ELECTRICITY PRICES AND RESOURCE ADEQUACY IN ZERO MARGINAL COST POWER SYSTEMS

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Zero Marginal Cost Power Systems

- Renewable energy resources such as wind and solar photovoltaic generation are increasingly displacing thermal electricity generation
- These resources have effectively no variable costs of generation, which at higher resource penetrations can lead to increased frequency of zero-price periods
- We study a hypothetical power system where all resources have zero marginal costs, leading to $0/MWh electricity prices in all time periods without scarcity pricing

Investment Signals and Competitive Equilibrium

- Electricity markets must balance supply (generation) and demand at every point in time
- During periods of capacity scarcity (when electricity demand approaches or exceeds supply), prices rise to reflect binding or near-binding generation constraints
- In these periods of scarcity, generators able to produce power earn significant operating profits, which help recover the unit's substantial capital costs
- In a zero marginal cost power system, these scarcity periods are the only means for generators to earn profit in the energy market
- Capacity scarcity and unserved energy are risky and socially undesirable, but become economically necessary to incentivize future generation investments
- How do alternative scarcity price signals impact both electricity price distributions and investment levels under competitive market equilibrium conditions?


Capacity Shortfall → High Electricity Prices → Profitable Generation Investments → Capacity Surplus → Low Electricity Prices → Unprofitable Generation Investments → Capacity Shortfall

Figure 1: Efficient capacity investment levels at competitive market equilibrium balance out the long-run value of serving electricity against the capital costs of providing that electricity

Model Formulation

- Model approximates competitive equilibrium investment levels by solving a mixed-integer linear or quadratic program to determine least-cost discrete investment choices for a hypothetical power system with no variable costs
- Available generation technologies are a zero marginal cost subset of RTS-GMLC [1] generators (utility PV, wind, hydro), plus four-hour battery storage in 100 MW increments
- Investment costs are derived from 2019 NREL ATB [2]
- Investment decisions consider one year of chronological hourly operations to capture variability of renewables and intertemporal storage constraints
- Problem is re-solved with discrete buildout decisions fixed to extract hourly price information (dual variables to the load balance constraints) from the resulting convex economic dispatch problem

Scarcity Signal Paradigms Considered

Inelastic Demand

- Simplest scenario: assumes price rises to system average value of lost load (VoLL) during periods with unserved energy
- No intermediate price signals to incentivize generation investments until load is dropped

Inelastic Demand with Reserve Product

- Price rises to administratively-set level (e.g 50% of VoLL) if any requested reserves cannot be provisioned

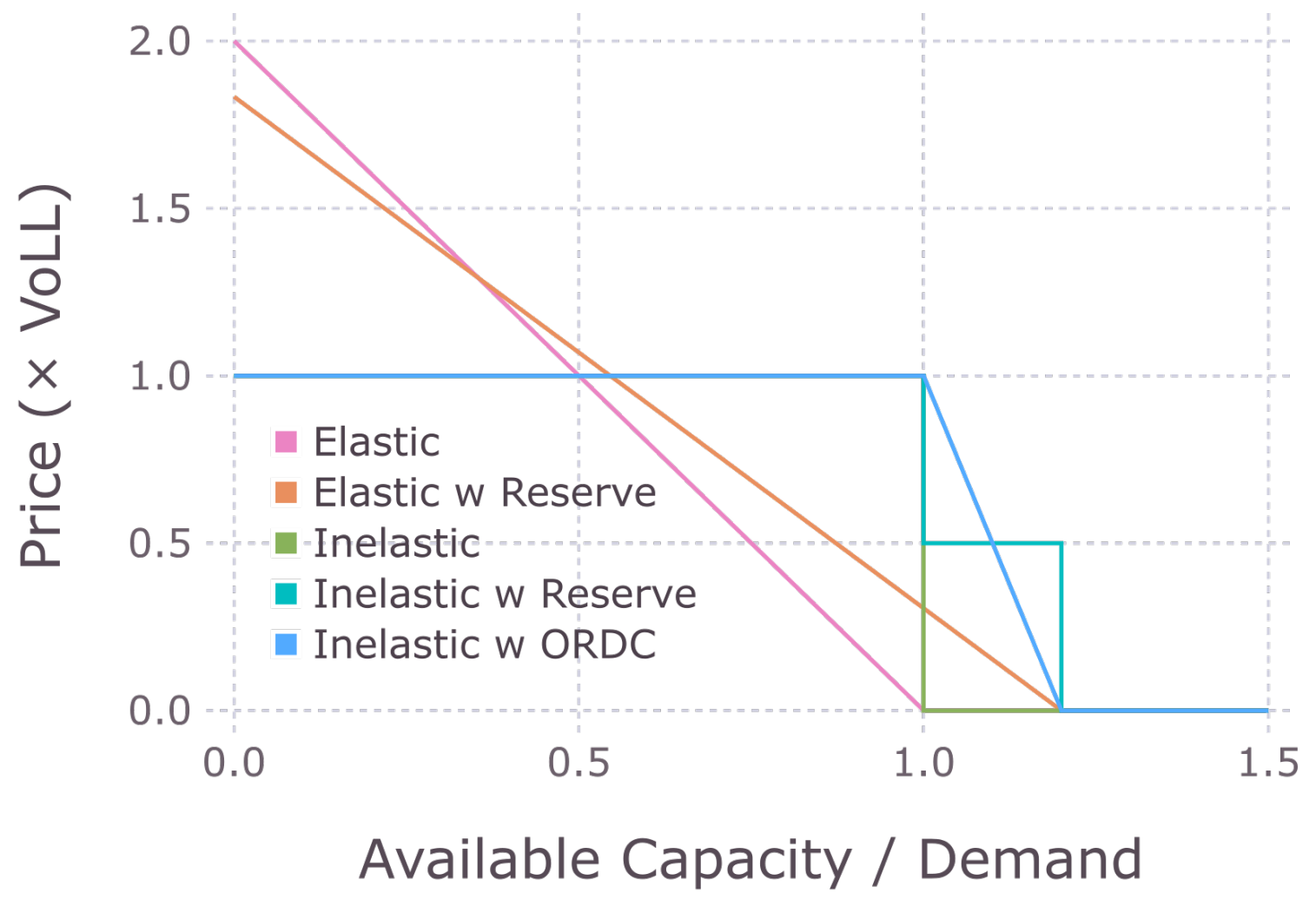

Figure 2: Implicit economic demand curves under five different scarcity signal paradigms

Inelastic Demand with Operating Reserve Demand Curve (ORDC) Reserve Product

- Price gradually rises to VoLL with increasing reserve shortfall

Elastic Demand

- Assumes technological and social/political capability for level of demand to respond to price
- During scarcity conditions, "unserved"/curtailed loads are those with lowest economic value

Elastic Demand with Reserve Signal

- Induces non-zero prices in advance of "shortfall" relative to reference demand

Price Impacts of Scarcity Signal Paradigms

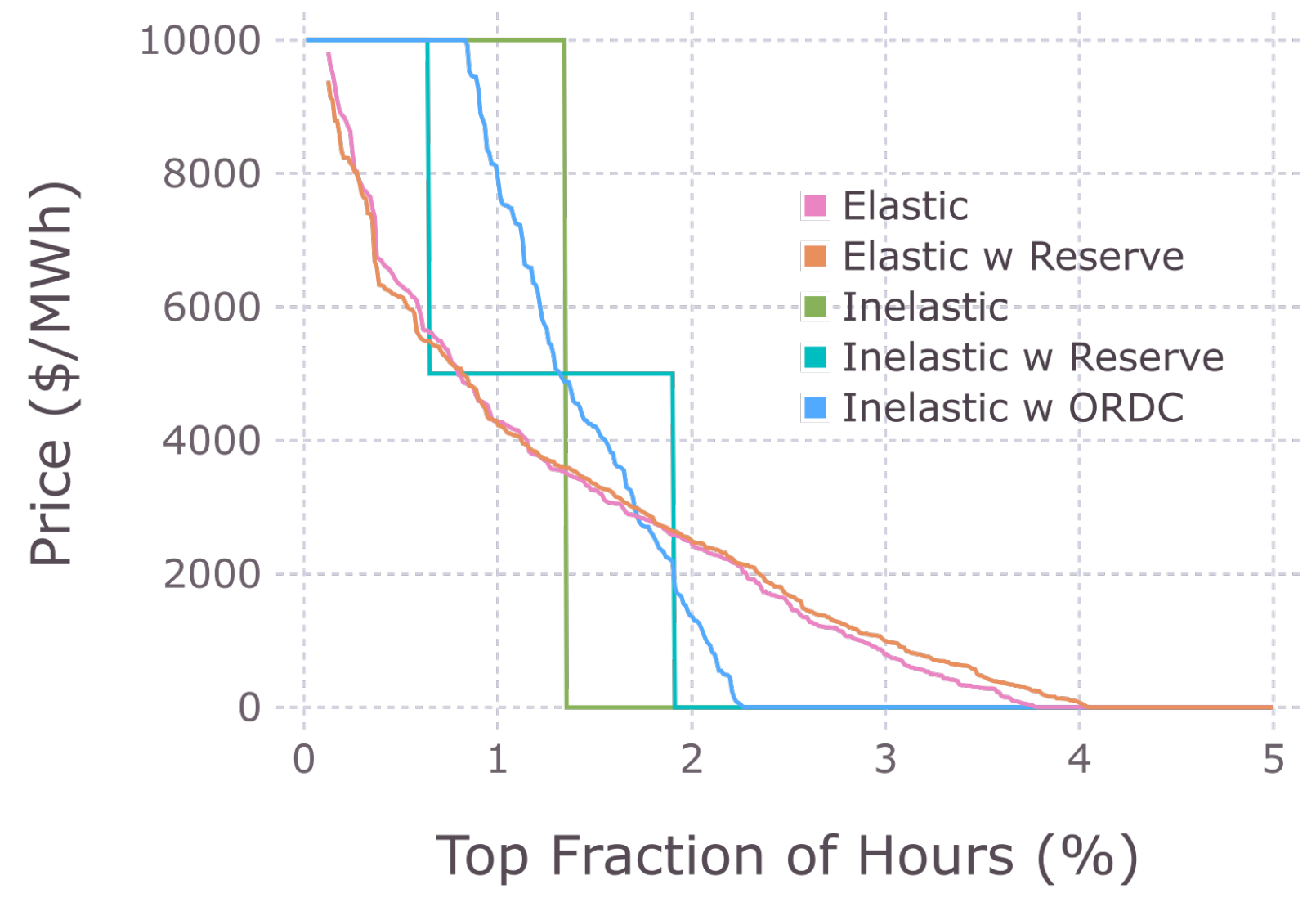

Figure 3: Price duration curves in the absence of storage, under each scarcity signal paradigm

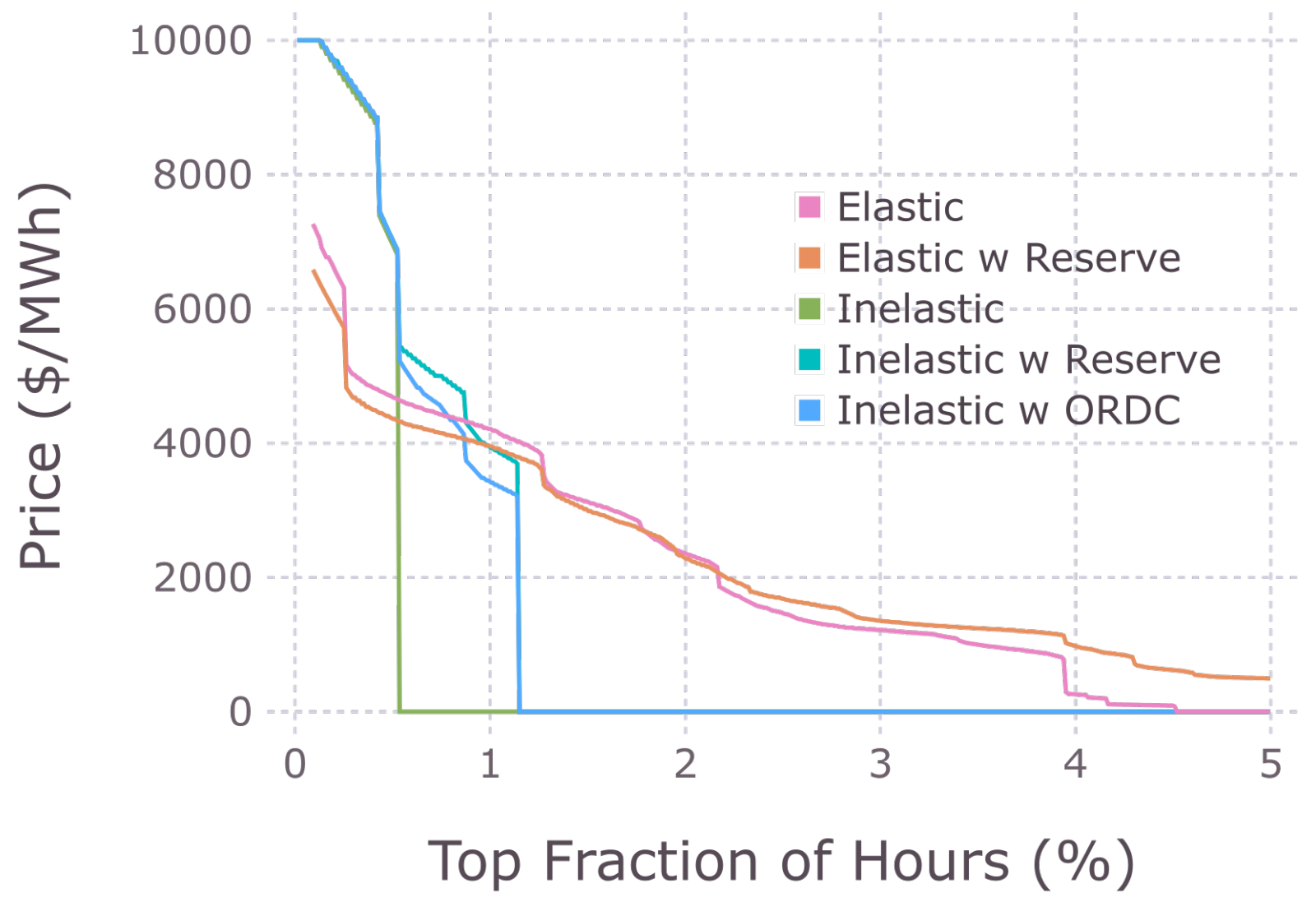

Figure 4: Price duration curves in the presence of storage, under each scarcity signal paradigm

- Non-zero pricing occurs in 0.5%-2% of time periods for inelastic demand, and 3.6%-7% of periods for elastic demand
- Without storage, reserves, or elastic demand, the system only experiences prices at $0/MWh or the system VoLL ($10,000/MWh)
- Augmenting inelastic demand with reserve requirements provides a third intermediate price level (conventional reserve) or a continuous range of intermediate prices (ORDC)
- Storage introduces intertemporal price dynamics that provide intermediate prices even without the ORDC
- Elastic demand provides a much more gradual increase in scarcity pricing
- Elastic demand results in "unserved" energy in significantly more time periods than the inelastic case, but the welfare cost of dropped load in the extra periods is much lower as well
- Adding a reserve requirement / price adder to the elastic demand case decreases prices during the most extreme shortfall periods, at the cost of more frequent periods with non-zero prices

Resource Adequacy Impacts of Scarcity Signal Paradigms

- Adding reserve requirements increases potential for scarcity pricing periods and thus generator revenue, incentivizing additional investment and improving resource adequacy
- Elastic demand scenarios have reduced resource adequacy since less valuable loads go unserved first, incurring lower welfare costs and sending weaker price signals than the inelastic cases where dropped loads are associated with the system average VoLL
- Increasing VoLL sends stronger price signals for investment and increases system resource adequacy (decreases unserved energy and load-dropping periods)

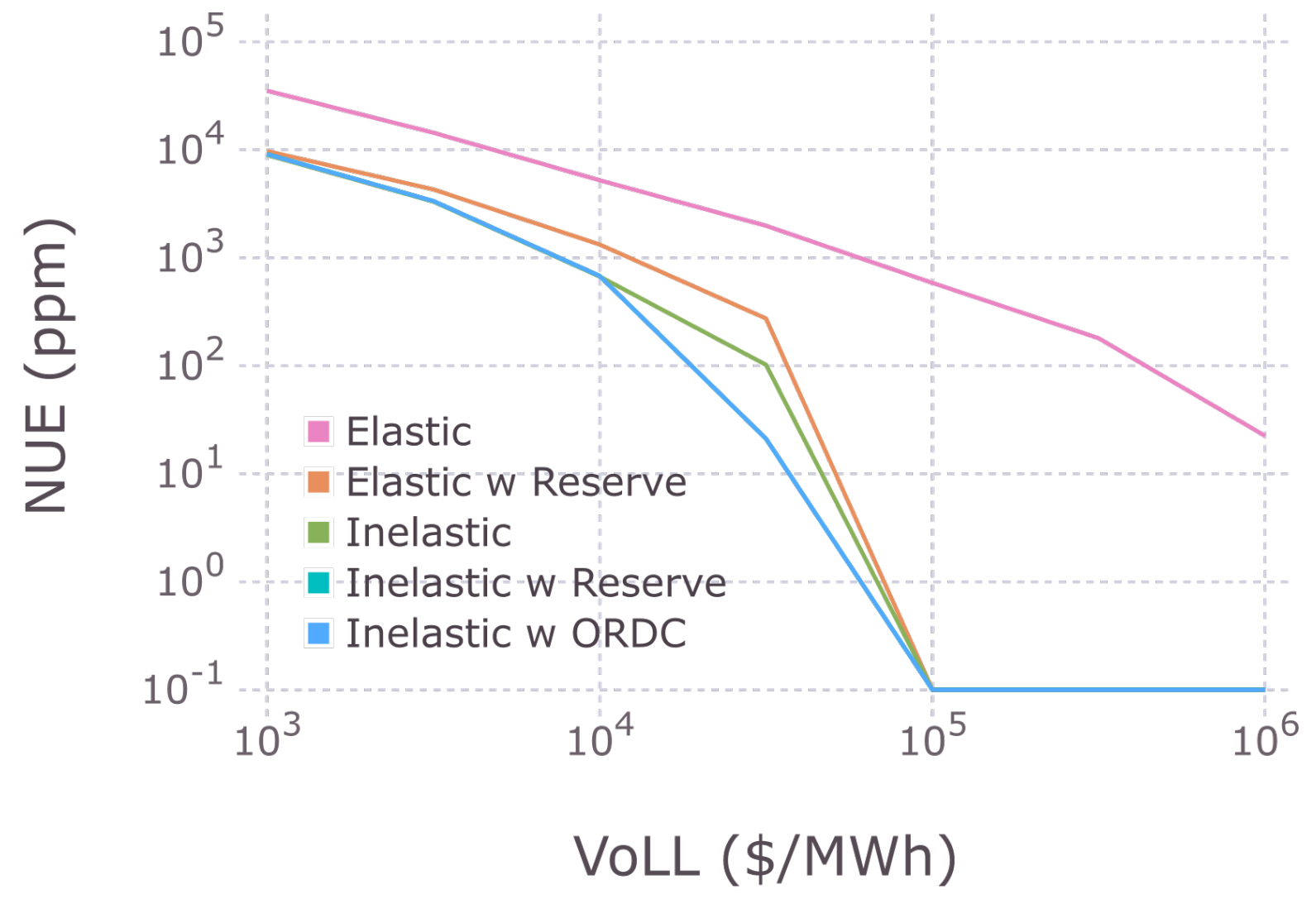

Figure 5: Normalized unserved energy (NUE) for each scarcity pricing paradigm, under varying price caps / VoLL

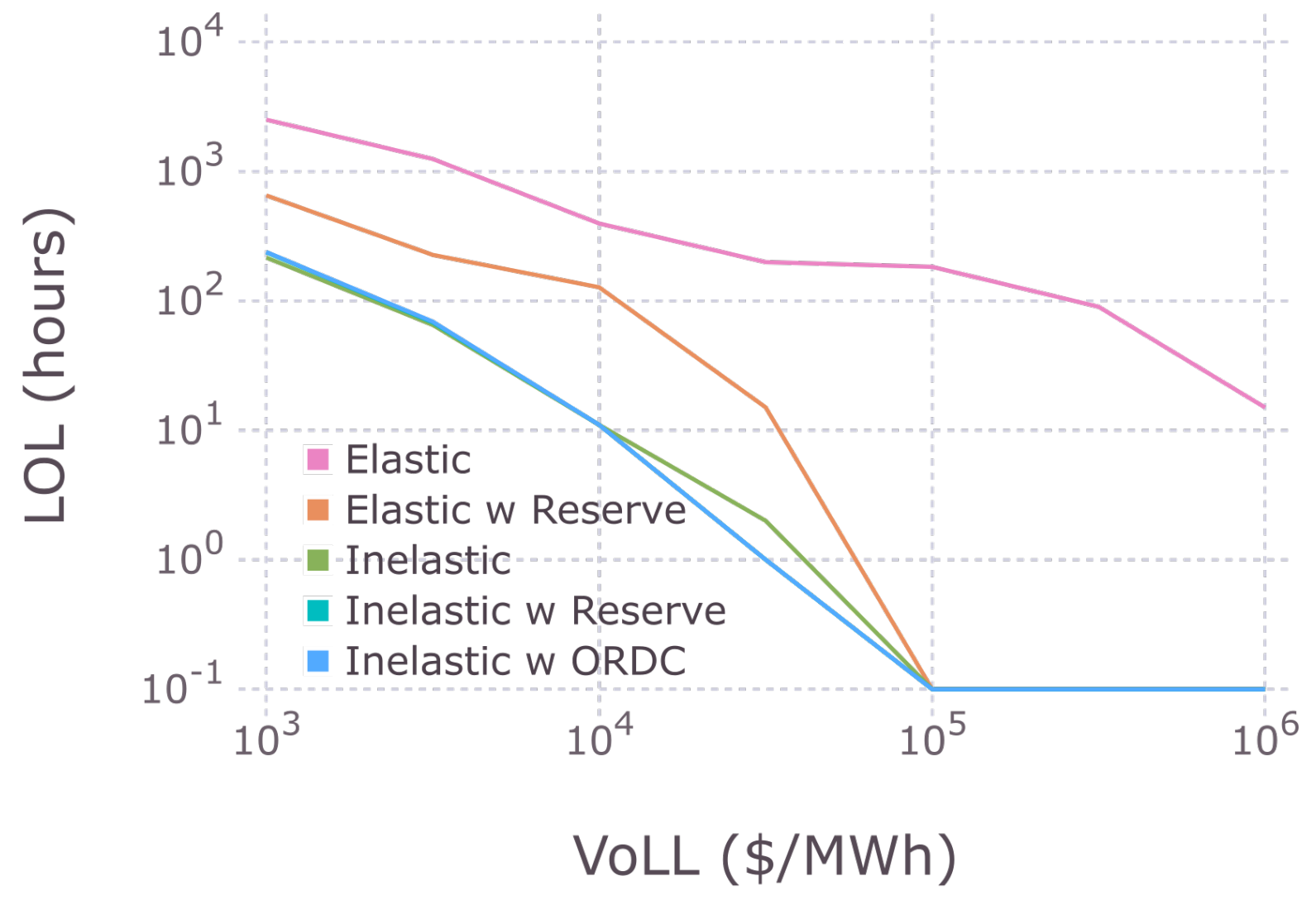

Figure 6: Count of hours with dropped load for each scarcity pricing paradigm, under varying price caps / VoLL

- Common industry resource adequacy thresholds of 2.4 hours/year LOLE/LOLH and 10 ppm NEUE are not achieved here at typical VoLL levels (in the range of $3,000/MWh to $30,000/MWh)
- VoLLs closer to $100,000/MWh are needed for most scarcity paradigms' economic equilibria to align with accepted adequacy targets

Future Work, References, and Acknowledgments

- Resource adequacy metrics presented here are based on deterministic annual time series of variable resource availability. Future work will investigate how to represent and incorporate resource adequacy uncertainty arising from both inter-annual variations in resource quality and intra-day weather effects.

- We have assumed the energy market price cap accurately reflects the system VoLL: future work will investigate the relation between lower price caps and required supplementary revenue from ancillary or forward markets for maintaining efficient levels of investment.

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[1] C. Barrows et. al., The IEEE Reliability Test System: A Proposed 2019 Update. IEEE Transactions on Power Systems, January 2020.

[2] L. Vimmerstedt et. al., 2019 Annual Technology Baseline (ATB): Cost and Performance Data for Electricity Generation Technologies. National Renewable Energy Laboratory, August 2019.

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