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Is there still merit in the merit order stack?

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The Merit Order Stack

- The energy economist's workhorse:
  - Green and Newbery (1992) — *Market power in GB*
  - Joskow and Kahn (2002)
  - Borenstein *et al.* (2002) — *Californian electricity crisis*
  - Lamont (2008)
  - Usaola *et al.* (2009)
  - Bushnell (2010) — *Investment with renewables*
  - Green and Vasilakos (2010)

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The Merit Order Stack

- Use the cheapest plants in order until demand is met
- Intersections on the total cost curve tell you optimal run times
- Load duration curve then gives optimal capacities

	Fixed Cost (£/kW-year)	Variable Cost (£/MWh)
Nuclear	470	5.00
Coal	208	47.78
CCGT	103	53.25
OCGT	72	93.30

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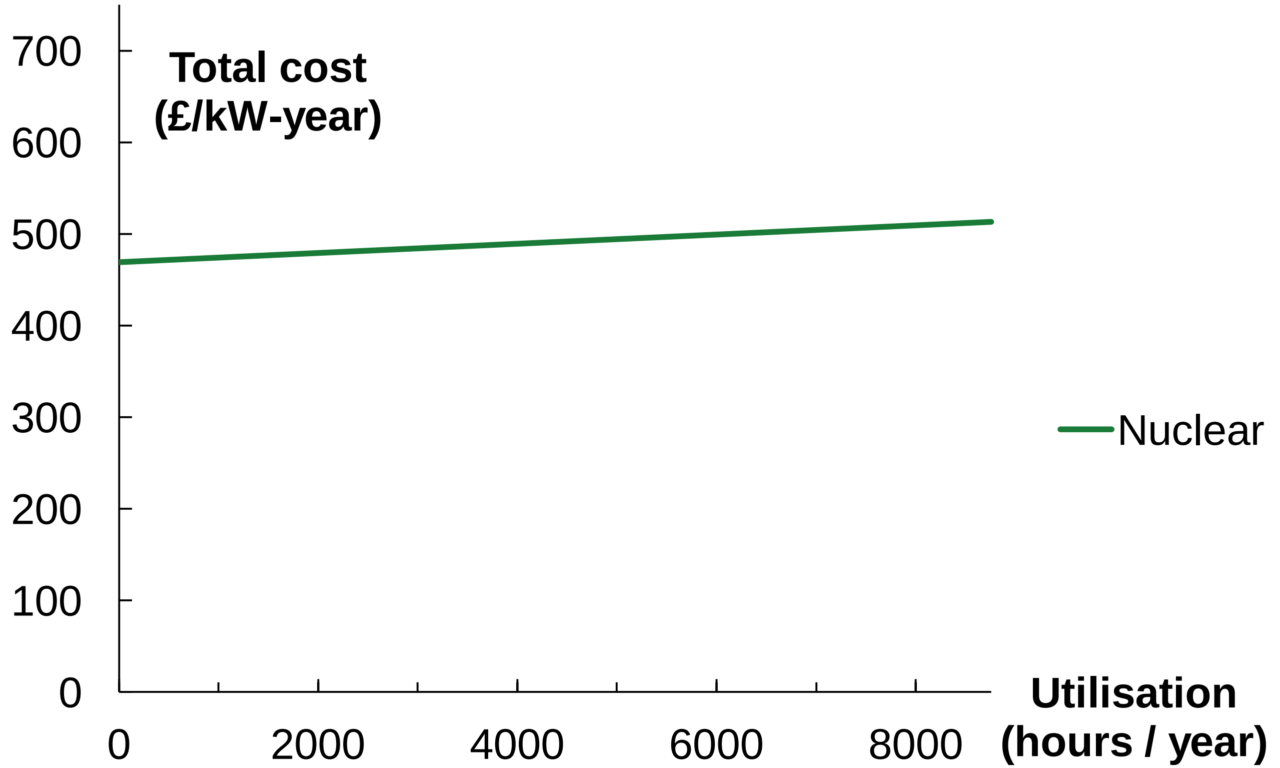

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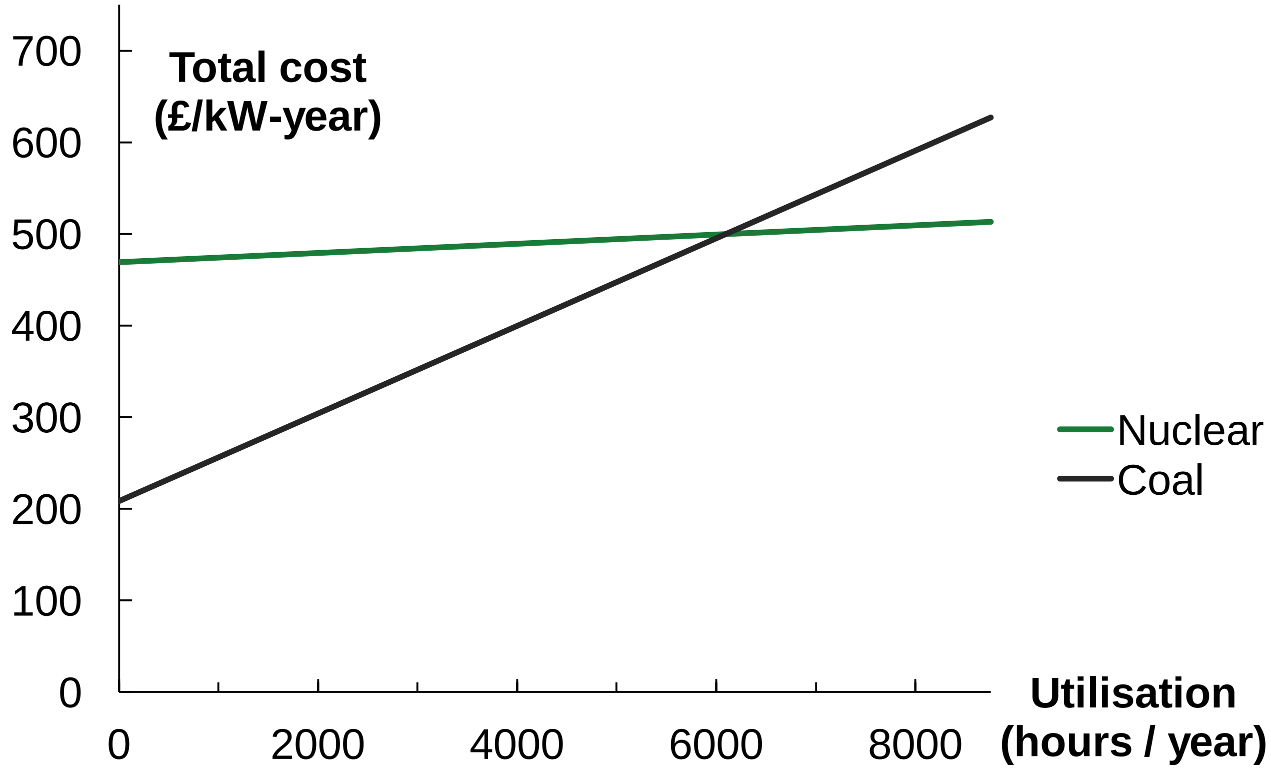

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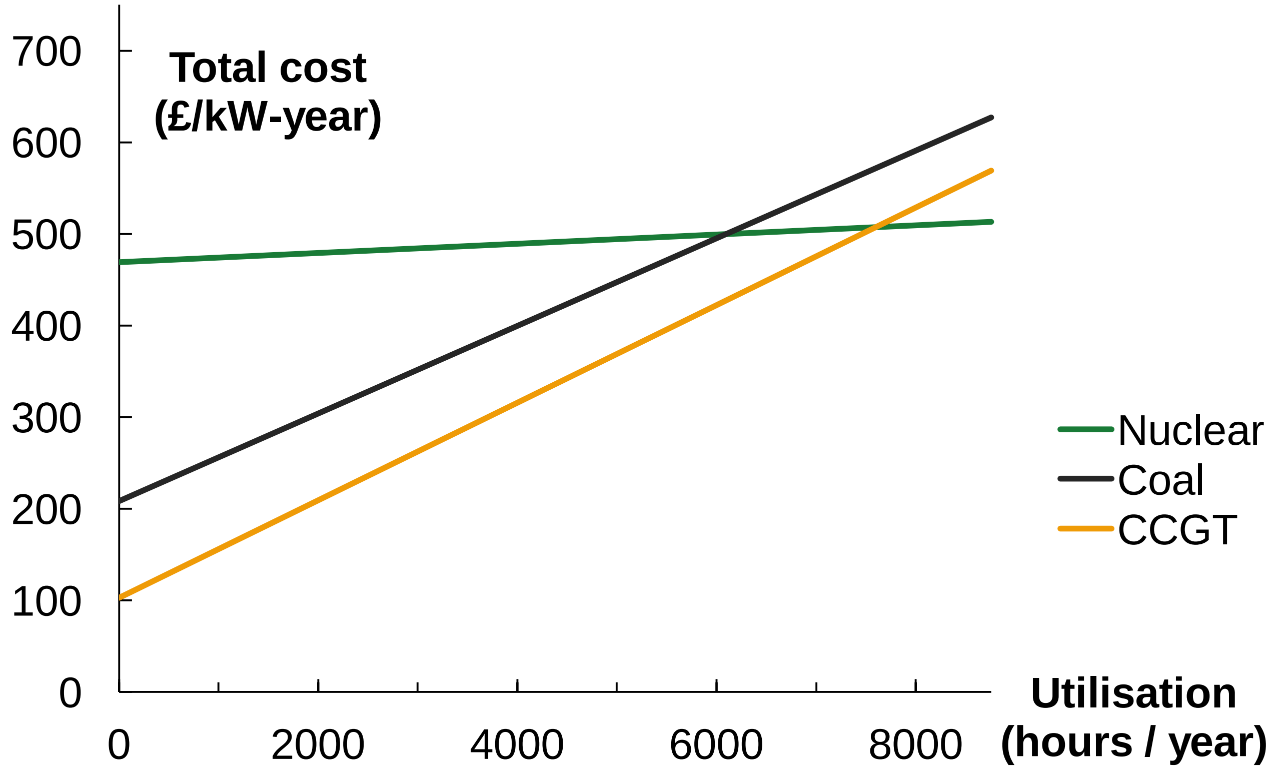

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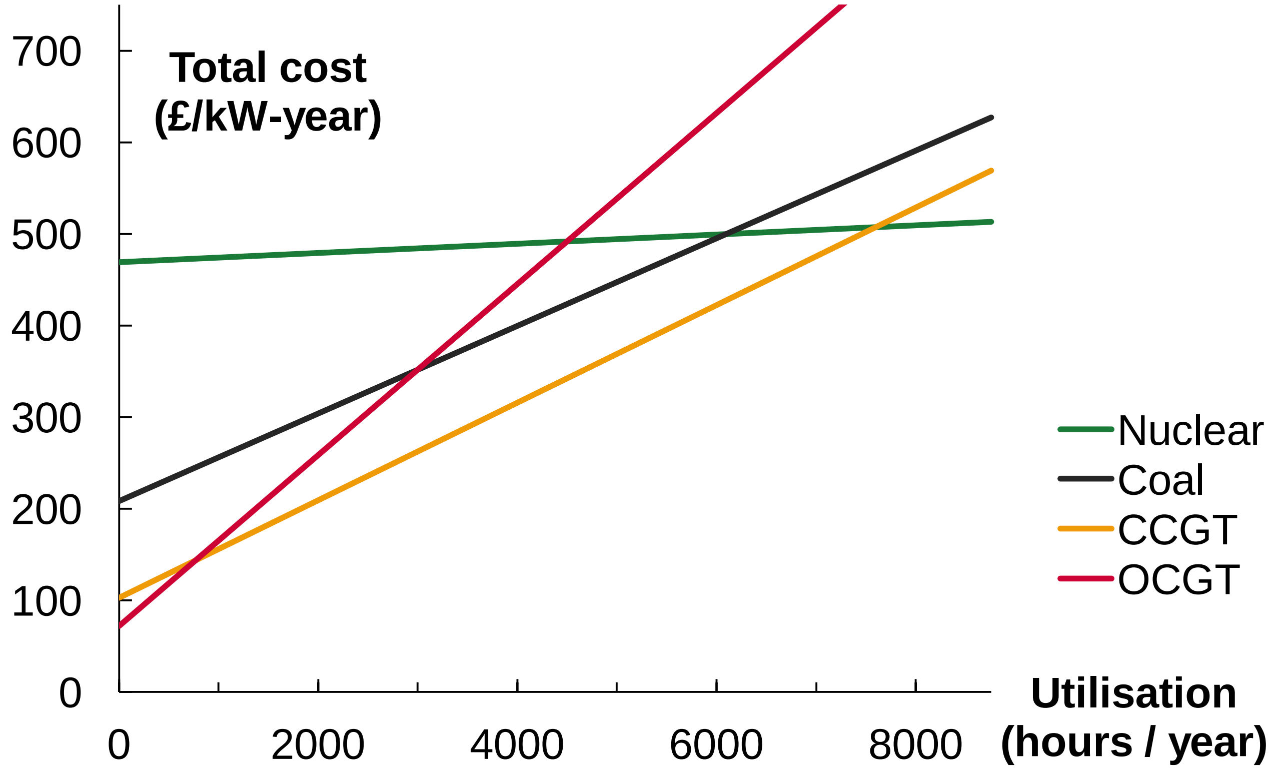

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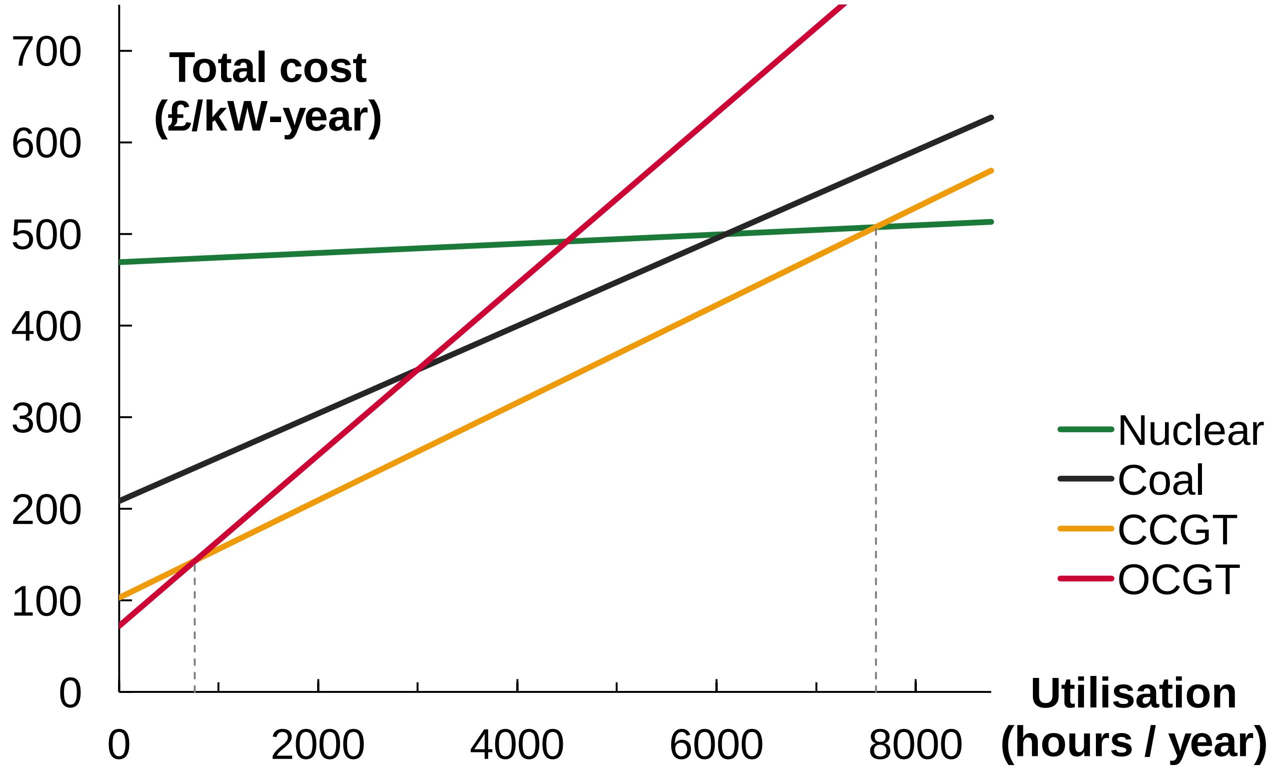

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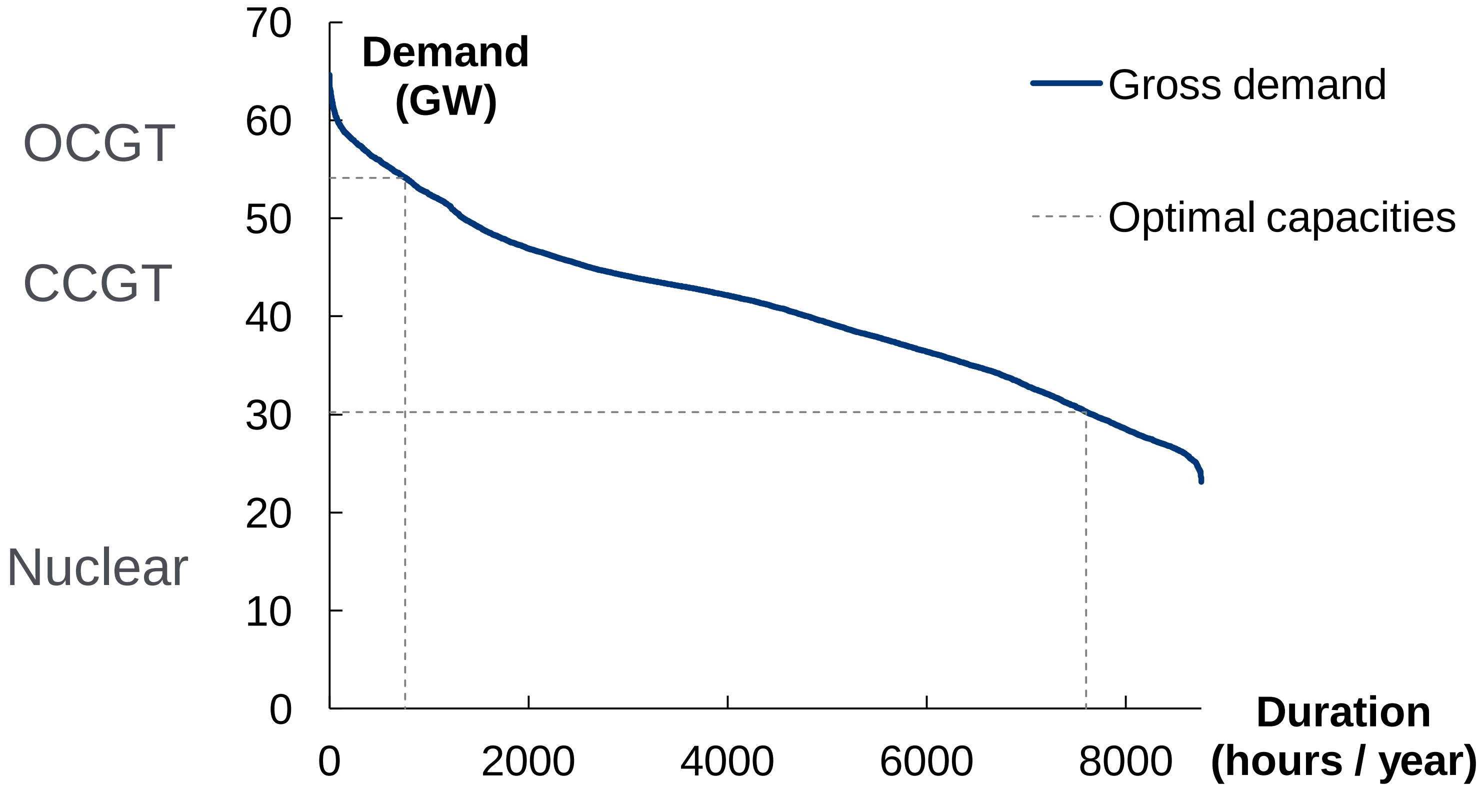

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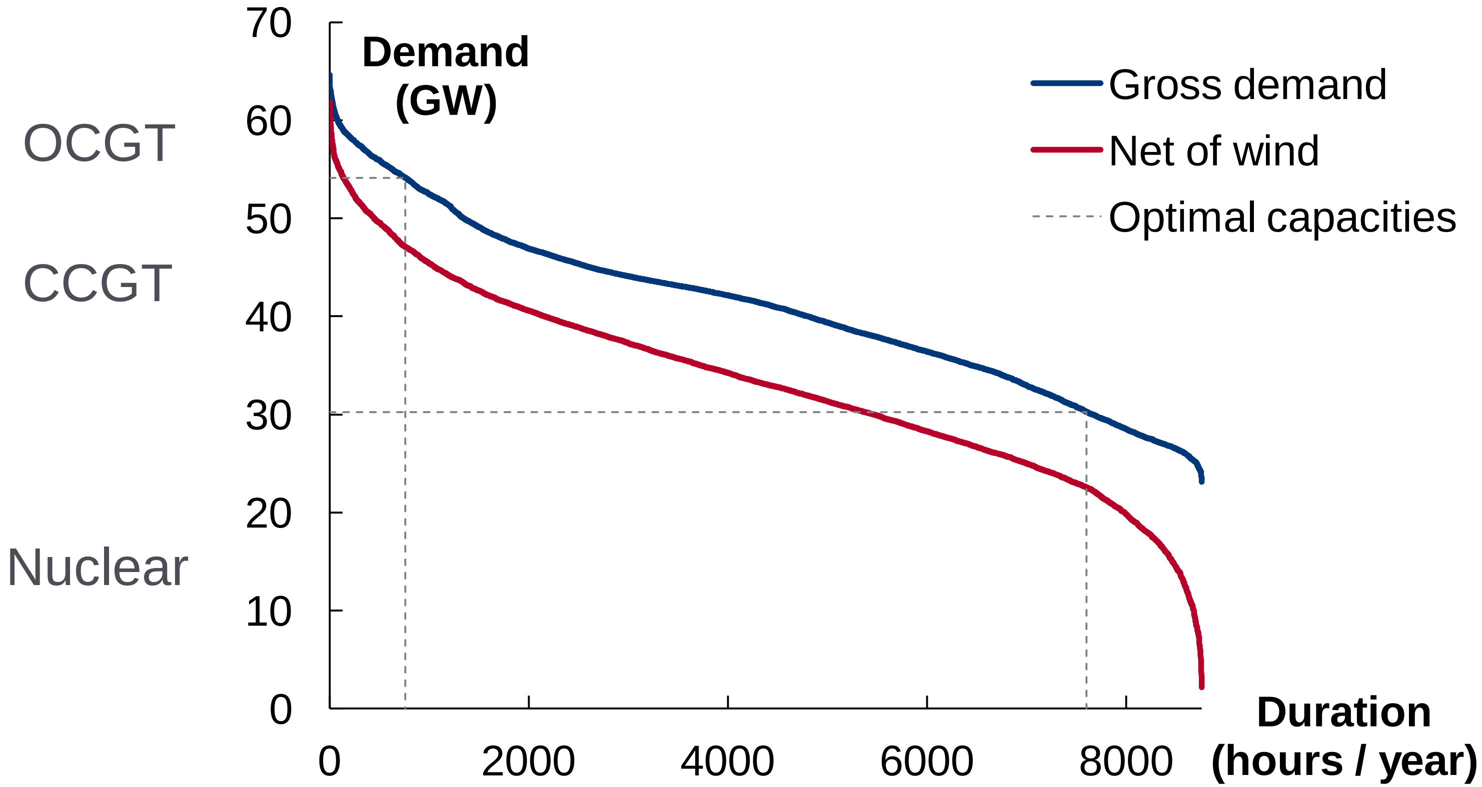

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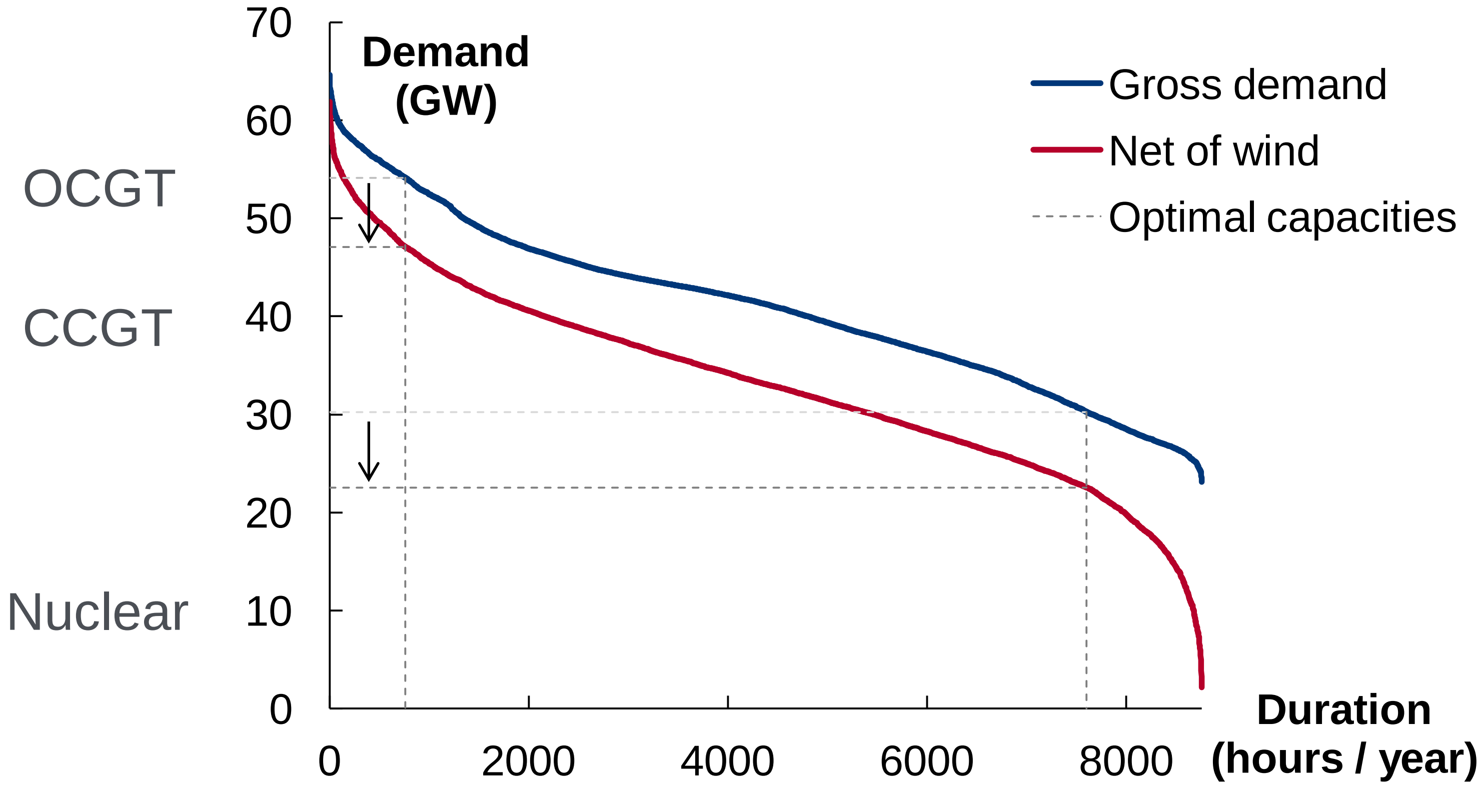

The Research Issue

The question...

Is the merit order stack model still a reliable tool in tomrrow’s more dynamic electricity systems?

- Dynamic constraints on operation are neglected
- The future is likely to be more unpredictable
- Perhaps we need to only rely on full dispatch models?

Fully Optimised Dispatch Model

Minimise the cost of electricity subject to several constraints:

- Supply must equal demand
- Available capacity must equal demand + reserve margin
- Hydro resources have finite storage capacity
- Price sensitive load shedding
- Individual plants have:
  - minimum stable output
  - minimum up-time and down-time
  - cost and time to start up
  - reduced efficiency at part load

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Fully Optimised Dispatch Model

- Less widely used in academic economics literature:
  - Mills and Wiser (2012)
  - Strbac *et al.* (2012)

- Much more computationally intensive
- Harder to perform Monte Carlo or sensitivity analysis
- Results tend to be less intuitive

Our Test

- Calibrate stack and dispatch models to GB in 2020:
  - Demand increases 0.7% p.a. to 350 TWh per year
  - 30 GW of wind plant is simulated from weather data
  - Plant costs from five recent studies (UK×3, EIA, IEA)
  - Fuel and carbon prices from government predictions

- Find the long-run equilibrium capacity mix
- Assess price levels
- Consider extensions to the stack model

Our Test: Plant Costs

	Capital Cost (£ / kW)	Fuel Cost (£ / MWh)	Carbon Cost (£ / MWh)	Start-up cost (£k)	Fixed Cost (£ / kW-year)	Variable Cost (£ / MWh)
Nuclear	3050	3.35	0.00	4000	470	5.00
Coal	1425	18.62	25.84	142	240	47.78
CCGT	700	34.52	10.77	33	103	53.25
OCGT	500	68.12	18.99	0.3	72	93.30
Oil	1200	113.07	27.23	0.5	188	149.27

Sources: Mott MacDonald (2010), Parsons Brinckerhoff (2011), Arup (2011), IEA (2010), EIA (2010)

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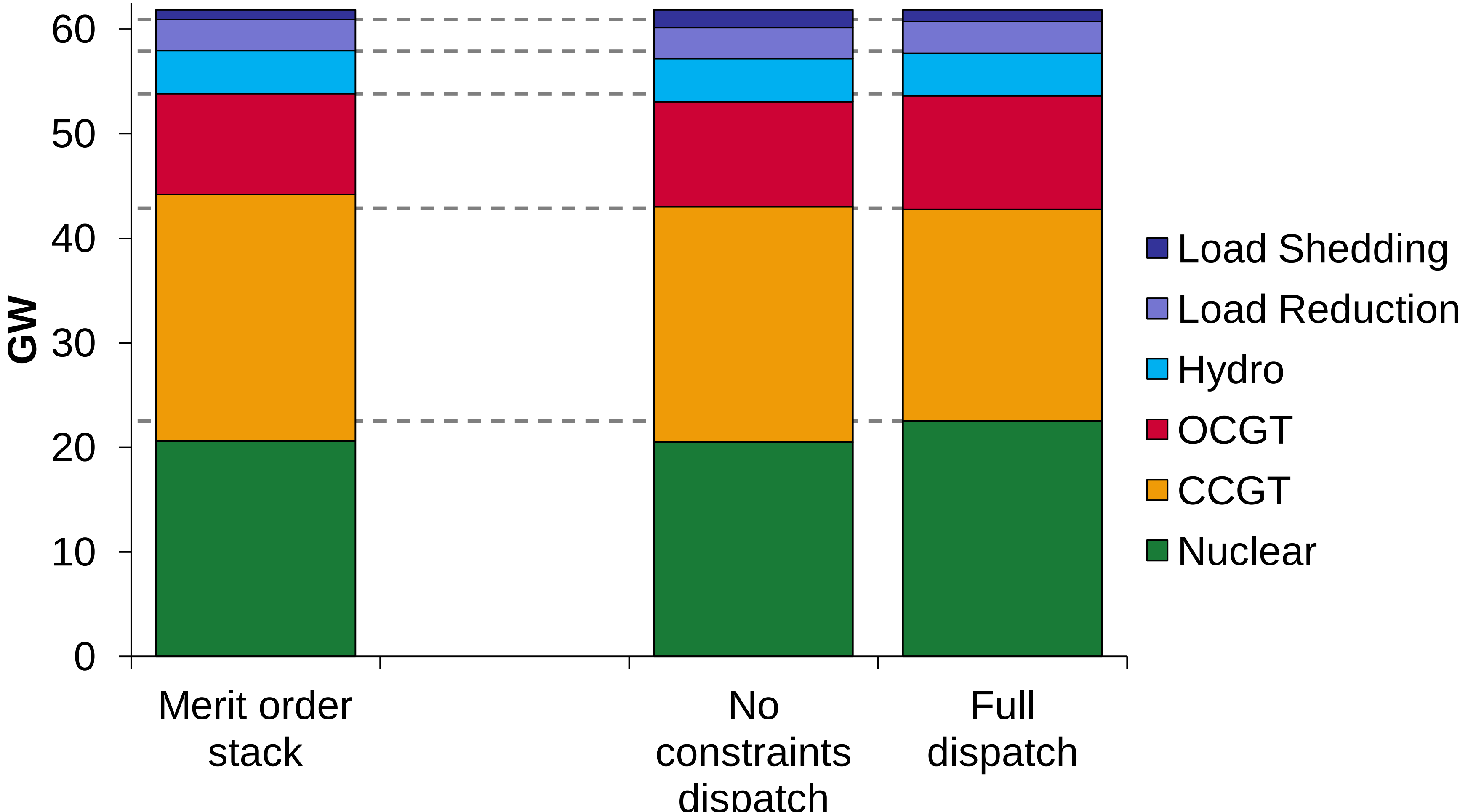
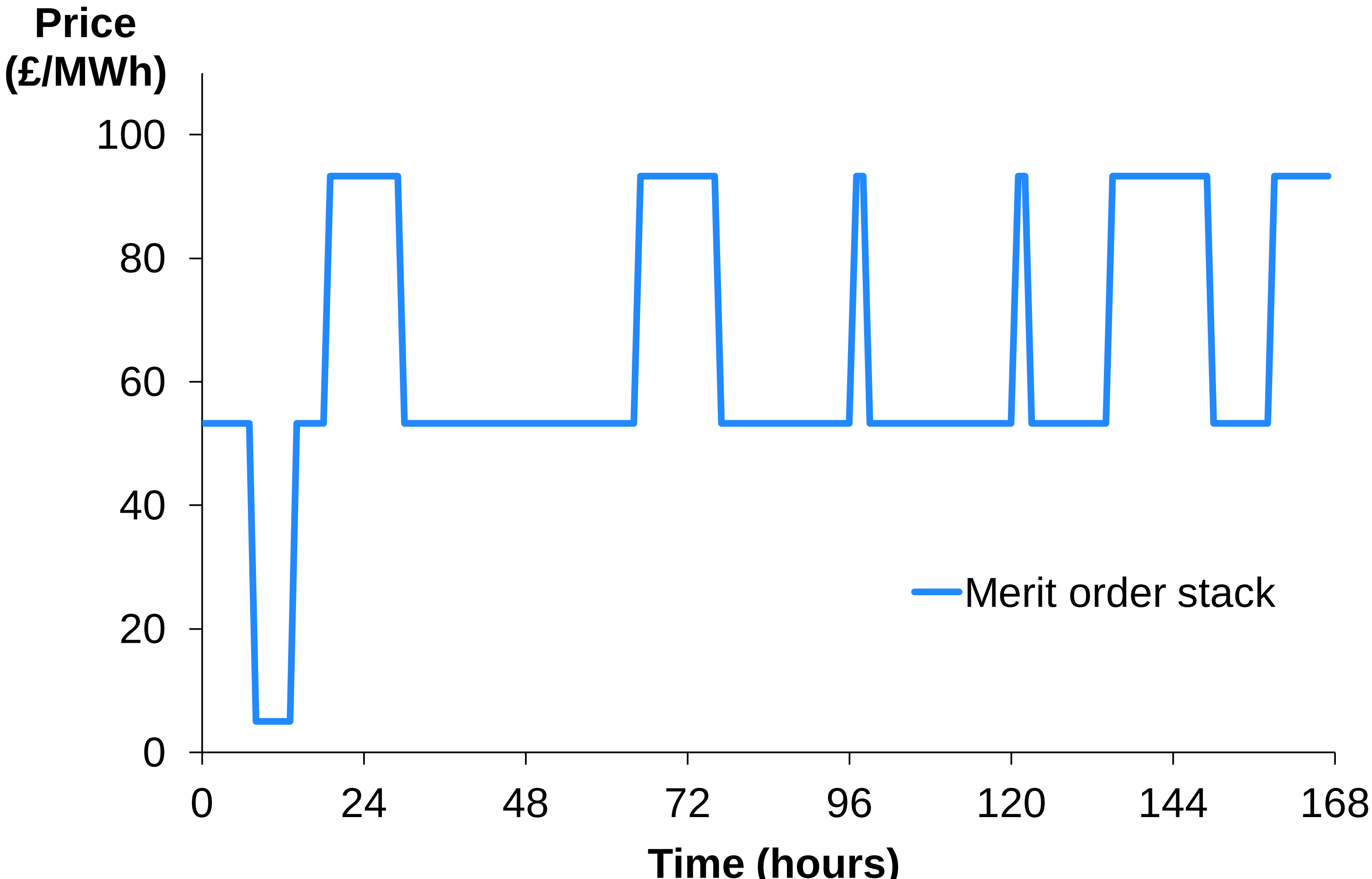
Results: Optimal Capacity Mix



Results: Electricity Prices



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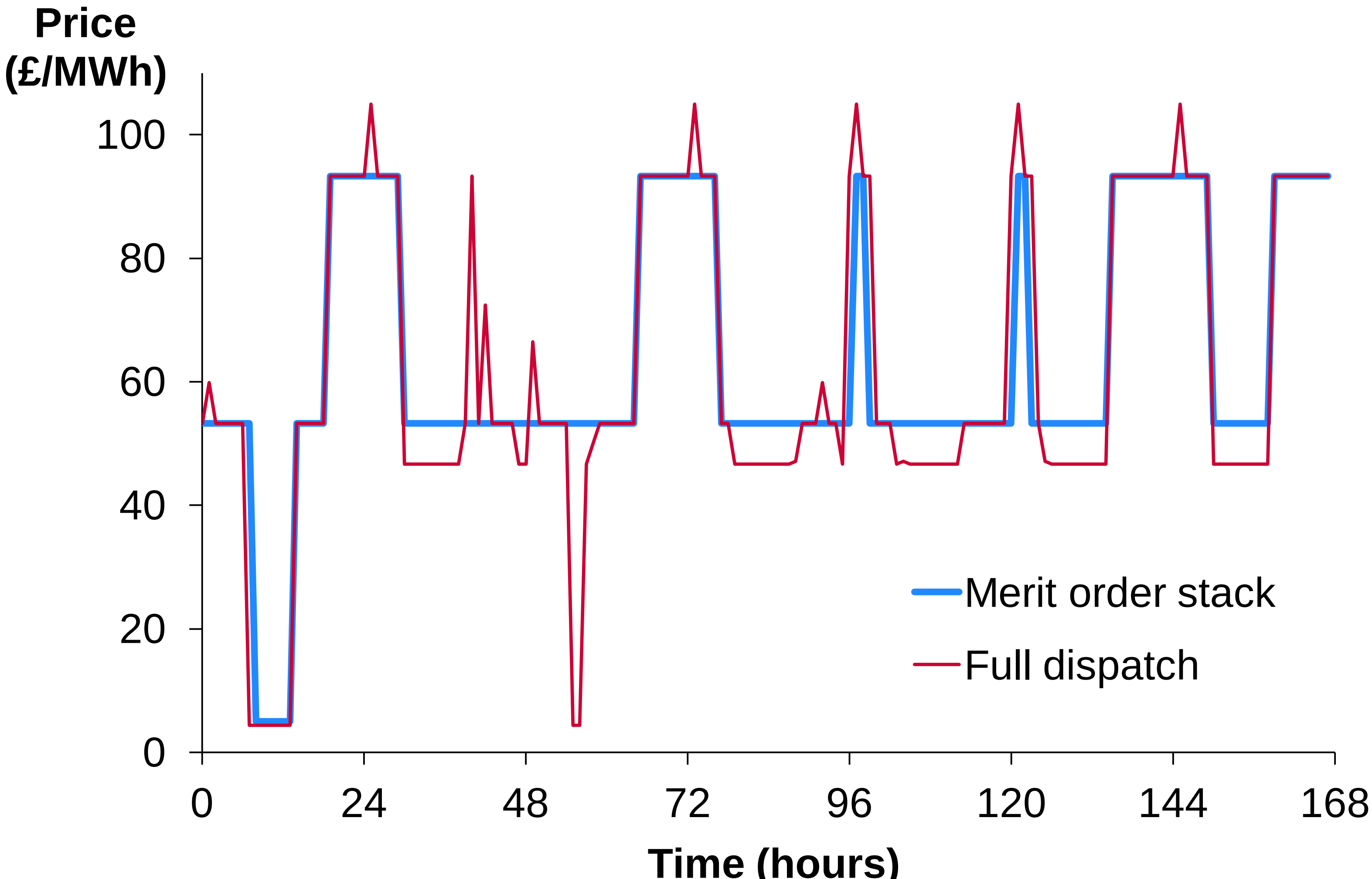

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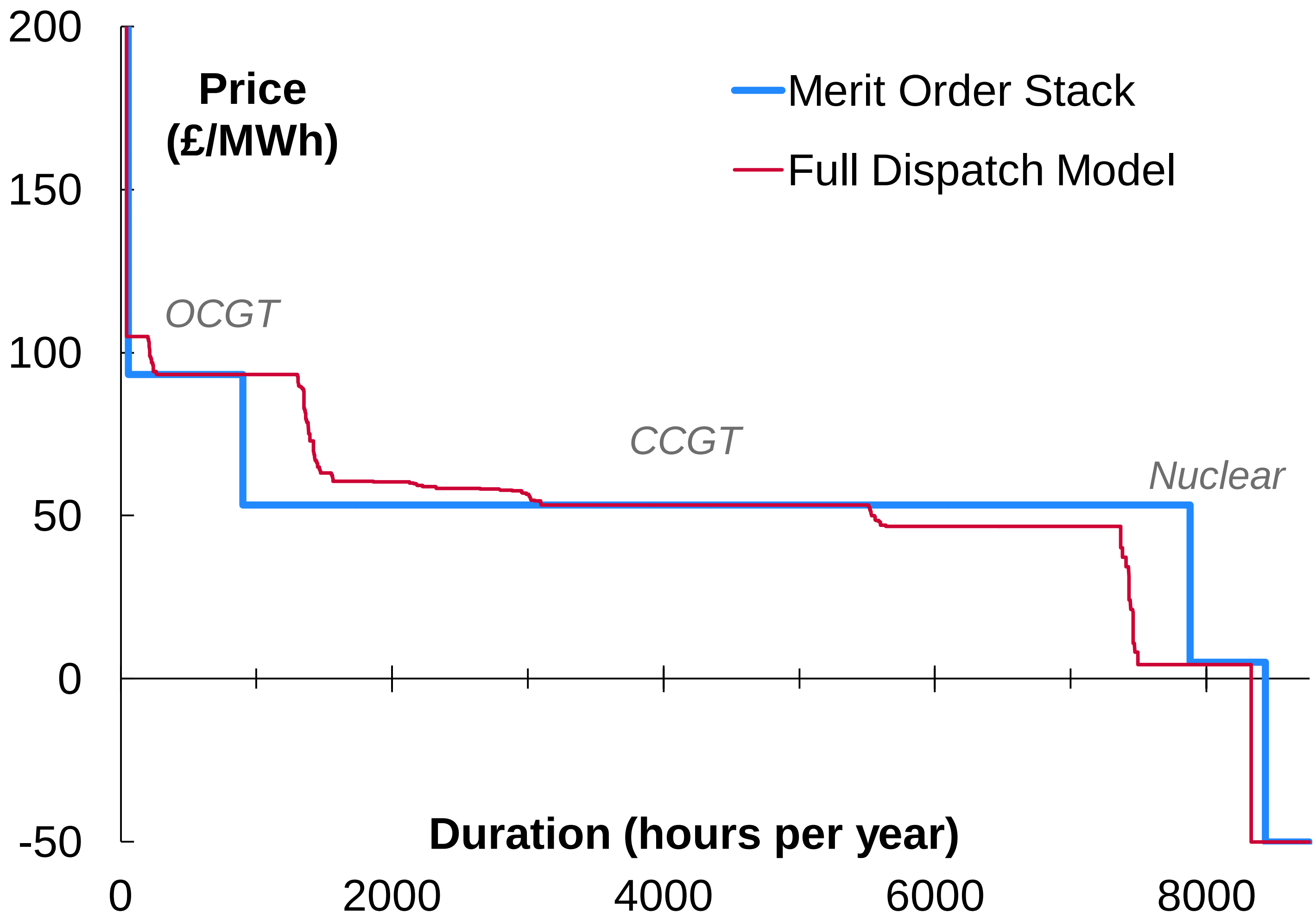

Results: In Summary

- Stack model performs reasonably with high levels of wind
- Errors in optimal capacity mix are ± 2.5 GW *(±10%)*
- Errors in annual output are compounded *(10–30%)*
- Prices show some deviations
    - Mostly from start-up and part-loading costs.

Can we do better?

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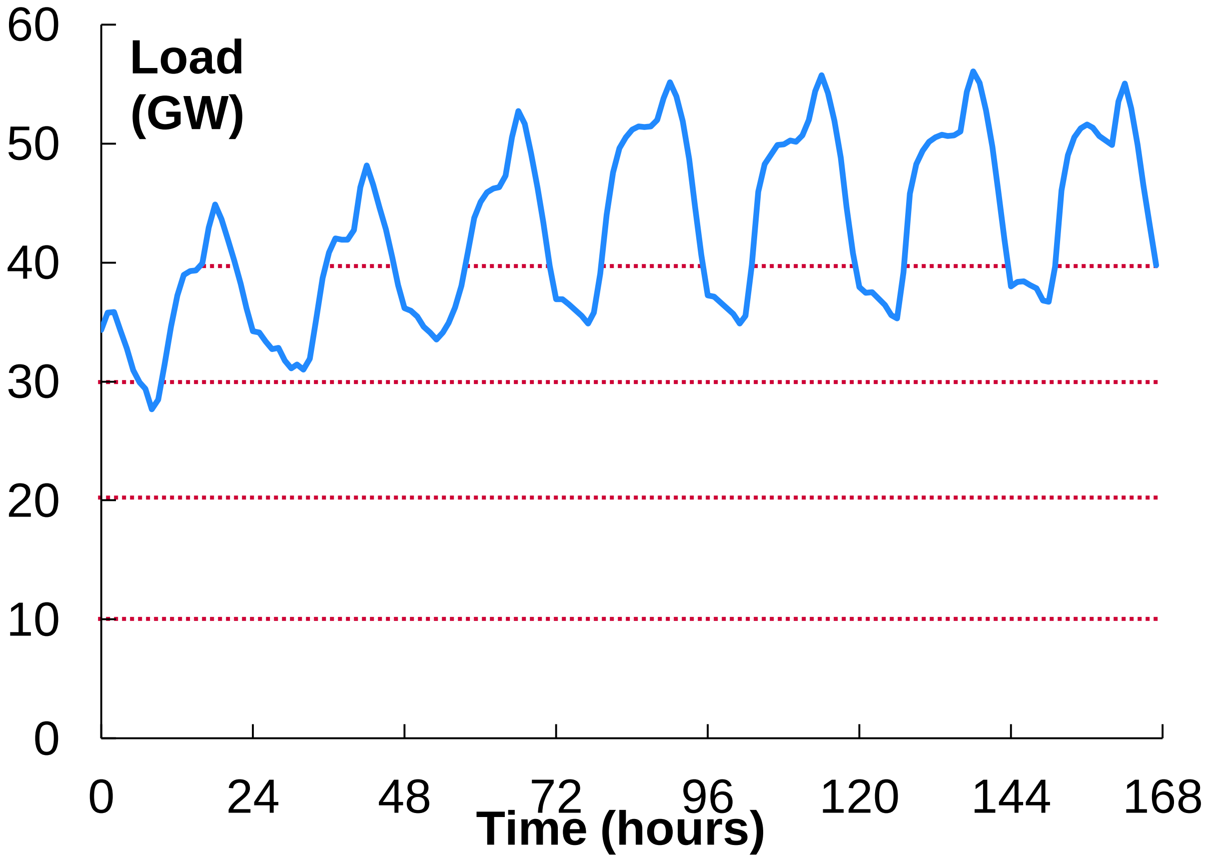
Extending the Stack Model

- Pre-treat input data to account for estimated start costs
  - Could use full dispatch to analyse the number of starts in a given scenario: e.g. Batlle and Rodilla (2012)
  - Instead use a simple algorithm which can transfer from system to system

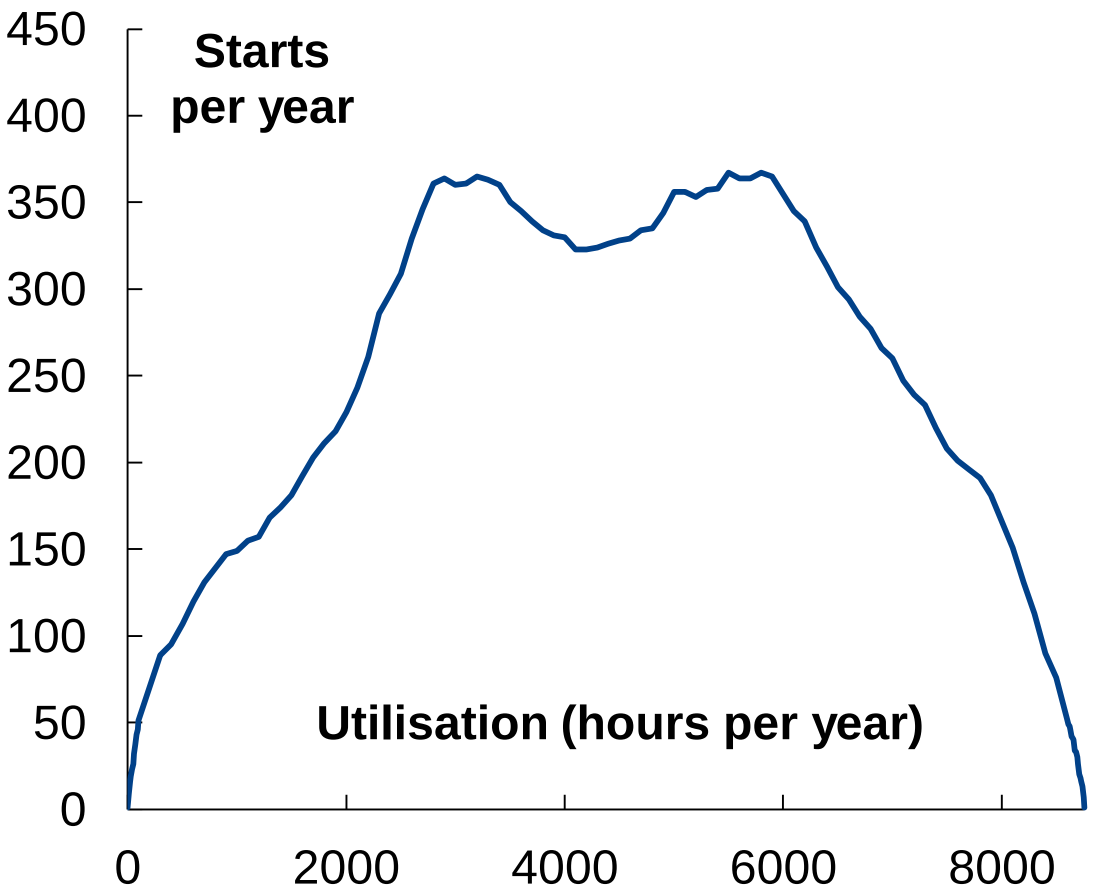
Extending the Stack Model: Factoring in Start-ups

- Simple estimate of number of starts for each level of plant:



Extending the Stack Model: Factoring in Start-ups

- Plot number of starts per year vs. annual run-time of plant:



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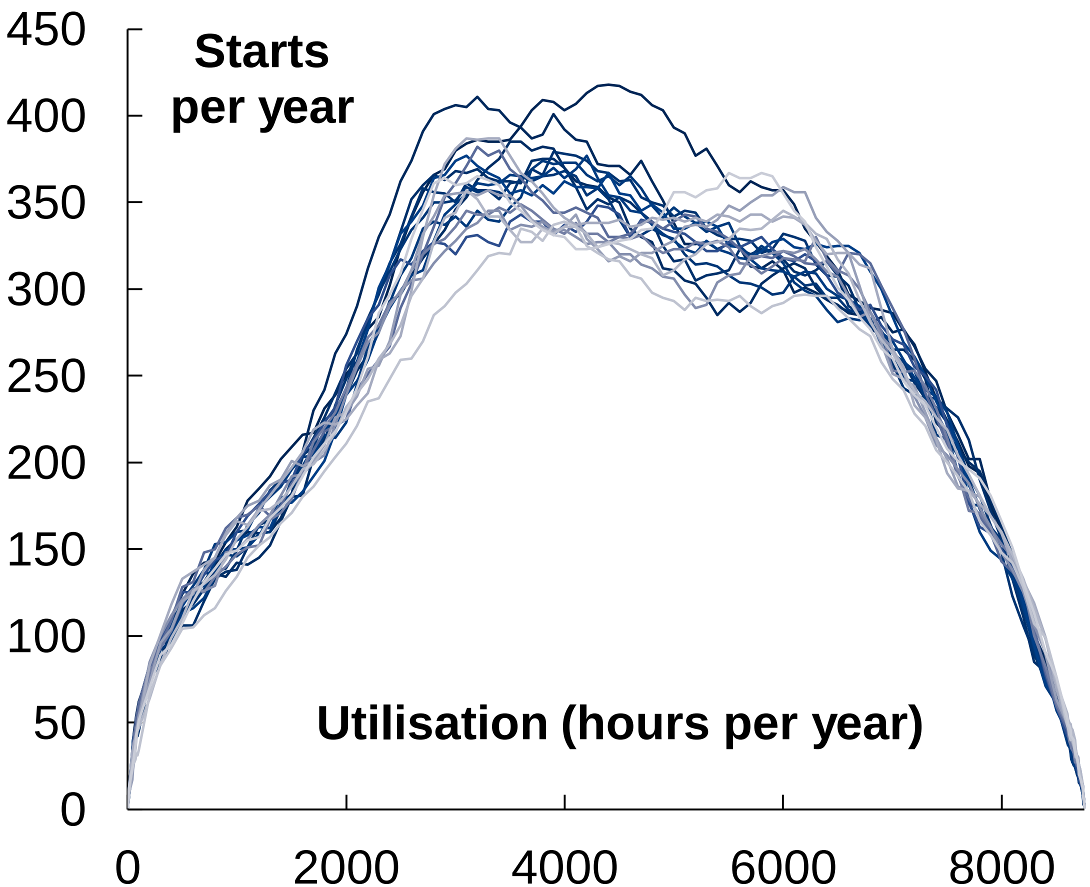

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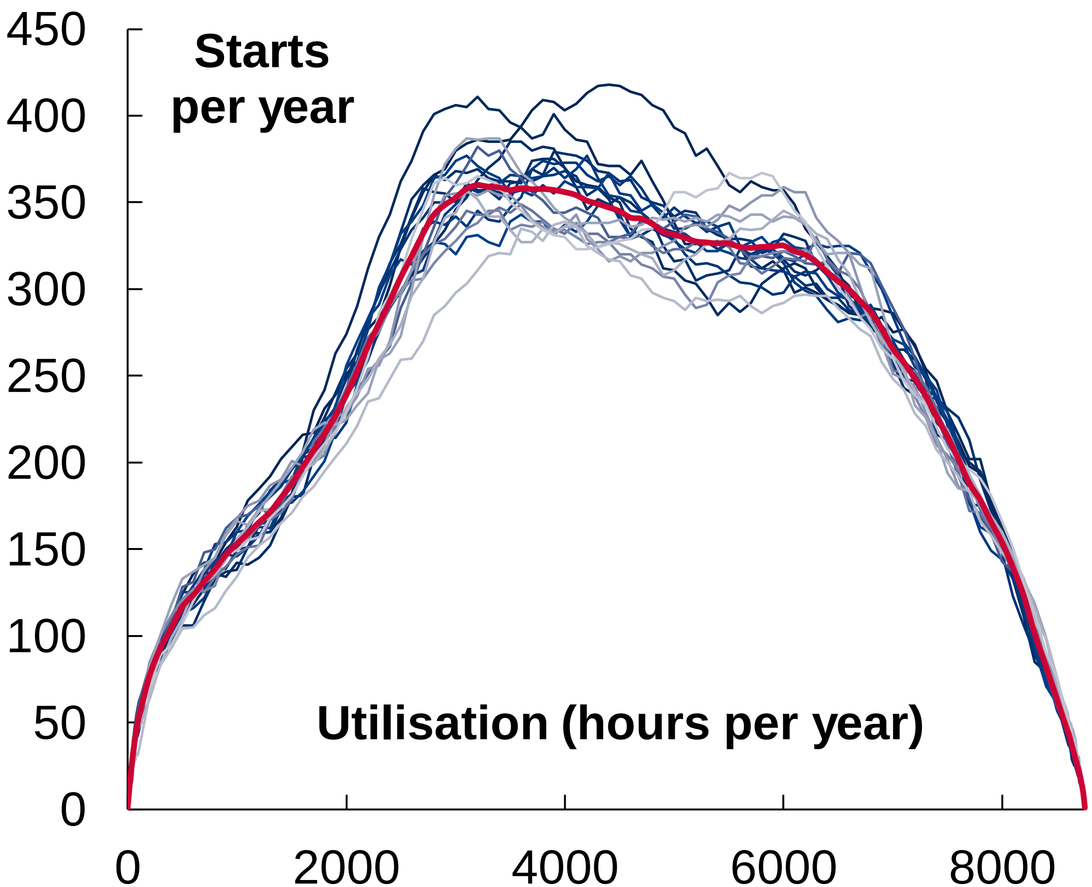

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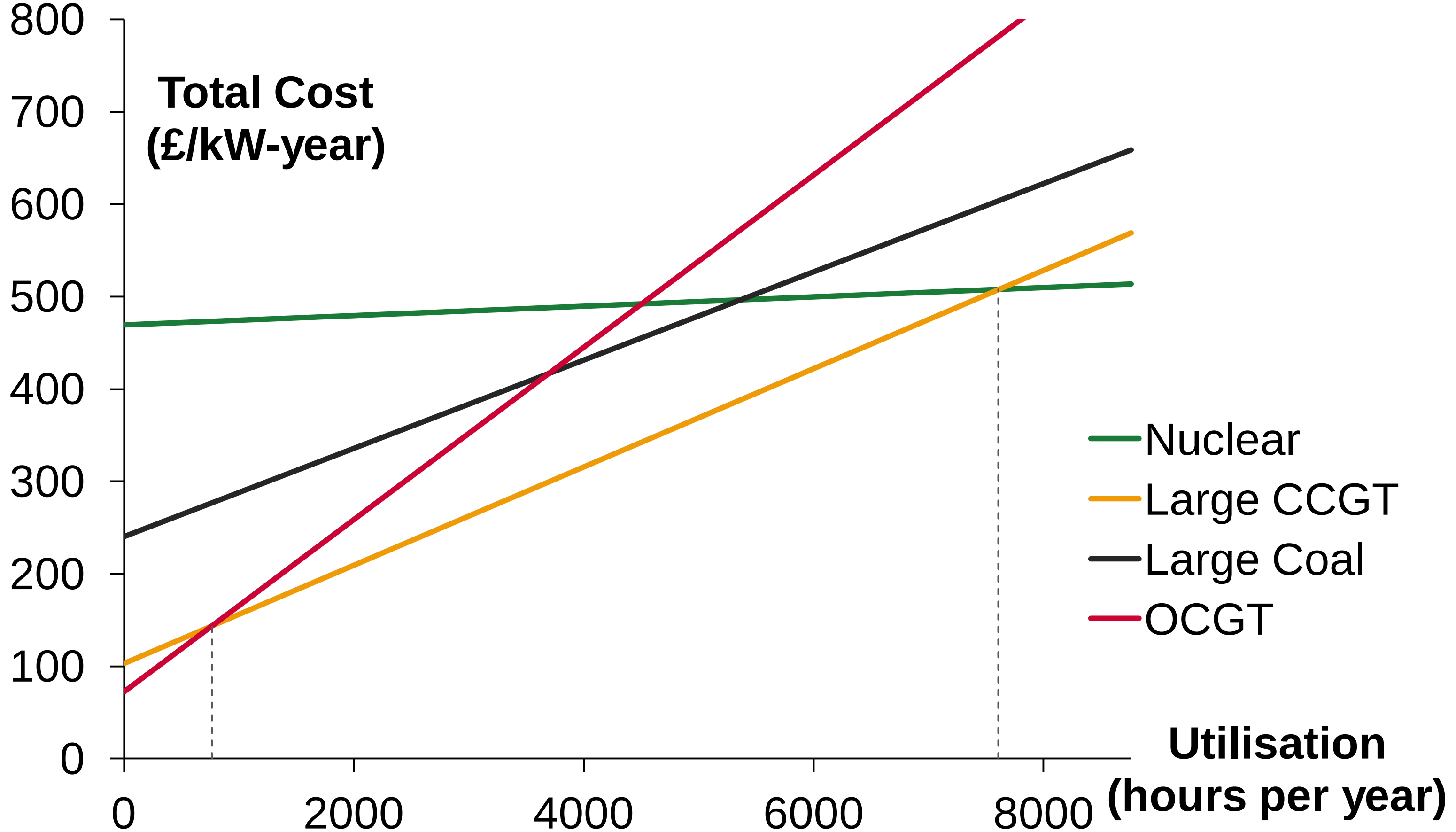

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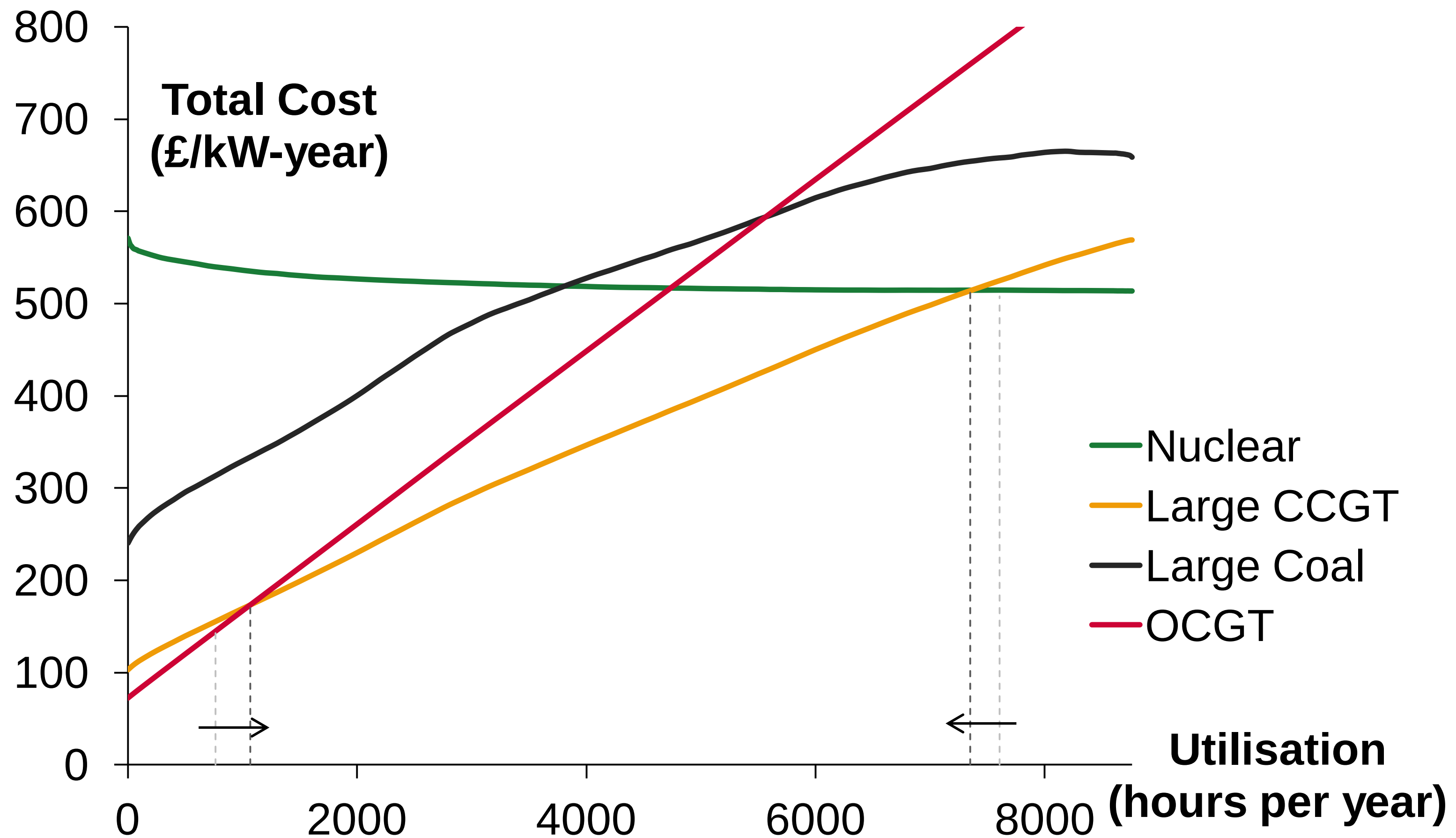

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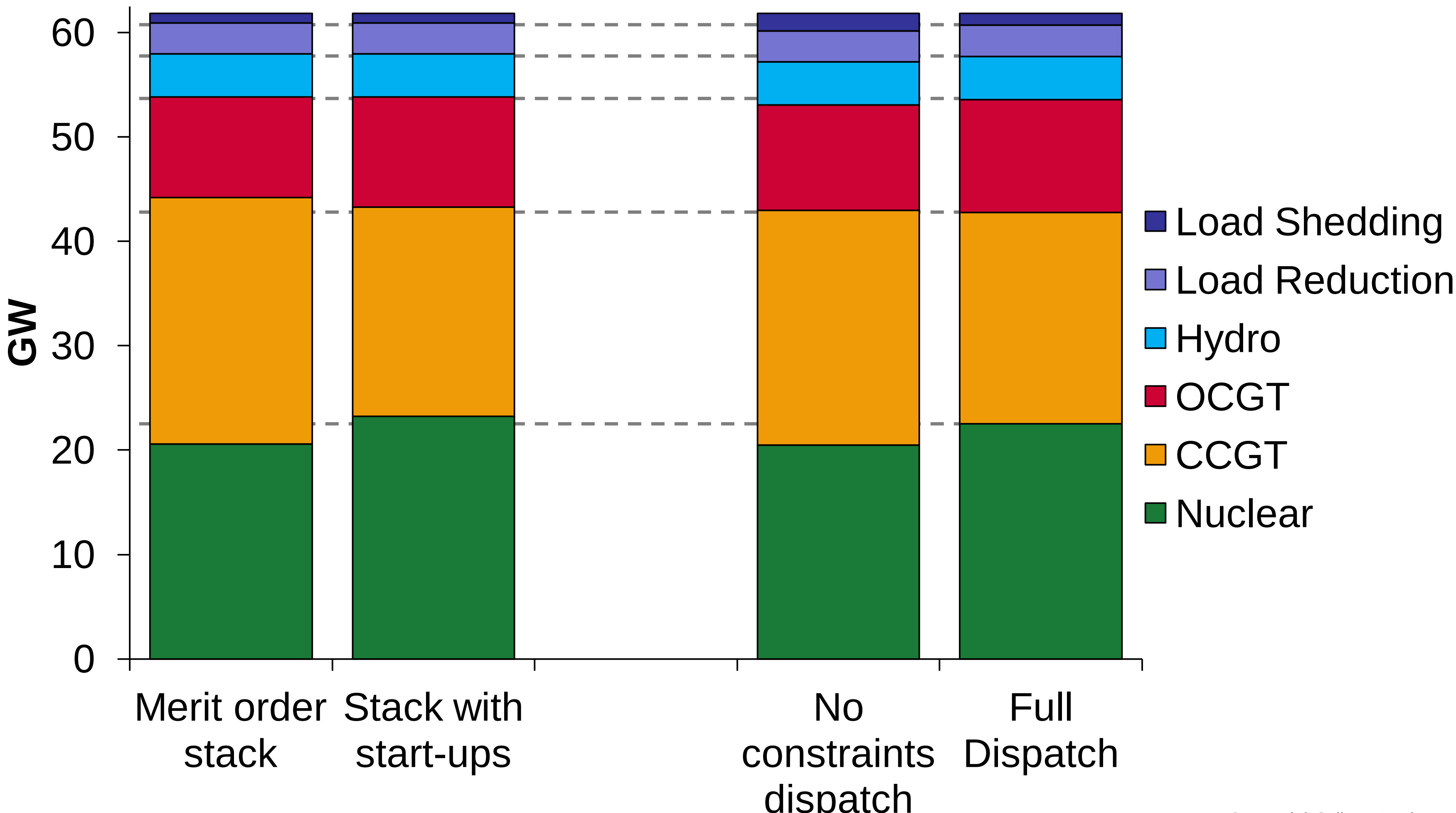
Results: Optimal Capacity Mix



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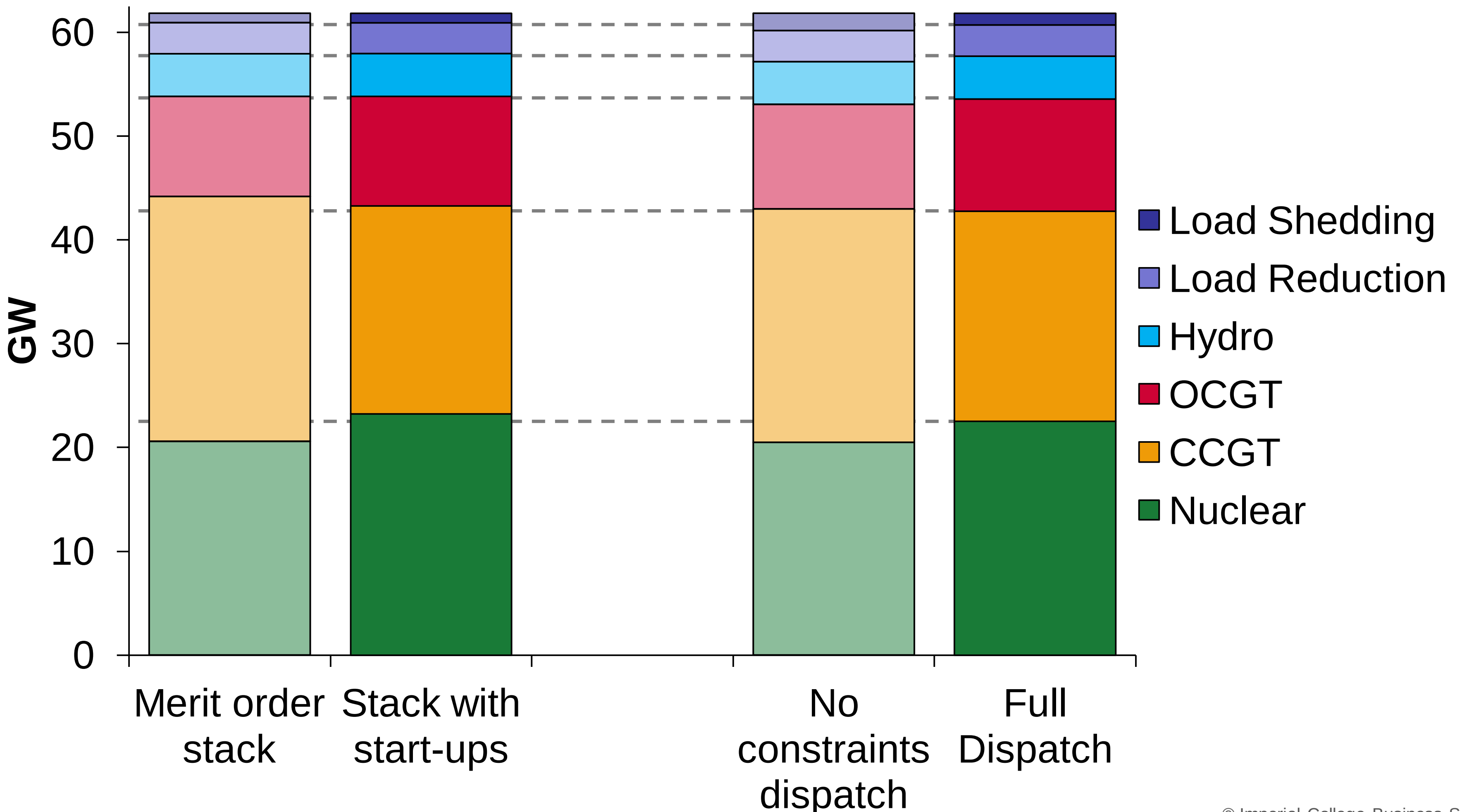

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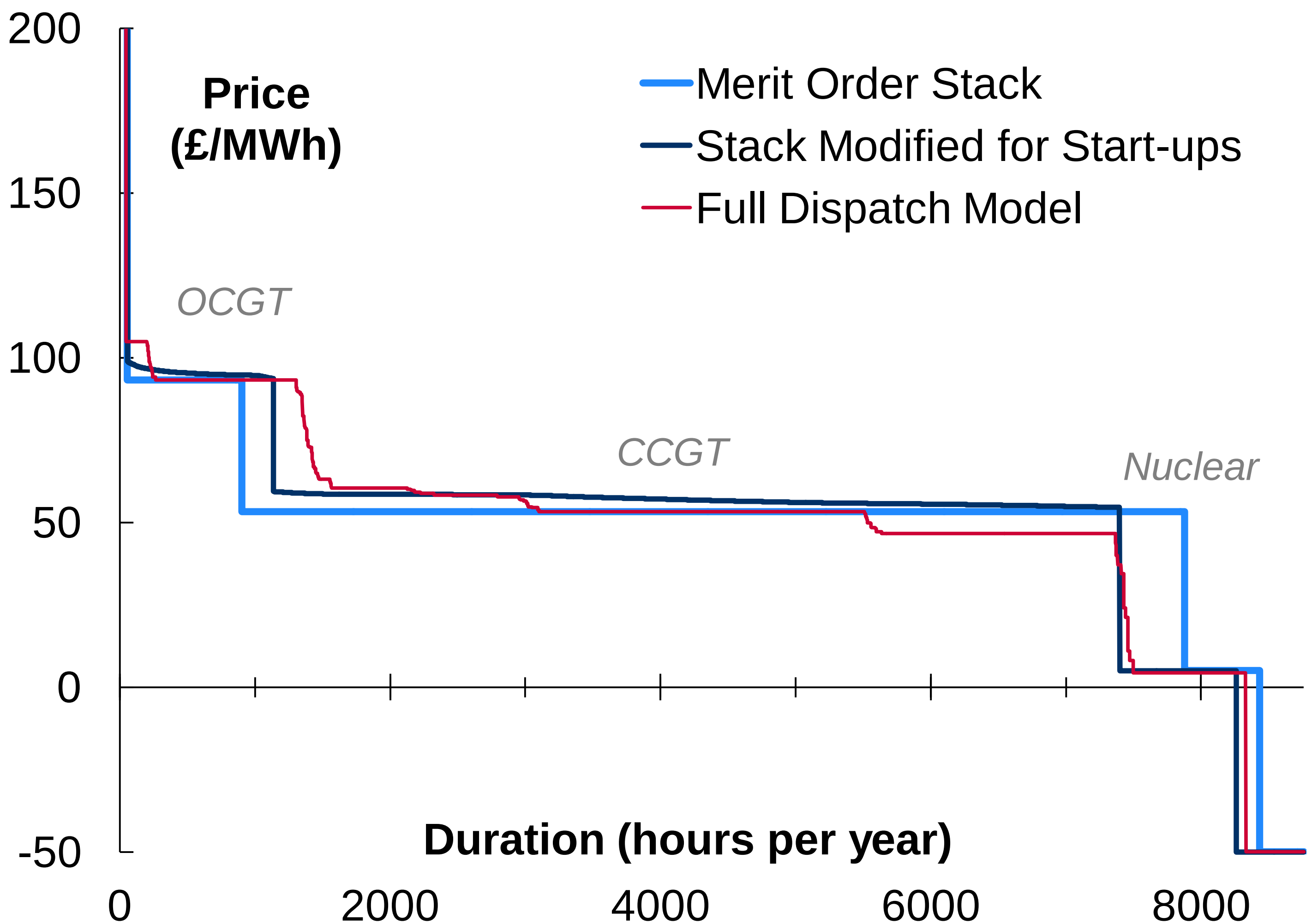
Results: Electricity Prices



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Results: In Summary

- Simple method to extend the merit order stack
  - Only requires data on the demand pattern
- Errors in the equilibrium capacity mix reduced by 2x
- Errors in the output by each type reduced by 2x
- Prices closer to a full dispatch model, but could be better

- Further work:
  - Factor in avoided start-ups as well (local minima)
  - Allocate start-cost to particular hours (duration of peak)

Thank you for your attention!

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