

## How to design and value ancillary services in IBR-dominated power systems?

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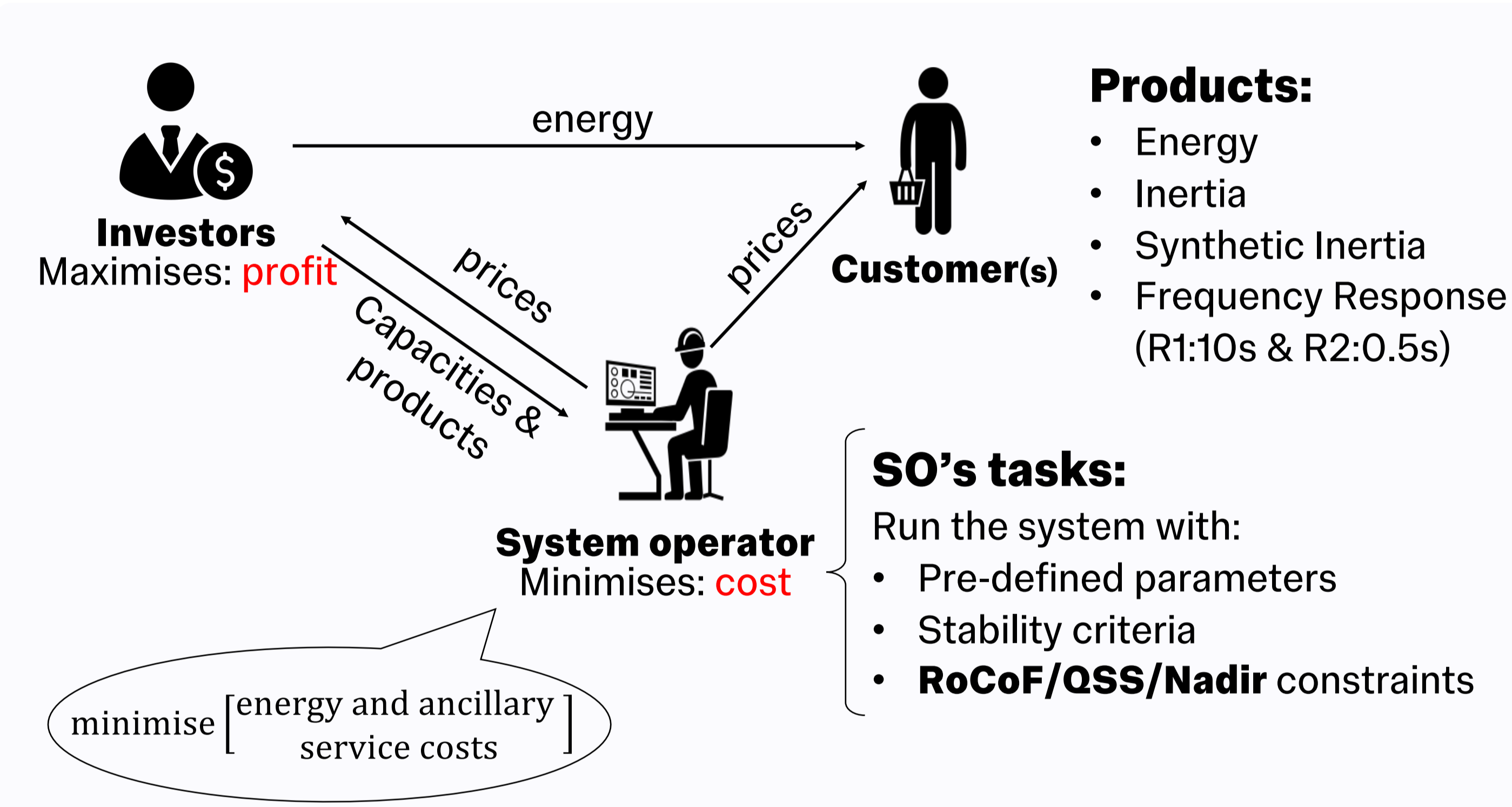
### Background and Motivation

- Rapid growth of IBRs, such as wind, solar, and batteries, is displacing synchronous generation.
- This reduces system inertia, leading to faster frequency dynamics ( $\uparrow$ RoCoF) and a lower nadir after disturbances.
- Existing electricity markets were designed for synchronous generation and do not explicitly price stability services, such as inertia.

### Main Research Gap

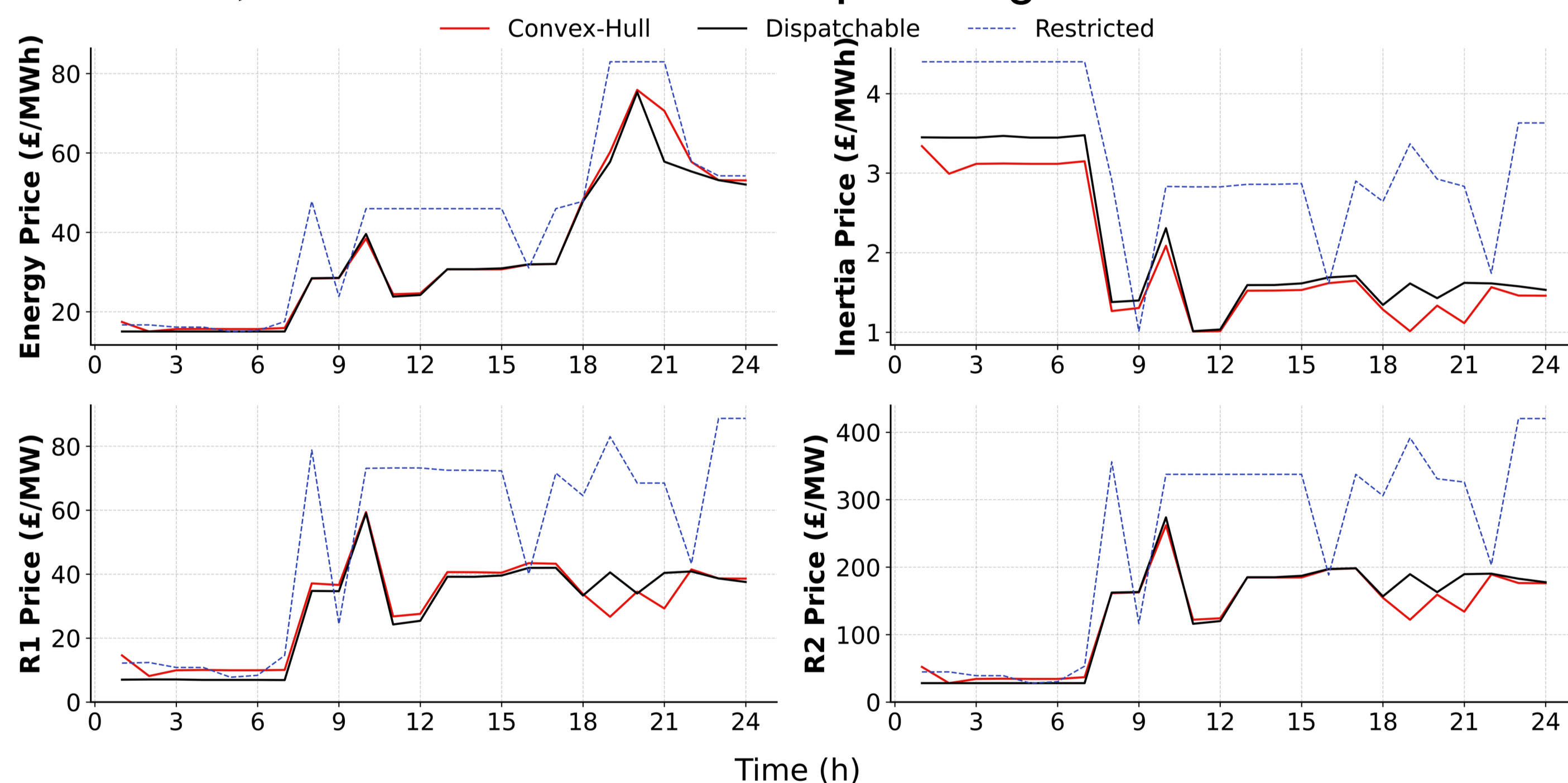
**Current electricity market designs do not adequately capture, value, or co-optimize stability-related ancillary services in low-inertia systems.**

### Day-ahead Market Model



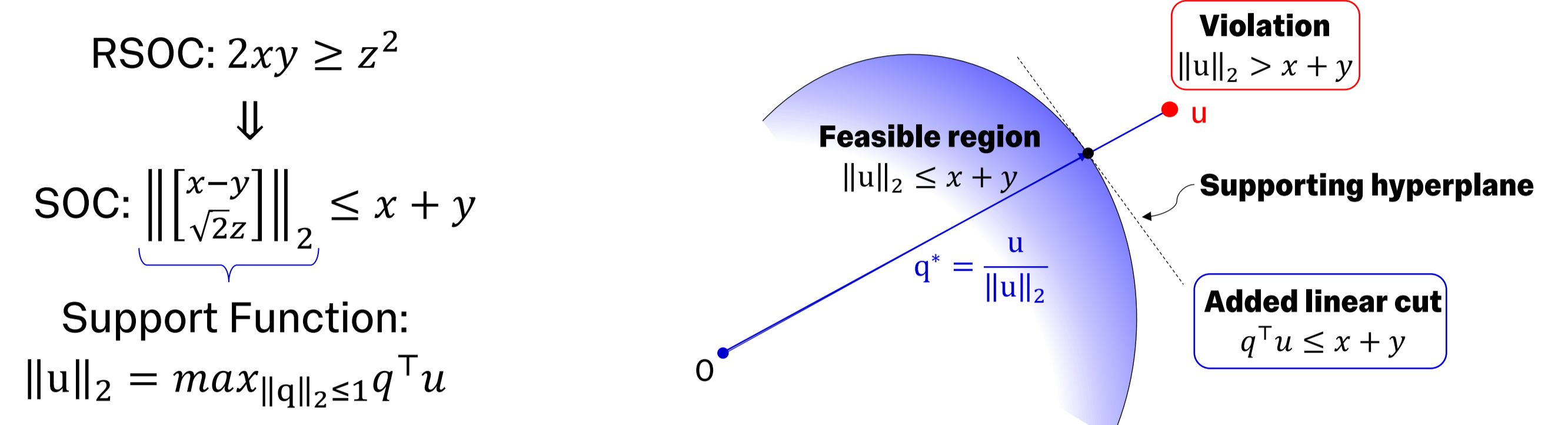
### Result 1: Market formulation strongly impacts price formation across products

Restricted pricing is challenged by Convex-Hull and Dispatchable methods, which offer more stable price signals.



### Methodology

- Co-optimisation framework for energy and ancillary services under system stability constraints.
- How to handle the bilinear nadir constraint?

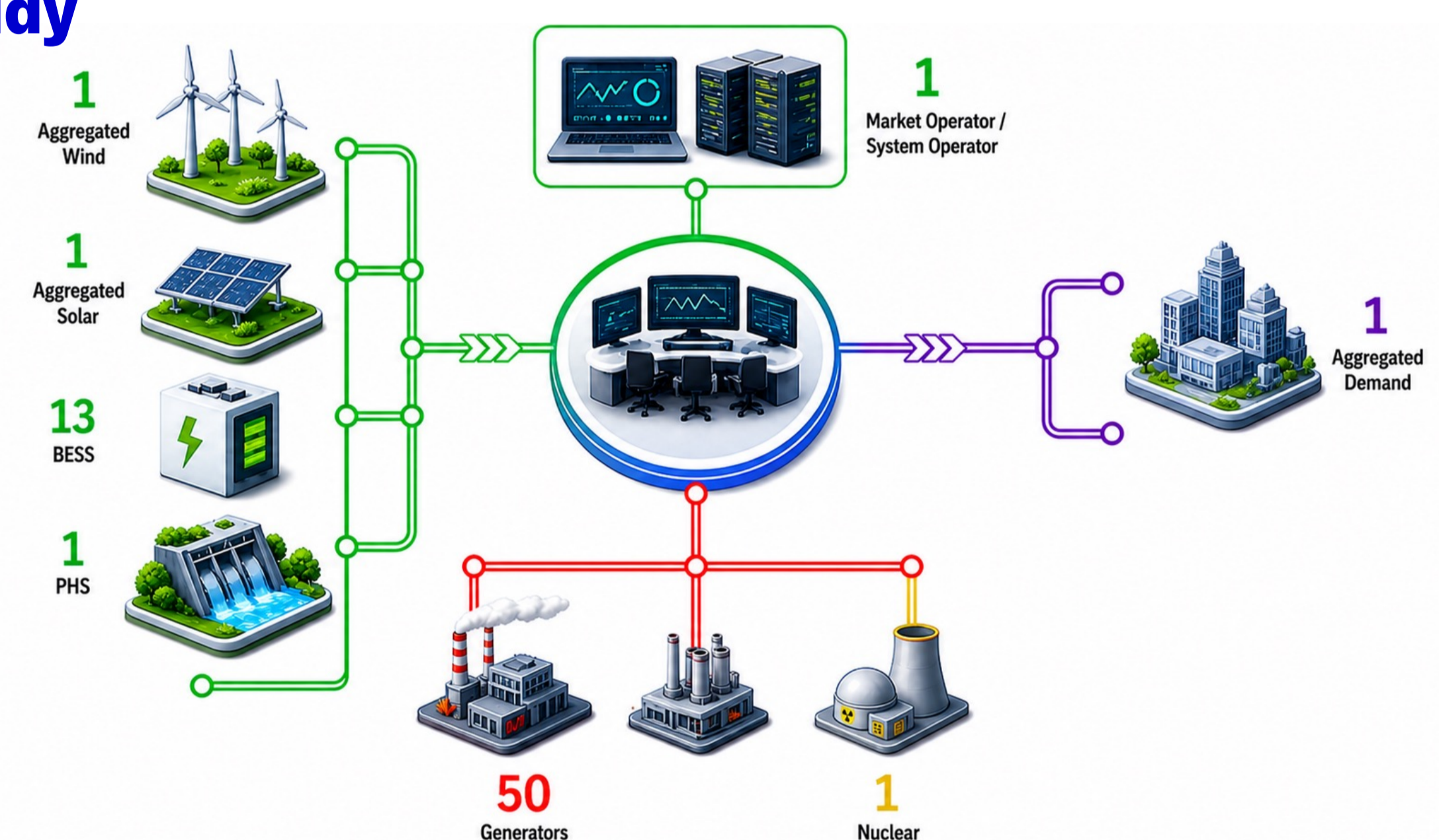


- How to derive marginal prices?

To **extract prices**, we need to **handle the binary variables**. We can apply the following approaches:

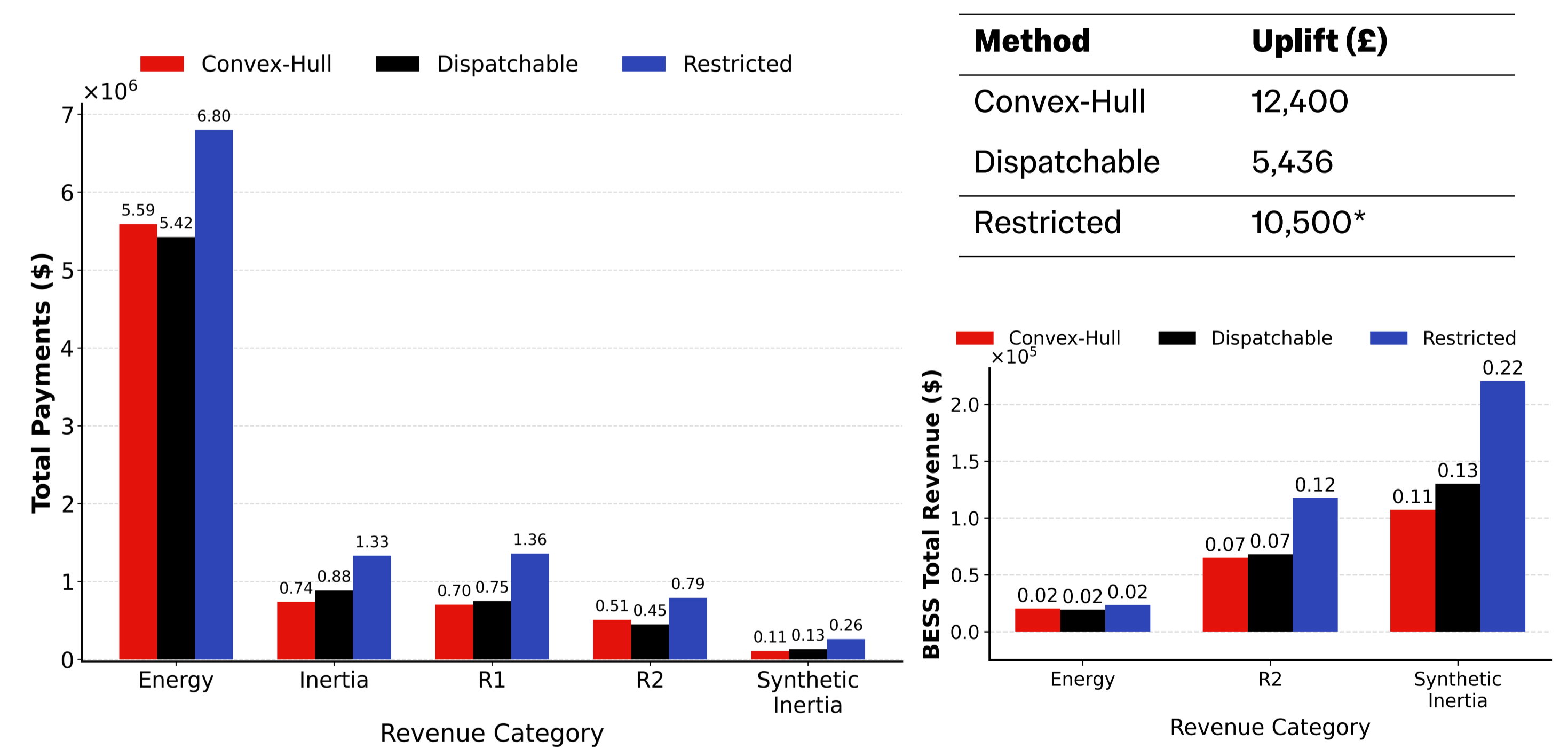
- **Restricted:**  $y = y$  (fix binaries)
- **Dispatchable:**  $0 \leq y \leq 1$  (relax binaries)
- **Convex-Hull:** column-generation algorithm

### Case Study



### Result 2: Market formulation impacts revenue and uplift

Restricted approach tends to overestimate revenues across all products. In contrast, the other two approaches provide more moderate and consistent outcomes.



Left: Total revenues across energy and ancillary services under Convex-Hull, Dispatchable, and Restricted formulations. Right: BESS revenue distribution across services. Table: Corresponding uplift comparison across formulations.

**Market design choices fundamentally alter price formation and resulting market outcomes.**

### Ongoing and Future Work

- Extend co-optimised market frameworks to include network constraints and more realistic system dynamics.
- Refine pricing mechanisms to better reflect the value of stability services in low-inertia systems.

#### Acknowledgments

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#### References

- [1] P. Andrianesis, D. Bertsimas, M. C. Caramanis, and W. W. Hogan, "Computation of Convex Hull Prices in Electricity Markets With Non-Convexities Using Dantzig-Wolfe Decomposition," *IEEE Trans. Power Syst.*, vol. 37, no. 4, pp. 2578-2589, Jul. 2022.
- [2] L. Badesa, F. Teng, and G. Strbac, "Pricing inertia and Frequency Response with diverse dynamics in a Mixed-Integer Second-Order Cone Programming formulation," *Appl. Energy*, vol. 260, Feb. 2020, Art. No. 114334.

