MARKET CONSIDERATIONS FOR A HIGH PENETRATION RENEWABLES SCENARIO

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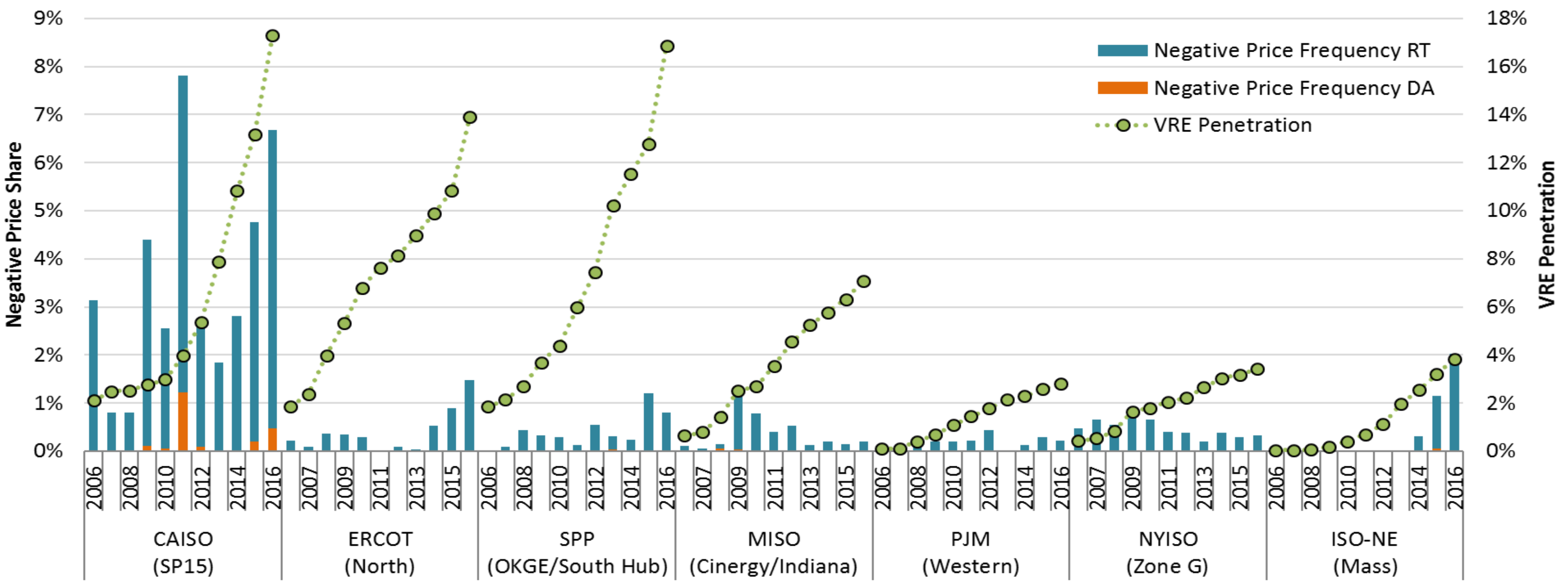
OUTLINE

- Renewable Energy and Electricity Market Prices
- Capacity Market Design
- A Multi-Agent Model for Generation Expansion
- Case Study
- Conclusions

IMPACTS OF VARIABLE RENEWABLES ON ELECTRICITY PRICES

- The merit order effect reduces electricity prices
  - Empirical literature indicates a larger effect in Europe than the U.S.
  - Low natural gas price main reason for lower electricity prices in U.S.
- The occurrence of negative prices has increased with higher VRE penetration levels in many locations

Percentage of Annual Prices that are below $0/MWh



Wiser et al. , LBNL/ANL Report, Nov. 2017.

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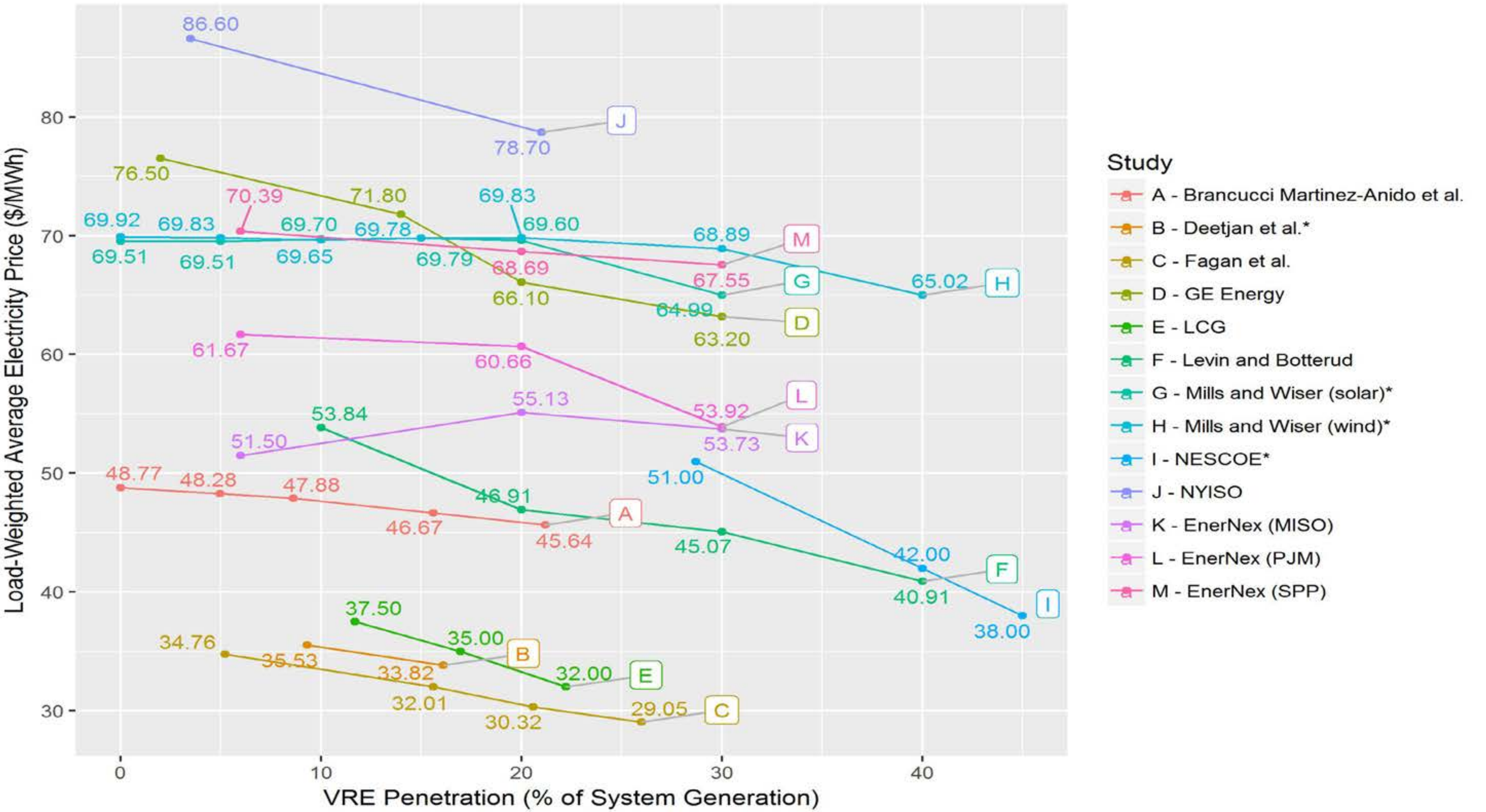
FUTURE PRICE IMPACTS OF VARIABLE RENEWABLES

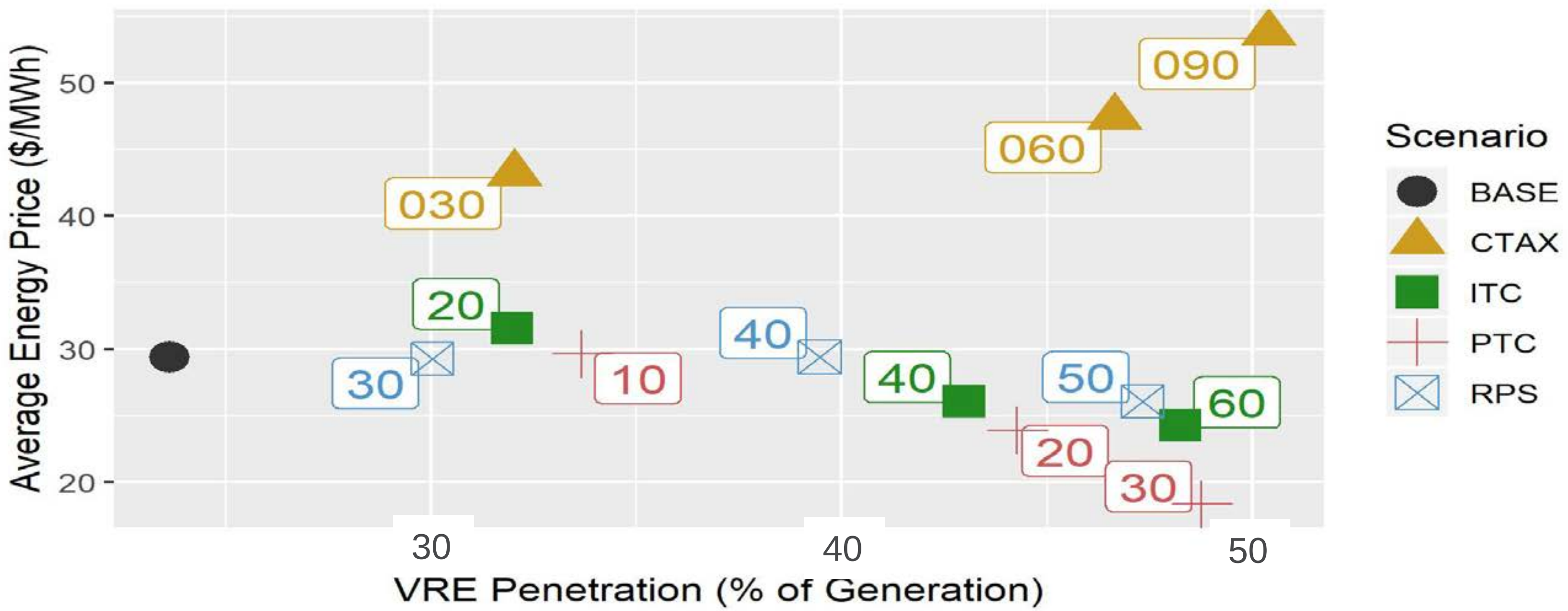


Wiser et al. , LBNL/ANL Report, Nov. 2017.

INCENTIVE SCHEMES INFLUENCE MARKET PRICES

Projected variable renewable energy (VRE) penetration levels and market prices for 2030 with different policies under least cost expansion ("ERCOT-like" system)

Policy	Abbreviation	Metric	Scenario Range
Carbon Tax	CTAX	$/ton	$30-$90
Investment Tax Credit	ITC	% of capital cost	20%-60%
Production Tax Credit	PTC	$/MWh	$10-$30
Renewable Portfolio Standard	RPS	% of generation	30%-50%



Levin et al., working paper, 2018.

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CAPACITY ADEQUACY MECHANISMS

- Different approaches to ensure resource adequacy in U.S. electricity markets
  - Energy only markets (ERCOT)
  - Capacity markets (PJM, ISO-NE, NYISO, MISO)
  - Capacity obligations (CAISO, SPP)
  - Integrated resource planning
- Multiple solutions in Europe as well

REVIEW OF U.S. CAPACITY MARKETS

The Electricity Journal 31 (2018) 65–74

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ELSEVIER

Capacity market design and renewable energy: Performance incentives, qualifying capacity, and demand curves

Conleigh Byers[a,b], Todd Levin[b], Audun Botterud[a,b,*]

- Four ISO/RTO systems have capacity markets
  - Many administrative parameters
  - No convergence on capacity market design
  - Frequent re-design (e.g. two-tier markets)
  - Limited attention in research domain

PERFORMANCE INCENTIVES IN CAPACITY MARKETS

ISO	Penalty	Charge	Quantity	Period	Yearly Cap	Applies to Variable Resources
PJM	**Strong**	Net CONE ($/MW-day)* 365 days/30	For each hour in which emergency conditions declared: MW in shortfall for each hour (adjusted downward)	Hour	1.5*Net CONE* 365 days *Maximum daily unforced capacity committed	Yes
ISO-NE	**Strong**	Capacity clearing price ($/MW-month)*12 months * Obligation MW*.05† †For shortage events of ≤ 5h	For each hour containing any part of a shortage event: 1 – (Available MW/ Obligation MW * minutes of shortage in hour / total minutes of shortage)	Hour	Capacity clearing price ($/MW-month)*12 * Obligation MW	No
MISO	Weak	Notified of deficiency by market monitor				Yes
NYISO	Moderate	1.5 * Spot market capacity clearing price	MW in shortfall for the month	Month	None	Yes

QUALIFYING CAPACITY FOR RENEWABLES AND STORAGE

ISO	Wind	Solar	Hydro	Battery Storage
PJM	Average hourly output (HE6-9* and HE18-21 Jan/Feb, HE15-20 Jun-Aug)	Average hourly output (HE6-9 and HE18-21 Jan/Feb, HE15-20 Jun-Aug)	Reservoir, Pumped storage, and Run-of-river: Average hourly output (HE6-9 and HE18-21 Jan/Feb, HE15-20 Jun-Aug)	Average hourly output (HE6-9 and HE18-21 Jan/Feb, HE15-20 Jun-Aug)
ISO-NE	Average of 5 prior years of median net outputs (Summer: HE14-18 June-Sept incl. shortage events, Winter: HE18-19 Oct-May incl. shortage events)	Average of 5 prior years of median net outputs (Summer: HE14-18 June-Sept incl. shortage events, Winter: HE18-19 Oct-May incl. shortage events)	Reservoir and Pumped storage: Audited output over 2-hour duration Run-of-river: Same as wind, solar	Audited output over 2-hour duration
MISO	**ELCC** based on 8 highest coincident-peak load hours of the preceding year	Average hourly output (HE15-17 Jun-Aug) for prior 3 years	Reservoir and Pumped Storage: Median head in prior 5-15 years (HE15-17 Jun-Aug) converted to expected output Run-of-river: median output from prior 3-15 years (HE15-17 Jun-Aug)	Not defined
NYISO	Average output (Summer: HE14-18 Jun-Aug, Winter: HE16-20 Dec-Feb) of preceding delivery period	Average output (Summer: HE14-18 Jun-Aug, Winter: HE16-20 Dec-Feb) of preceding delivery period	Reservoir and Pumped Storage: Average output over 4-hour period with average stream flow and storage conditions Run-of-river: average output during 20 highest load hours in prior 5 capability periods (Winter: Nov-Apr, Summer: May-Oct)	Not defined

CAPACITY DEMAND CURVES

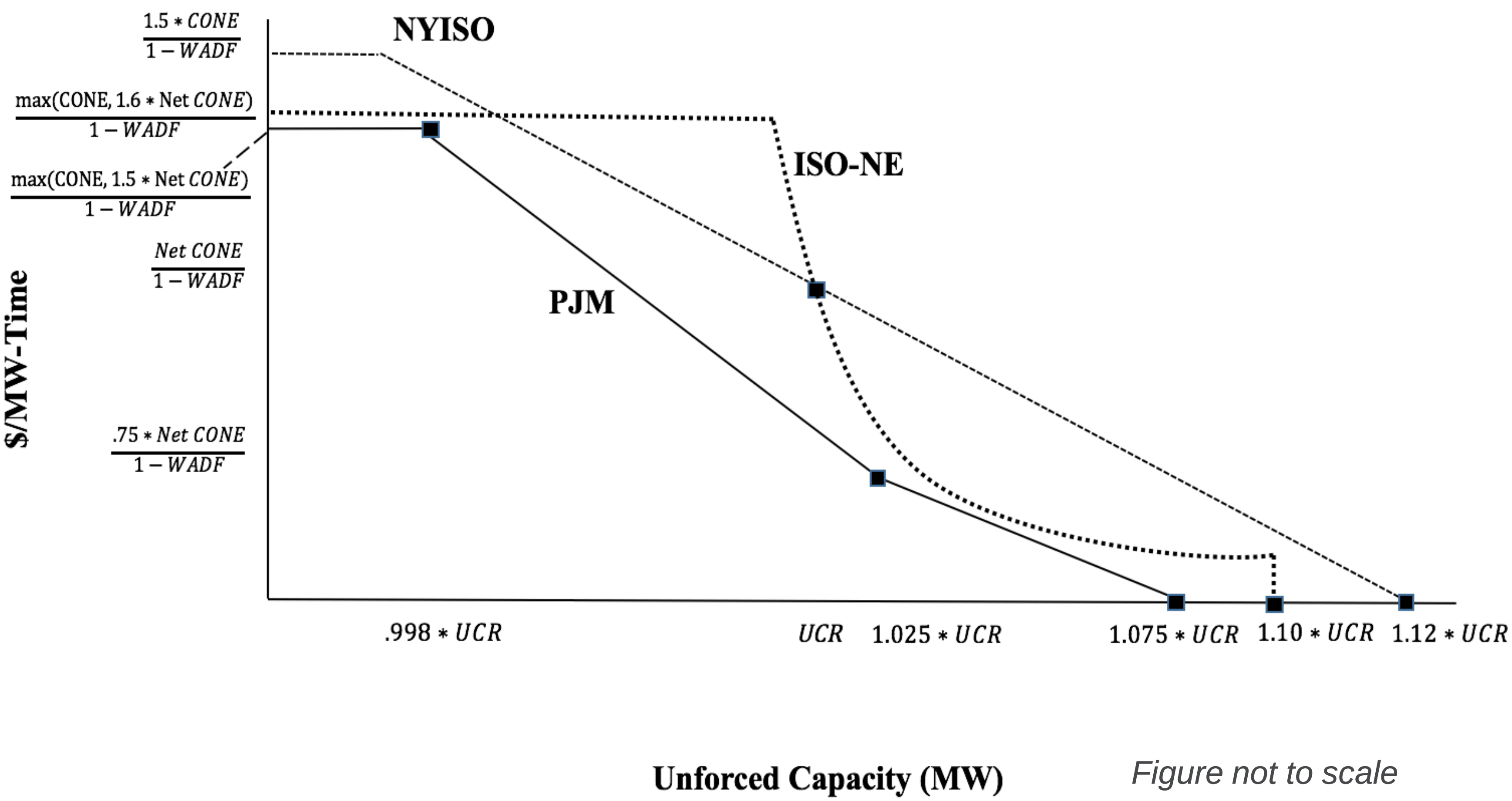
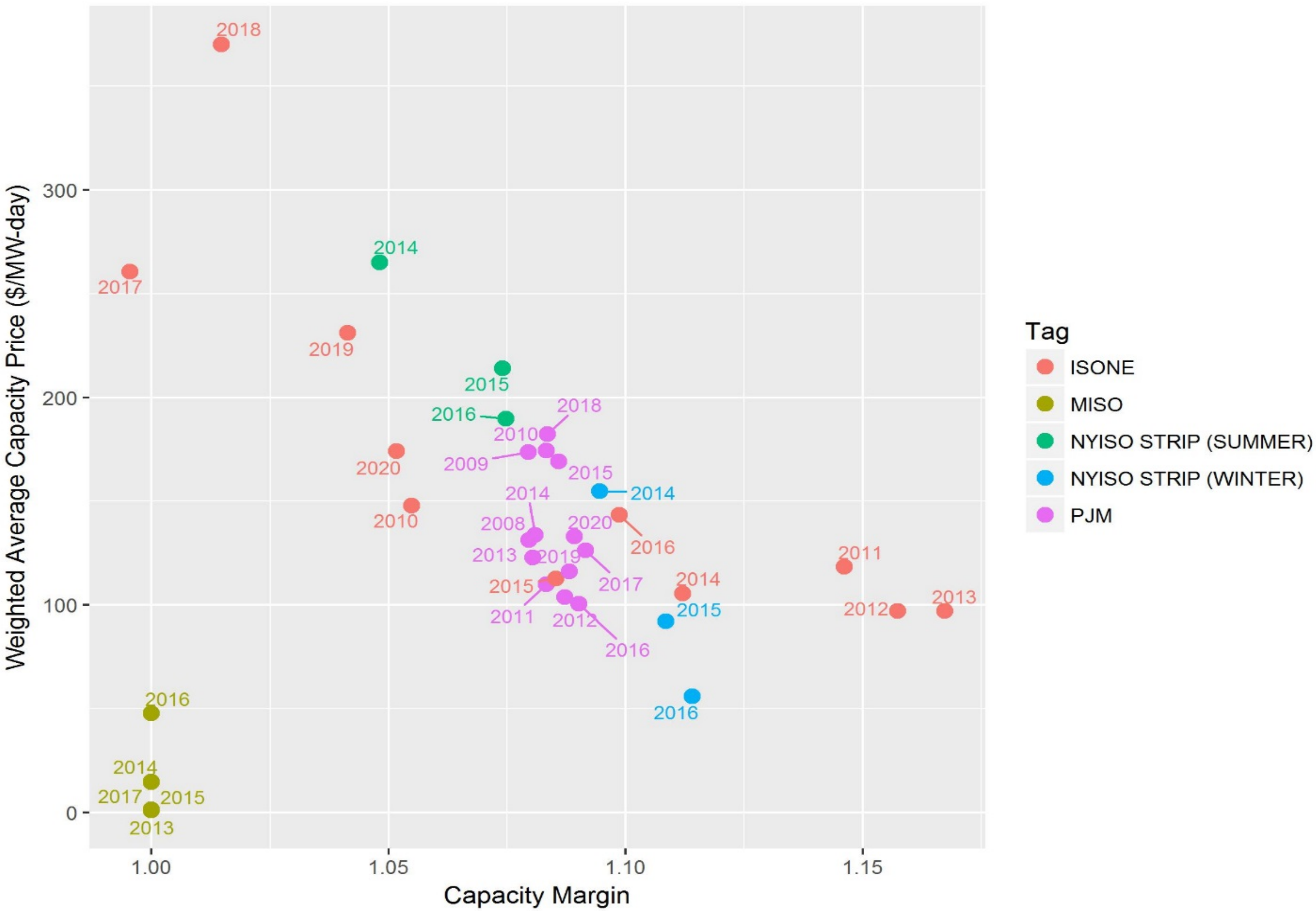


Figure not to scale

Byers et al. Electricity Journal, 31(1): 65-74, 2018.

HISTORICAL CAPACITY MARKET PRICES



Byers et al. Electricity Journal, 31(1): 65-74, 2018.

LIMITED ASSESSMENT OF U.S. CAPACITY MARKETS

United States Government Accountability Office

GAO

Report to Congressional Committees

December 2017

ELECTRICITY MARKETS

Four Regions Use Capacity Markets to Help Ensure Adequate Resources, but FERC Has Not Fully Assessed Their Performance

- $51 billion paid in four U.S. capacity markets, 2013-2016
- Lack of performance goals for capacity markets
- Better assessment needed

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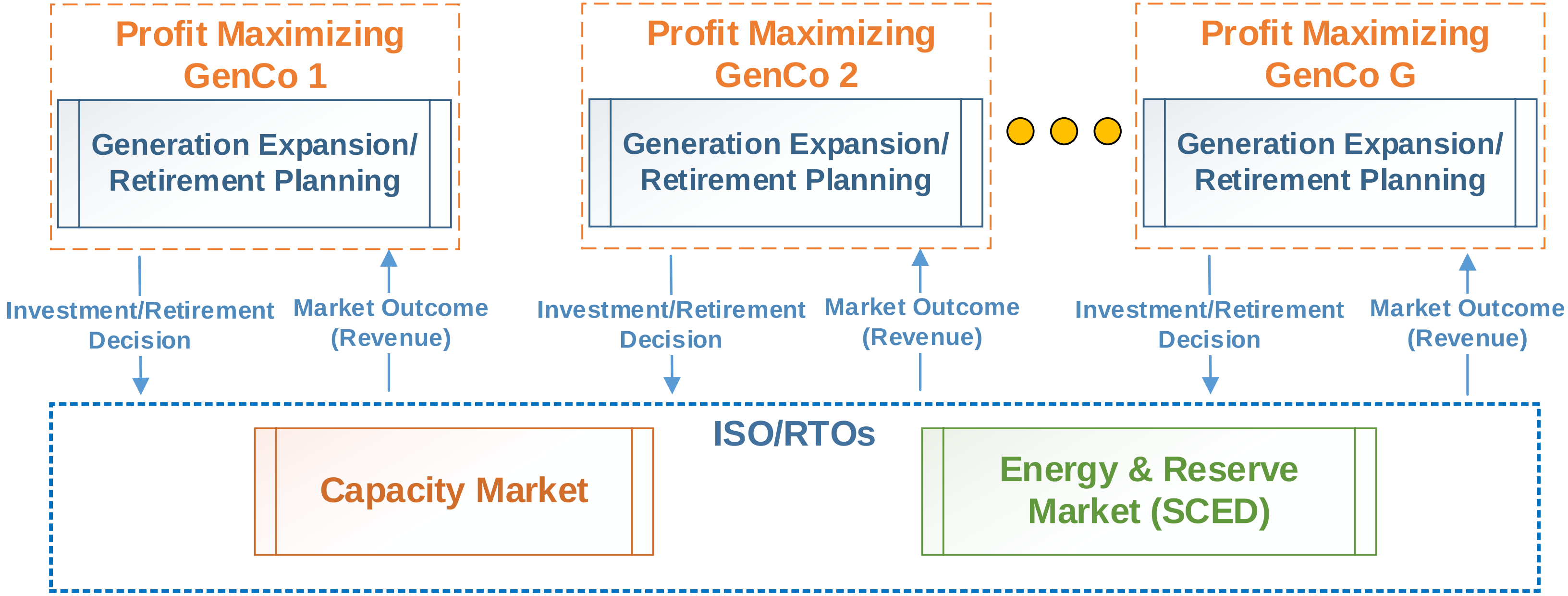
RESEARCH MOTIVATION

- Traditional centralized capacity expansion models
  - Minimizes system cost, cannot capture the decision making of individual generation GenCos
  - Limited ability to evaluate the effectiveness of capacity remuneration mechanisms (CRMs)
- Other tools needed to investigate market dynamics and resource adequacy in a competitive market environment

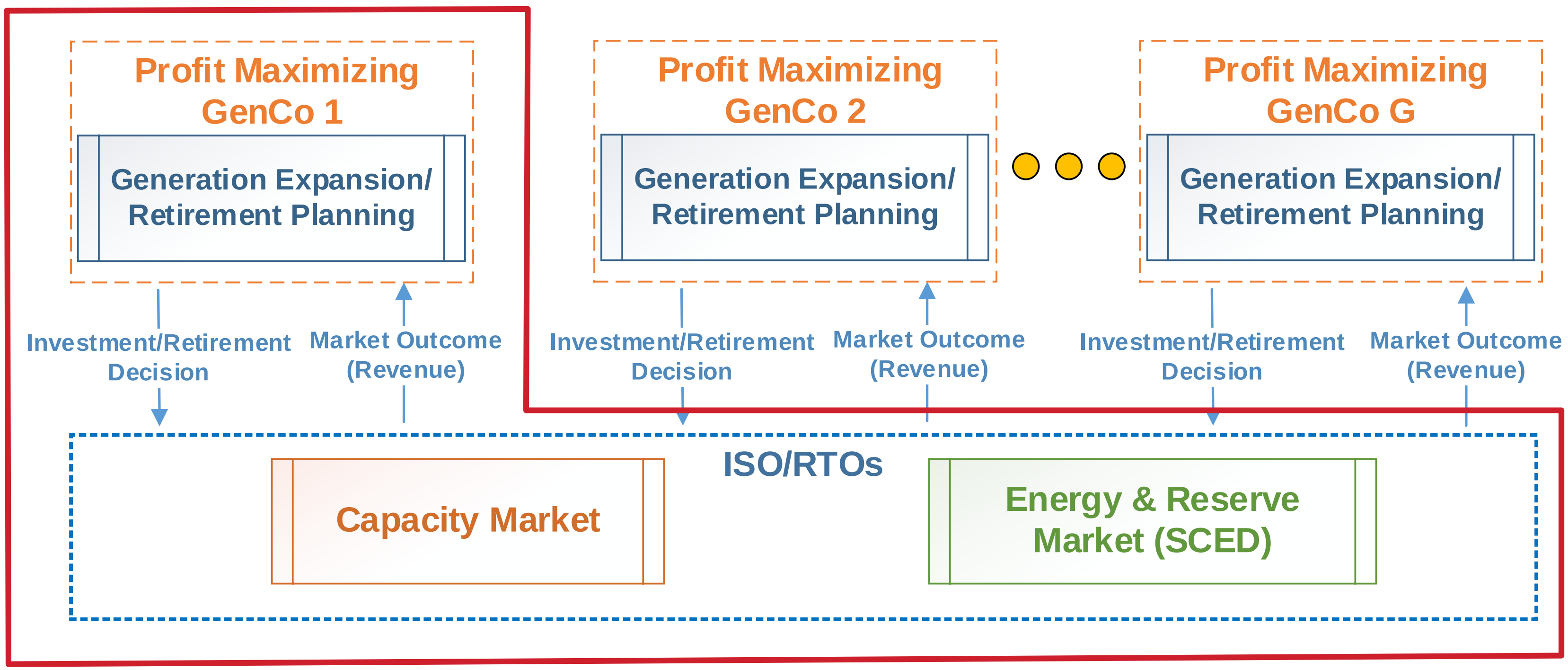
MULTI-AGENT RESOURCE PLANNING MODEL

- Captures strategic interactions between individual GenCos' investment decisions through
- Finds an equilibrium investment/retirement solution
- Considers revenues from capacity + energy/reserve markets
- Bi-level programming formulation



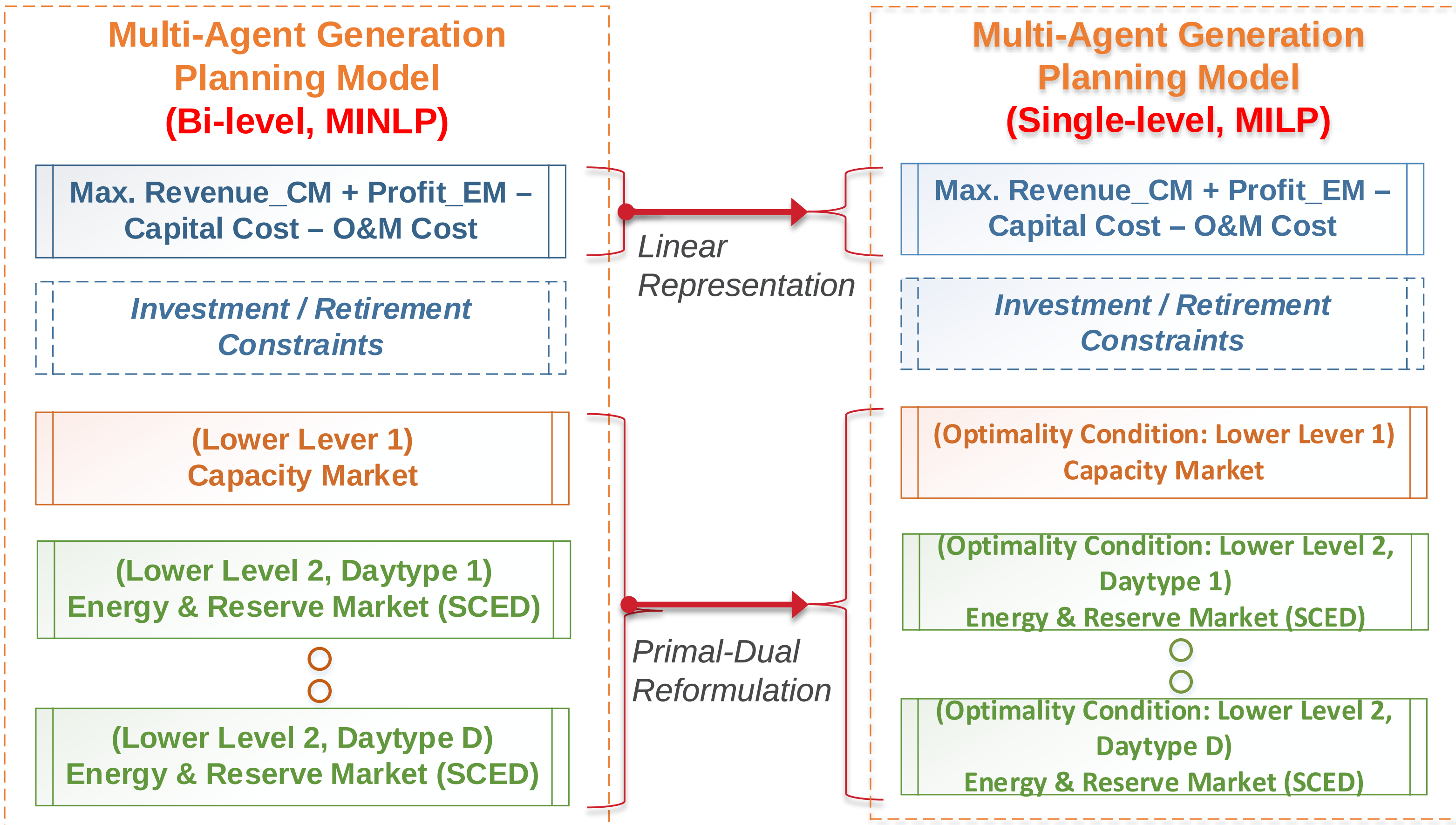
SOLUTION APPROACH

- A GenCo's decision solved individually as Stackelberg leader-follower game
- Nash Equilibrium among GenCos found with "diagonalization method"



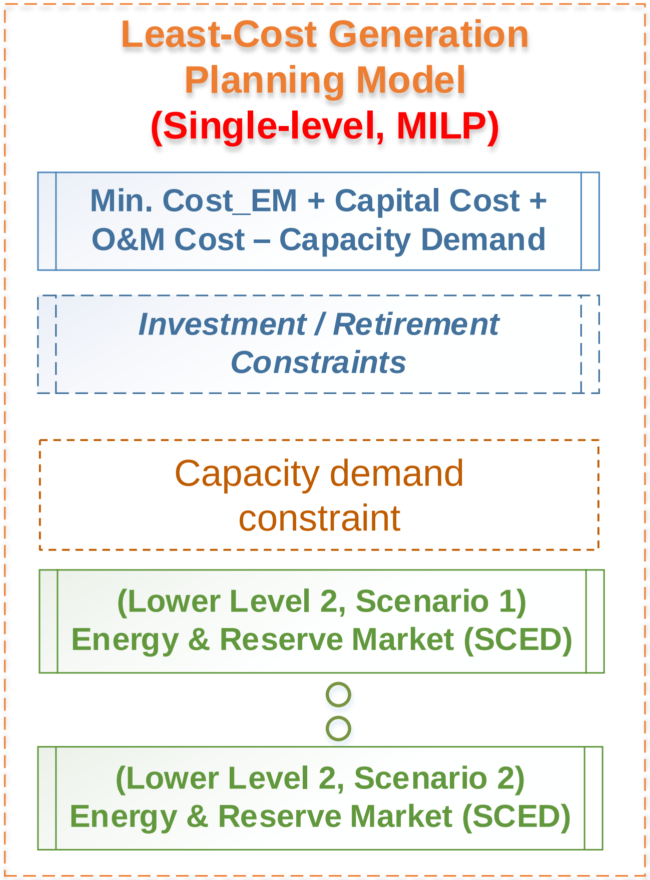
INDIVIDUAL GENCO PROBLEM

- Mathematical Problem with Equilibrium Constraints (MPEC)
  - MPEC re-formulated as a MILP
  - MILP solution method: dual decomposition



LEAST-COST MODEL FOR COMPARISON

- Least-cost model finds optimal generation portfolio while minimizing system-wide costs



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CASE STUDY

- "ERCOT-like" system for 2030
  - Projected peak load: 86,613 MW (1.57% increase per year)
  - Simple transmission system (9 nodes, 44 lines)
  - 30 representative days (scenario reduction)
- Generating Companies (GenCos)
  - No. of existing GenCos: 23
  - No. of new entrants: 4
  - No. of existing thermal units: 176 → 52

Node	1	2	3	4	5	6	7	8	9	Total ICAP	Capacity Factor	Total UCAP
Coal	2,127	8,347	1,770	1,804	538	925	0	0	0	15,511	1.00	15,511
NGCC	8,451	11,854	6,914	1,758	498	300	3,259	0	0	33,035	1.00	33,035
NGCT	5,373	5,040	804	2,646	1,845	811	672	1,210	0	18,401	1.00	18,401
Nuclear	0	2,328	2,632	0	0	0	0	0	0	4,960	1.00	4,960
Wind	0	3,756	4,967	12,793	0	0	0	0	0	21,516	0.19	4,191
Solar	0	0	1,493	0	0	0	0	0	0	1,493	0.75	1,120
Total	15,952	31,325	18,581	19,001	2,881	2,035	3,932	1,210	0	**94,916**		**77,218**

ANALYSIS DESIGN

- Investment Options

Type	Size (MW)	Overnight cost ($/kW)	Life Cycle	Fixed O&M Cost ($/kW/Year)	Variable O&M Cost ($/MWh)	Fuel Cost ($/MMBTU)
NGCC	400	912	30	13.16	3.60	4.26
NGCT	210	968	30	7.34	15.45	4.26

- Cost of New Entry (CONE)
  - Capital cost, fixed O&M cost of NGCT unit ($108.5/MW-day)
  - Net CONE = CONE – revenue offset from energy/reserves

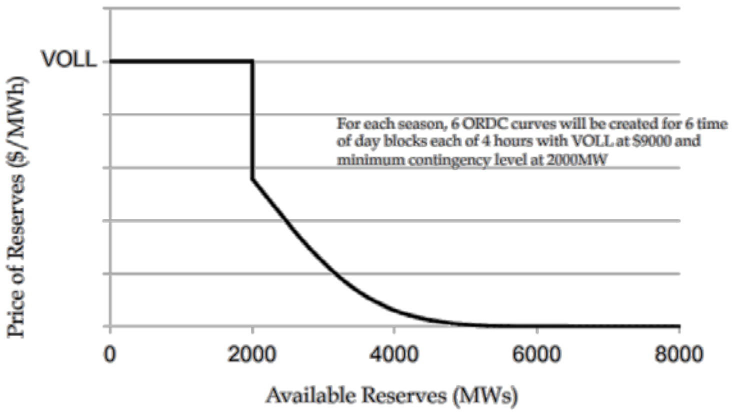
- VRE Penetration Levels

Scenario	Wind Capacity (MW)	Penetration Level (%)
Scenario 1 (Base)	21,516	18.4
Scenario 2	30,070	25.7
Scenario 3	38,625	33.1

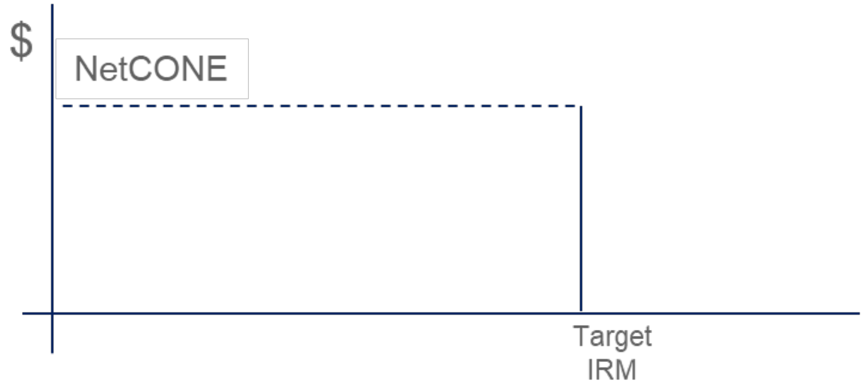
MARKET DESIGN OPTIONS

- Market design parameters
  - Target installed reserve margin (IRM): 13.75%

Market Design	Load Shedding Penalty	Reserve Shortage Penalty	Capacity Market Demand Curve
“ERCOT”	$9,001	ORDC ($9,000 Max)	N/A
“PJM”	$2,100	$850(~96%); $300(96~100%)	Sloped
“MISO”	$3,500	$3,500 (~4%); $2,250 (4~96%); $200 (96~100%)	Vertical (Fixed)



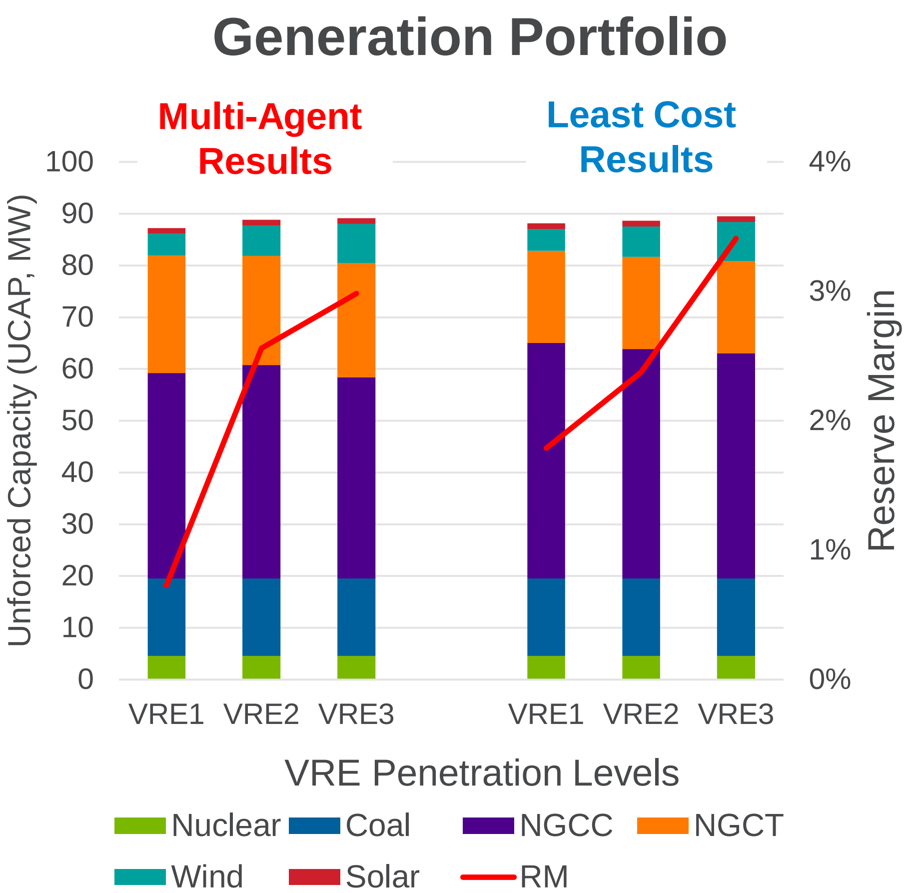
<ERCOT Operating Reserve Demand Curve(ORDC)*>

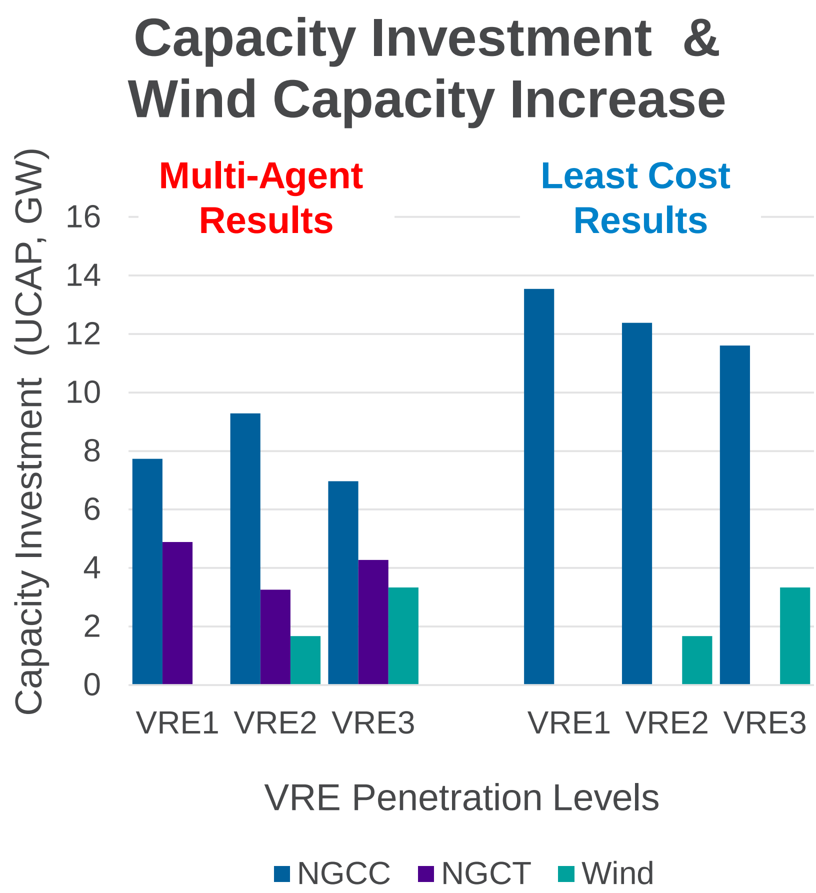


<MISO Capacity Market Demand Curve>

** R. Surendran et al., “Scarcity Pricing in ERCOT,” FERC Technical Conference, June 27, 2016*

GENERATION EXPANSION (“ERCOT-LIKE” MARKET DESIGN)

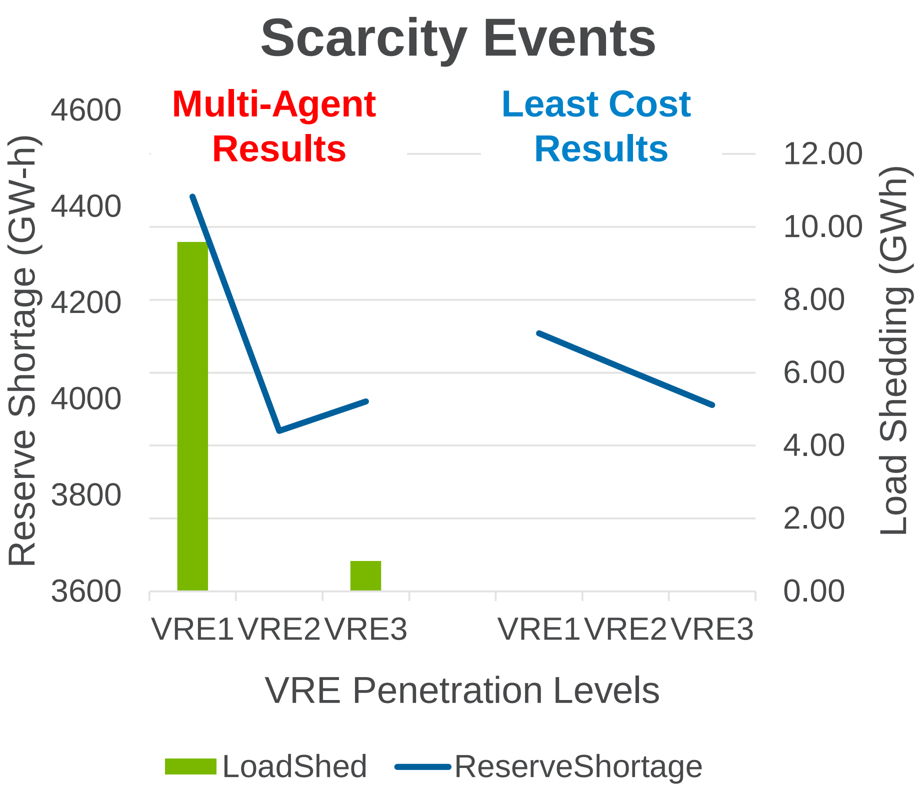


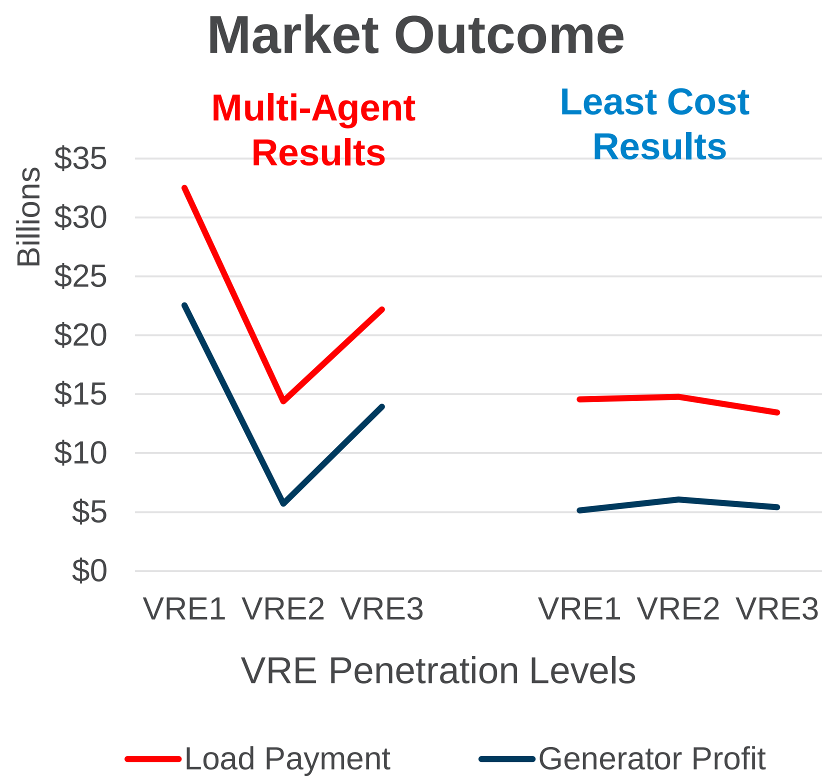


- Least cost model tends to give more capacity
- Installed capacity below target
  – Wind power only uncertainty considered

- Multi-agent model gives more NGCT
  – Higher marginal cost than NGCC

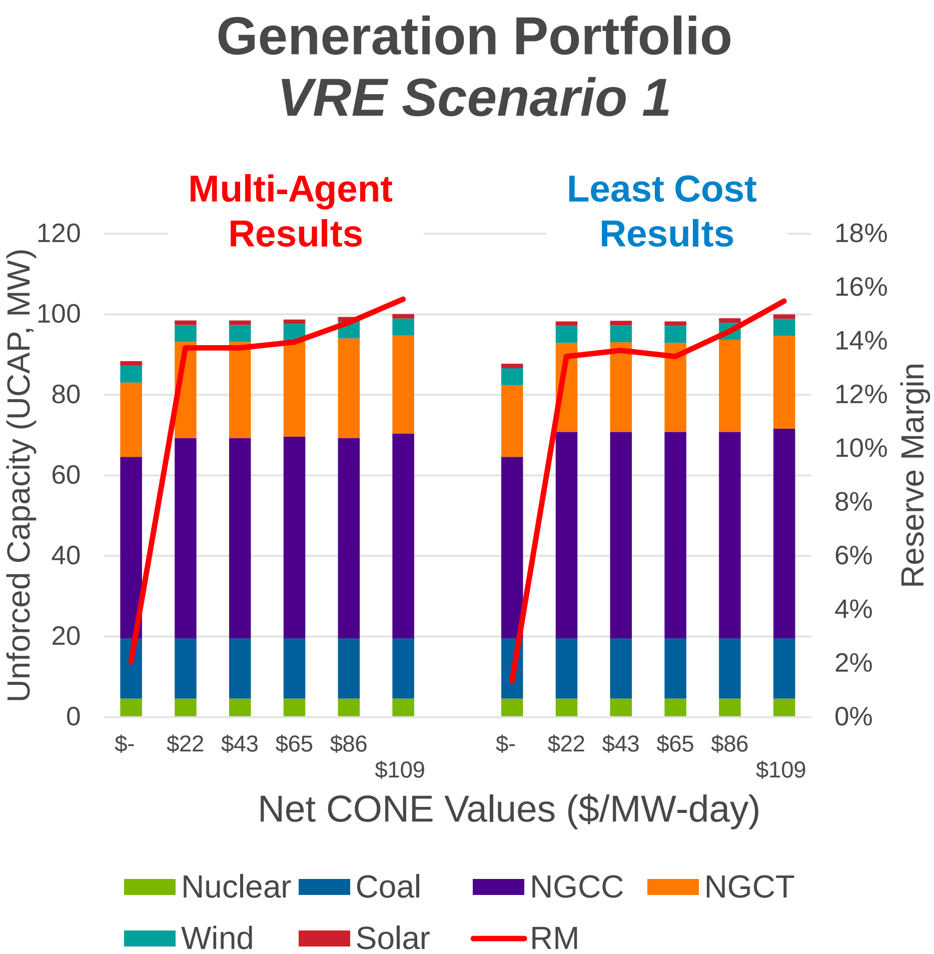
MARKET OUTCOME (“ERCOT-LIKE” MARKET DESIGN)

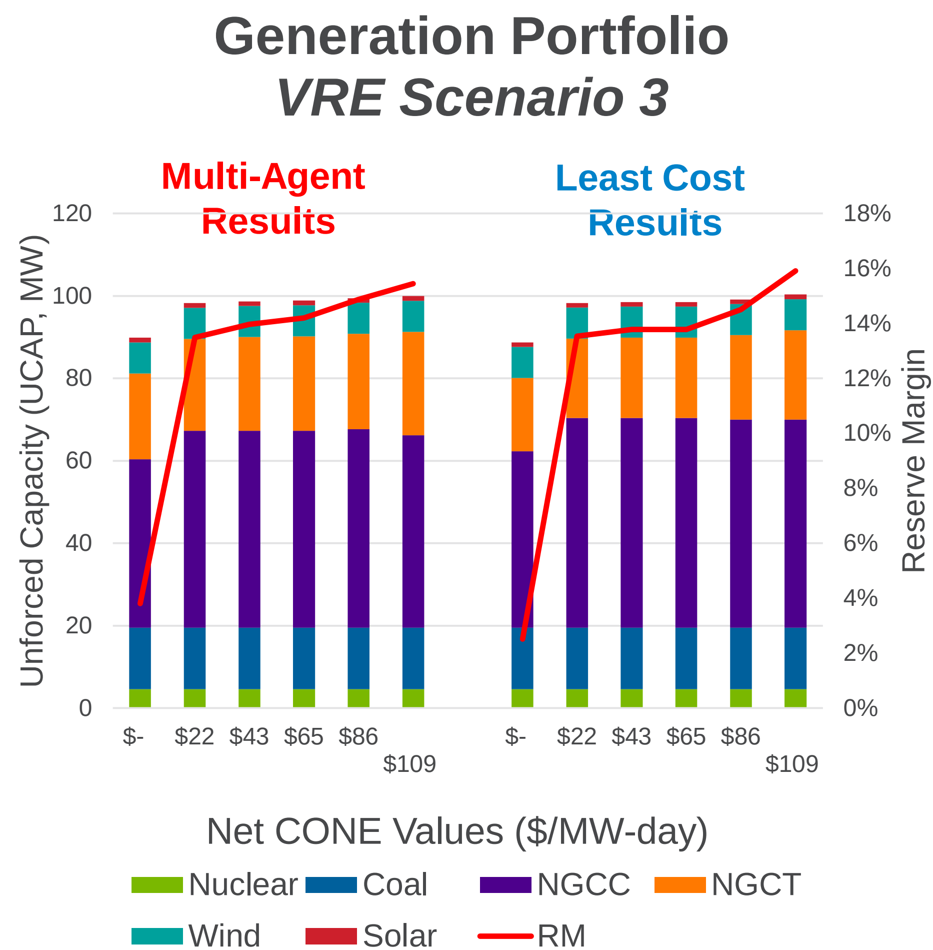




- Small differences in reserve levels give large changes in market outcome
  - Prices reach $9000/MWh under load shedding
  - No consideration of demand response, energy storage, other flexibility solutions

GENERATION EXPANSION ("PJM-LIKE" MARKET DESIGN)

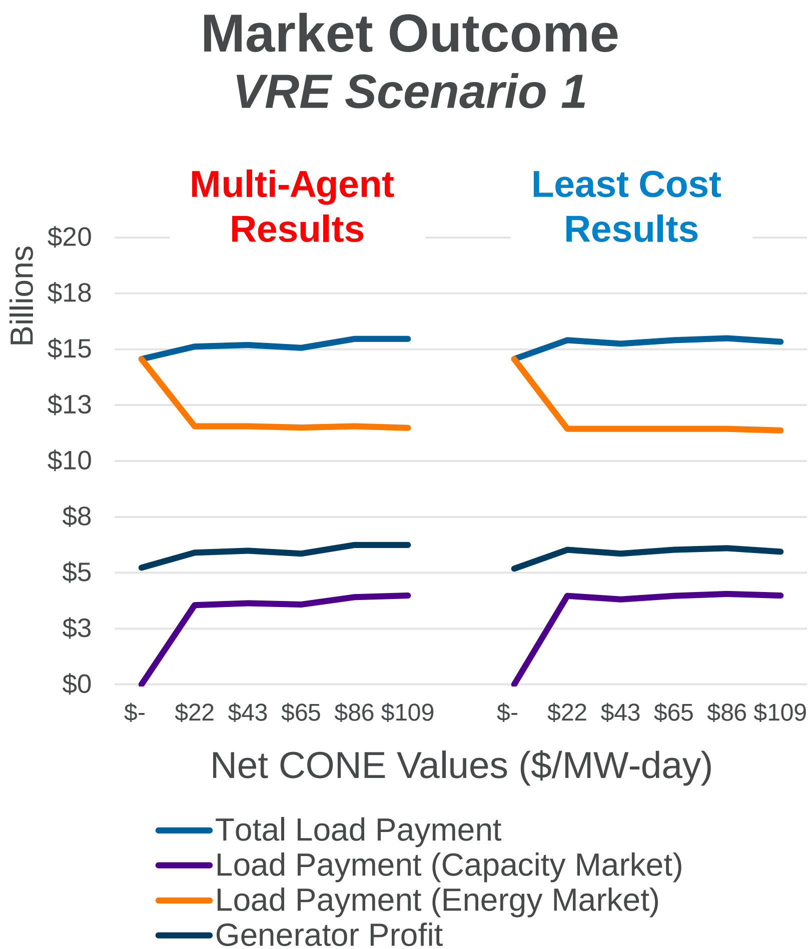


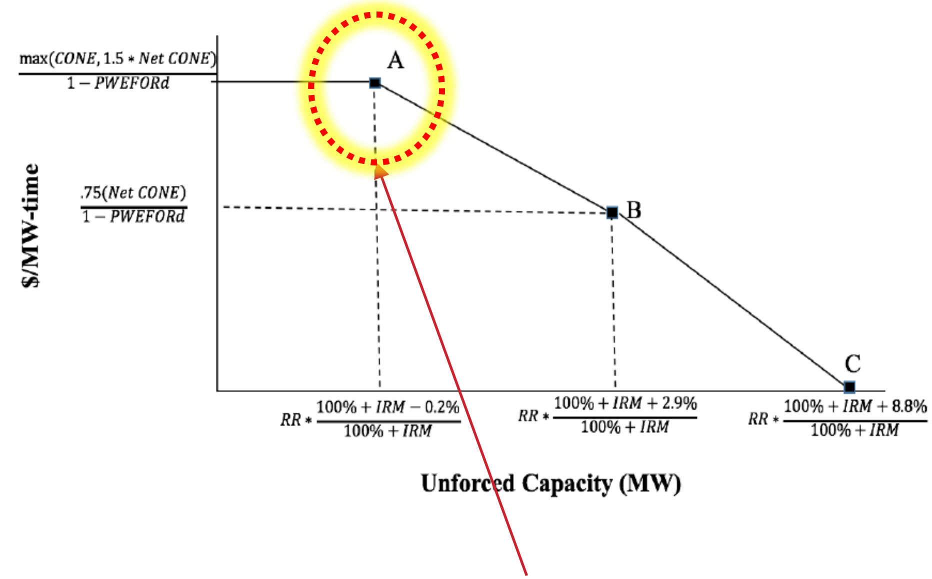


- Capacity target reached with capacity market
- Limited impacts of Net CONE assumption
- Small difference btw. multi-agent and least cost expansion

- Increasing VRE from 18% to 33% has limited impacts on results

MARKET OUTCOME (“PJM-LIKE” MARKET DESIGN)



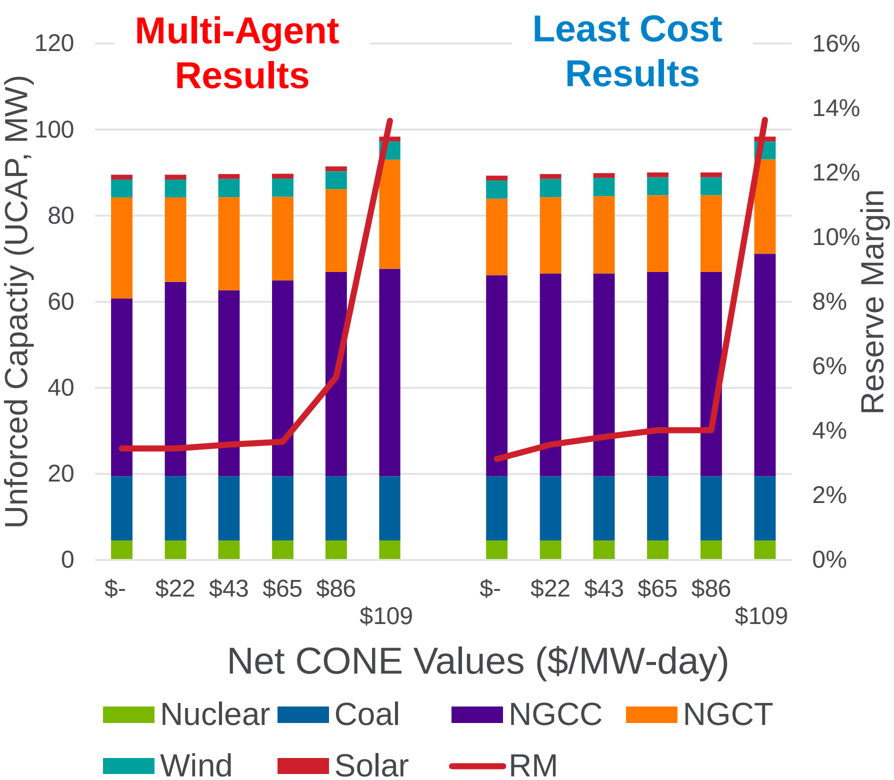


The capacity markets are mostly cleared around point A where the price is close to (or above) CONE

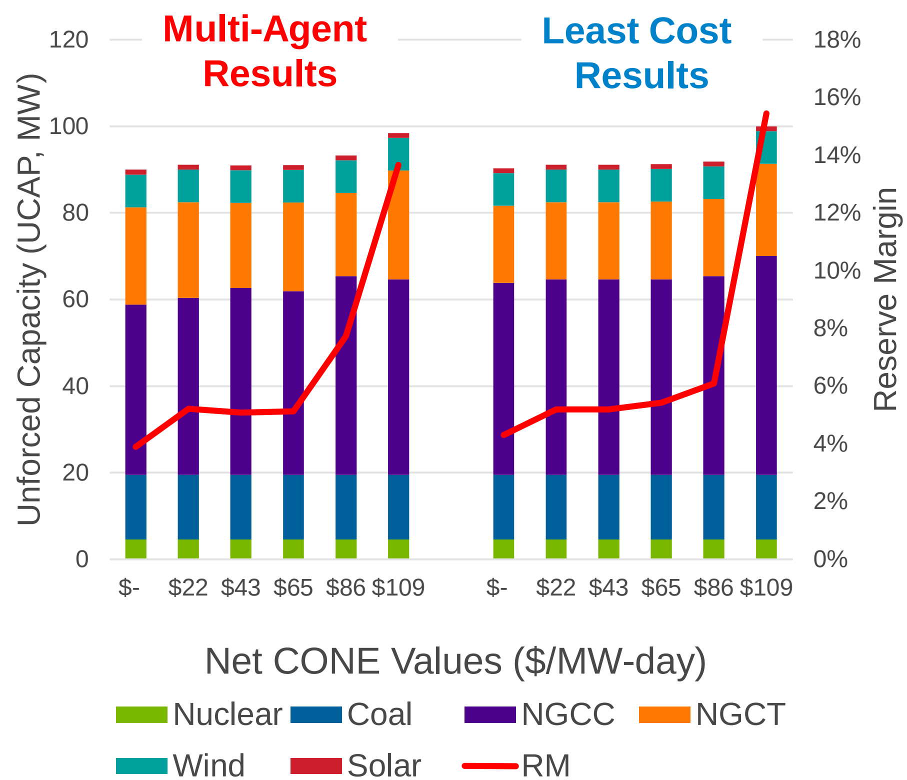
- Energy and capacity payments relatively stable for different Net CONE values
- Similar results under higher VRE penetration (VRE 3 scenario)

GENERATION EXPANSION ("MISO-LIKE" MARKET DESIGN)

Generation Portfolio
VRE Scenario 1



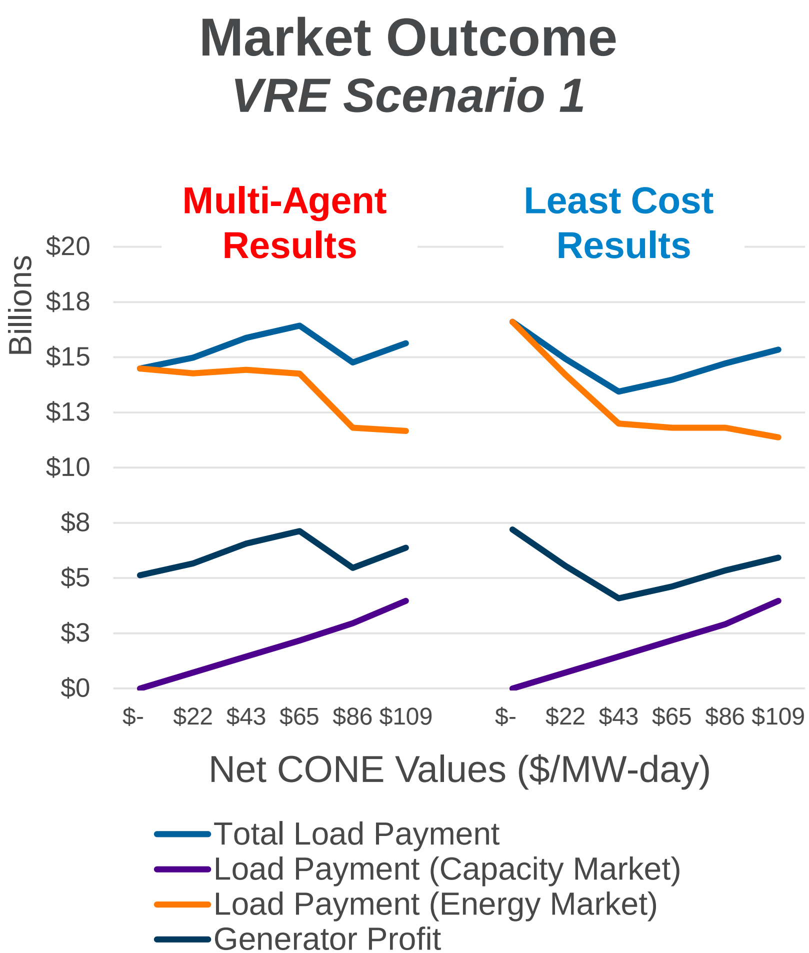
Generation Portfolio
VRE Scenario 3

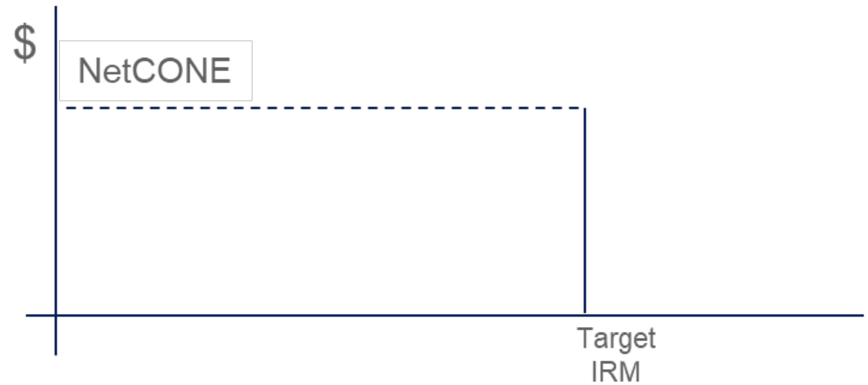


- Capacity target reached with high Net CONE
- Small difference btw. multi-agent and least cost expansion

- Similar results for high VRE penetration levels (33%)

MARKET OUTCOME ("MISO-LIKE" MARKET DESIGN)





A vertical capacity demand curve capped by Net Cone does not promote sufficient investments with lower Net CONE values

- Capacity payments increase with Net CONE values
- Similar results under higher VRE penetration (VRE 3 scenario)

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CONCLUSIONS

- VRE influence electricity markets
  – Incentive schemes may have substantial impacts on prices
- Open questions around resource adequacy with VRE
  – Capacity markets are complex and not well understood
  – Solutions need to enable economic entry and exit
- A multi-agent model for capacity expansion
  – Considers market interactions between competing GenCos
  – Models revenues from energy, reserves, and capacity markets
- Case study results
  – Energy only design may work well, but small margins of error
  – Capacity markets benefit from using a capacity demand curve
  – Proper market signals can guide the market outcome towards a least-cost optimum, also with high VRE levels
- Next steps
  – Finalize and document current analysis
  – Improve computational performance to solve larger systems
  – Consider wider range of market design parameters

REFERENCES AND ACKNOWLEDGEMENTS

Kwon J., Zhou Z., Levin T., Botterud A., "A Stochastic Multi-Agent Resource Planning Model: The Impact of Capacity Remuneration Mechanisms," 2018 Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Boise ID, Jun. 2018.

Byers C., Levin T., Botterud A., "Capacity market design and renewable energy: Performance incentives, qualifying capacity, and demand curves," *Electricity Journal*, Vol. 31, No. 1, pp. 65-74, 2018.

Levin T., Kwon J., Botterud A., "The Impacts of Renewables Support Schemes and Carbon Policies on Electricity Markets," Working Paper, Oct. 2018.

Wiser R., Mills A.D., Seel J., Levin T., Botterud A., "Impacts of Variable Renewable Energy on Bulk Power System Assets, Pricing, and Costs," Technical Report LBNL-2001082," Nov. 2017.

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THANK YOU

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