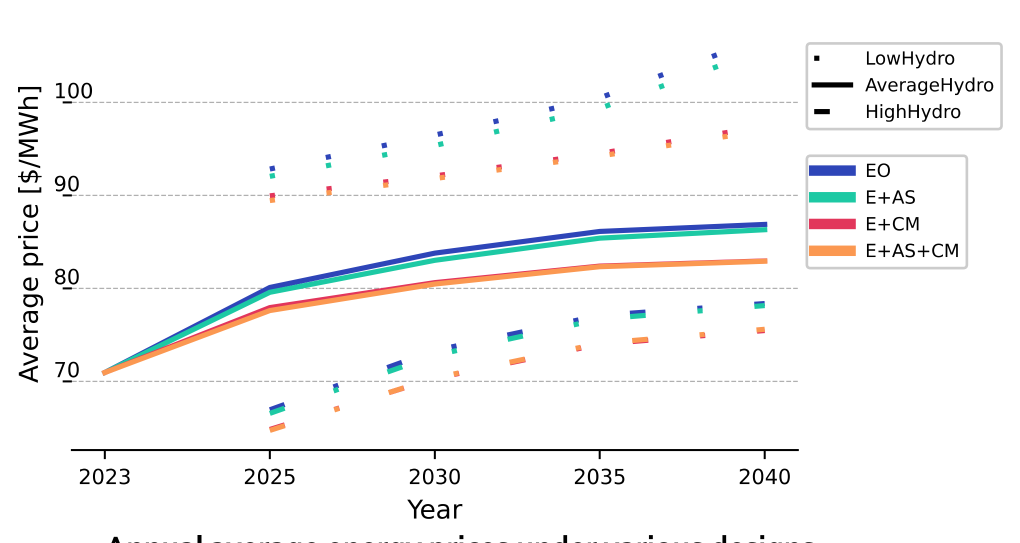
1) **Energy-only market (EO)** – trading and pricing of electricity based solely on the energy component, without incorporating capacity payments. Reserves are allocated based on fixed, predetermined requirements, and their payments are not included in the objective functions of individual players.
2) **Energy market with ancillary services co-optimization (E+AS)** - jointly optimize the procurement of energy and reserves, ensuring the reliable operation of the power system.
3) **Energy and capacity market (E+CM)** - incorporates both energy trading and a capacity market.
4) **Energy and capacity market with reserves co-optimization (E+AS+CM)**

Energy only market	Energy market with co-optimization of ancillary services	Energy and capacity market	Energy market with co-optimization of ancillary services and capacity market

Georgia – Market Led Capacity Expansion



Cumulative new capacity under various market designs



Annual average energy prices under various designs

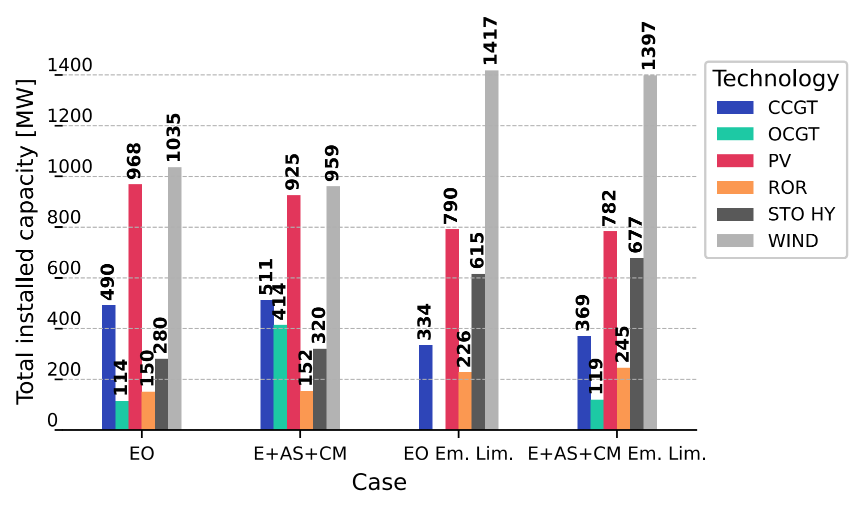
The market-led capacity expansion model presented before allowed us to answer the following questions:

- Are resulting market prices sufficient to support VRE investments?
  - **Yes, to an extent.** Wind and solar technologies are the dominant investments in the system.
- What is the impact on conventional, flexible technologies?
  - Very little influence on CCGT deployment -> **The market is already saturated**
  - OCGT expansion is influenced by the design choice
- How are prices affected by design and hydrological scenario?
  - CM **decreases both energy and AS prices**
  - Hydrology is a crucial determinant of prices.

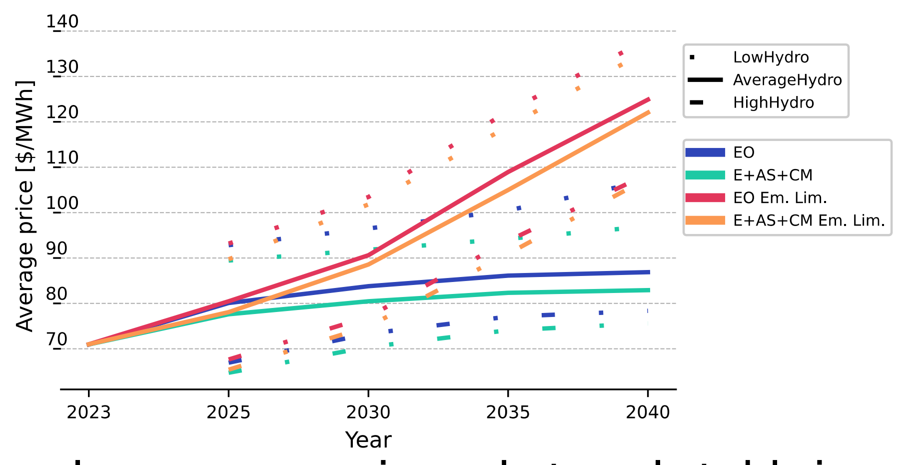
Georgia – Emission Constrained Expansion

We can force emission reduction by imposing emission limit and trading. Then the following questions arise:

- How are renewable investments affected?
  - A significant **preference for wind power** under emission constraints.
- How are the investments in conventional technologies affected?
  - **Substantial decrease in CCGT** capacity despite their role in reserve provision.
  - OCGTs still appear in the mix for this design option with capacity market and ancillary services co-optimization, **drawing most of their revenues from the reserve and capacity market**.
- How does emission limit affect prices?
  - Increase by 30-40$/MWh in average prices.



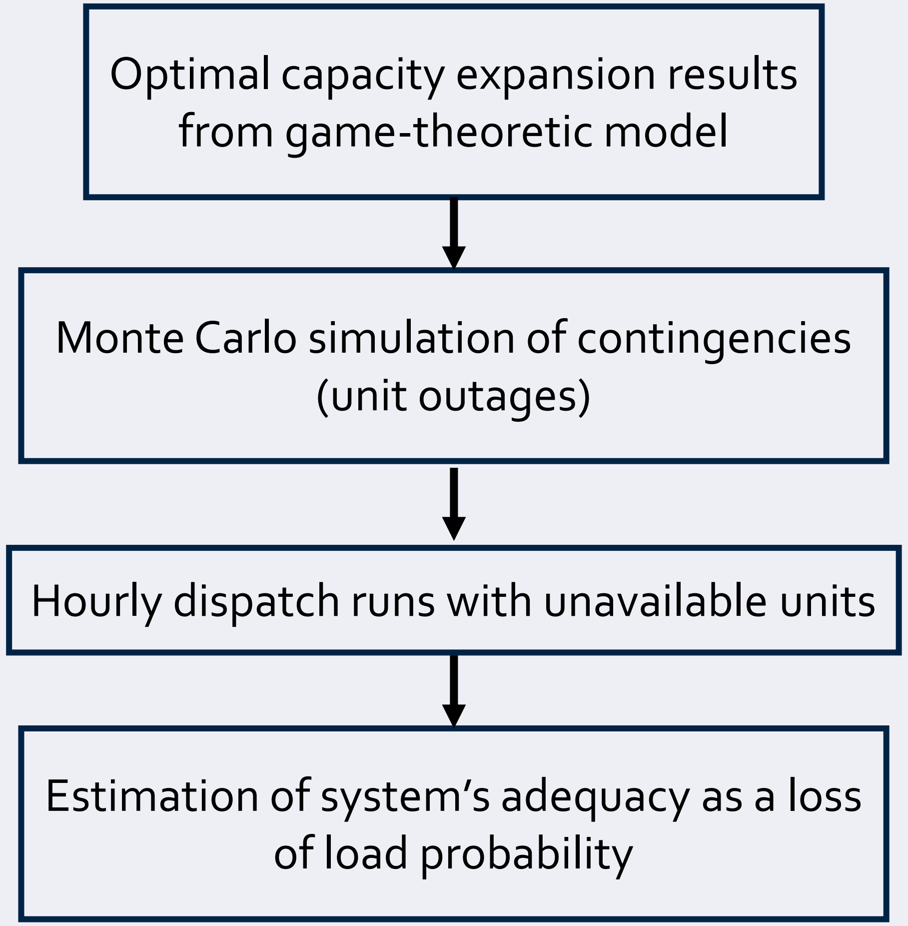
Cumulative new installed capacity with and without emission limits for two selected designs



Annual average energy prices under two selected designs with and without emission limits

Market designs – How do we test robustness?

Cournot-based capacity expansion model, as it stands, **is not equipped to evaluate a system's reliability under stress conditions** that could cause supply shortages and price spikes.

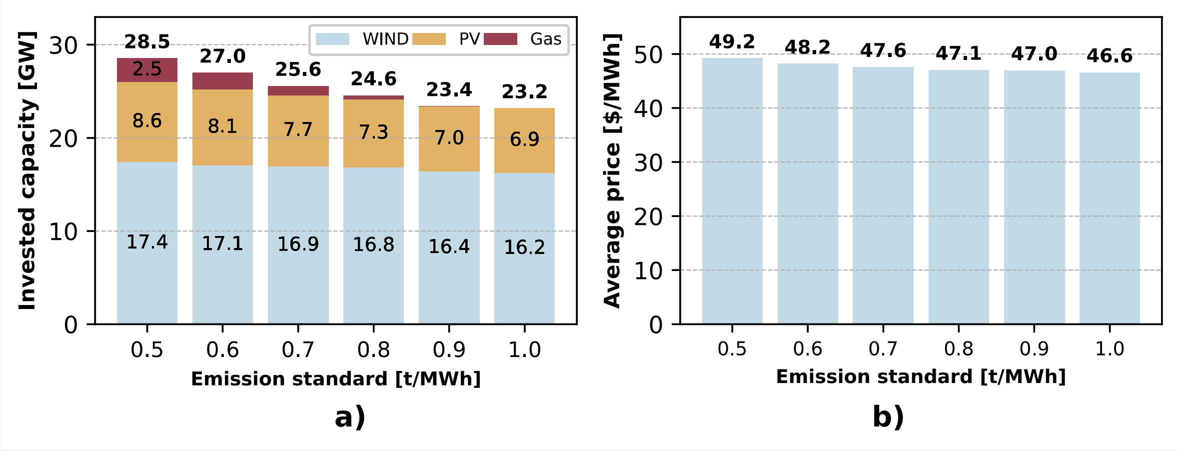


Emission case	Case/ Parameter	Low hydro			Average hydro		
		LOLH	LOLP	EEU	LOLH	LOLP	EEU
	Unit	hours	%	MWh	hours	%	MWh
No emiss. Limit	EO	646.05	0.7370	183495	5.62	0.0014	355
	E+AS	423.80	0.4147	103246	7.07	0.0013	317
	E+CM	6.76	0.0006	151	5.10	0.0004	106
	E+AS+CM	11.65	0.0076	1884	4.37	0.0003	72
Emiss. Limit	EO	319.38	0.3651	90905	2.39	0.0001	20
	E+AS	225.37	0.2307	57441	2.18	0.0000	9
	E+CM	88.50	0.0886	22051	6.66	0.0001	18
	E+AS+CM	28.60	0.0249	6205	3.64	0.0001	29

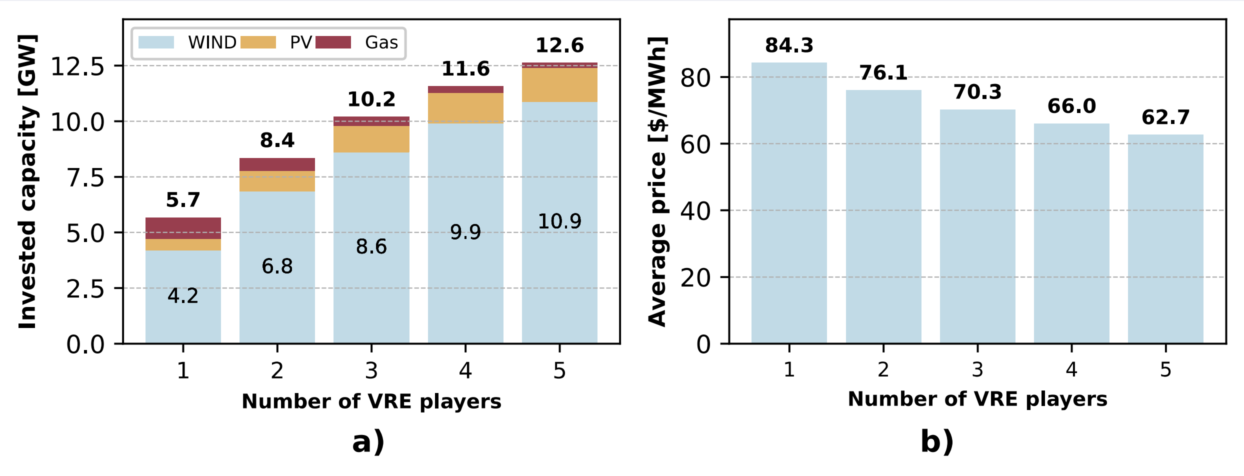
Resource adequacy metrics

Ukraine – testing policies and competition

- **With carbon pricing, how much would it cost to decarbonize the system?**
  - Ukraine can reach very substantial decarbonization depth while staying below **$50/t** for carbon and compromising with maximum **$8/MWh** increase in average market prices.
- **What is the impact of alternative environmental policies?**
  - Performance-based permit-trading policy incentivises not only VRE but lower-carbon conventional units as well.
- **How does competition affect the uptake and prices?**
  - Between one and five investors, prices decreased from $84.3/MWh to $62.7/MWh, while total investment increased from 5.7GW to 12.6GW.



Impact of emission standards on total investments (a) and average prices (b).



Impact of the number of investors on total investments (a) and average prices in 2040 (b).

India – testing policies and competition (work in progress)

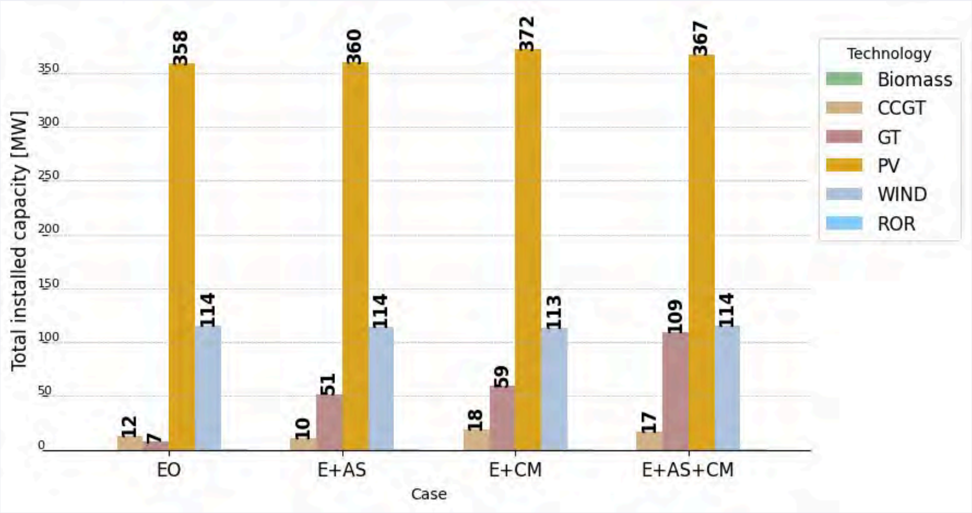
- Similar setup as for Georgia, but for multi-zonal Indian wholesale market.

Key result 1

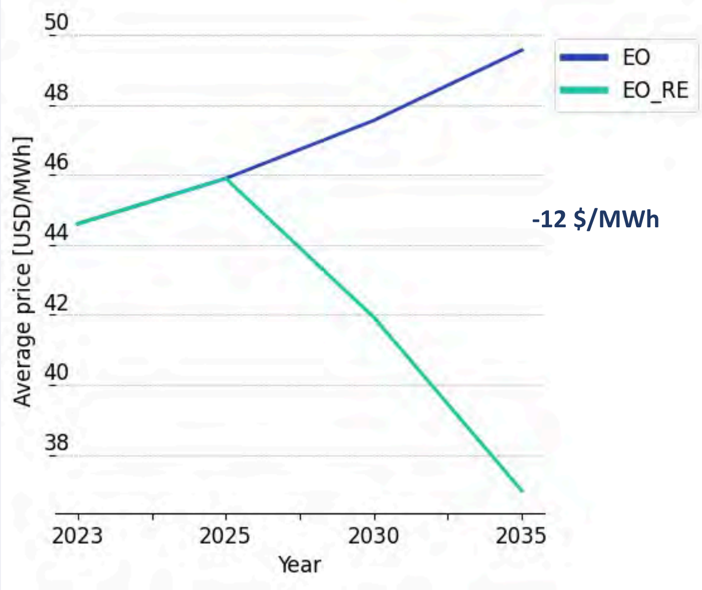
Adding co-optimization of the market leads to greater gas development and can substitute part of the role of the capacity market.

Key result 2

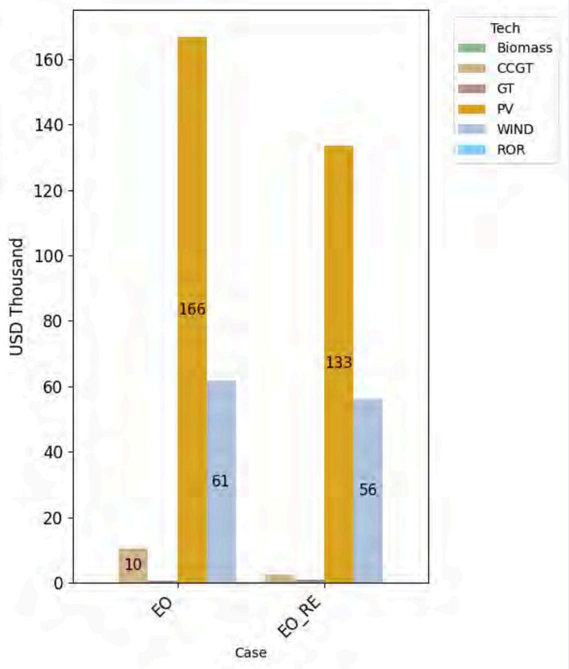
Out-of-market uptake of VRE decreases price, and diminishes market-based revenues:



Total new capacity installed depending on the market design



Average annual price depending on the policy



Total participants profit

Discussion on the methodology

- Since starting this stream of work three years ago, the **body of literature significantly expanded**. However…
- Many proposals are still mainly conceptual, while the **methodologies** to test alternative designs **are unclear**. The application of novel market modeling techniques common in the US, Australia, and Europe, is nearly **non-existent in the developing world context**.
- **Application of models is essential** as the answer is unlikely to be the same across vastly different systems. The market performance will depend on a series of country-specific contexts, including systems size, current energy mix, political dynamics, or state of market regulation.
- Our **Market Design Laboratory** shows the advantages of these models in answering some of the most crucial questions in the regulator and policy space, including the big ones:

Could better designed electricity markets help drive decarbonization?

DEBABRATA CHATTOPADHYAY & ADAM SUSKI | NOVEMBER 01, 2022

Some posed questions we were able to answer:

1. Asked in: Georgia; Asked by: System operator
Question: Is there a risk of inadequacy with energy-only market design?
Answer: YES! LOLP high under energy-only design. Additional revenue streams needed.

2. Asked in: Georgia; Asked by: Ministry of Finance
Question: What are the factors affecting fiscal risks of the market opening?
Answer: Gas prices and hydro availability could put financial stability into jeopardy.

3. Asked in: Ukraine; Asked by: International observers.
Question: Is there an exercise of market power?
Answer: YES! Least-cost prices on average 11$/MWh higher.

4. Asked in: Ukraine; Asked by: World Bank.
Question: How will the new proposed storage affect AS prices?
Answer: Price decrease of 35% with 1000MW unit.

5. Asked in: India; Asked by: Central Electricity Regulatory Commission.
Question: What are the impacts of market coupling?
Answer: Lower price and volatility, higher liquidity.

References

ESMAP WEBINAR

- [1] D. Chattopadhyay and A. Suski, "**Market Design Laboratory: A summary of World Bank analytical work**", May 2024
- [2] S.K. Soonee, D. Chattopadhyay, P. Chitkara, **"Unlocking value ; potential benefits of power market coupling along with SCED in India"**, September 2023
- [3] S.K. Soonee, P Chitkara, A. Chopra, A. Pande , D. Chattopadhyay, "**Coupling Of Power Exchanges Along With Sced In India**", October 2023
- [4] A. Suski, D. Chattopadhyay and C. Nicolas, "**Testing Alternative Electricity Market Design Performances: Methodology and Case Study**" IEEE Transactions on Energy Markets, Policy and Regulation (2024).
- [5] A. Suski and D. Chattopadhyay, "**Game-theoretic capacity expansion analysis under carbon emission constraints**," *IEEE Transactions on Power Systems*, pp. 1–15, 2023, doi: 10.1109/TPWRS.2023.3234223.
- [6] A. Suski and D. Chattopadhyay, "**Multicommodity Nash-Cournot Market Model with Strategic Storage Operator**," in *IEEE Transactions on Energy Markets, Policy and Regulation*, doi: 10.1109/TEMPR.2023.3299514.
- [7] A. Suski and D. Chattopadhyay, "**Game-theoretic Analysis of the Ukraine Day-ahead Electricity Market**," in *IEEE PES General Meeting 2022*, 2022.
- [8] A. Suski and D. Chattopadhyay, "**A Cournot Modeling Framework to Test Alternative Market Design Options for Decarbonization**," in *IEEE PES General Meeting 2023*, 2023.
- [9] D. Chattopadhyay and A. Suski, "**Should Electricity Market Designs Be Improved to Drive Decarbonization?**," *Policy Research Working Papers*, World Bank, Washington, DC., 2022, doi: 10.1596/1813-9450-10207
- [10] D. Chattopadhyay, S. K. Chatterjee, and S. K. Soonee. "**Spotlight on the spot market: A review of the Indian wholesale electricity market.**" The Electricity Journal 36.1 (2023): 107239.


ESMAP
Energy Sector Management
Assistance Program
THE WORLD BANK
IBRD • IDA
THANK YOU.