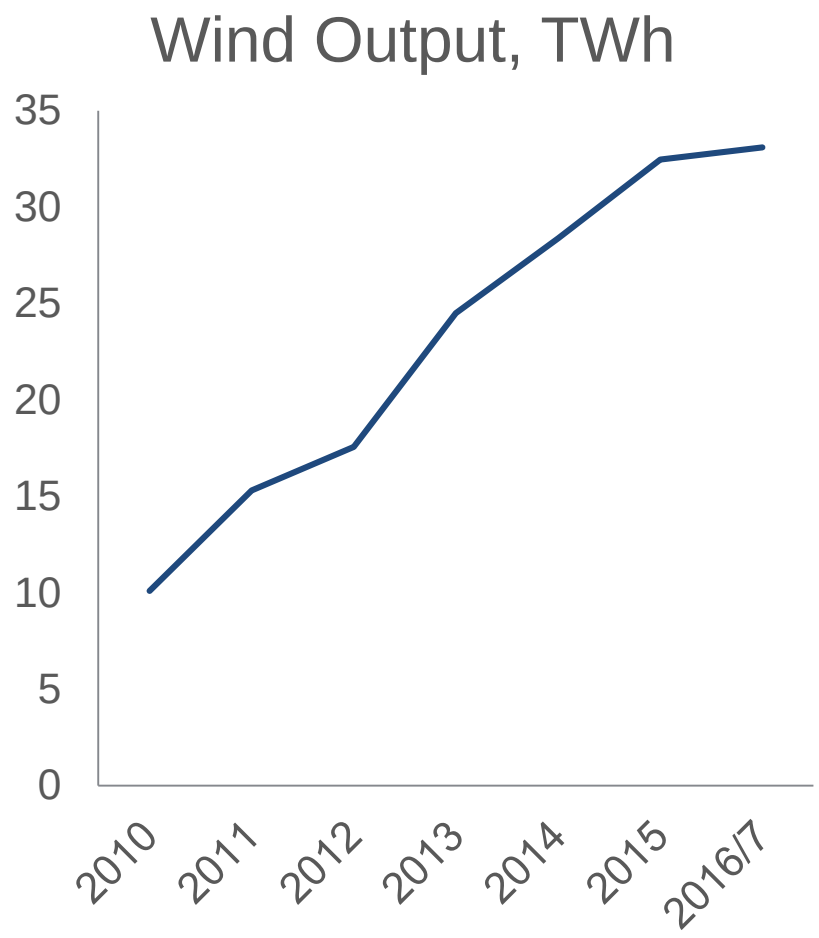
Electricity, Renewables and Storage

Professor Richard Green

Two recent trends in British electricity:

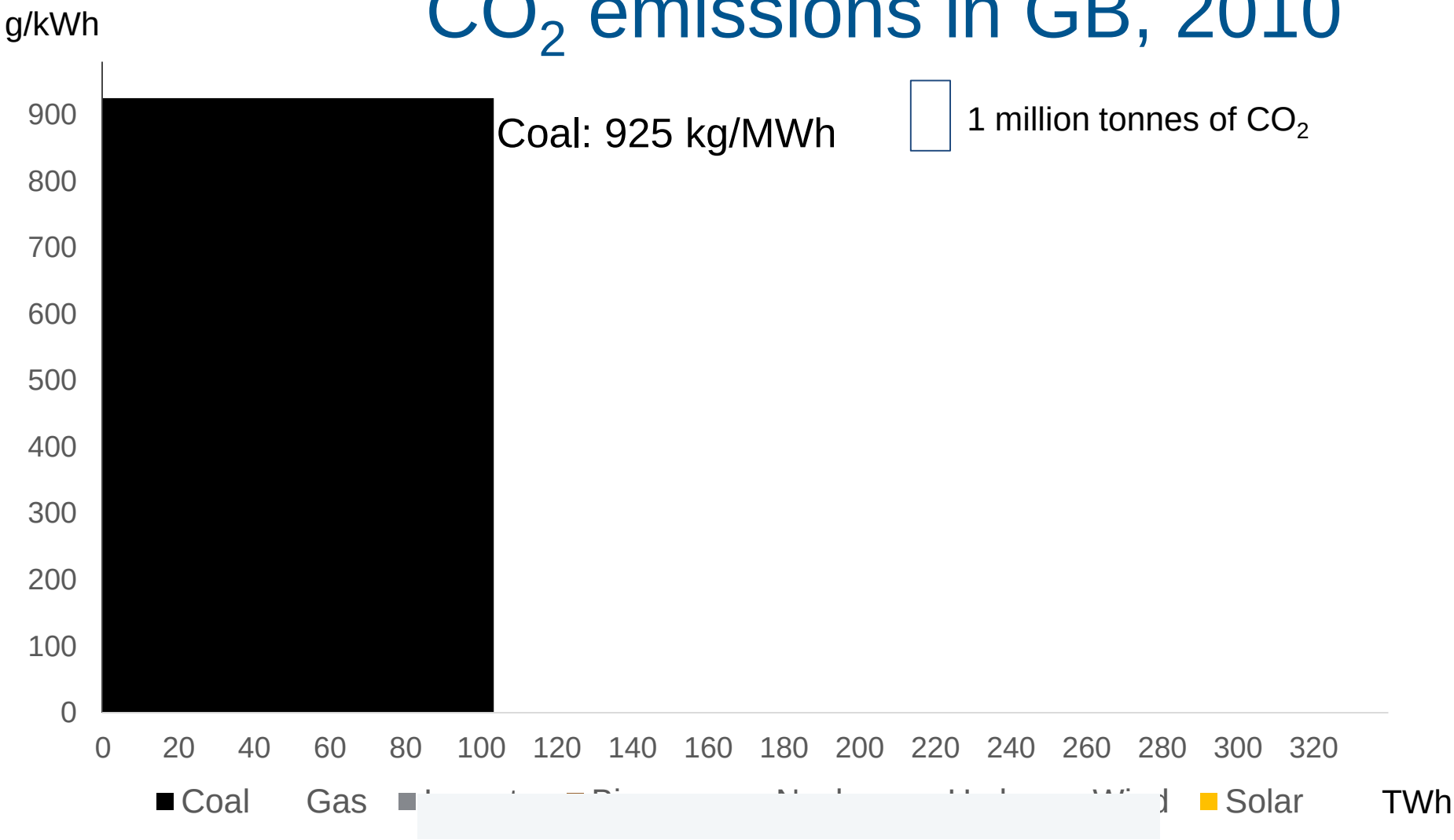
The Rise of Wind



How much CO_2 does wind power save?

What does this depend upon?

Electricity Generated and CO_2 emissions in GB, 2010



Source: www.electricinsights.co.uk (Imperial College and Drax Power)

Electricity Generated and CO_2 emissions in GB, 2010

Electricity Generated and CO_2 emissions in GB, 2010

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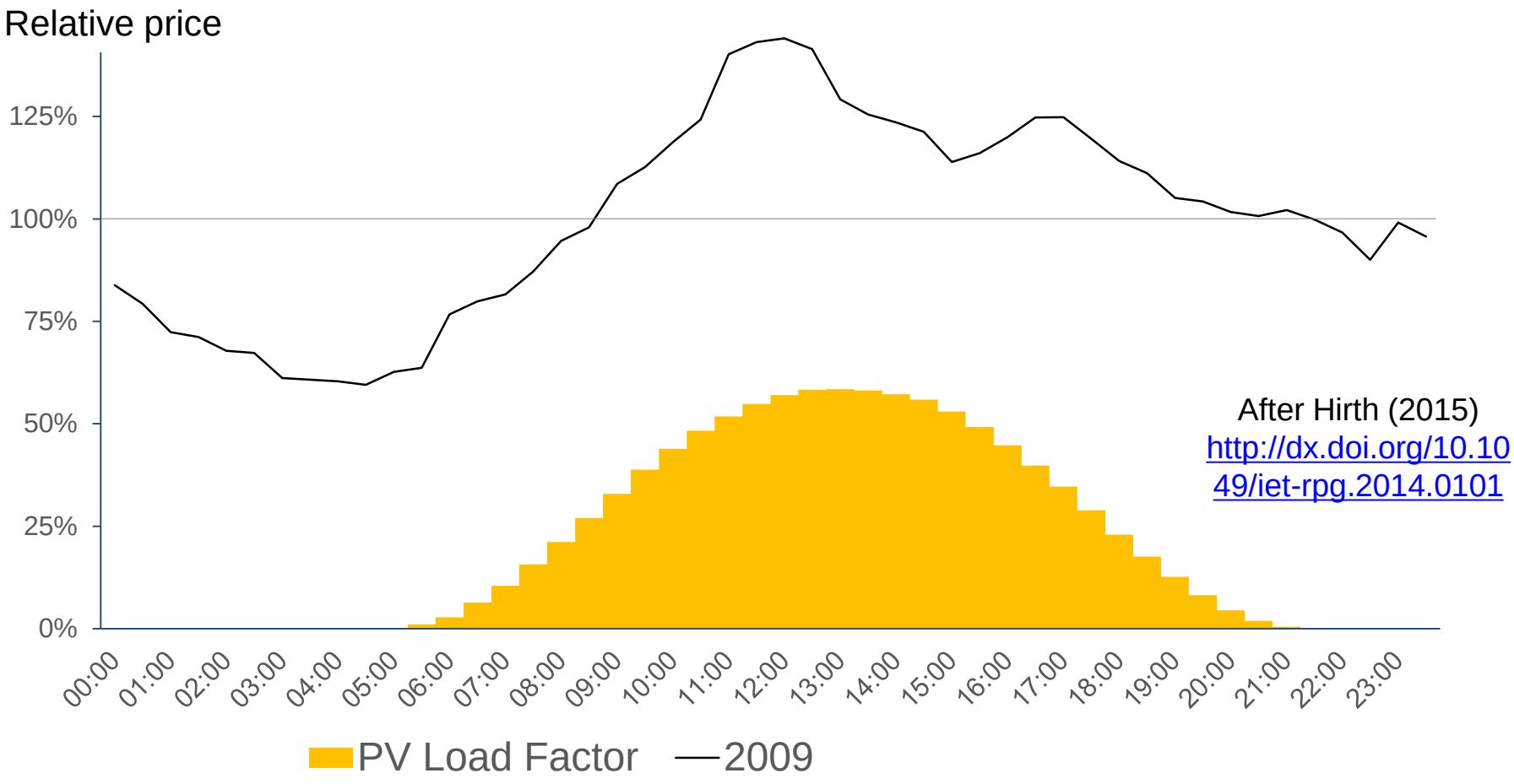
PV and Relative Prices

Great Britain, May-July



After Hirth (2015)
http://dx.doi.org/10.1049/iet-rpg.2014.0101

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PV and Relative Prices

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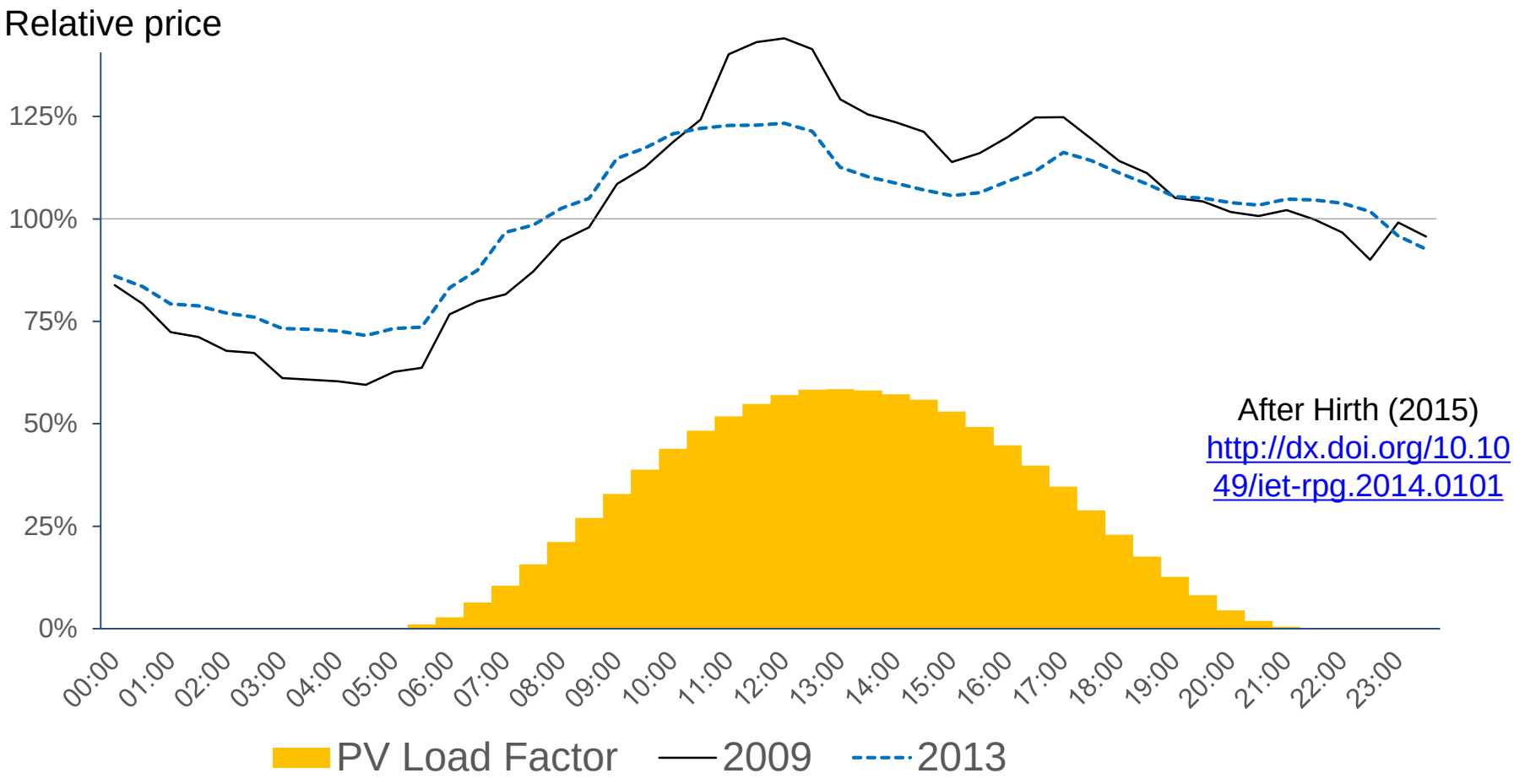

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PV and Relative Prices

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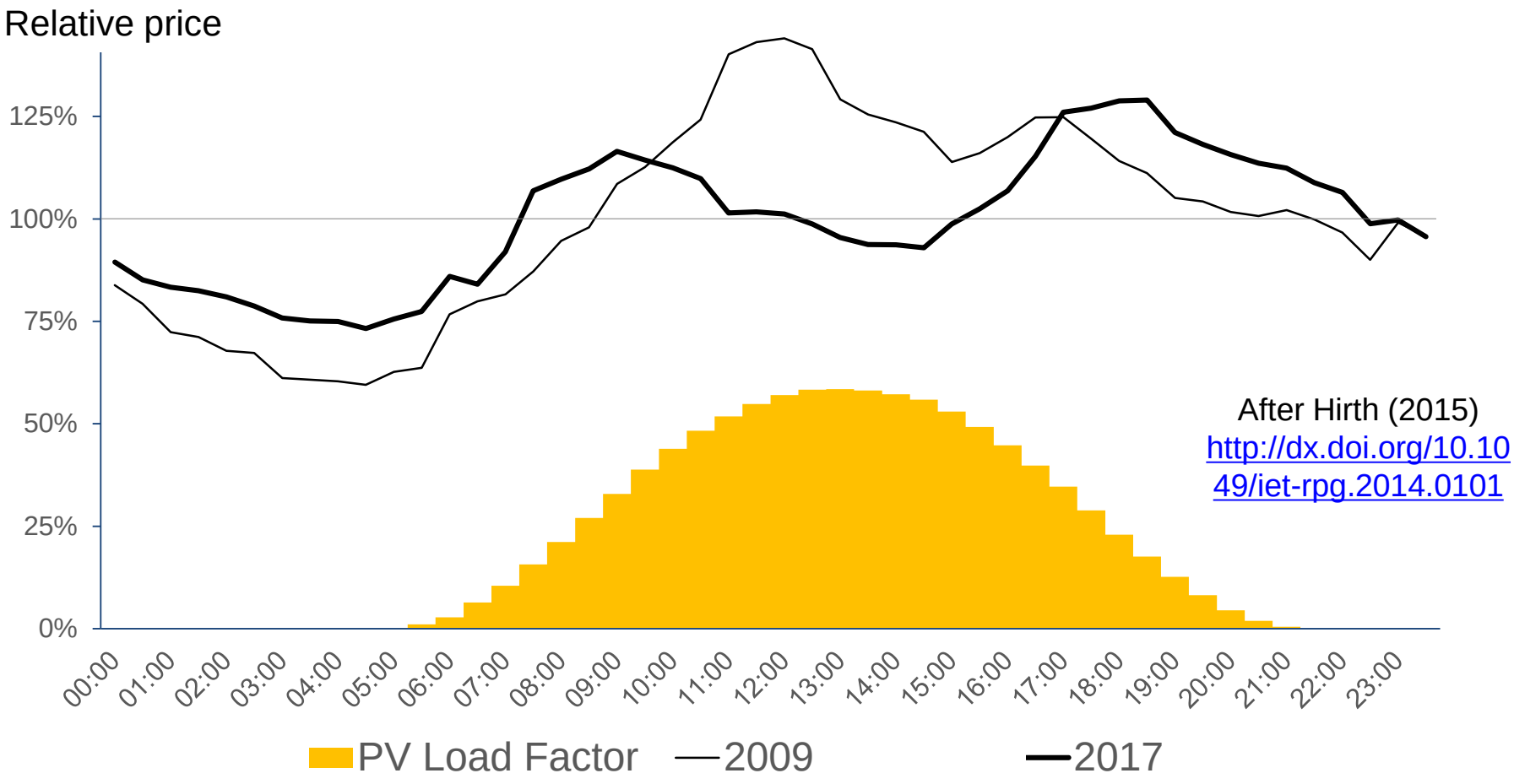

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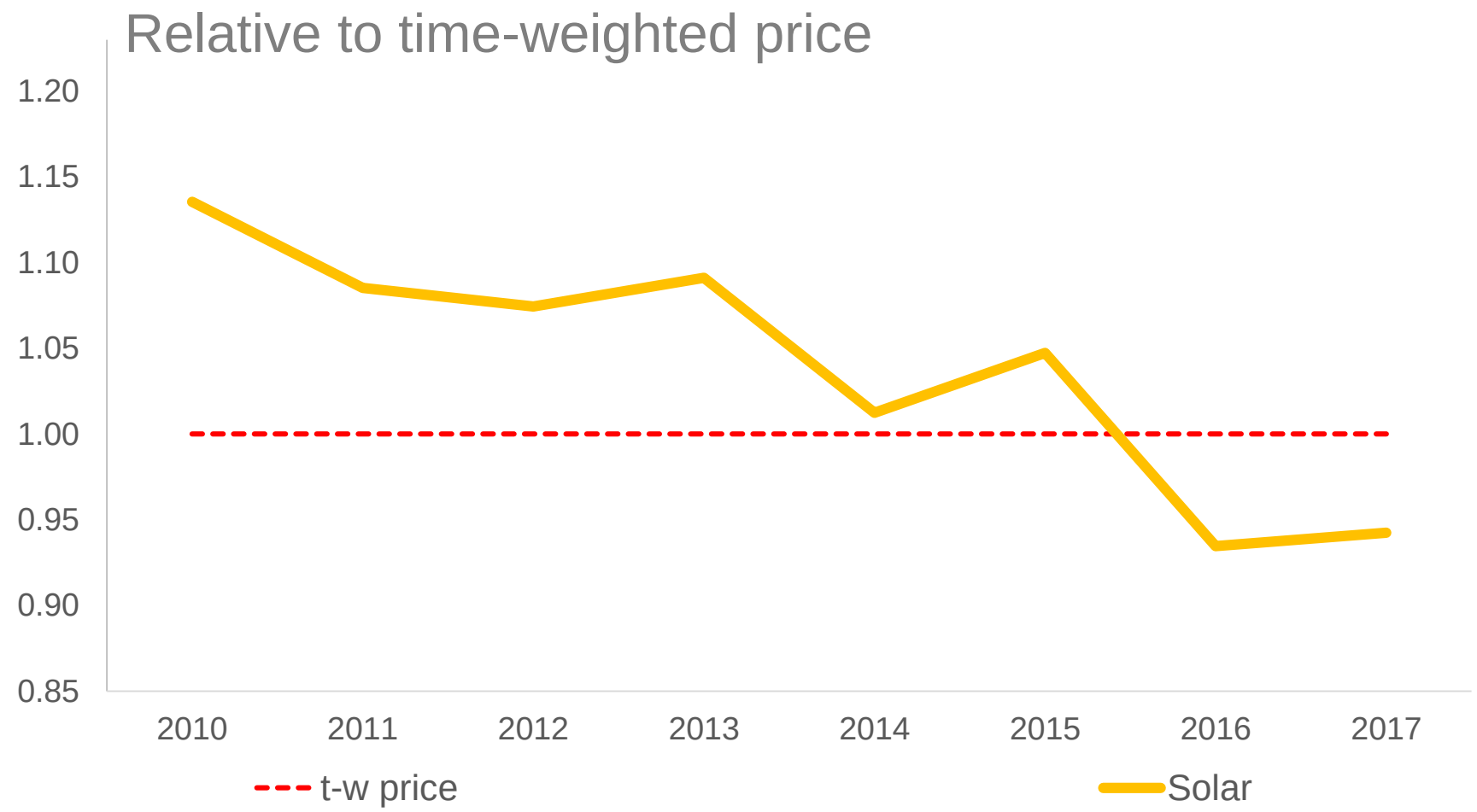
Output-weighted prices



Source: ElectricInsights.co.uk

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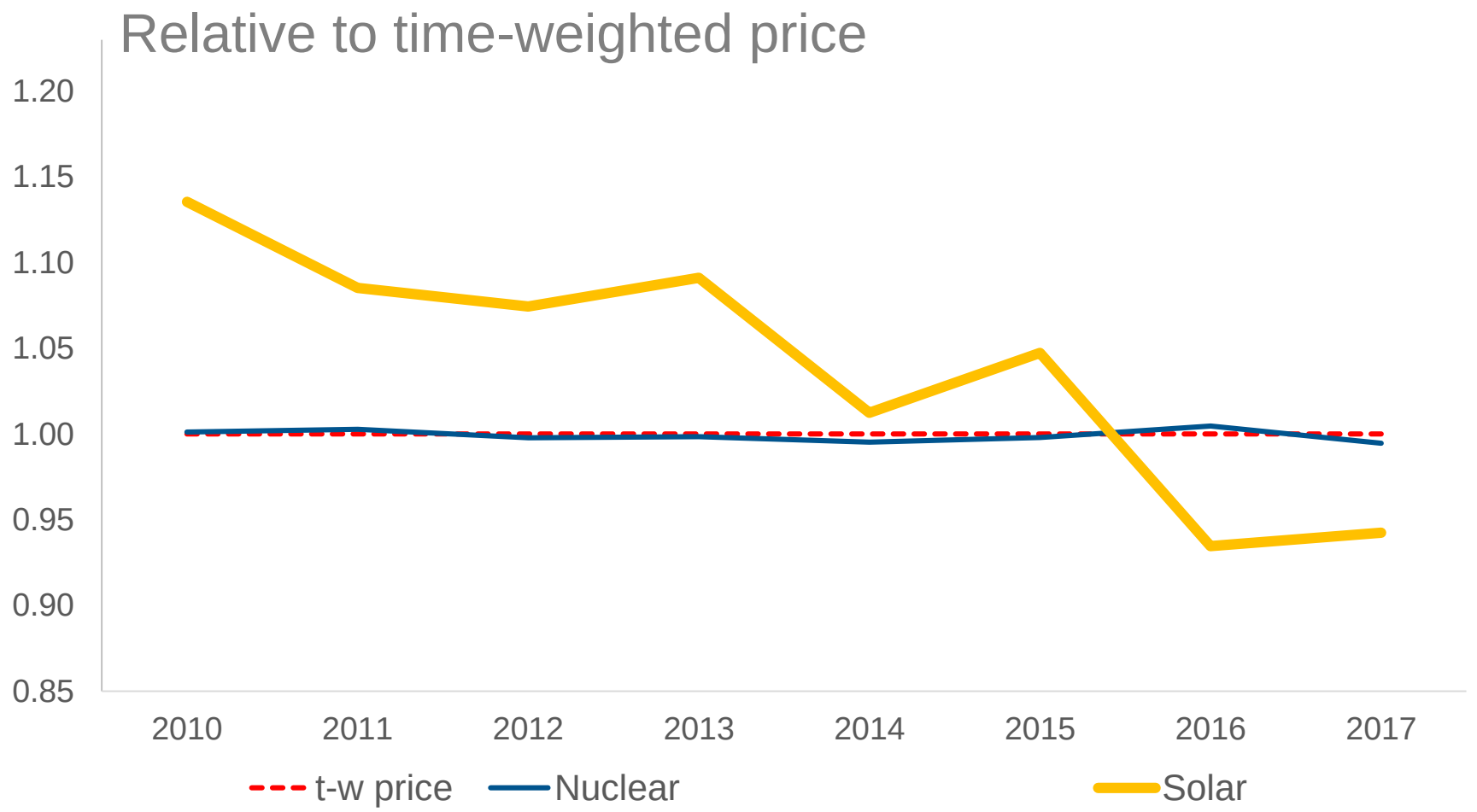
Output-weighted prices



Source: ElectricInsights.co.uk

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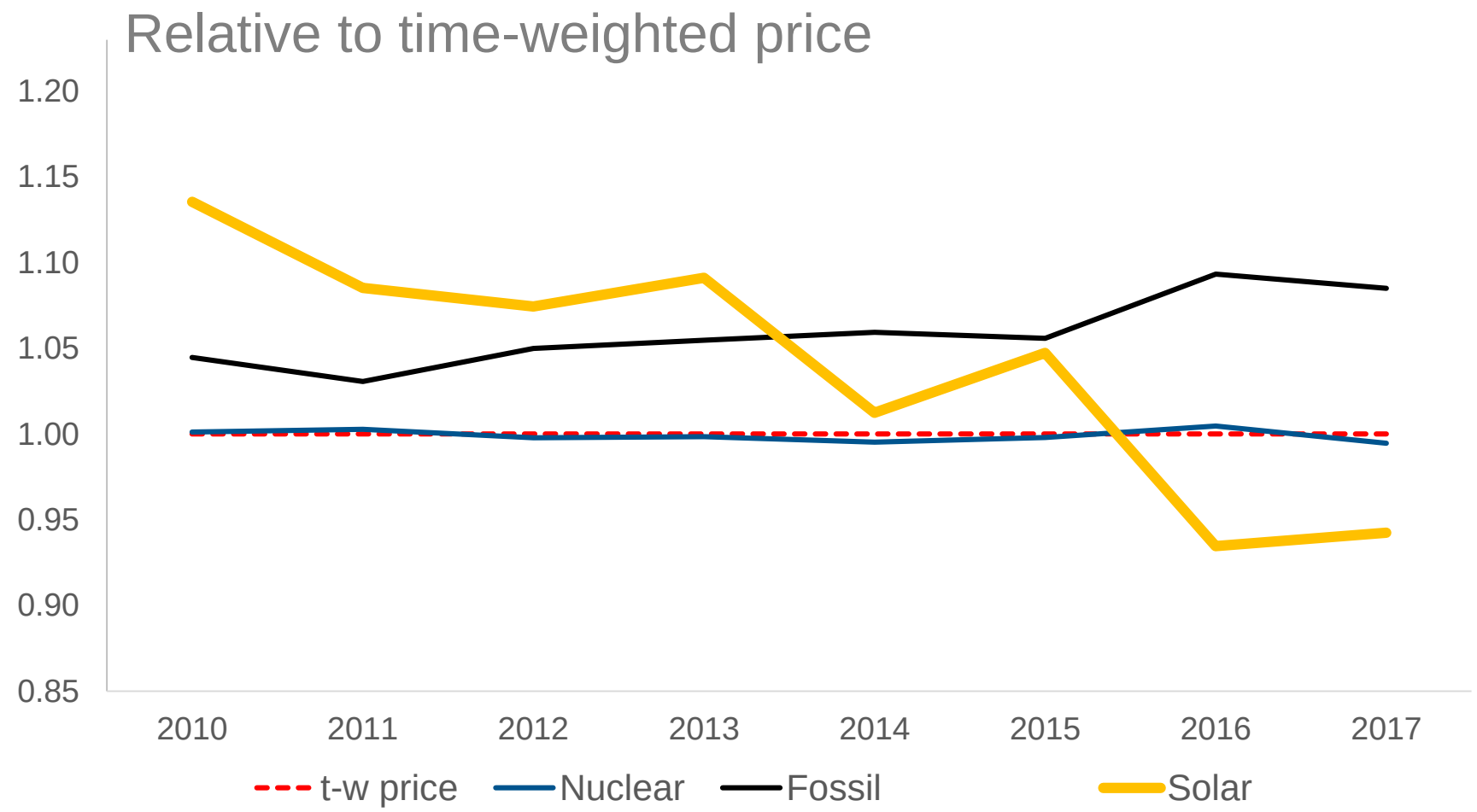
Output-weighted prices



Source: ElectricInsights.co.uk

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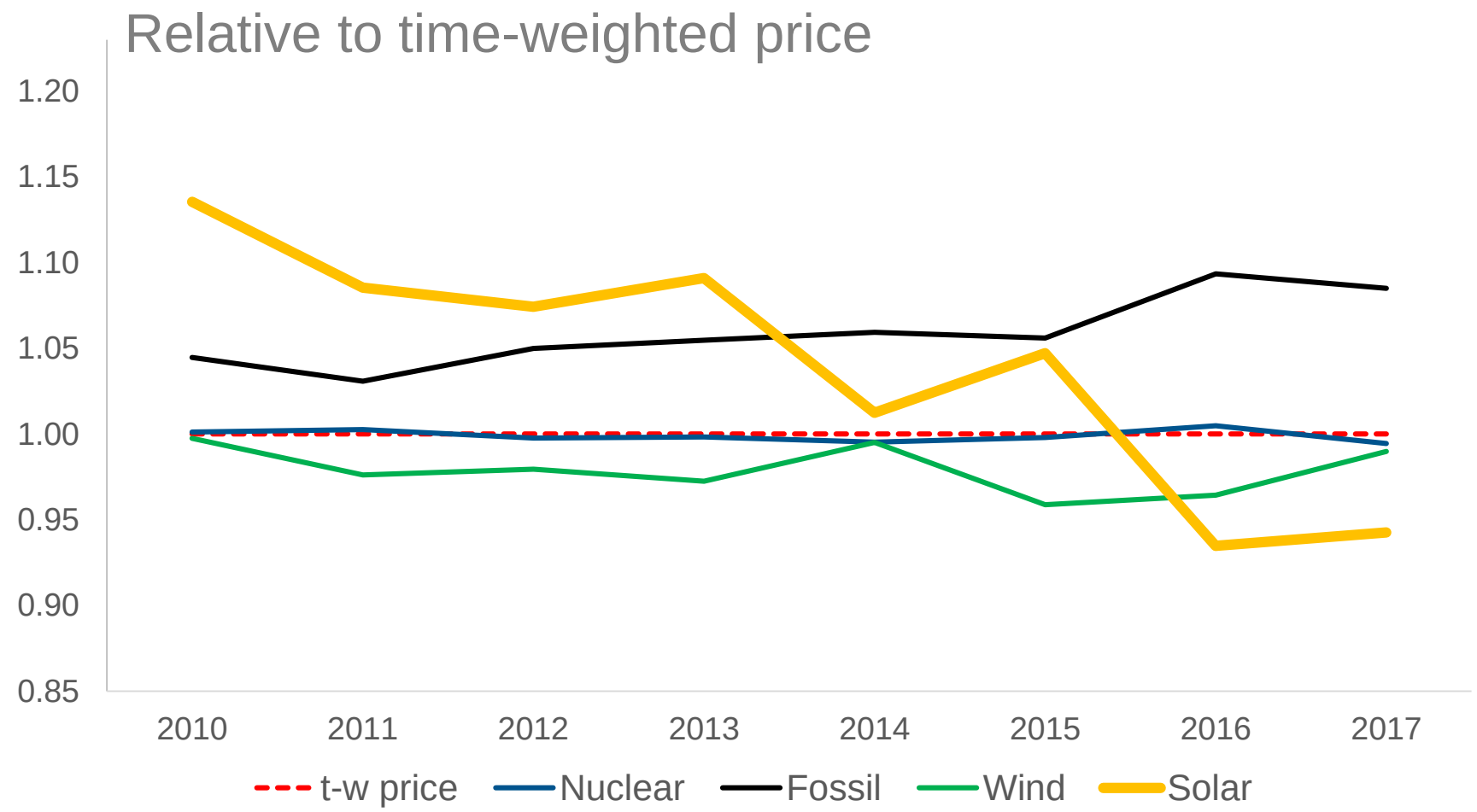
Output-weighted prices



Source: ElectricInsights.co.uk

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Imperial means Intelligent Business

Renewables in a Power Market

Part Two: Killing the market?

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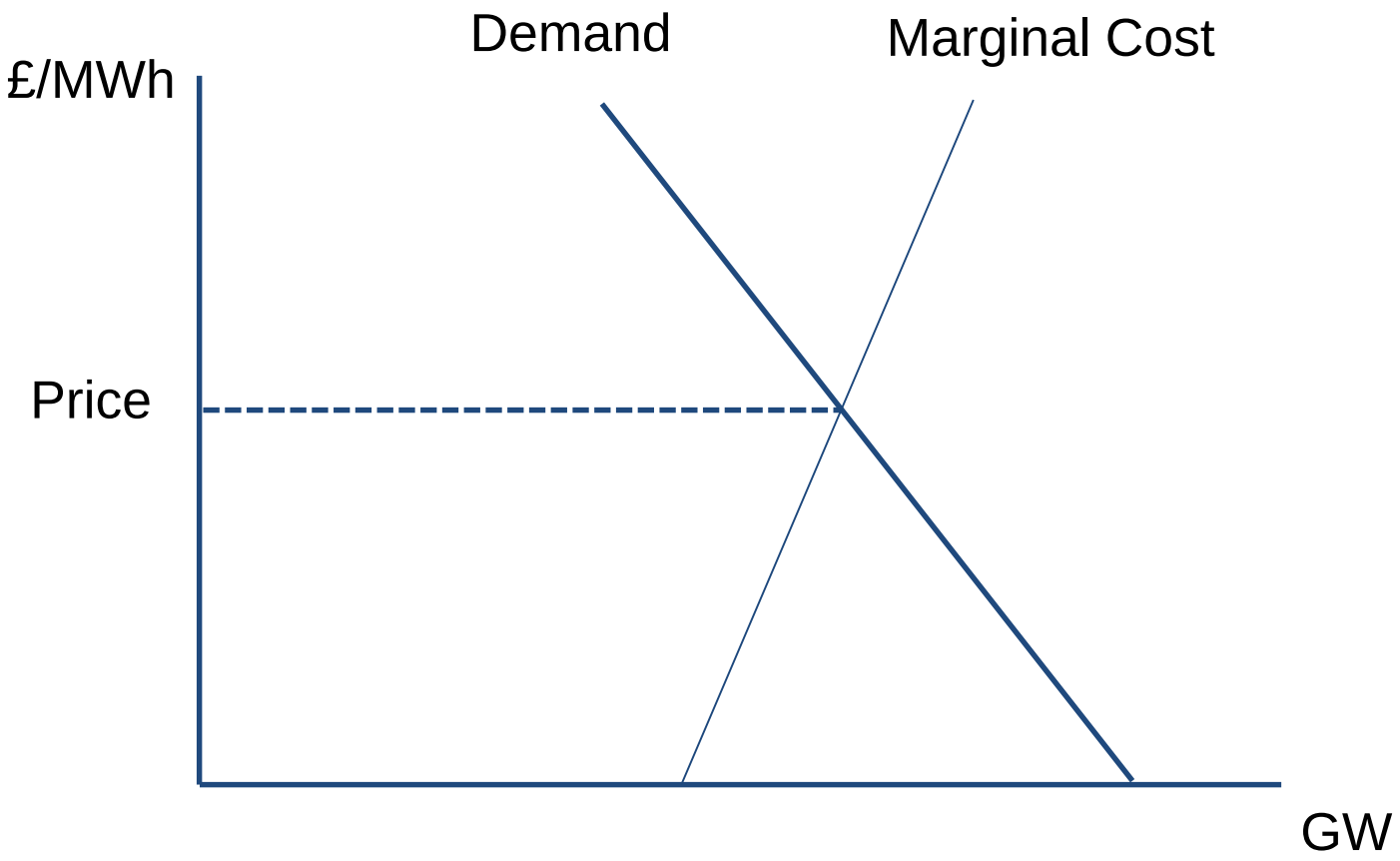
Supply and Demand



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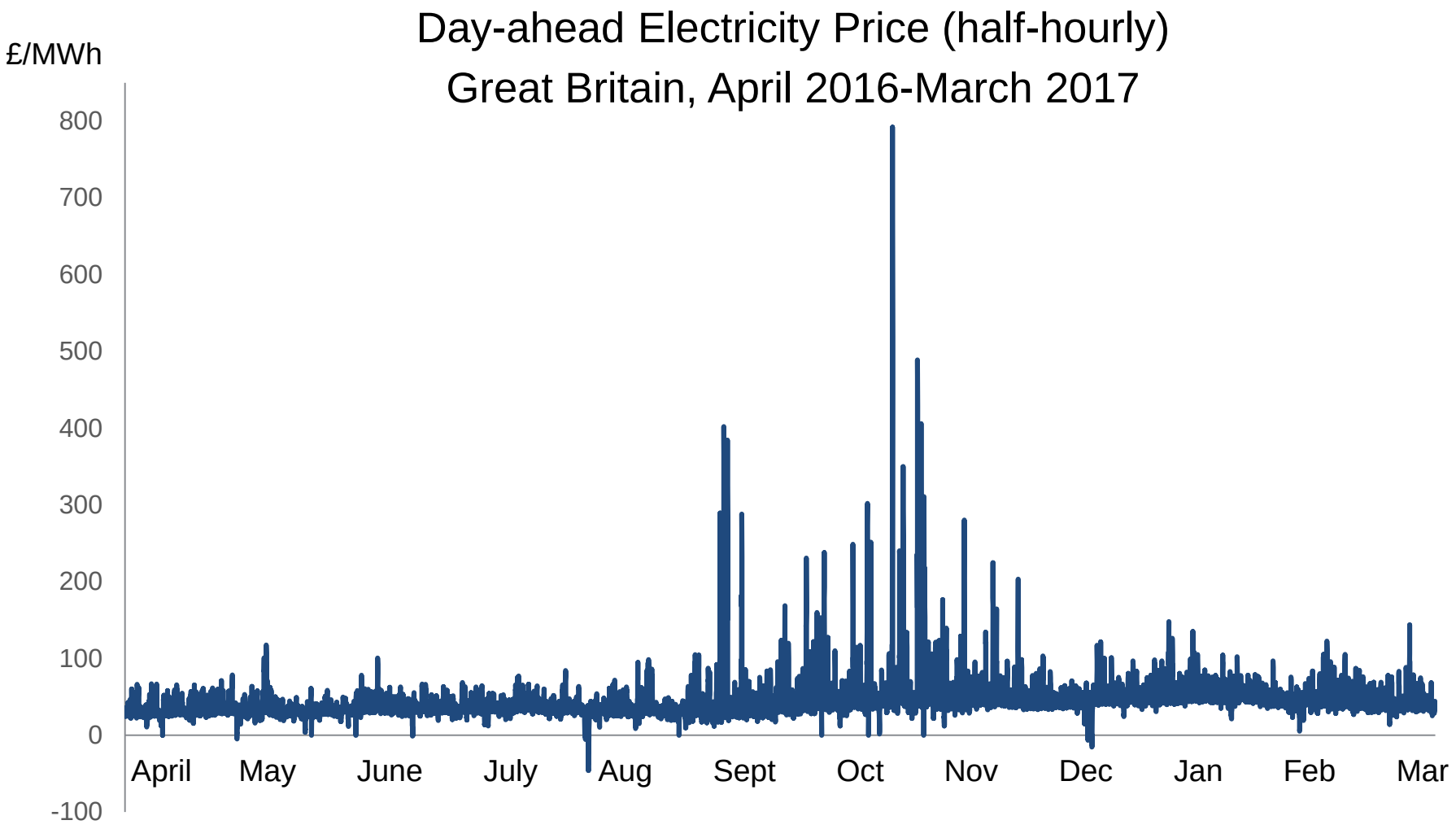
A volatile market



Source: ElectricInsights.co.uk

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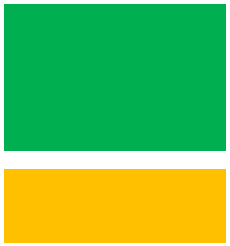
Simulating the future

Power Market with Renewable and Thermal plant

- Model dispatch and prices over a year
- Thought experiment for future capacities
  - 15 GW onshore wind
  - 50 GW offshore wind
  - 15 GW solar PV



- Gas-fired CCGT and Peaking plants (OCGT)

- Some demand response

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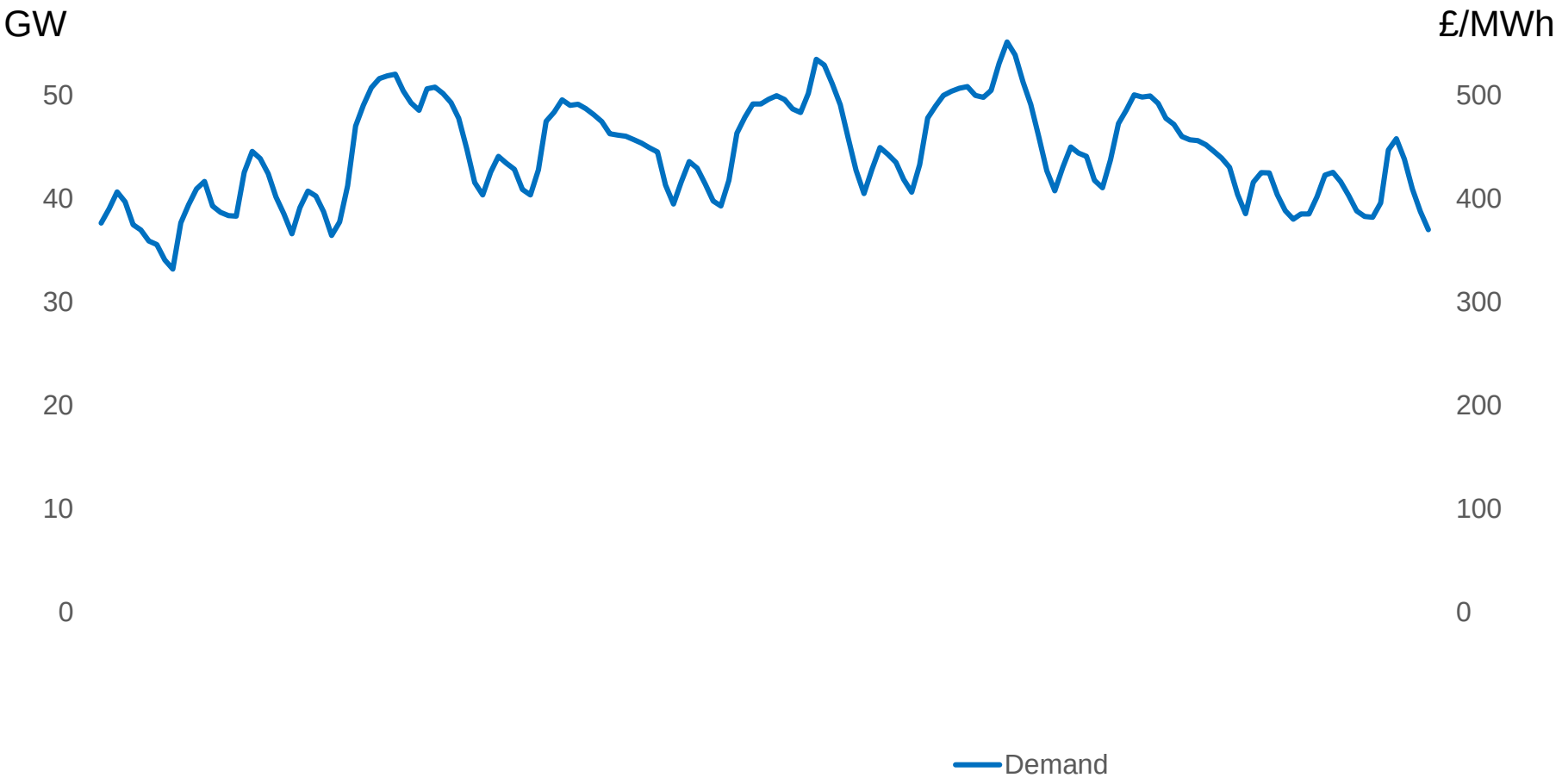
A simulated future

Week 7 of "2010"



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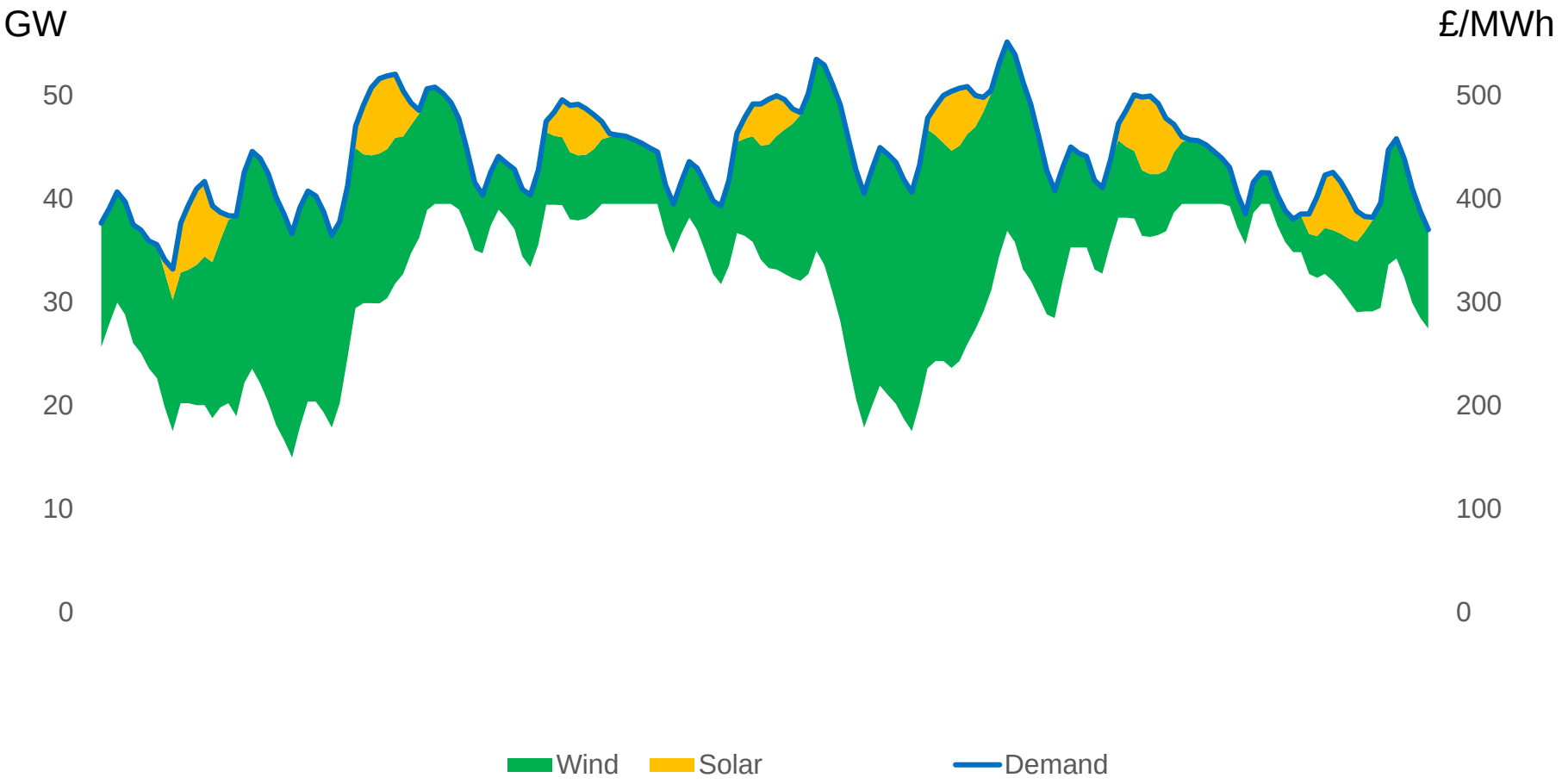

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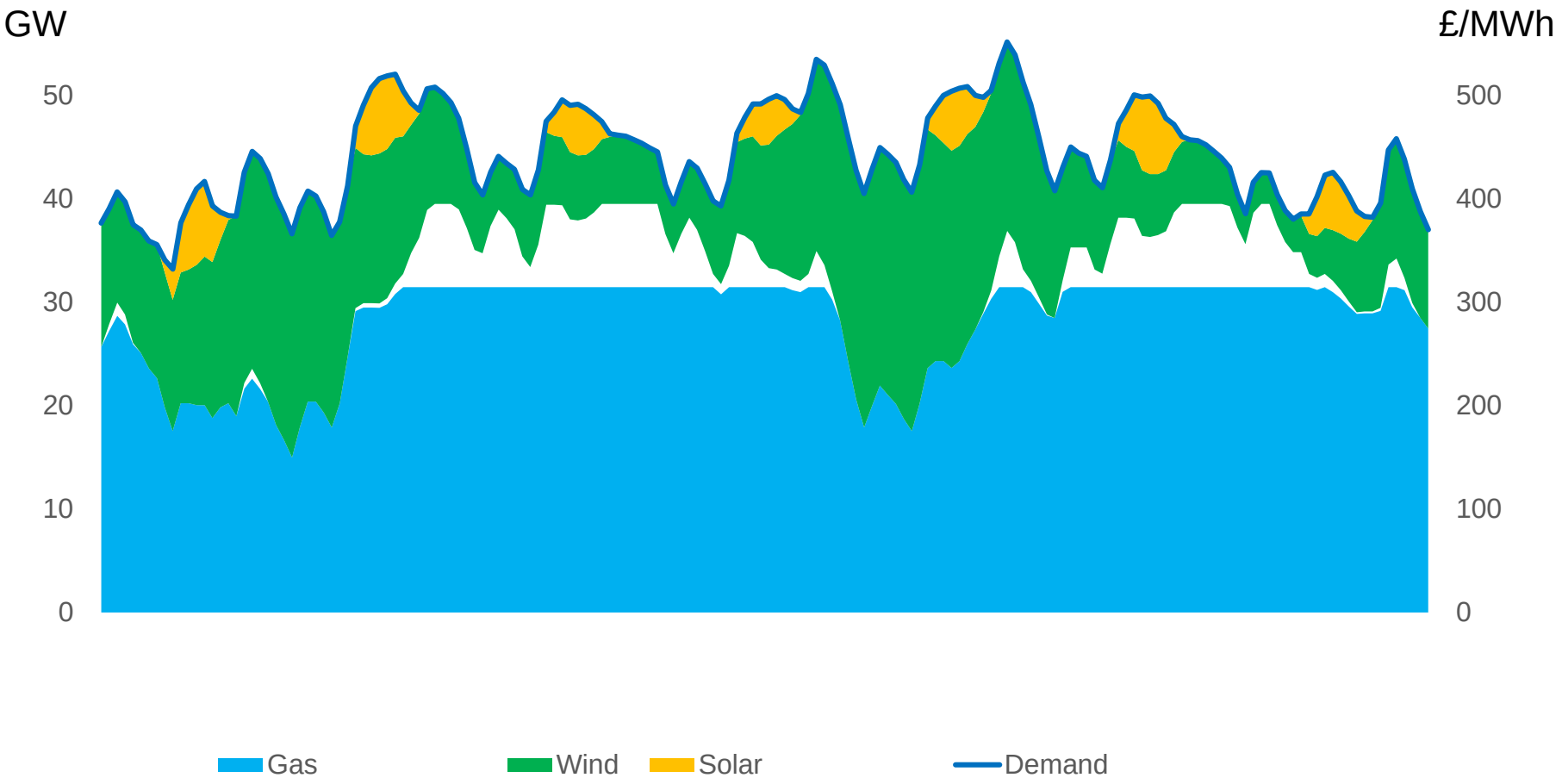

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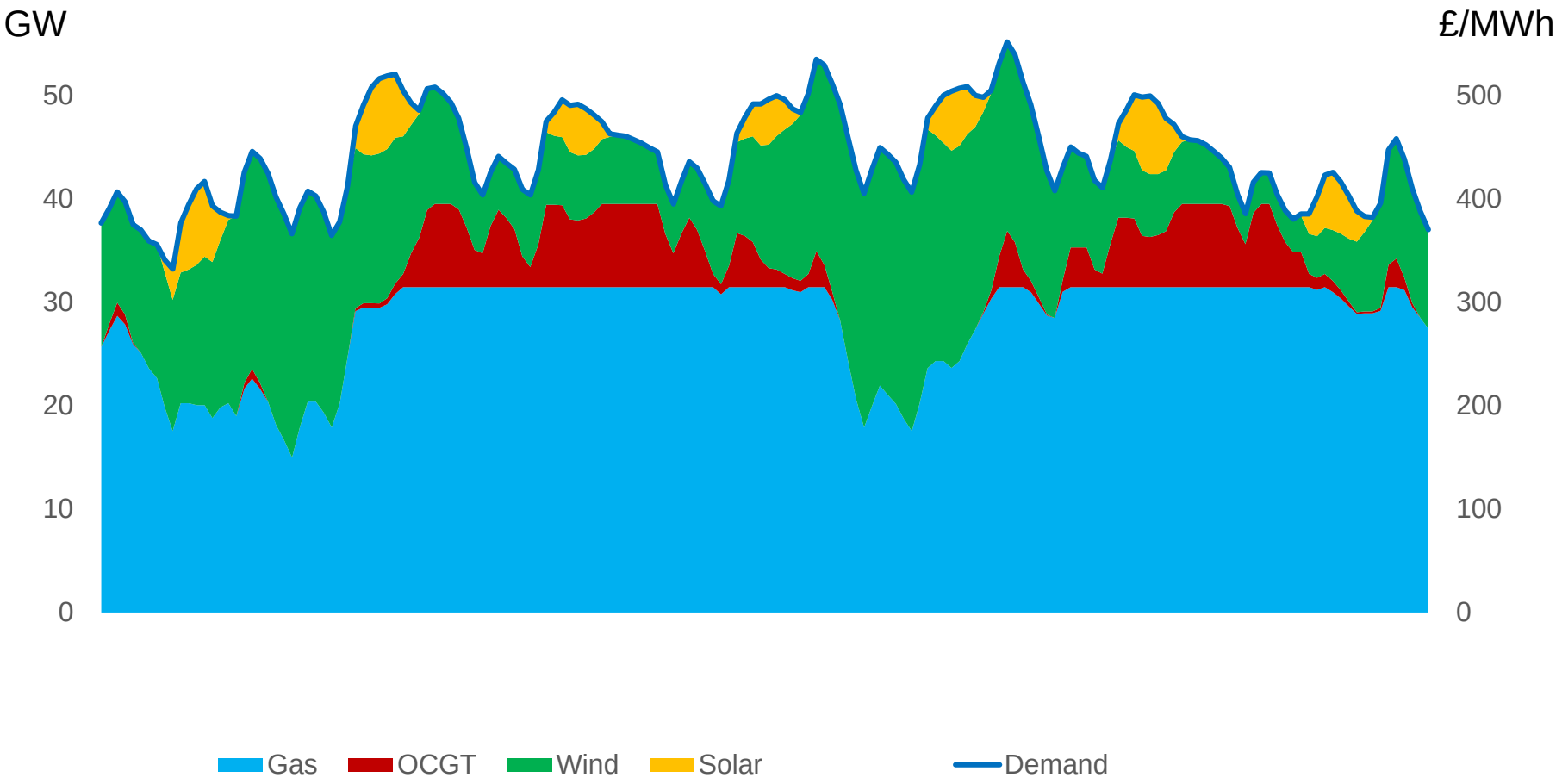

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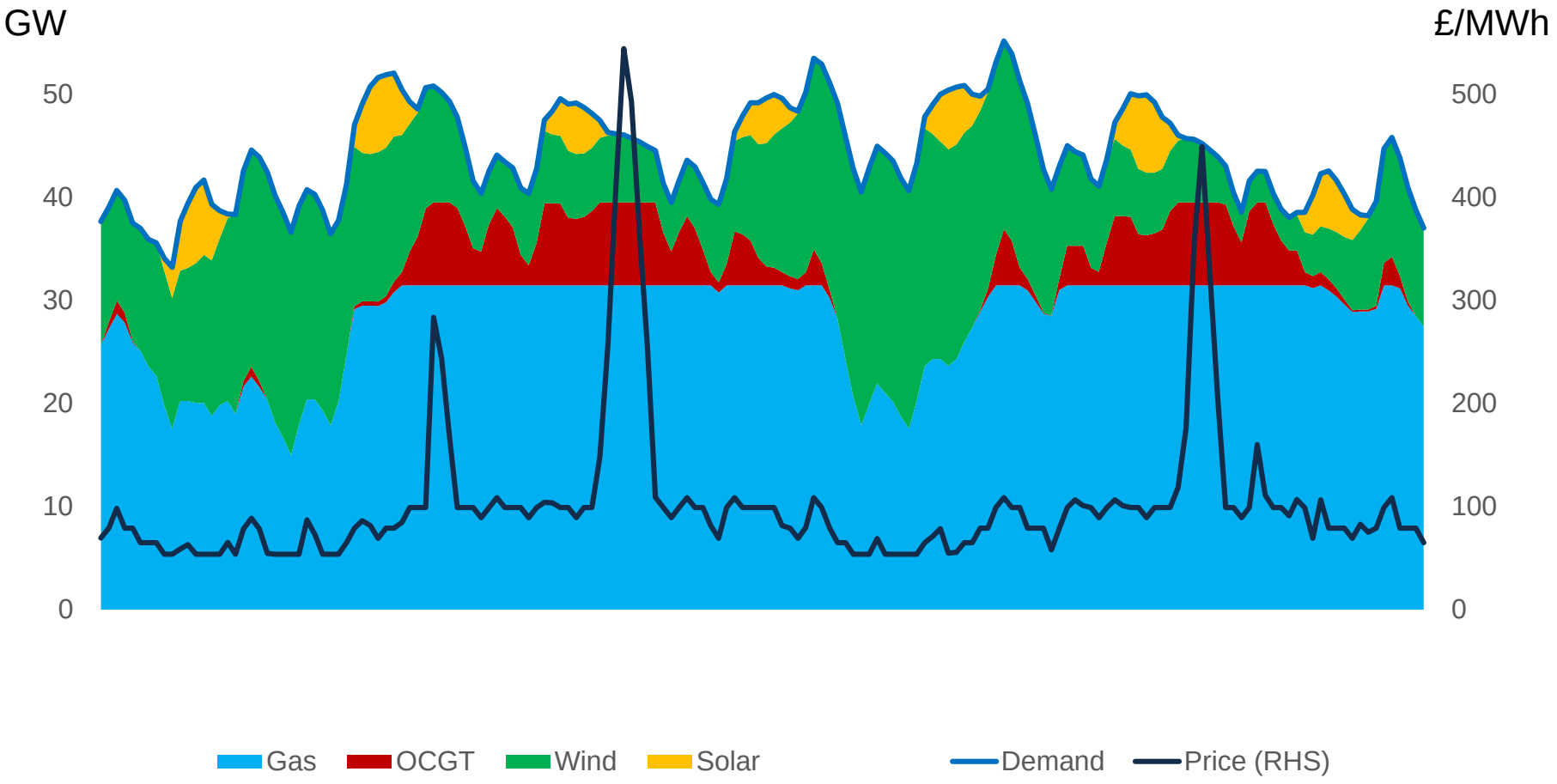

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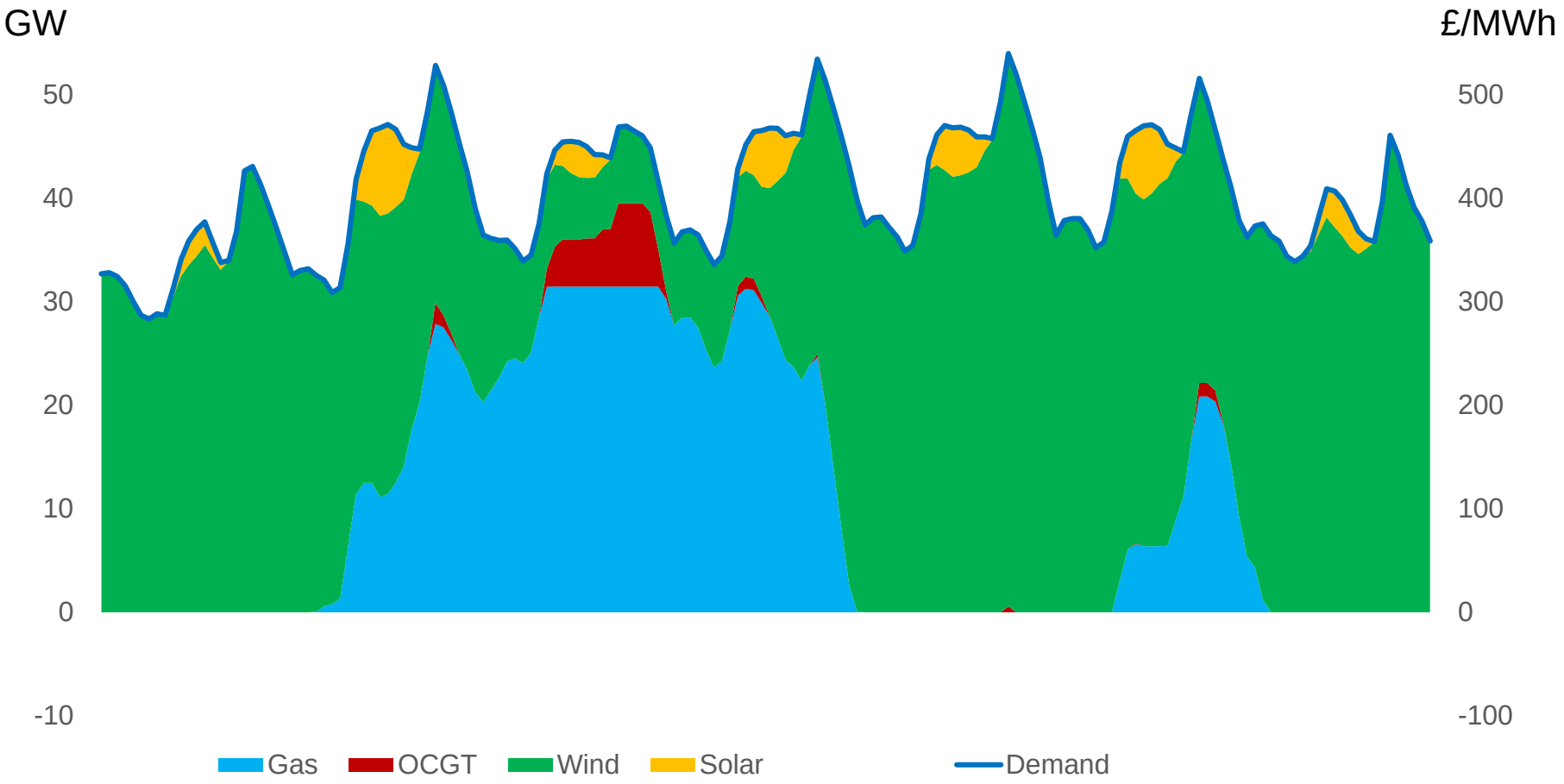
A simulated future

Week 44 of "2010"



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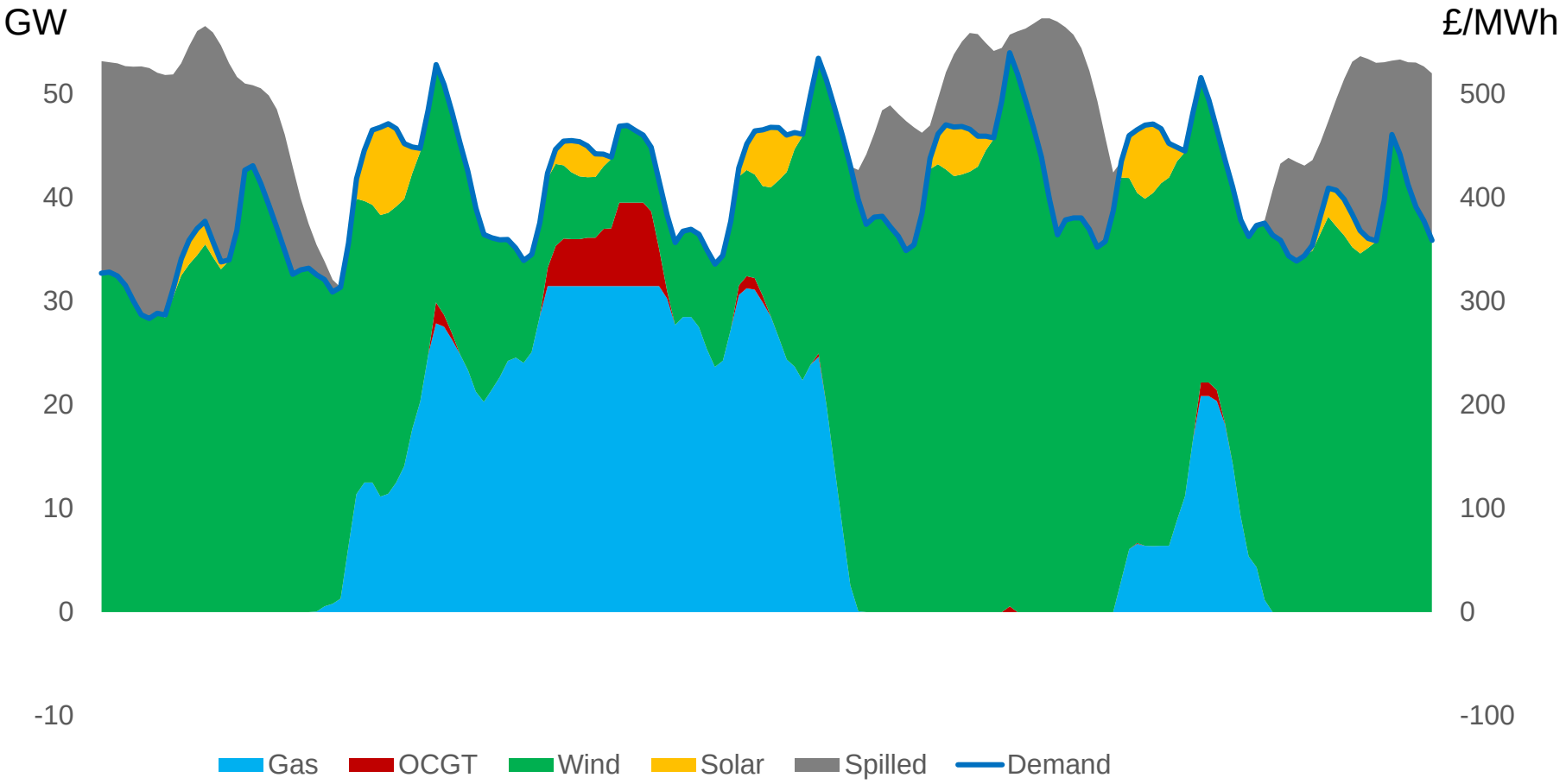
A simulated future

Week 44 of "2010"



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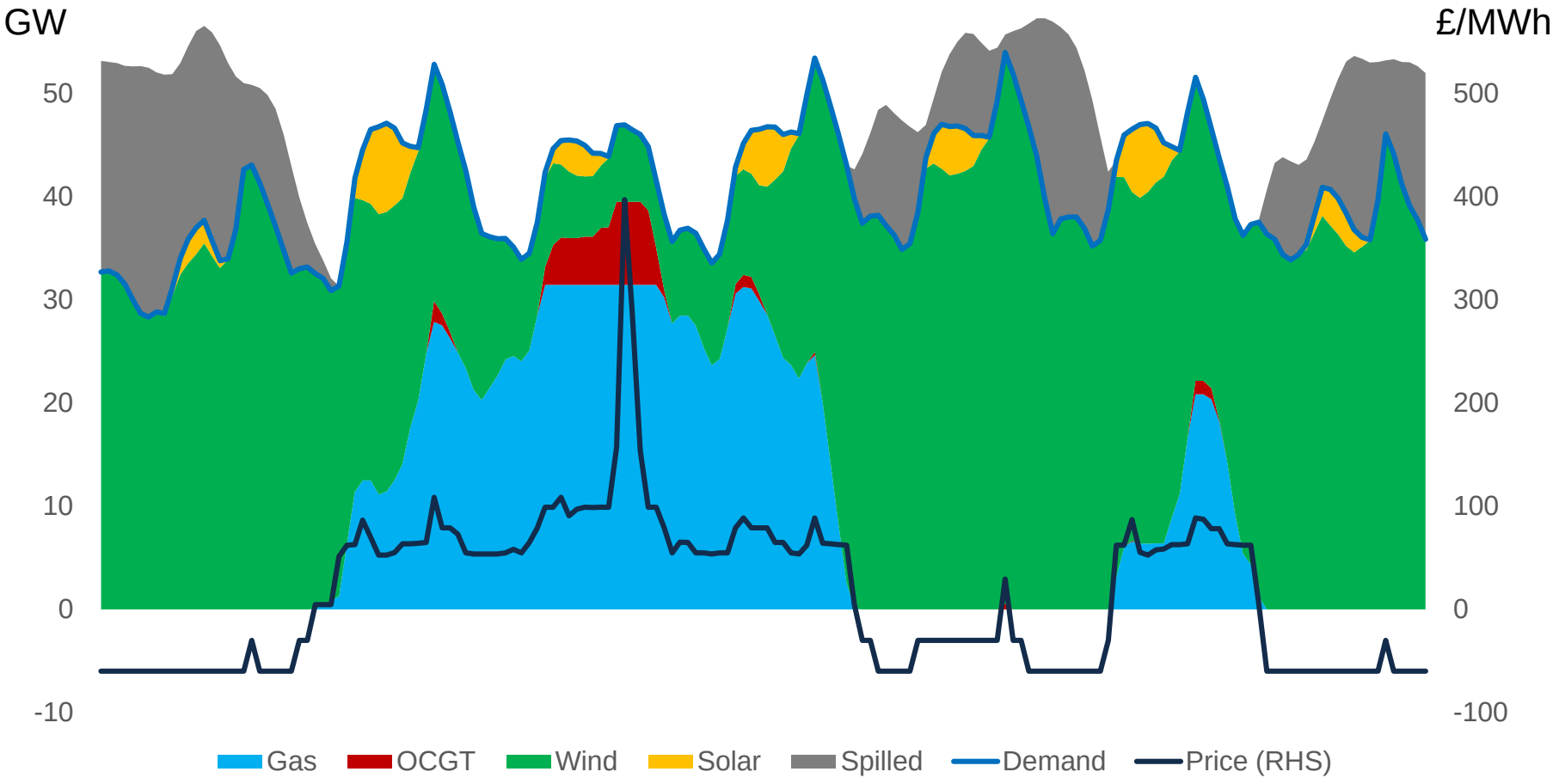
A simulated future

Week 44 of "2010"



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A barrier to renewables?

Relative revenues by type of plant

overall

Adding a little storage

Highest and lowest prices eliminated

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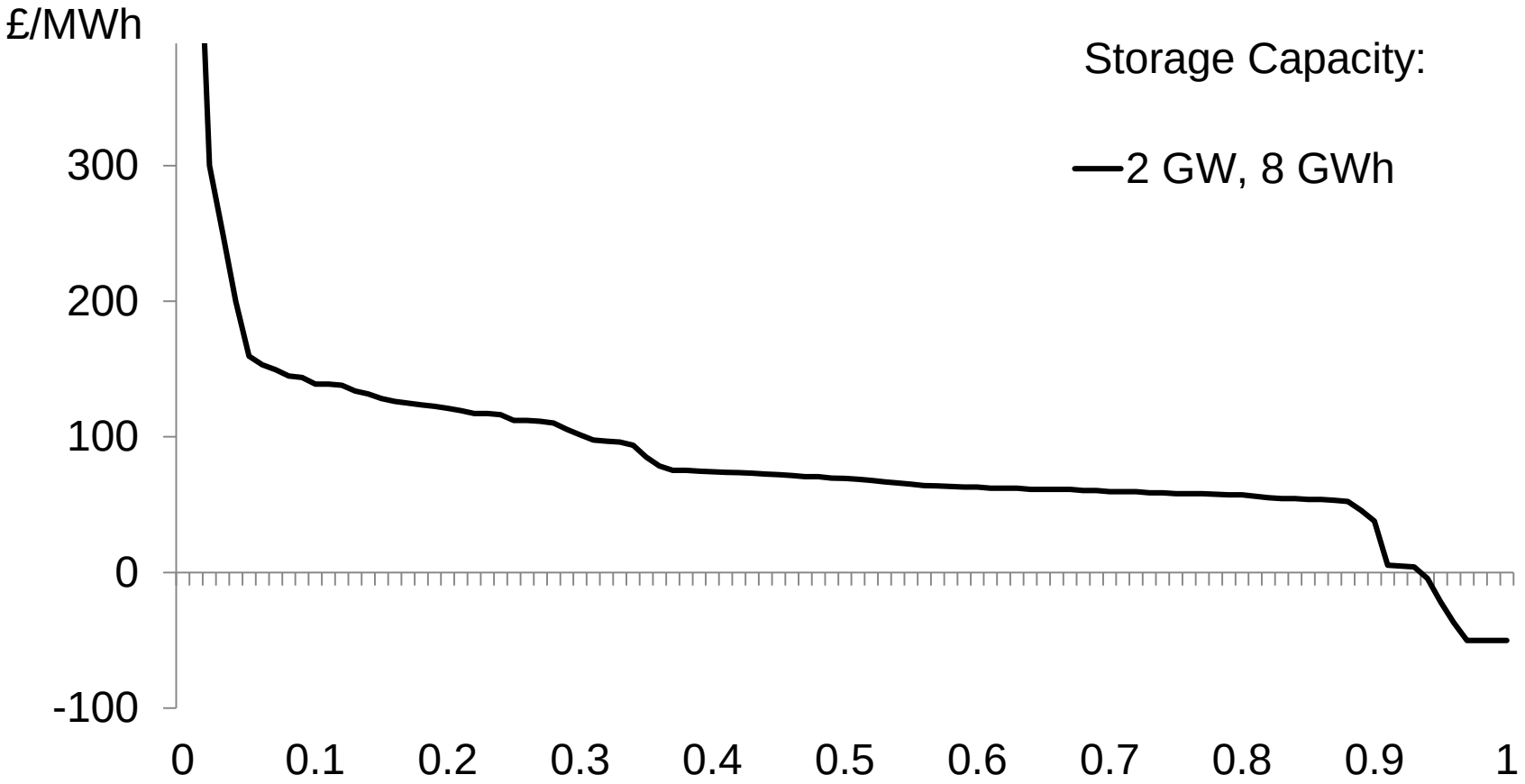
Price-duration curves

- GB, 2030 with endogenous generation capacity



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Price-duration curves

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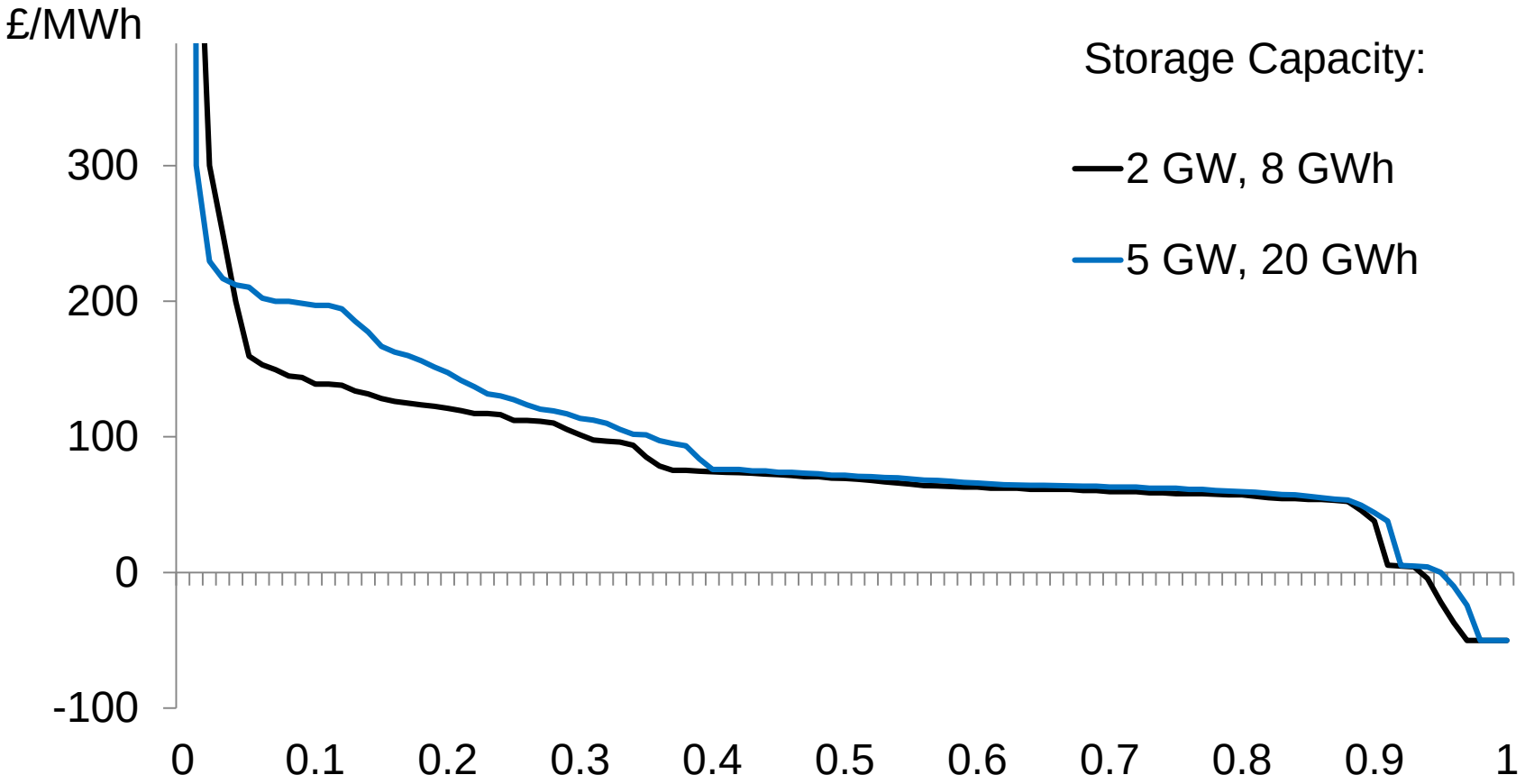

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Price-duration curves

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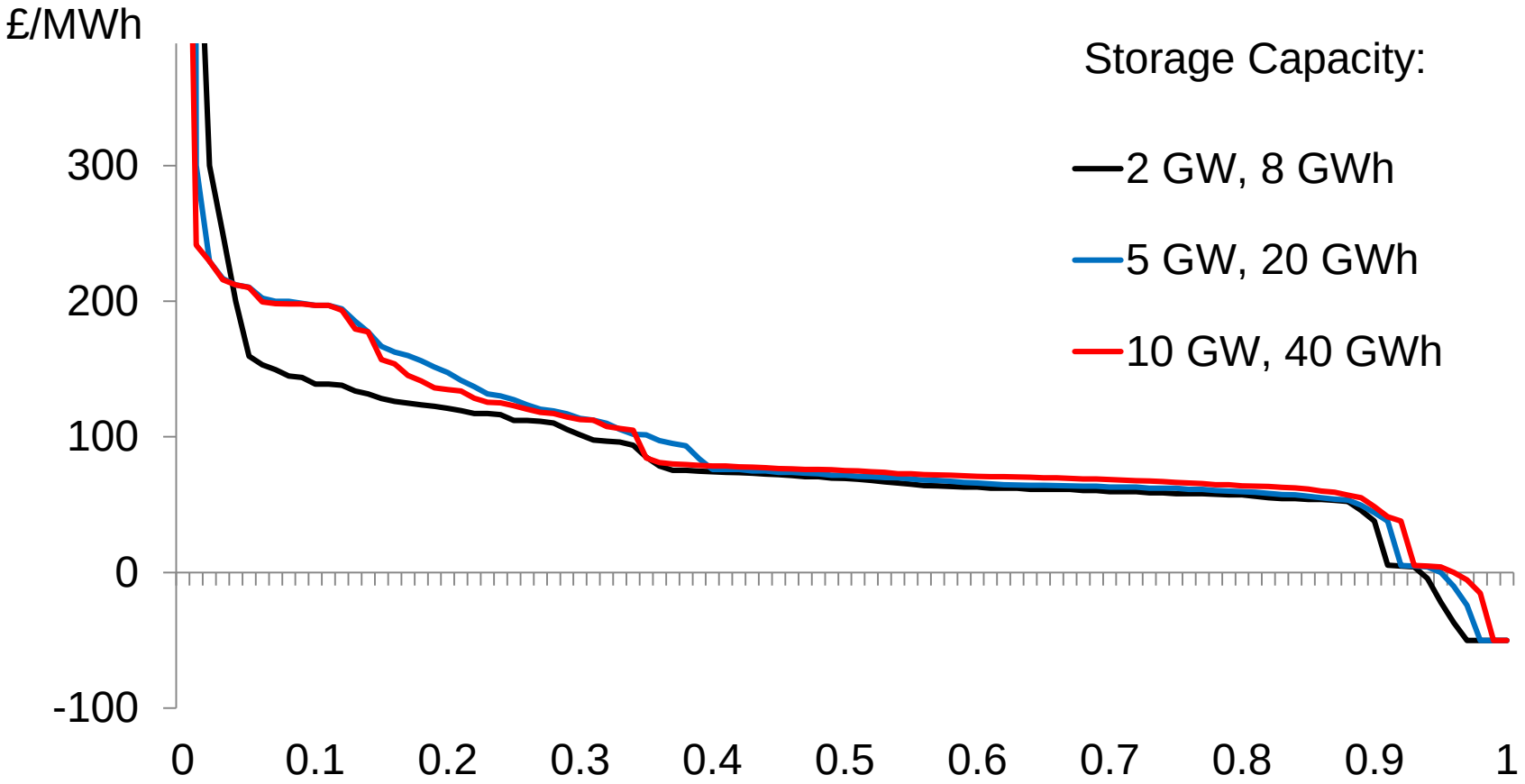

Renewables in an Energy Market

How storage changes price-setting, if there's enough of it

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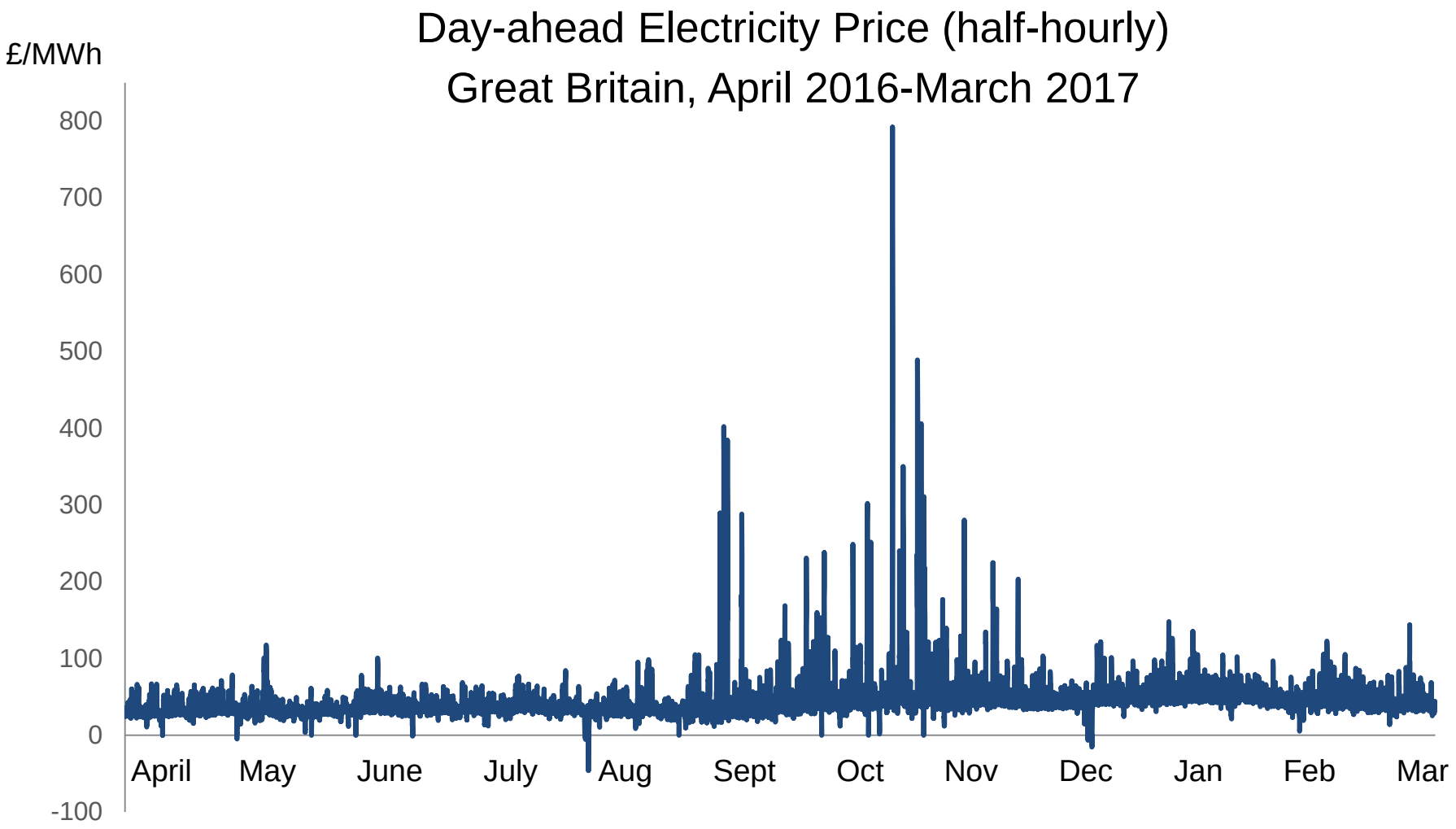
A volatile market



Source: ElectricInsights.co.uk

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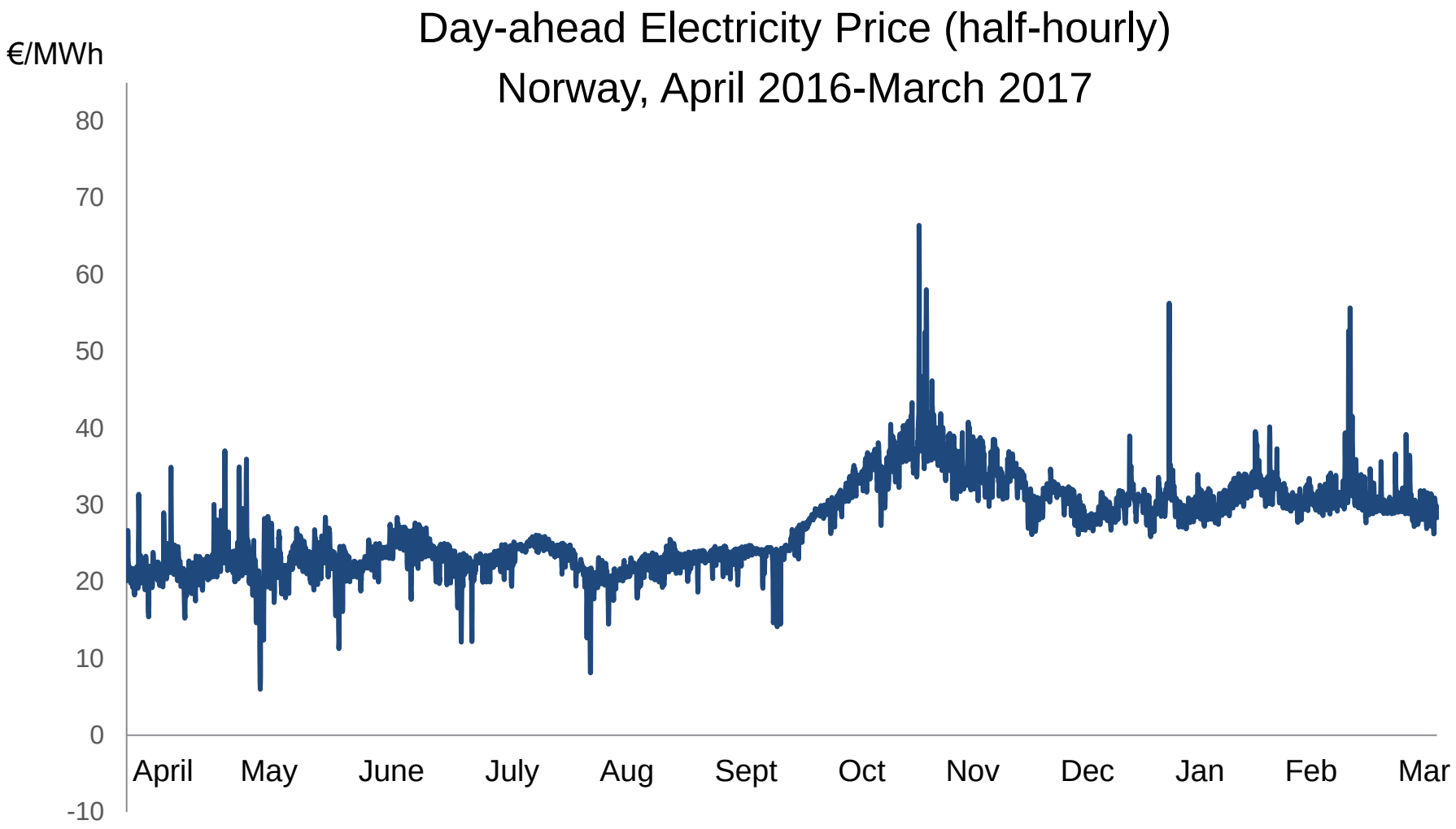
A less volatile market



Source: Energinet.dk

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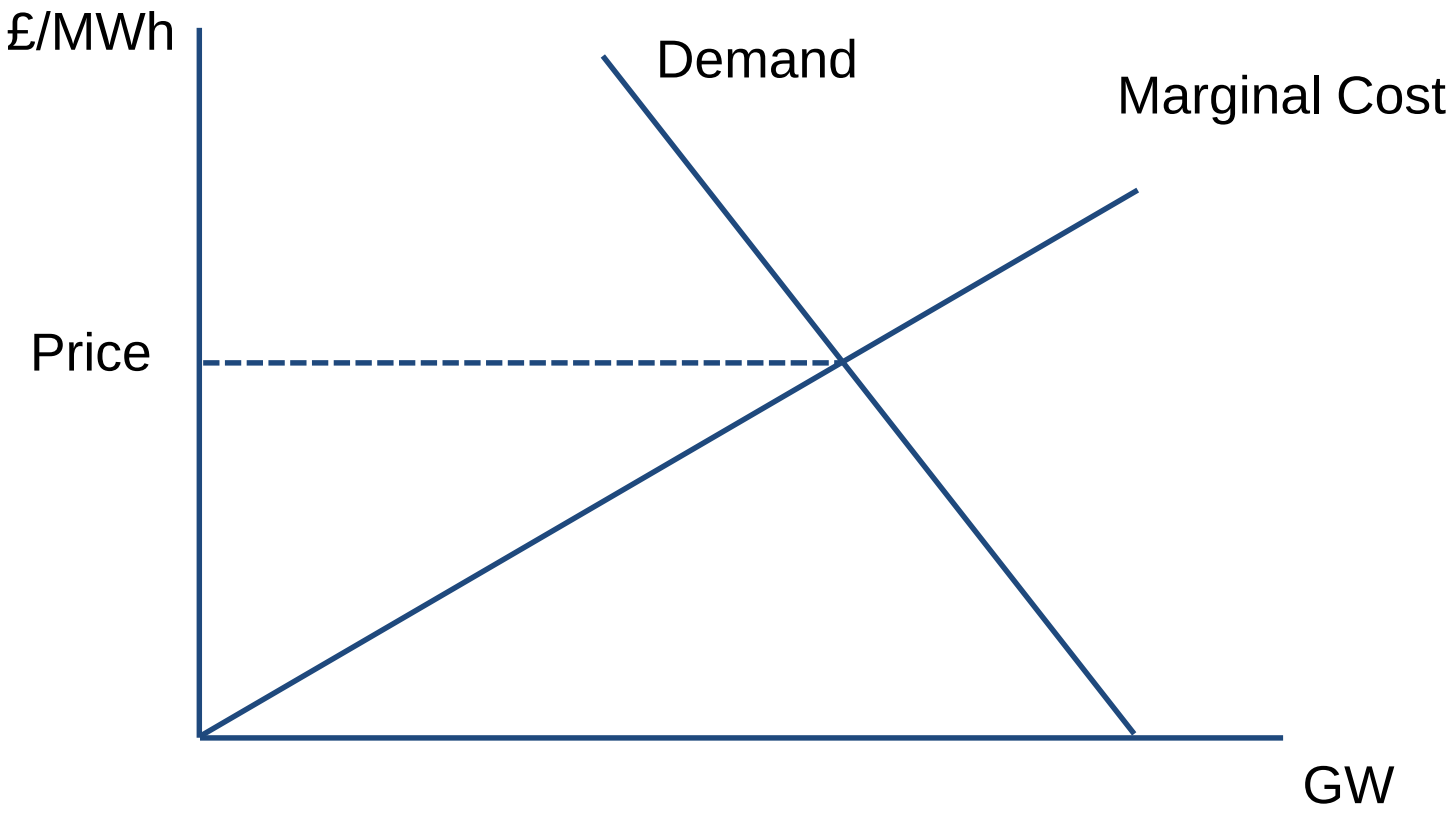
Supply and Demand



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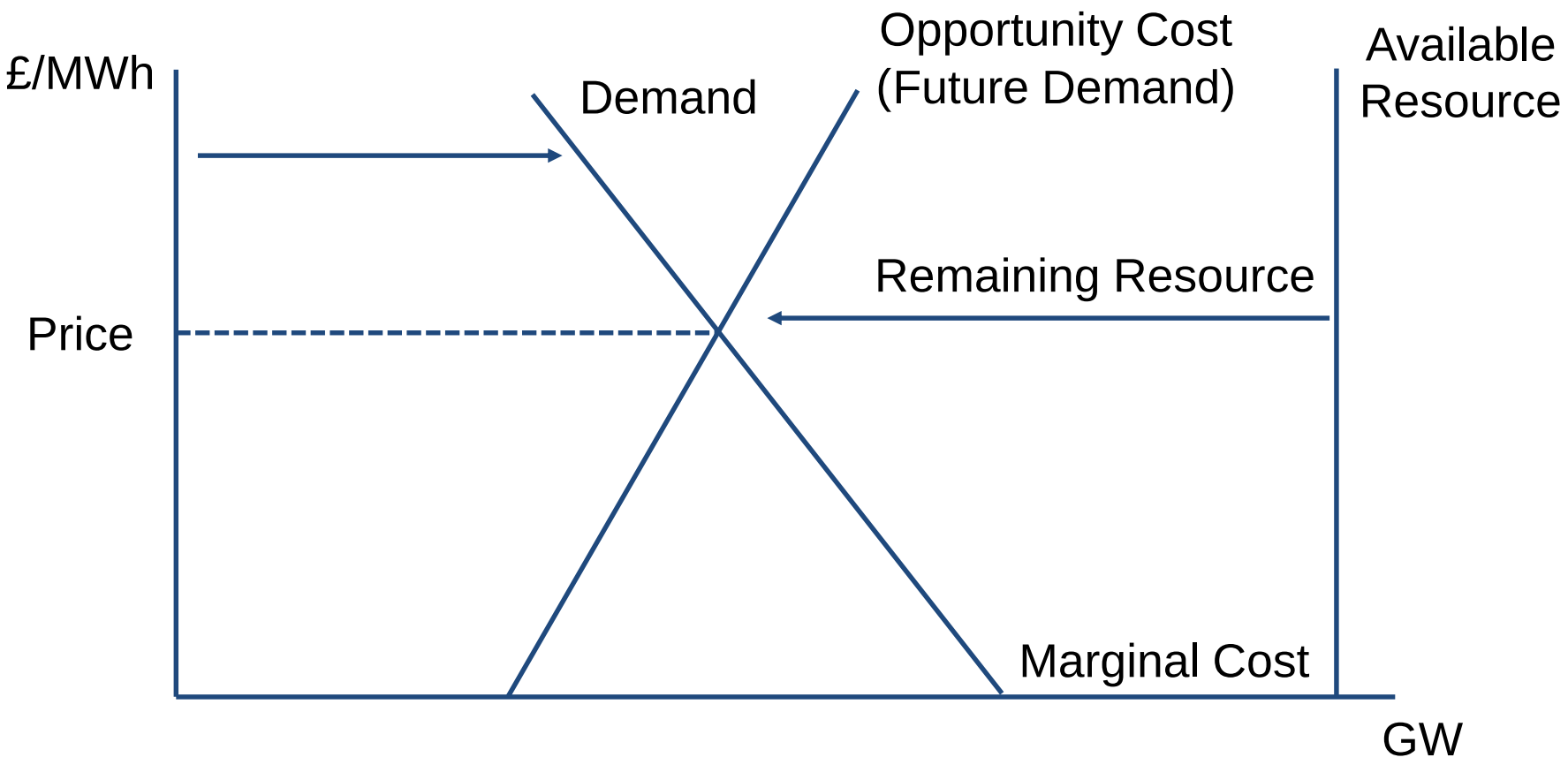
Supply and Demand



Finn's bathtub, from Forsund (2007) *Hydropower Economics,* Springer

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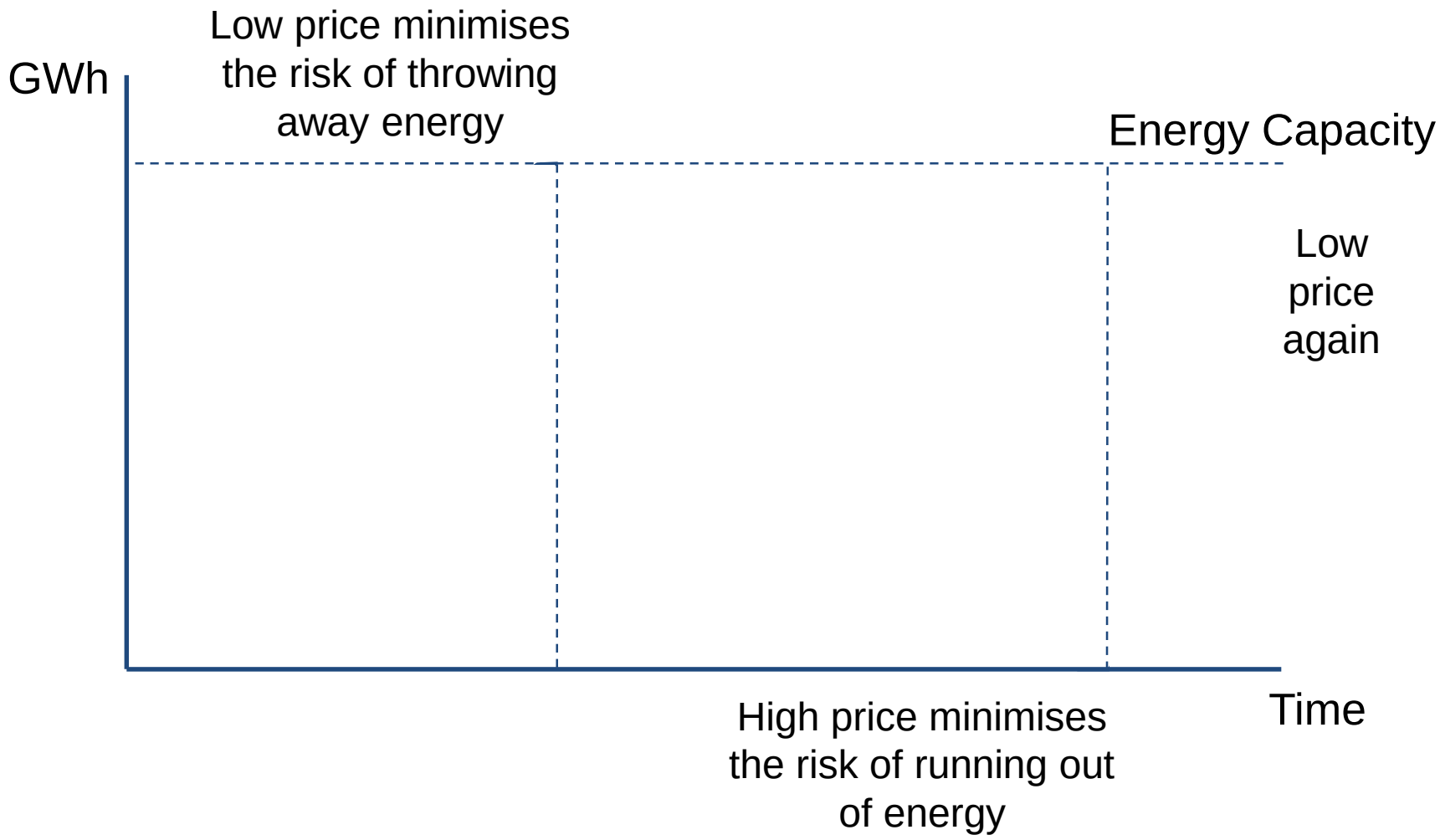
Reservoir Levels



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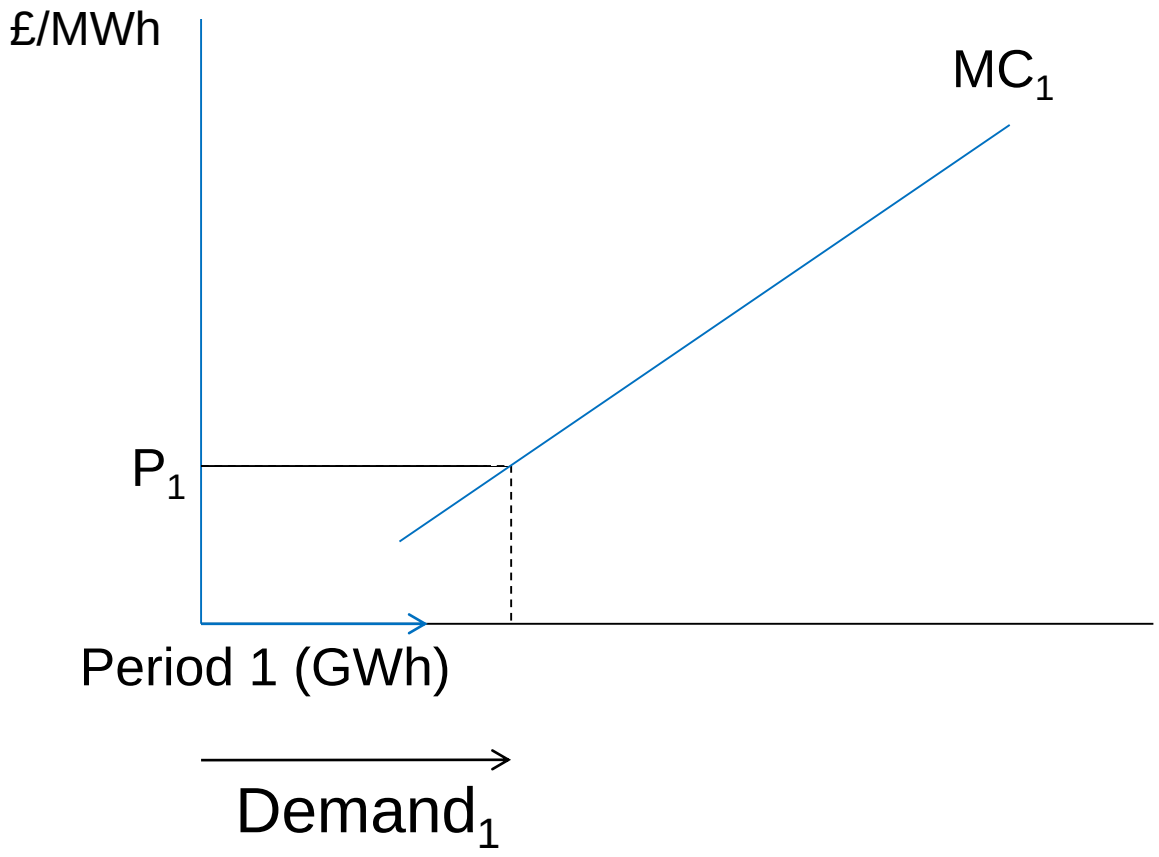
Richard's bath-tub

Storage with generation



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Richard's bath-tub

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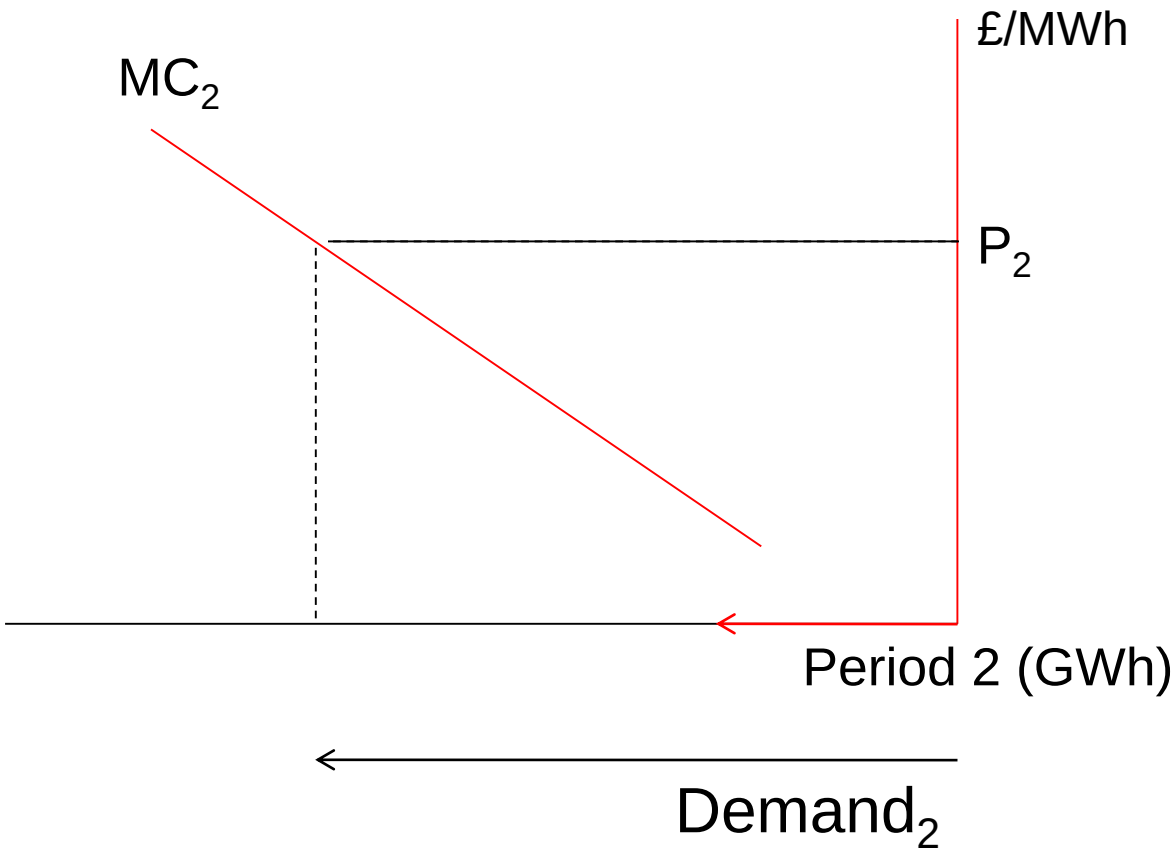

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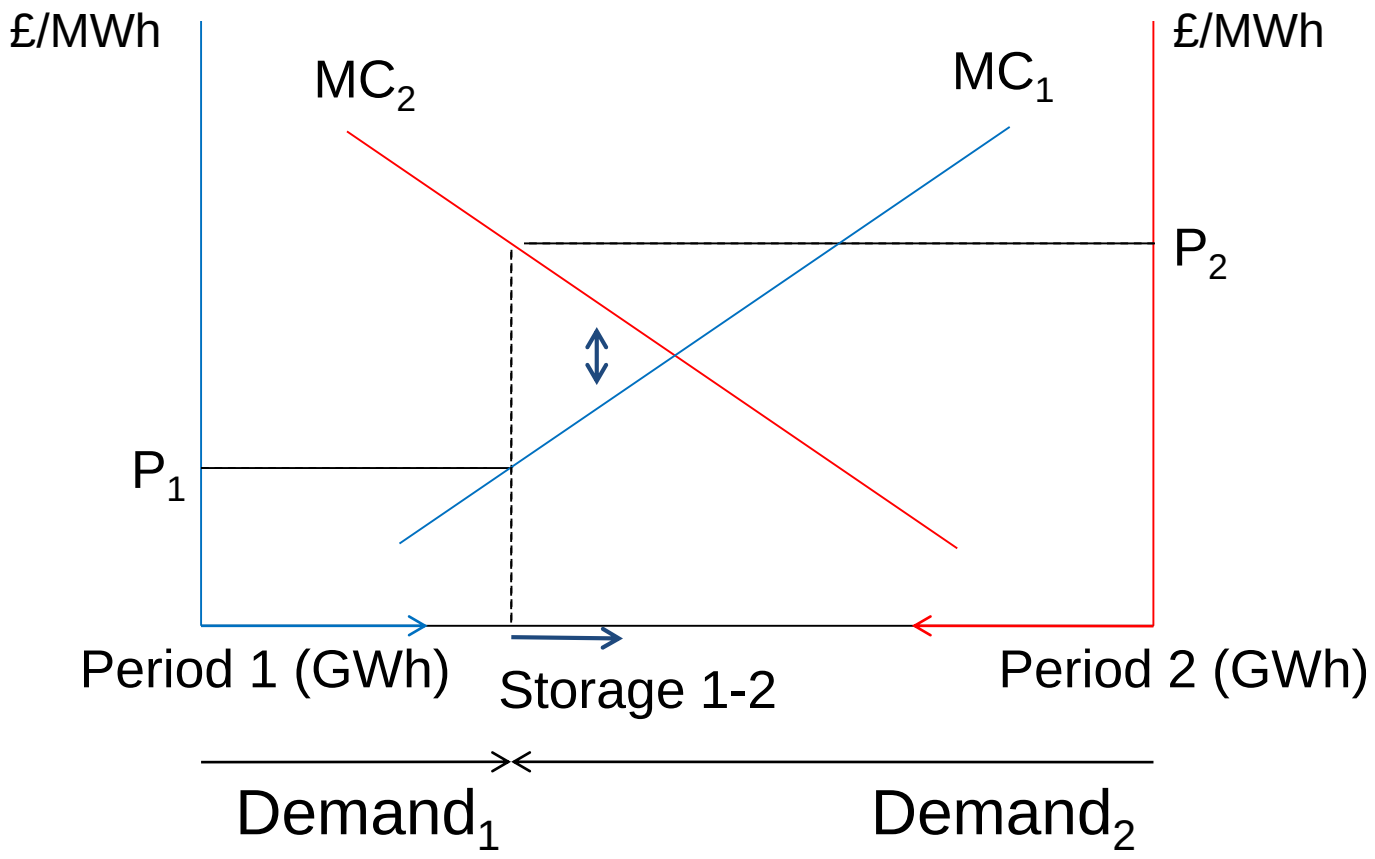
Richard's bath-tub

Storage with generation



The maximum amount of storage is limited by its energy capacity (horizontal arrow)

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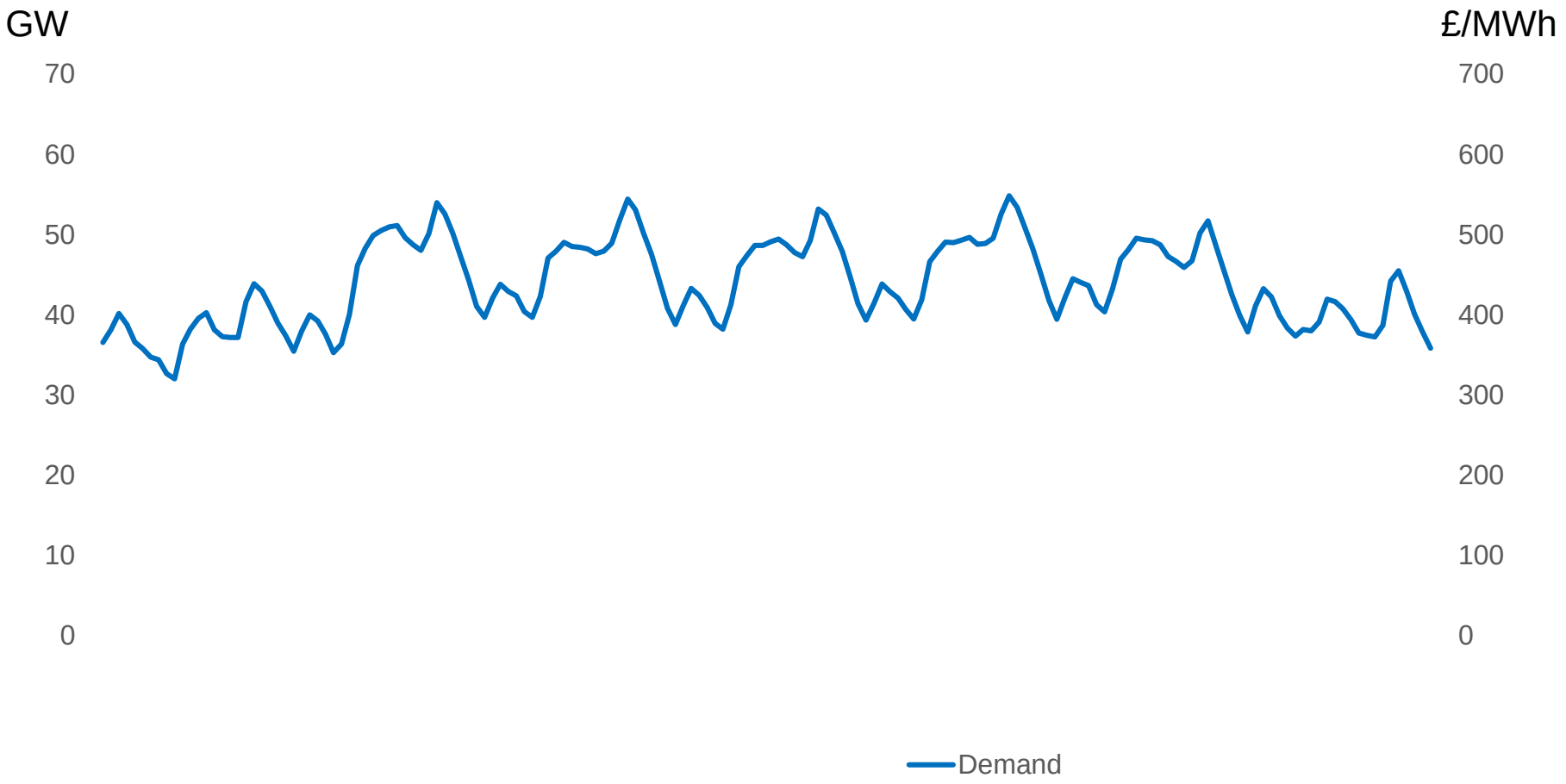
A simulated future

Energy Market: Week 7 of "2010"



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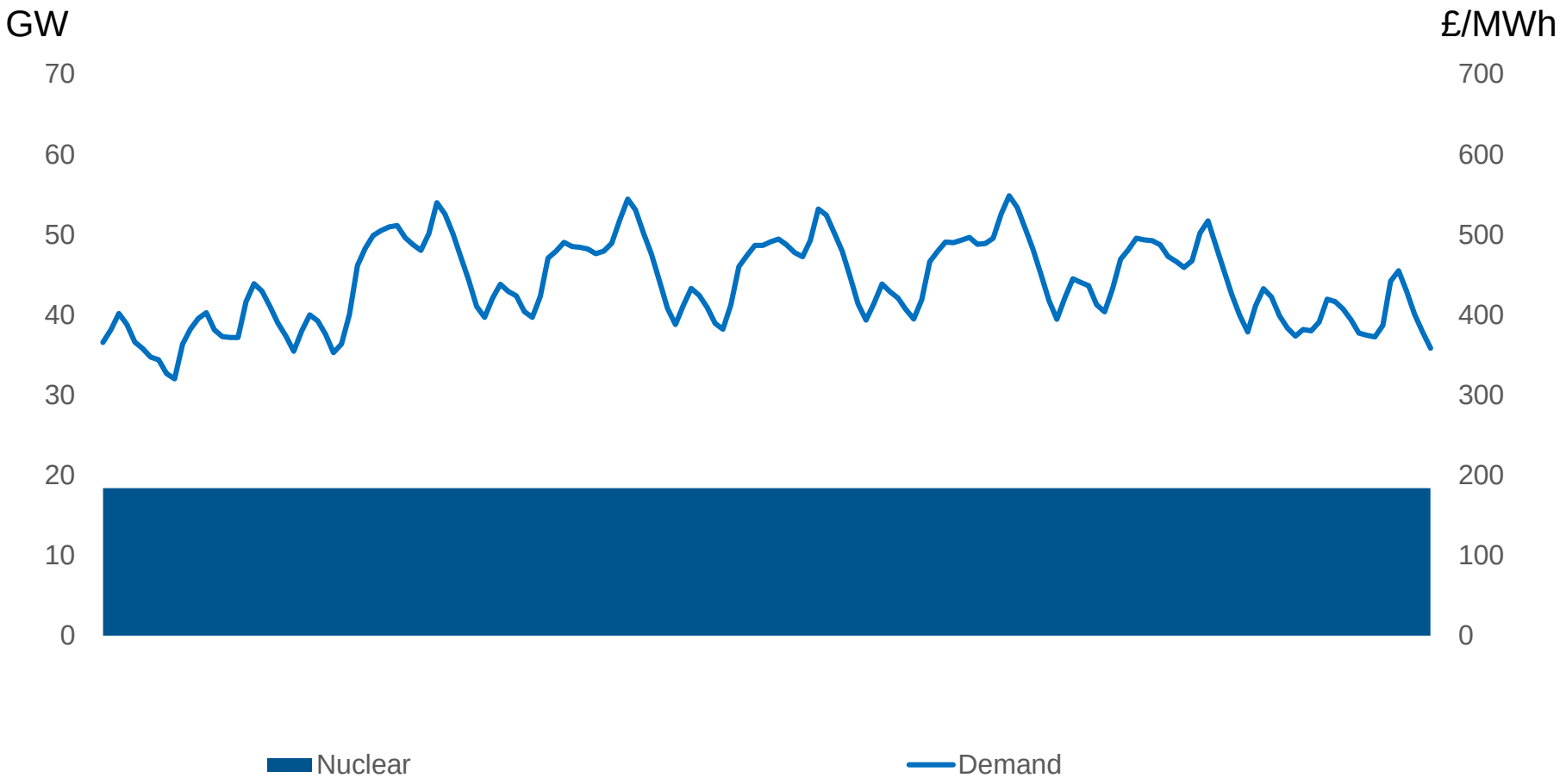

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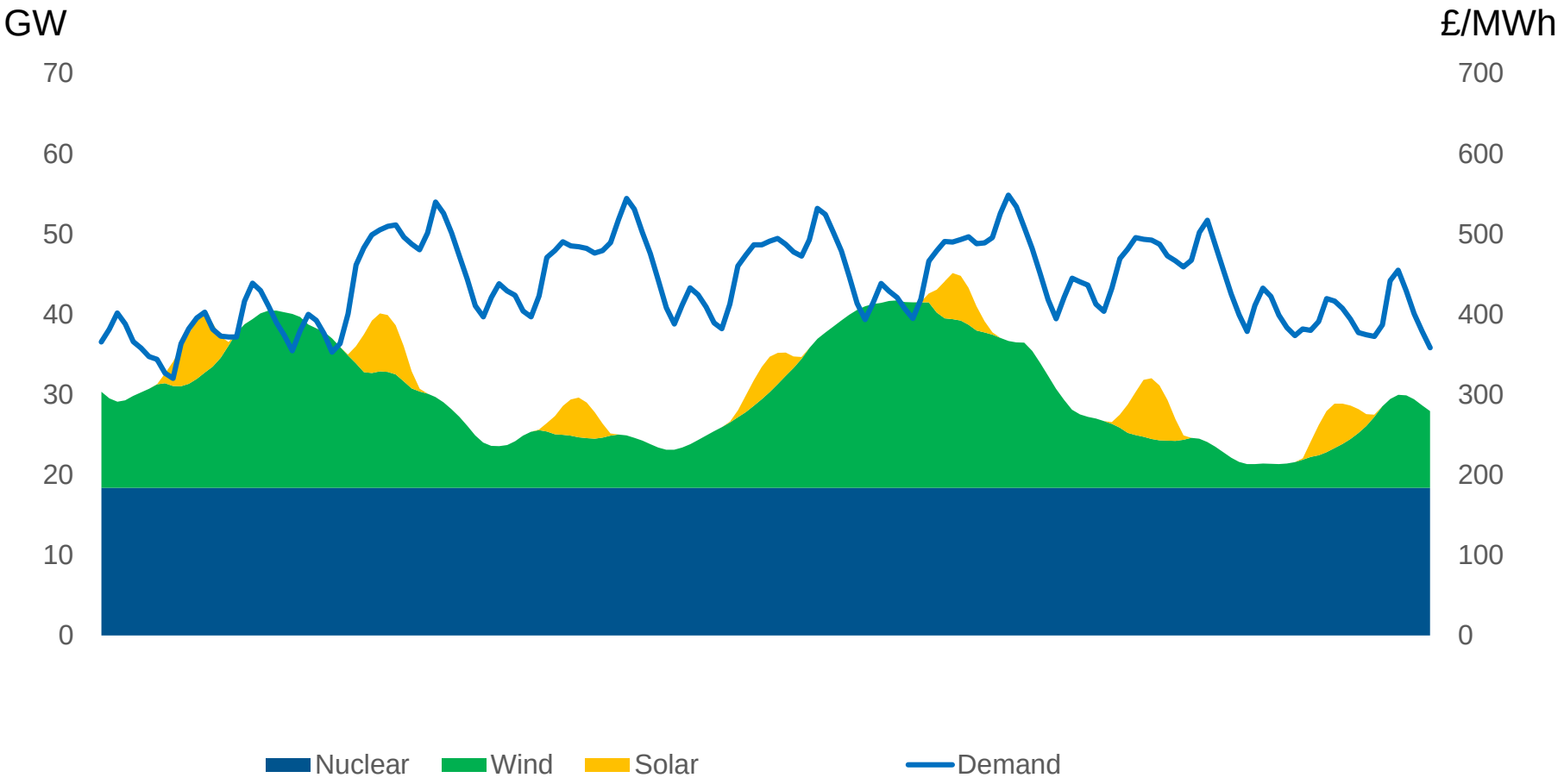

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A simulated future

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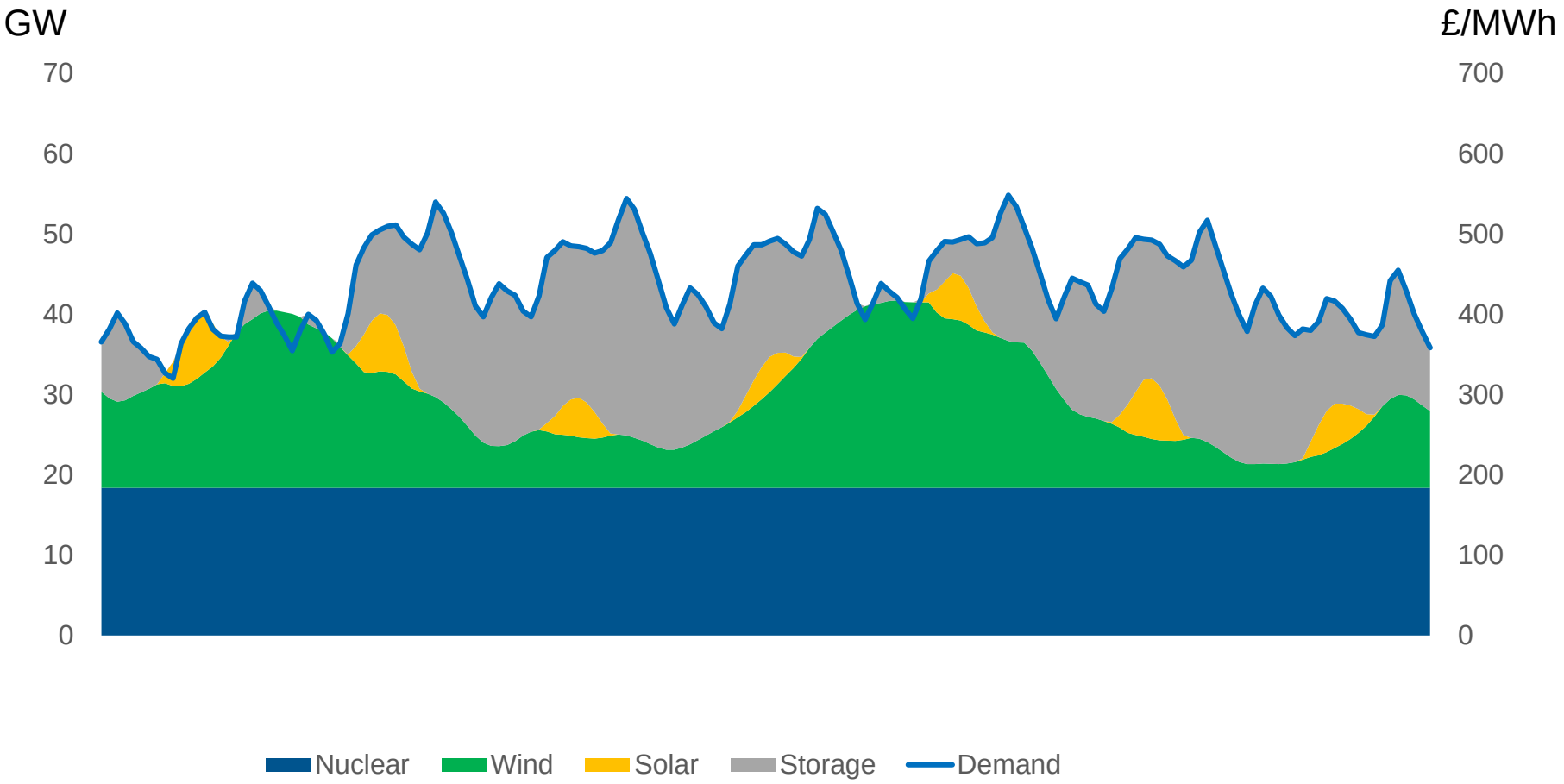

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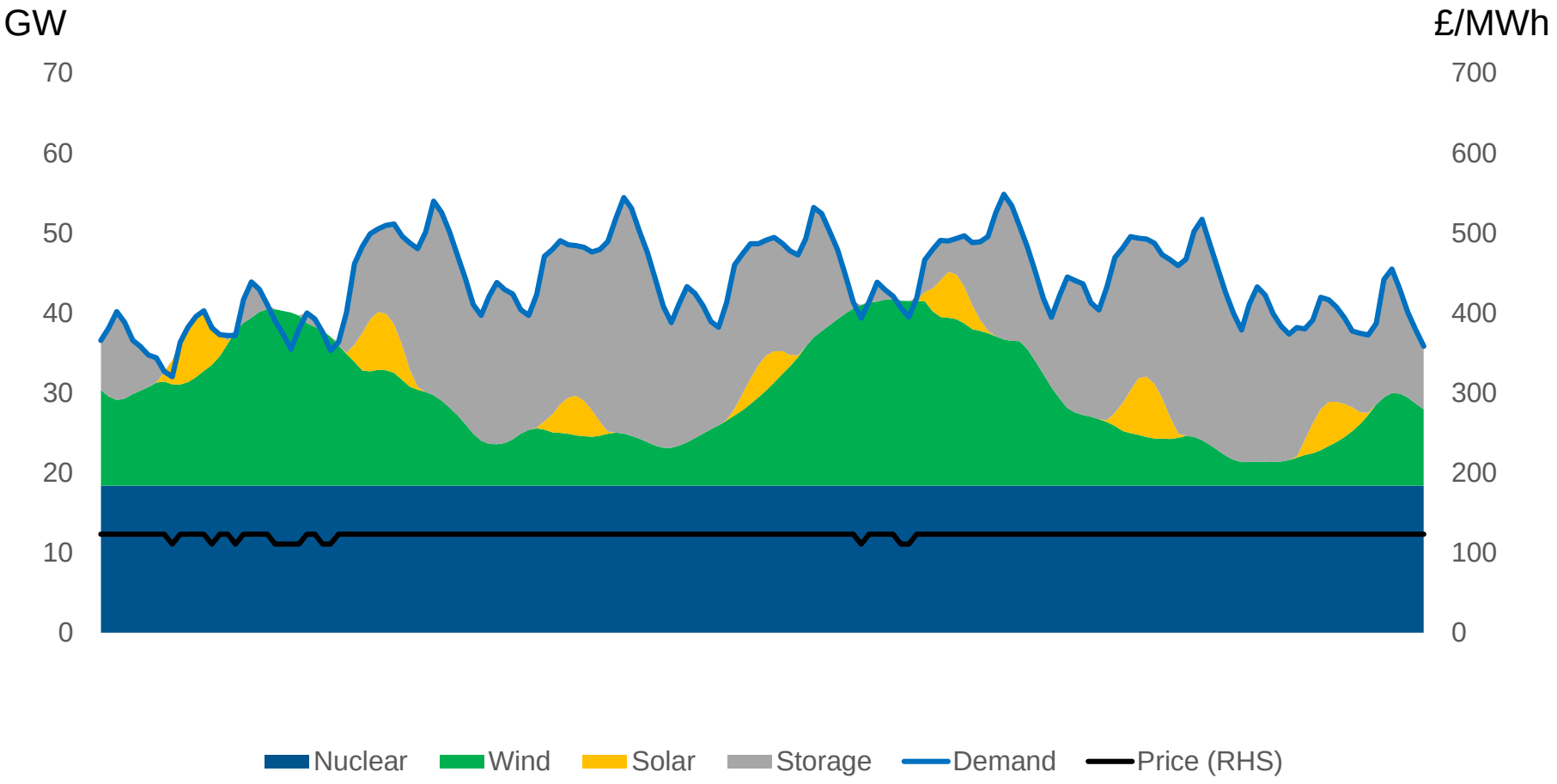

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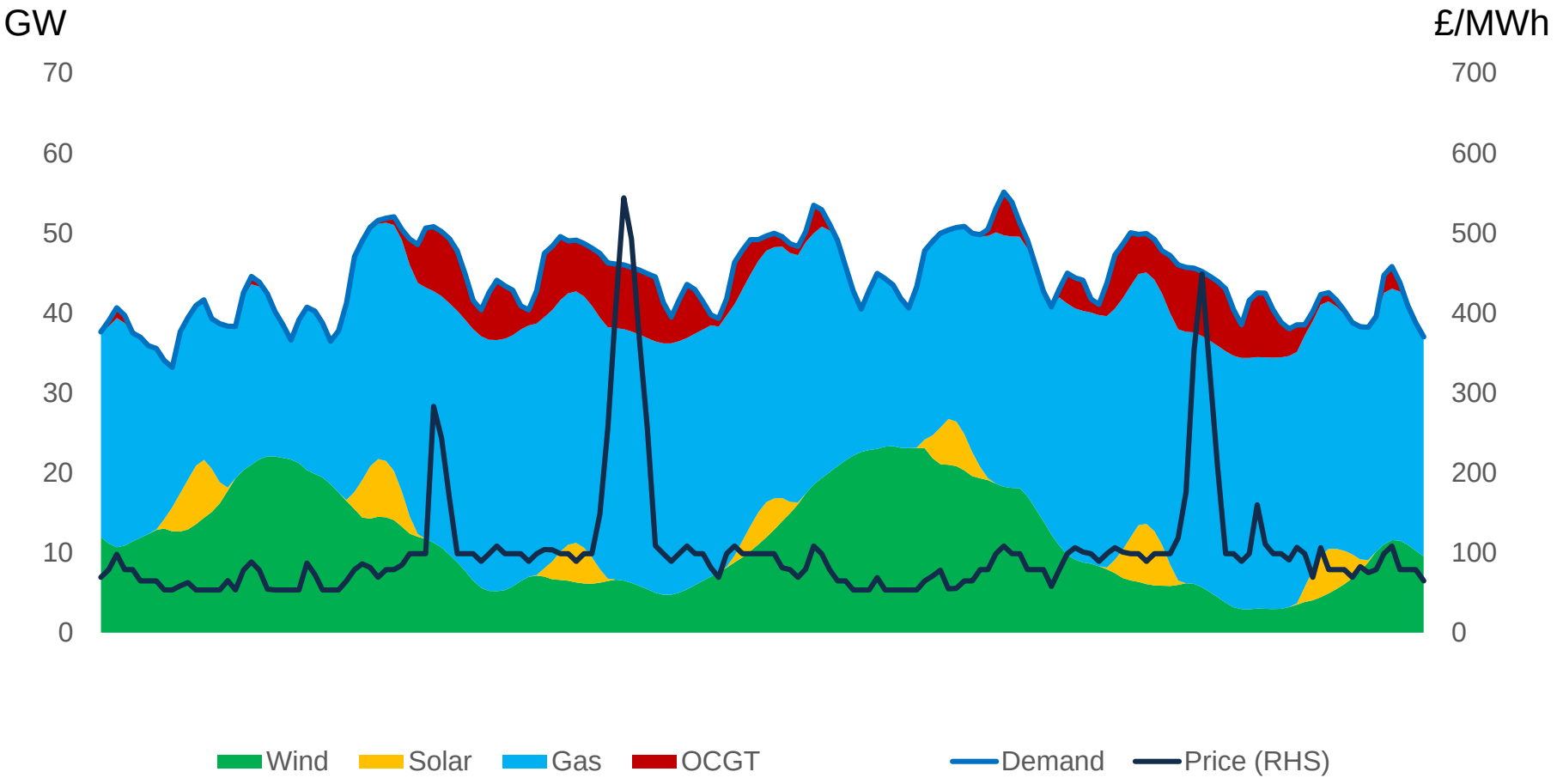
A simulated future

Power Market: Week 7 of "2010"



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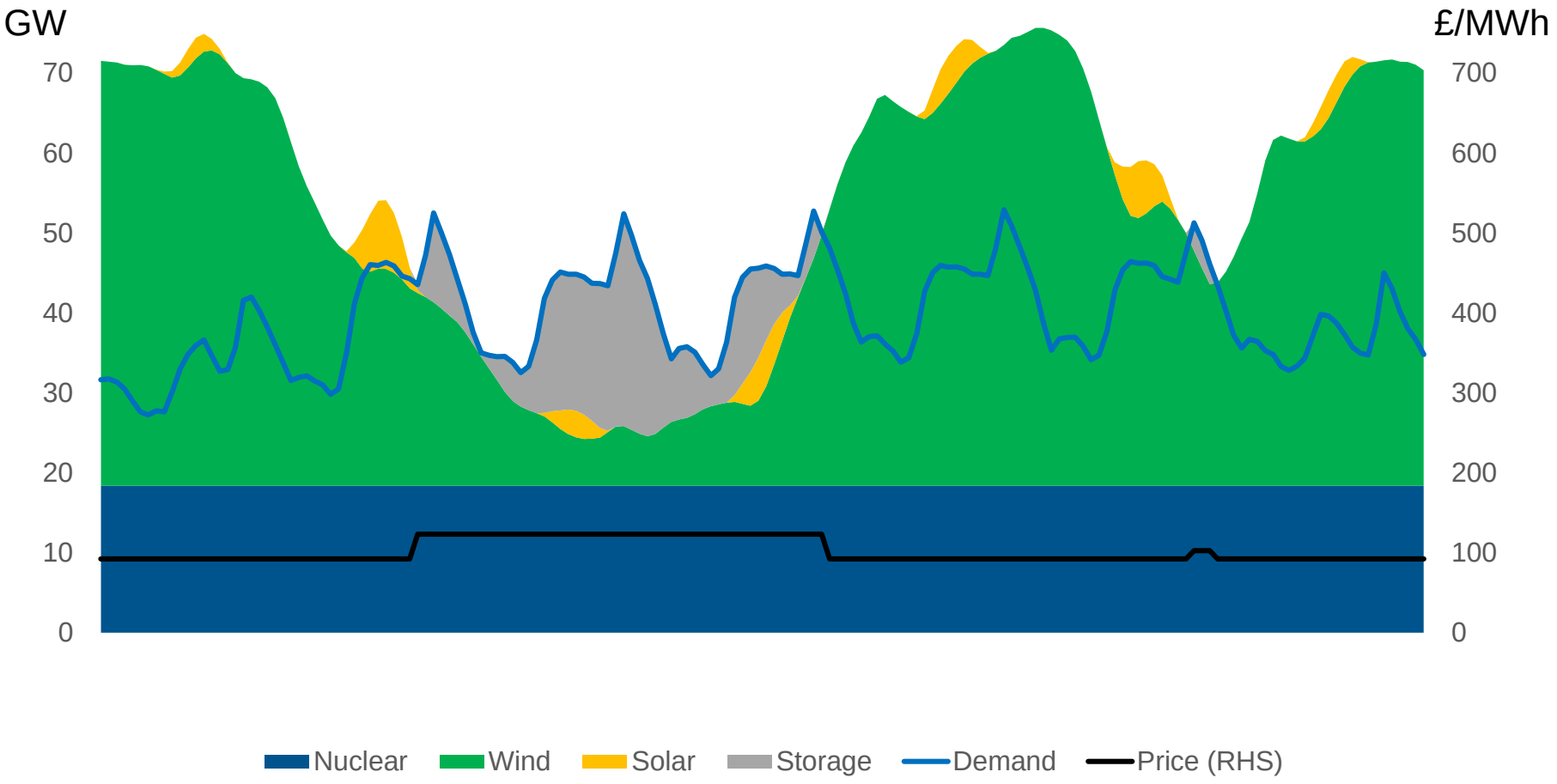
A simulated future

Energy Market: Week 44 of "2010"



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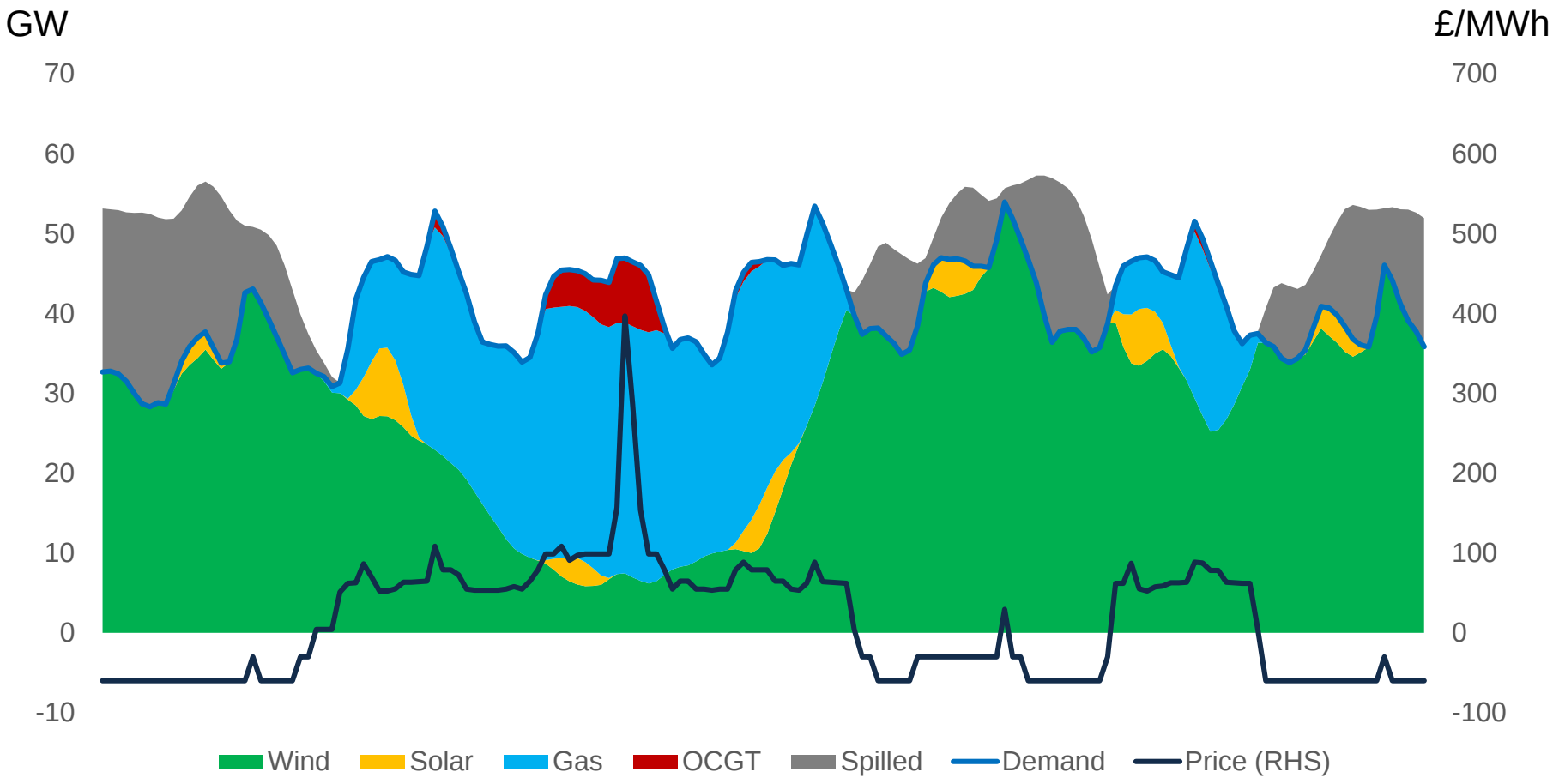
A simulated future

Power Market: Week 44 of "2010"



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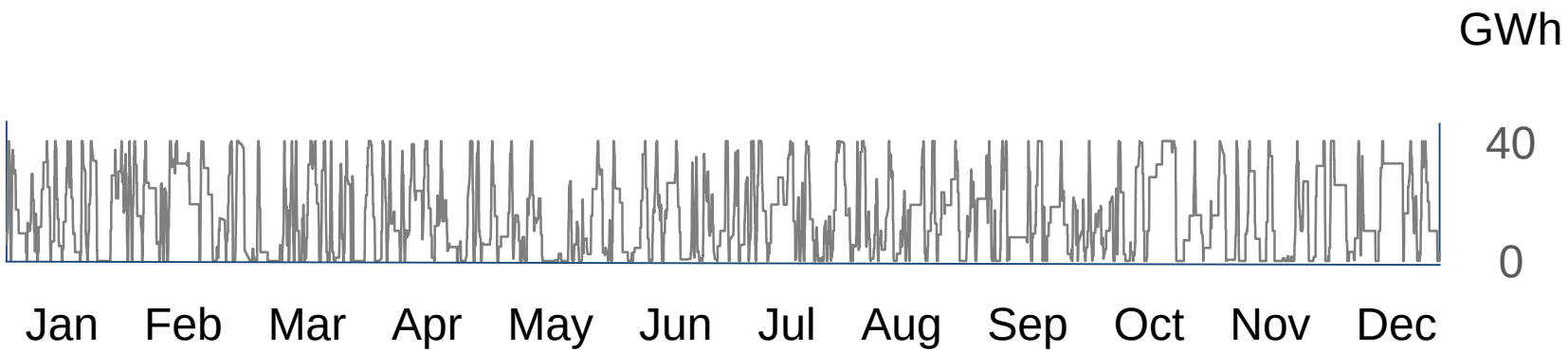
Stored Energy Levels

8760 hours of "2010"

—Peaking Storage



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Stored Energy Levels

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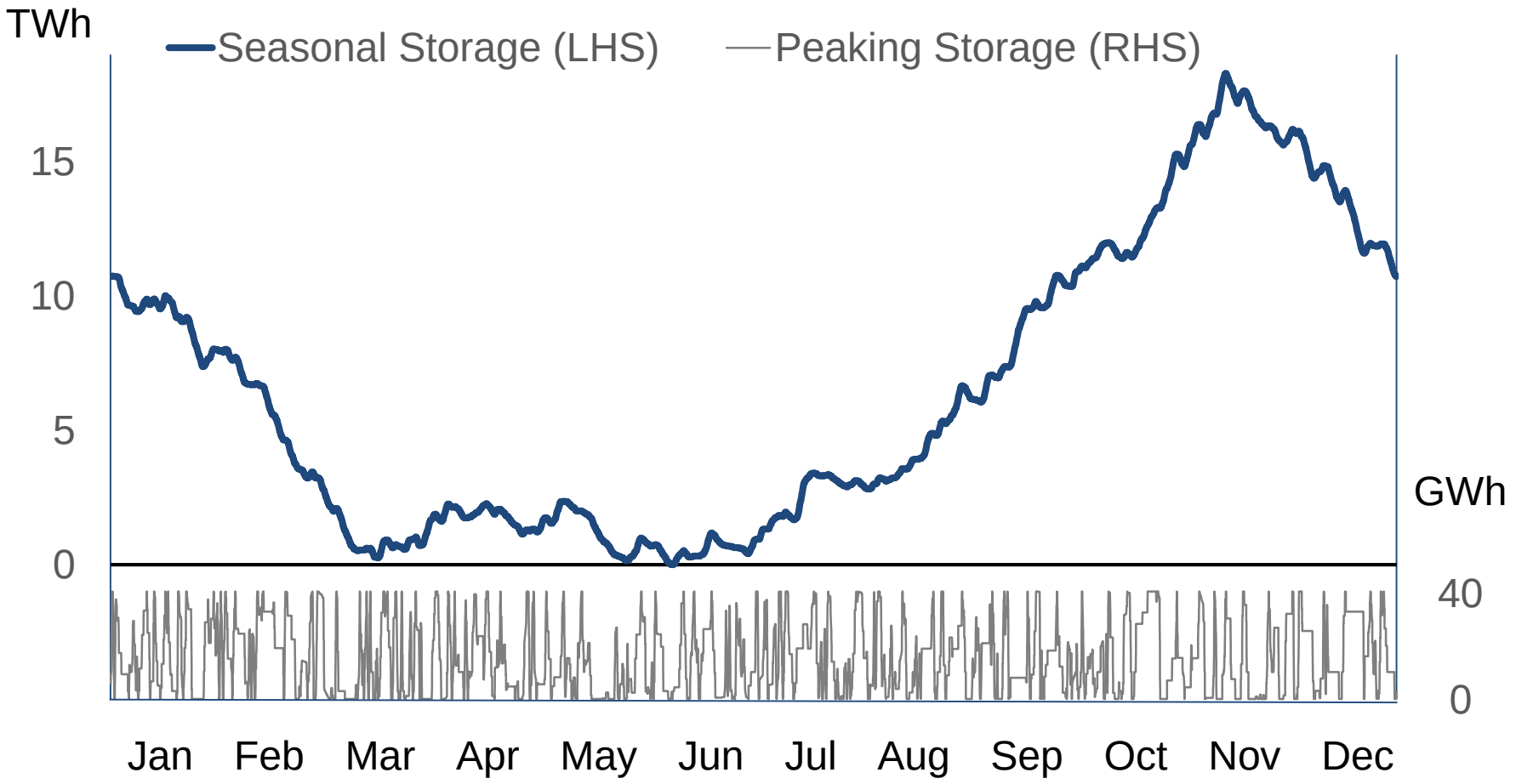

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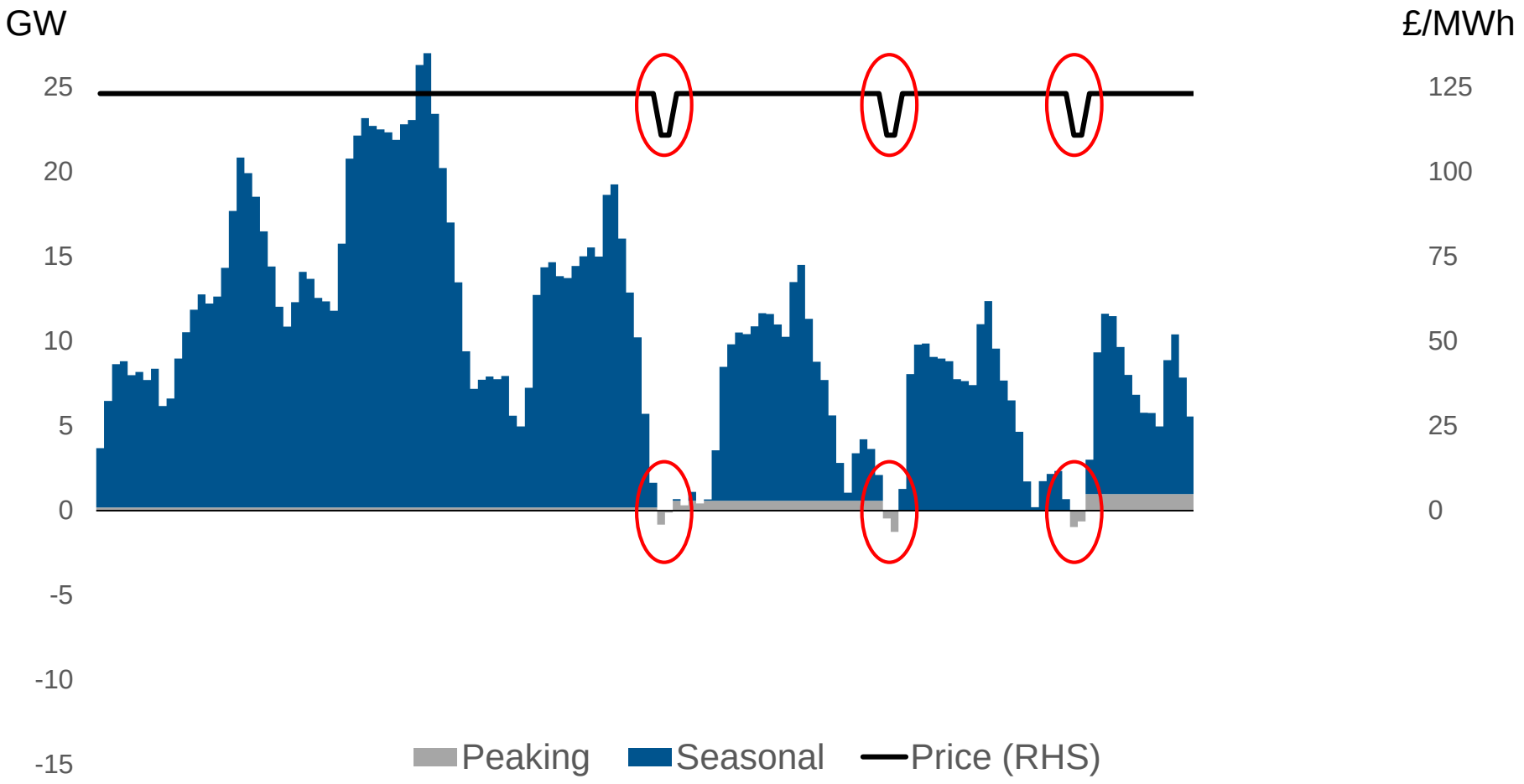
Storage flows and prices

Week 47 of "2010"



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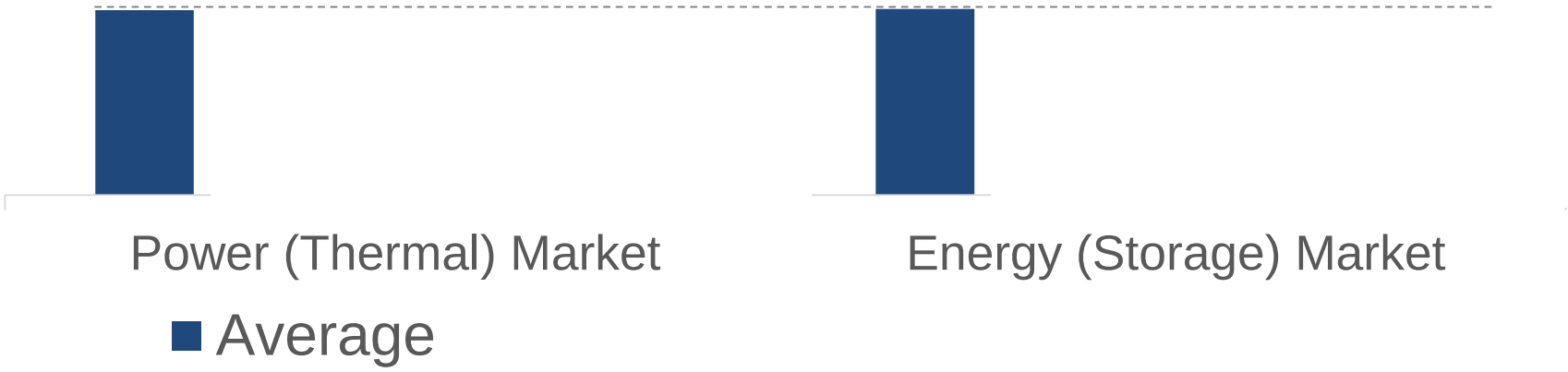
A more level playing field?

Revenues by type of plant



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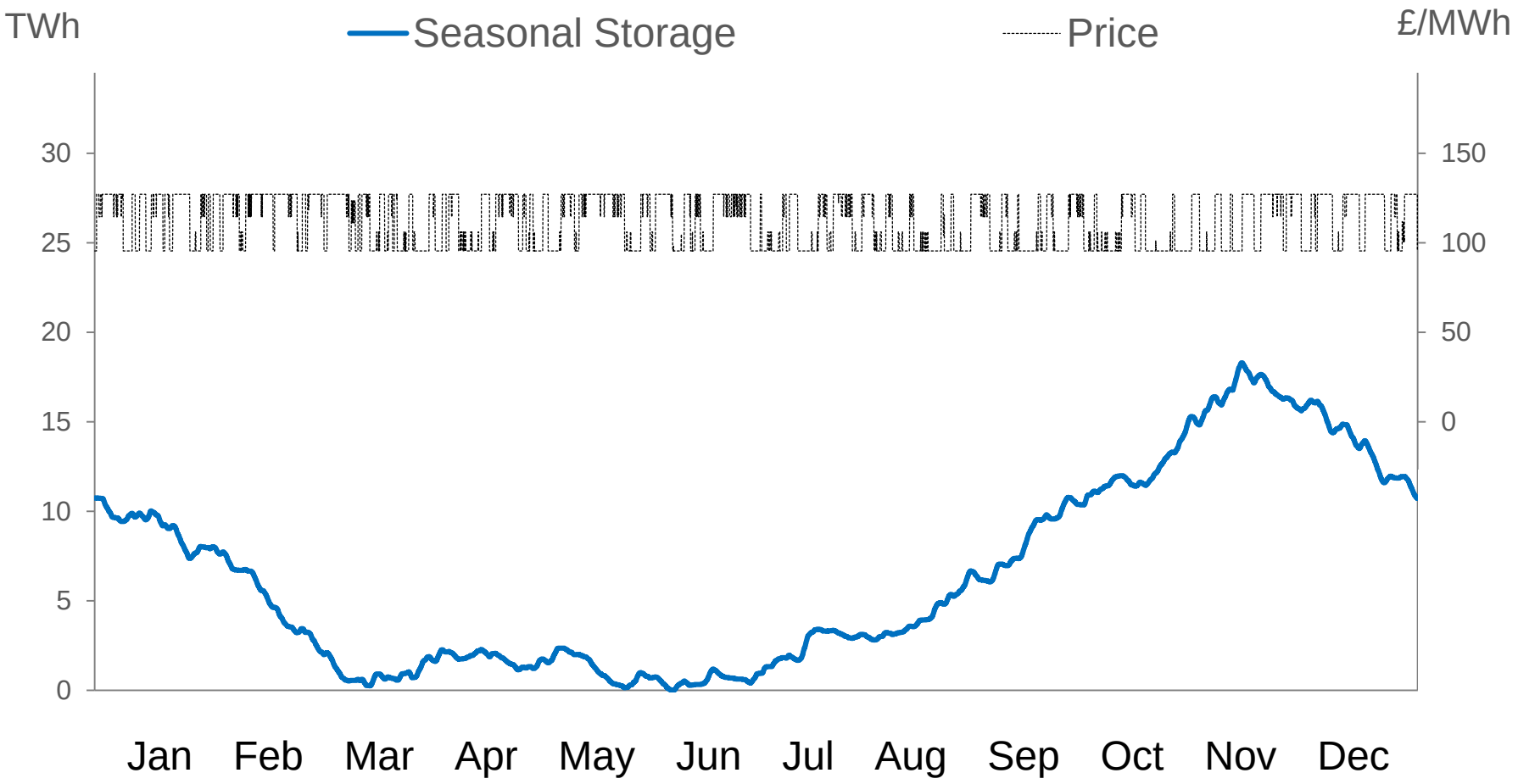
A storage-renewable market

18 TWh or more in "2010"



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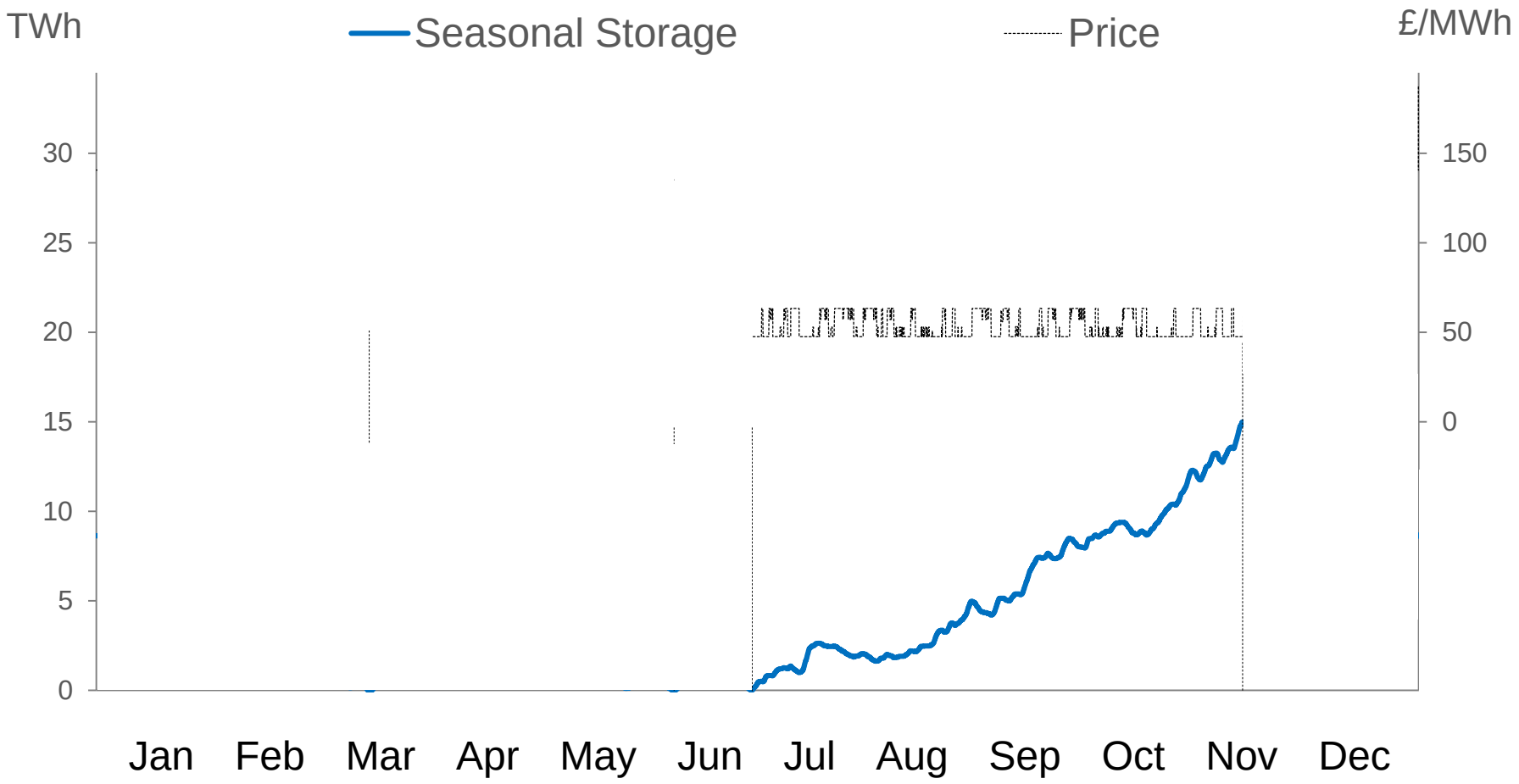
A storage-renewable market

15 TWh capacity in "2010"



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Imperial means Intelligent Business

Beyond the power market

What else can storage do?

(Mostly material from Goran Strbac)

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My model is too simple

- I have ignored:
  - Real-time balancing
  - Uncertainty
  - Transmission constraints
  - Distribution constraints
  - Inertia
- Storage can provide:
  - Balancing energy
  - Reserve
  - T-constraint relief
  - D-constraint relief
  - Fast response

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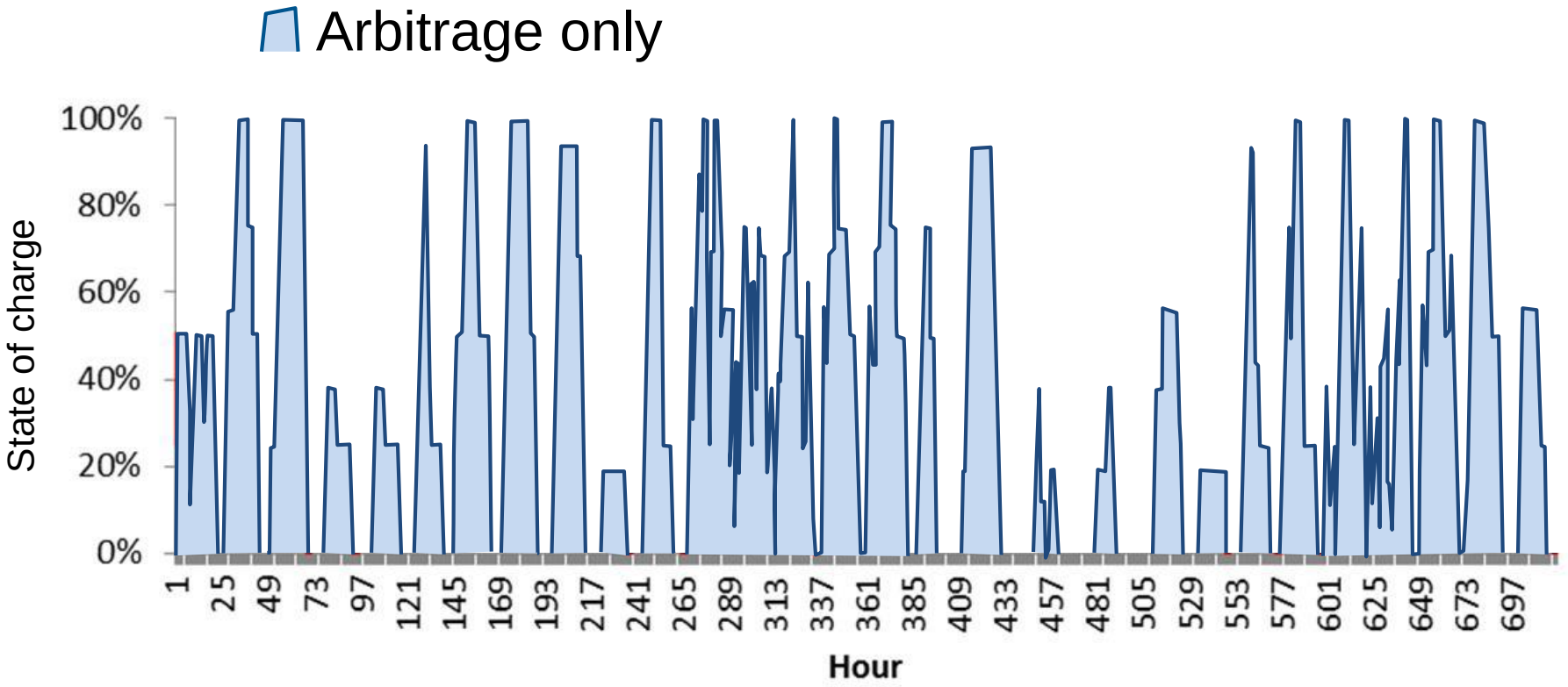
It's profitable to be charged more



Source: Teng, F. and G. Strbac (2016), "Business Cases for energy storage with multiple service provision" *J. Mod. Power Syst. Clean Energy* DOI 10.1007/s40565-016-0244-1

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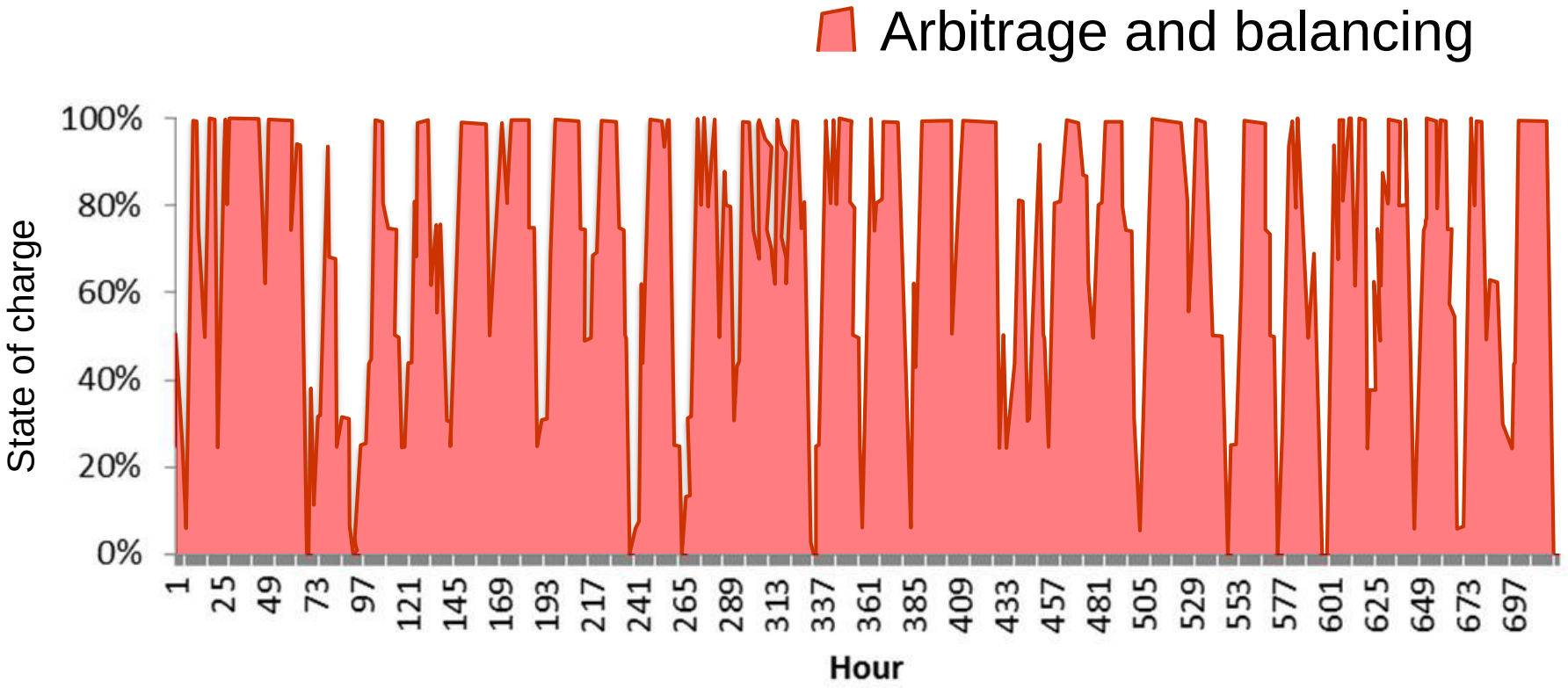

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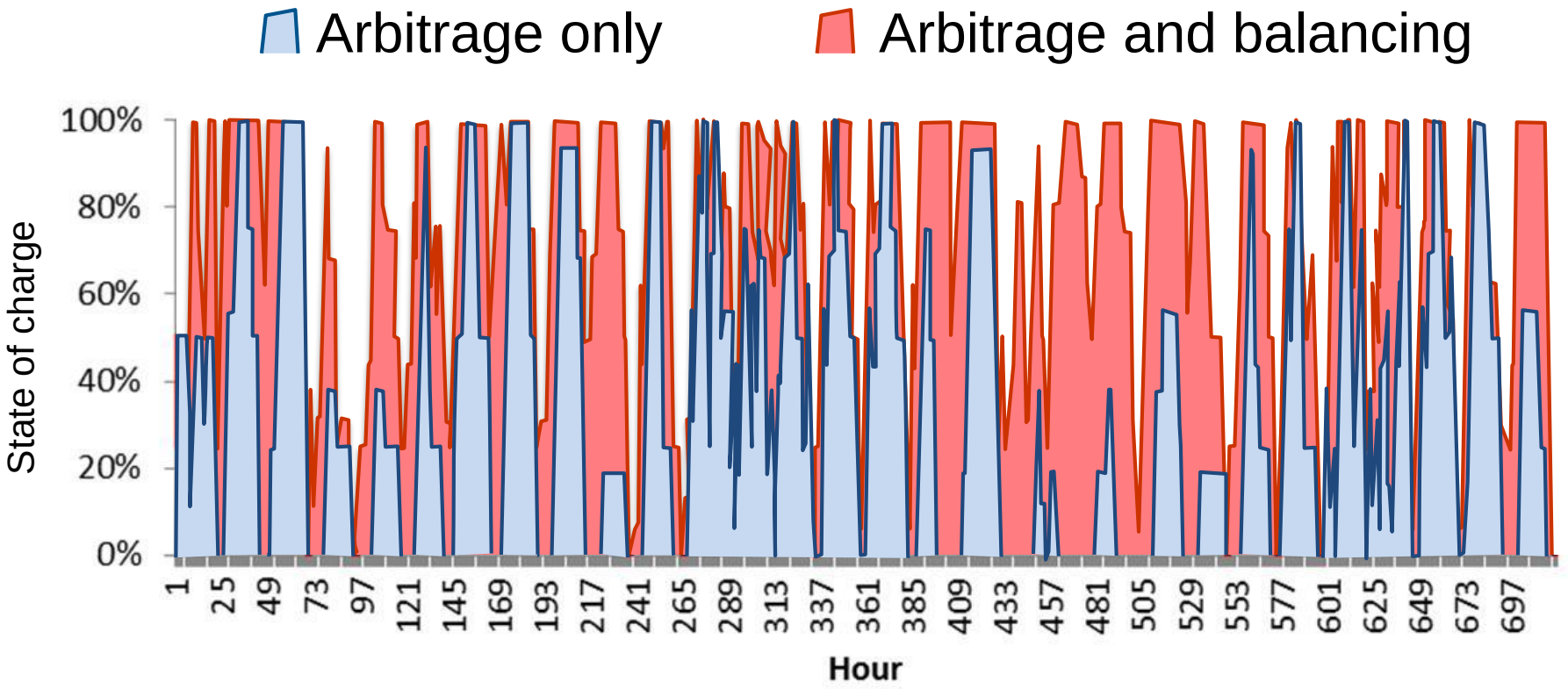

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Whole-system modelling:

multi-service provision by storage

- **Arbitrage**
  - ✓ Participate in day-ahead energy market

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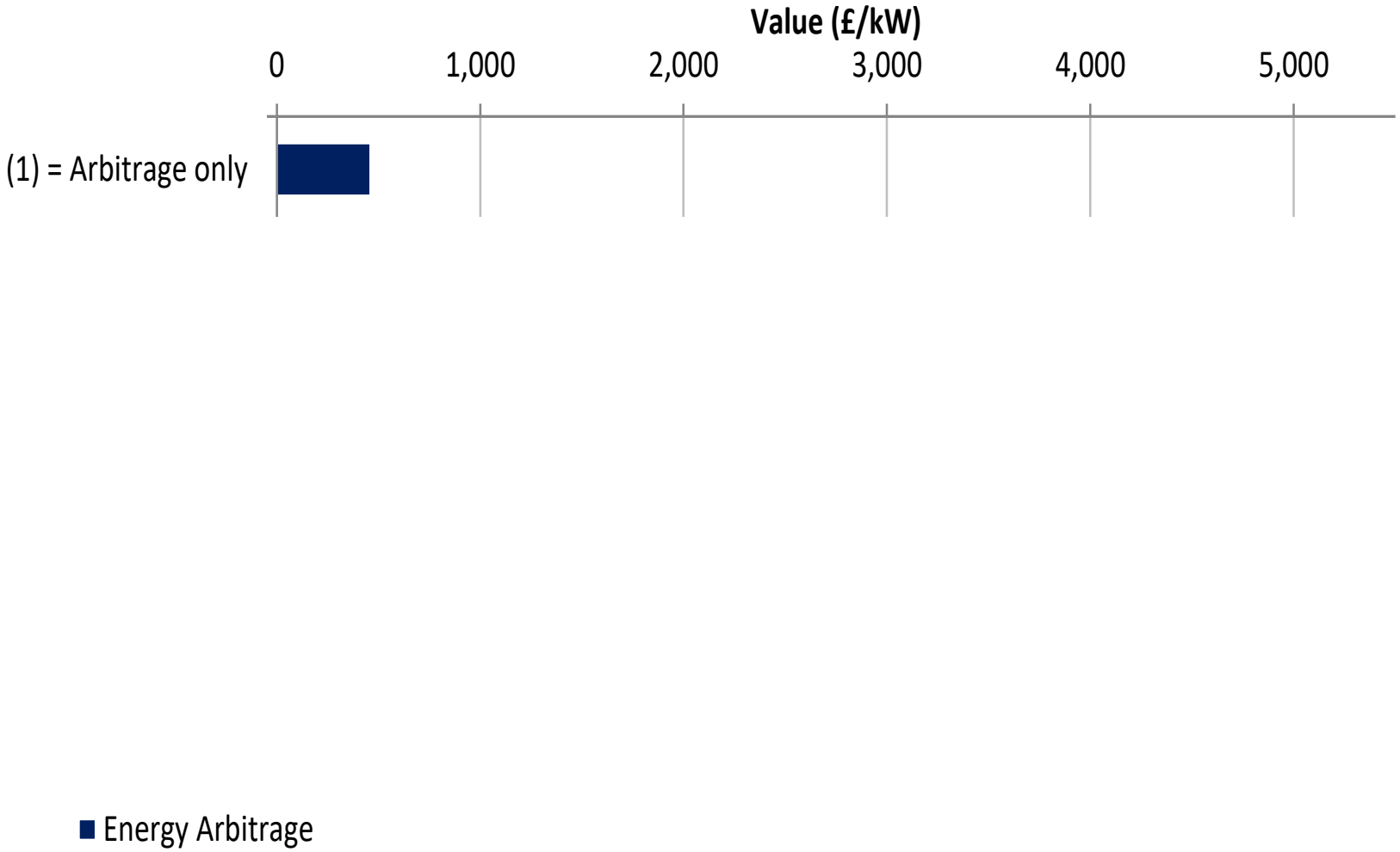
Whole-system value and business case for energy storage



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Whole-system modelling:

multi-service provision by storage

- **Arbitrage**
  - ✓ Participate in day-ahead energy market
- **Balancing services**
  - ✓ Participate in real-time balancing market

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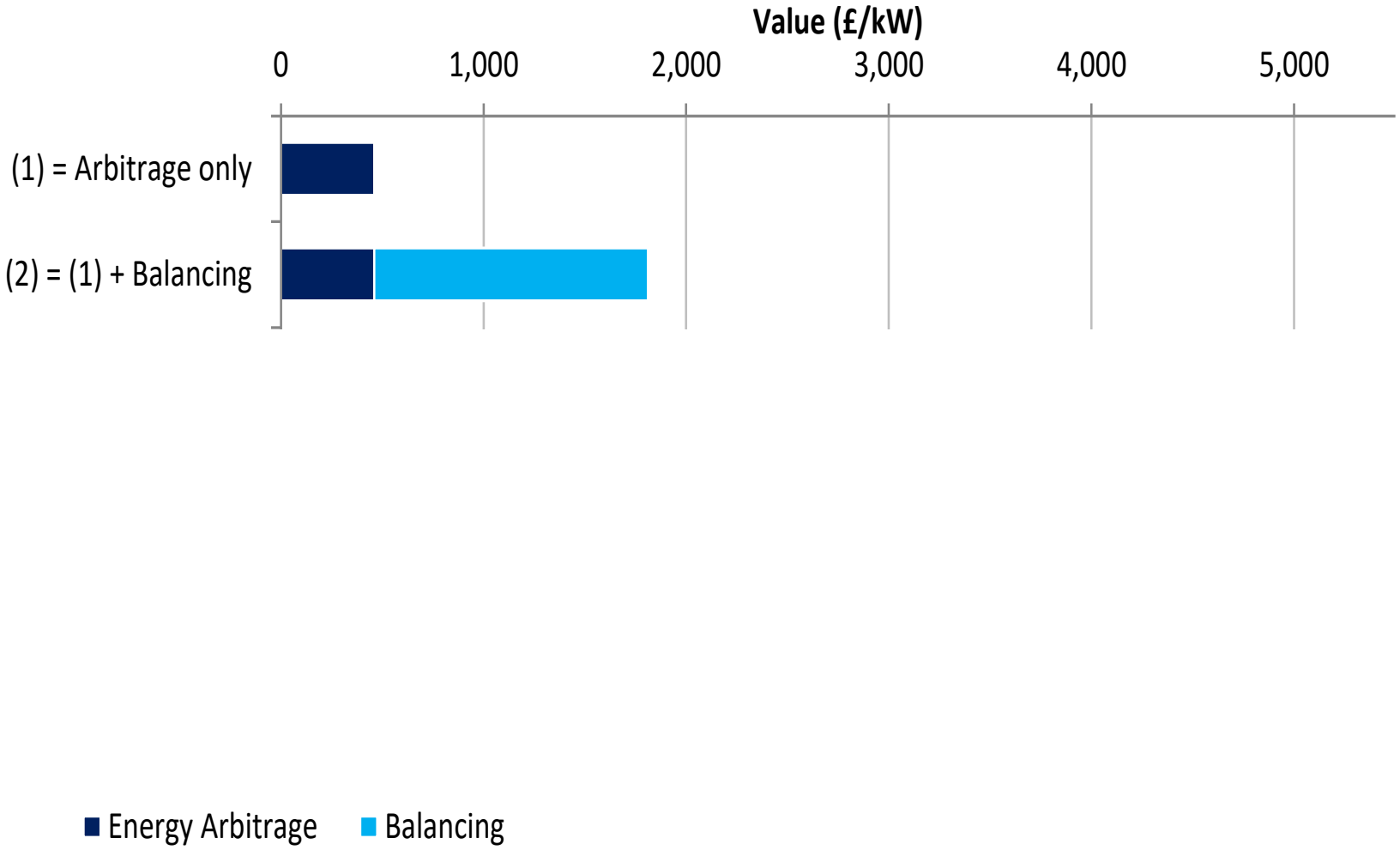
Whole-system value and business case for energy storage:

access to revenues from providing multiple services is critical



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Whole-system modelling:

multi-service provision by storage

- **Arbitrage**
  - ✓ Participate in day-ahead energy market
- **Balancing services**
  - ✓ Participate in real-time balancing market
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  - ✓ Reducing need for T & D network reinforcements

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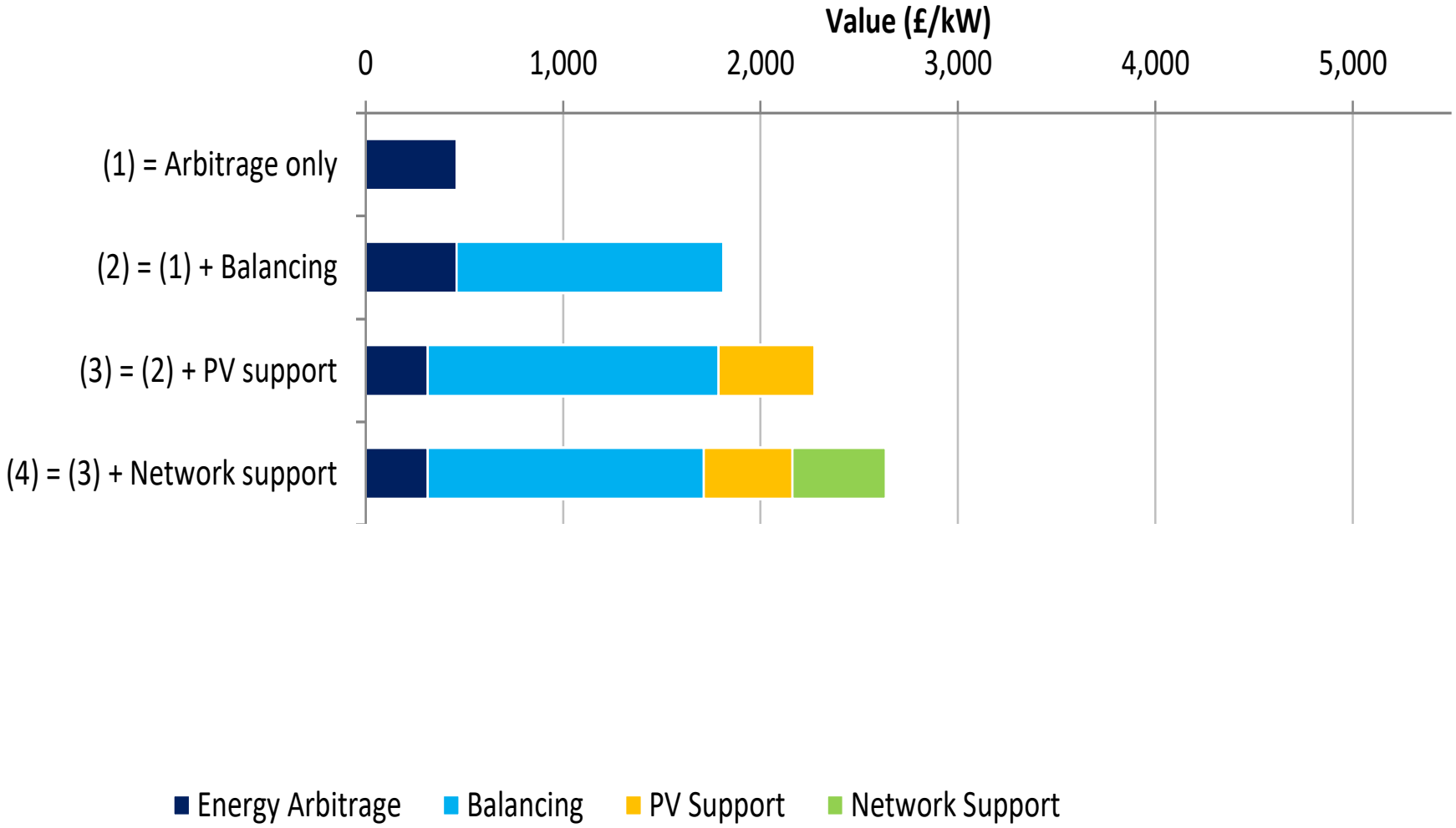

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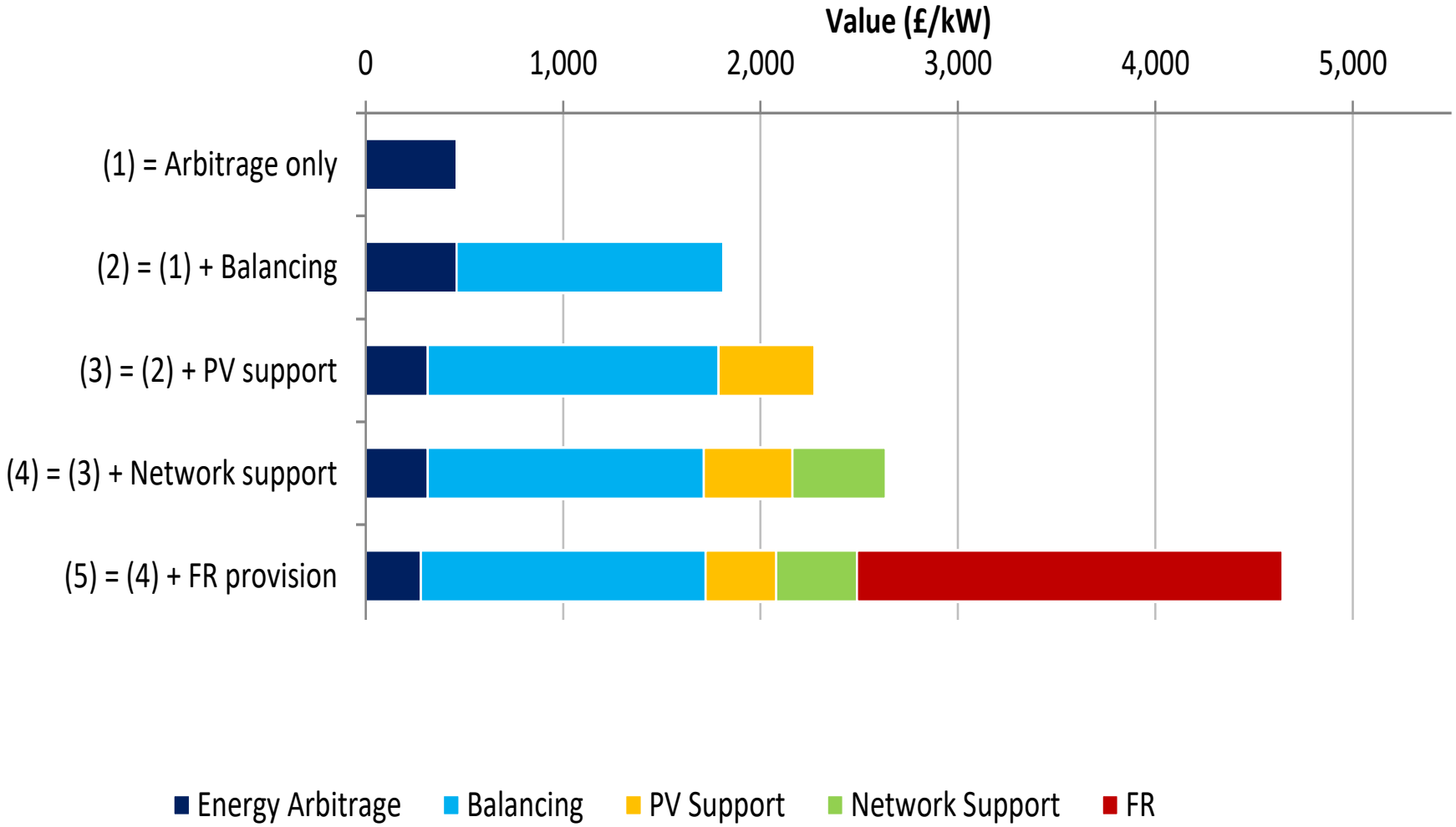

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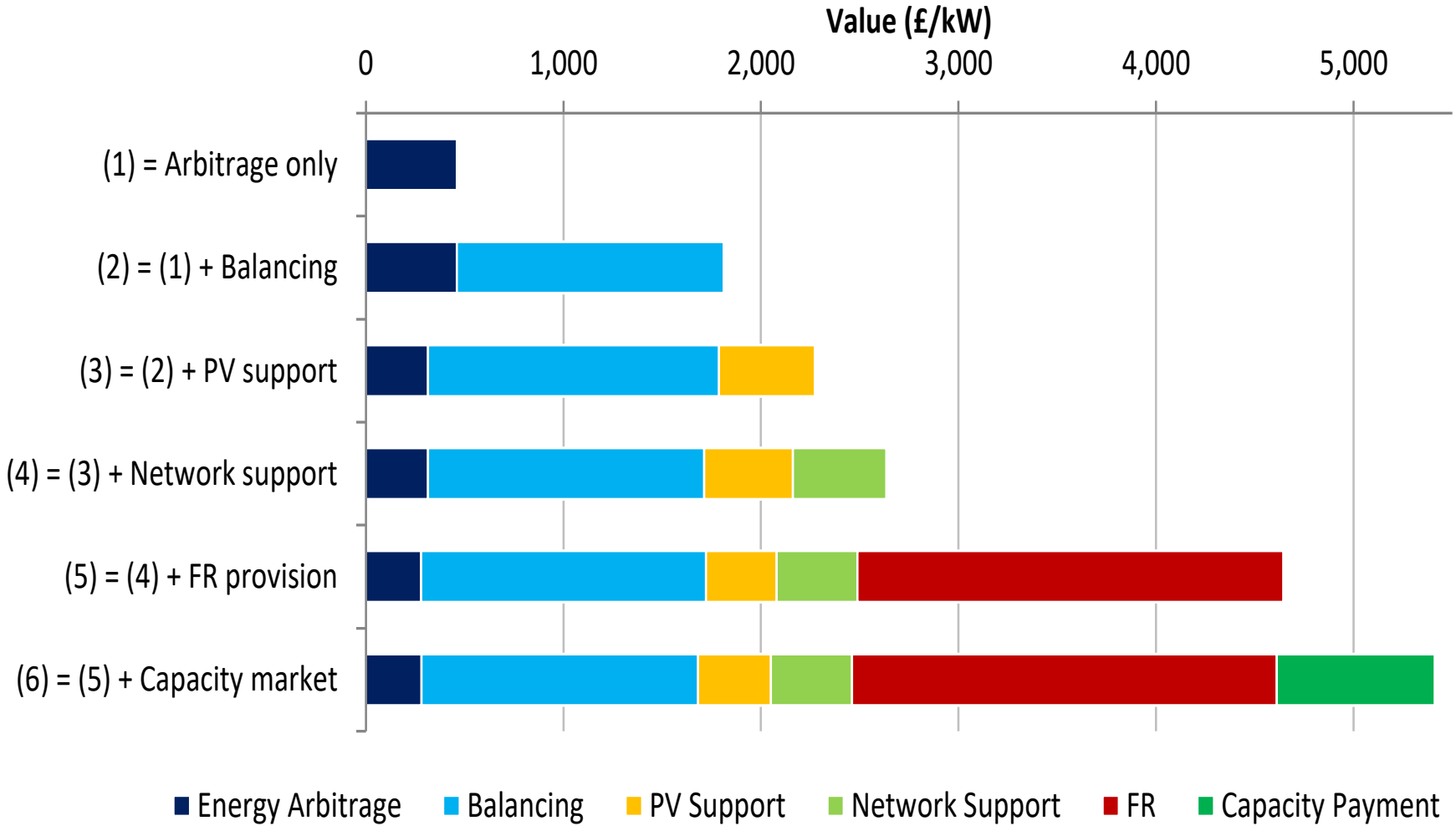

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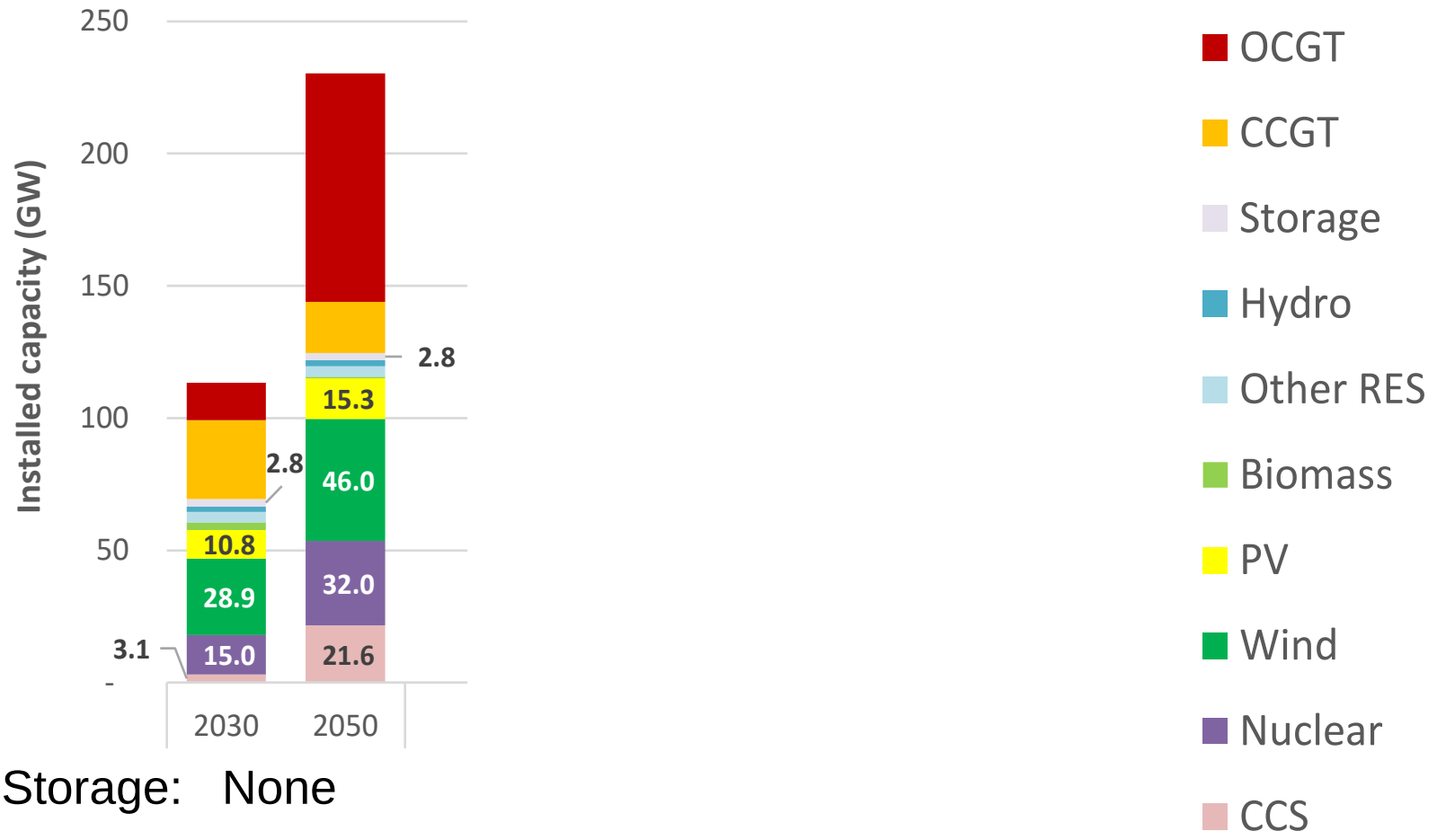
Energy Storage: *hitting CO2 targets of 100 g/kWh in 2030 and 25 g/kWh in 2050*



New Storage: None

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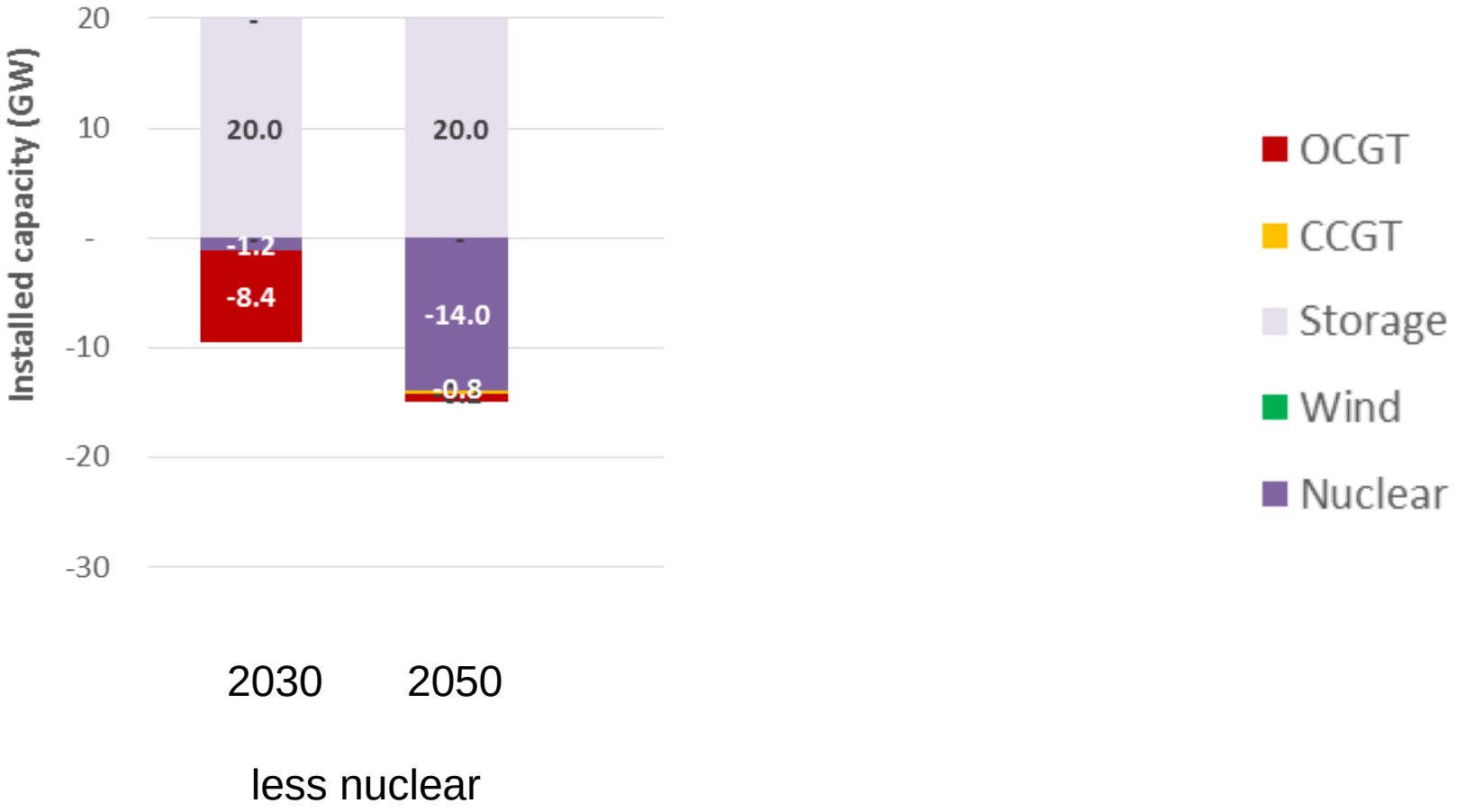
Energy Storage: *hitting CO2 targets with less investment in low carbon generation*

Change in installed capacity if 20 GW of storage added



less nuclear

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- **Option value**
  - ✓ Providing flexibility to deal with uncertainty

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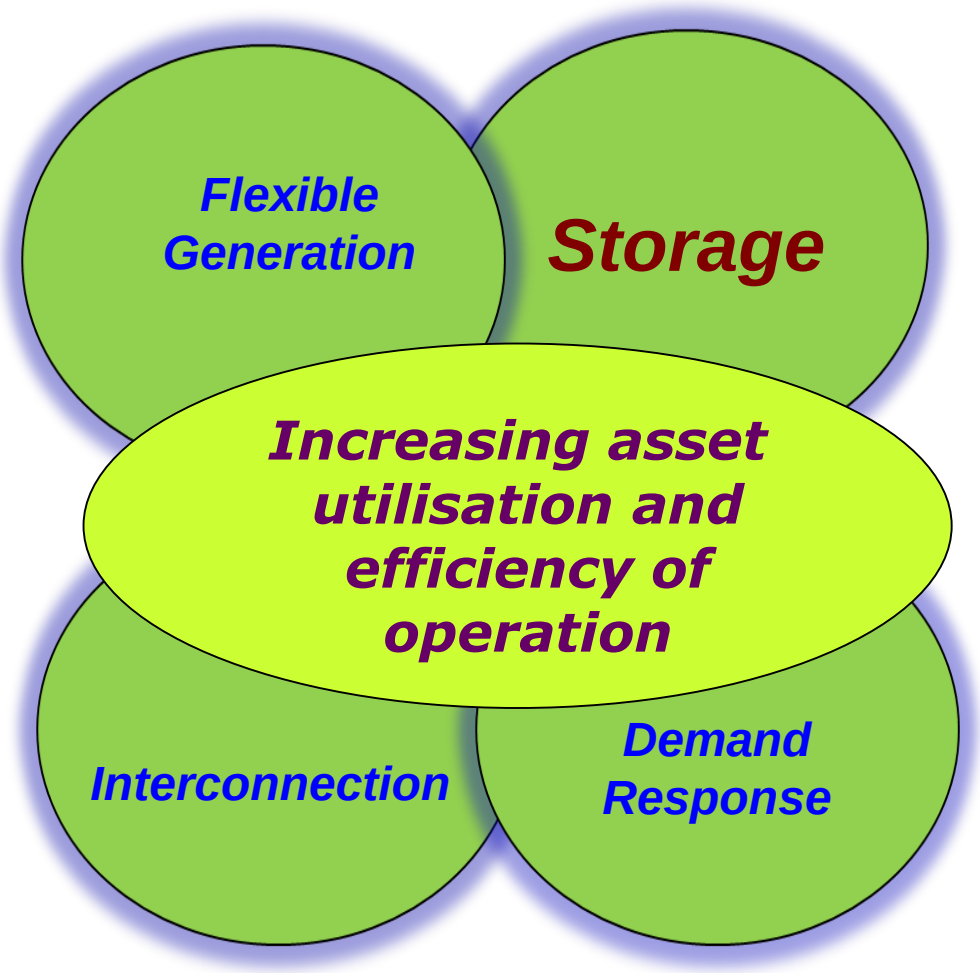
What about the competition for energy storage?



Cost effectiveness of alternative technology options are system specific

Comprehensive whole-system analysis carried out:

(1) Assessing the performance and cost targets for alternative flexible technologies

(2) Understanding the competitiveness and synergies between alternative flexible technologies

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Key findings

- Significant role of ES in facilitating cost effective transition to low carbon energy system
- Cost-efficient deployment of new ES in the UK in 2030 may reach nearly 20 GW if it is available at low cost; however, DSR represents a key competitor that could limit the business case for ES
- ES can provide a range of system services such as balancing, security of supply (local and national level), managing uncertainties (option value)
- We need regulations and market rules that capture the value of as many of these as possible

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Imperial means Intelligent Business

UKERC

Thanks to:

Research Councils UK Energy For a Low Carbon Future

EPSRC Engineering and Physical Sciences Research Council

Corporate Renewable Procurement: Opportunities in India

- **Online executive education programme** led by faculty from Imperial College Business School in partnership with the Confederation of Indian Industries

- **Invitation-only and free** to selected participants; enrolment capped at 30 individuals comprising a diverse mix of corporates, utilities, financiers, policymakers and regulators

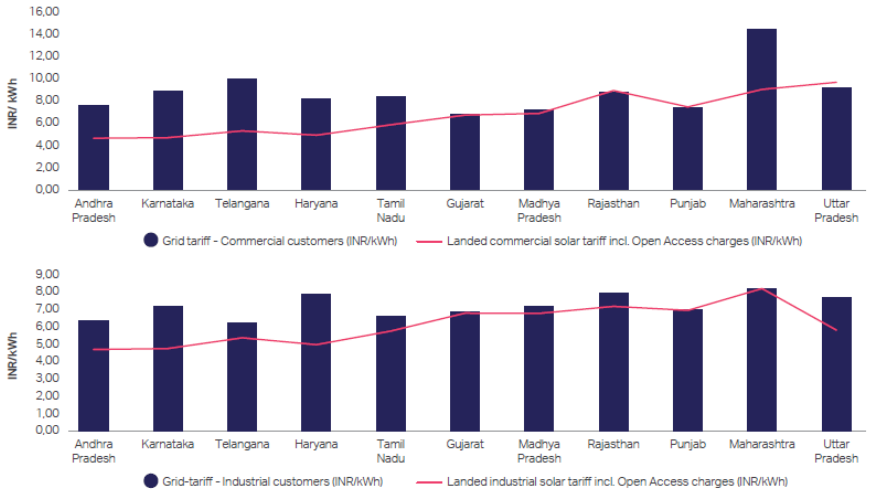
- Participants to develop the skills to **expand corporate renewable power use in India** and collaborate on solutions to overcome obstacles

- Selected **case studies and industry guest speakers**

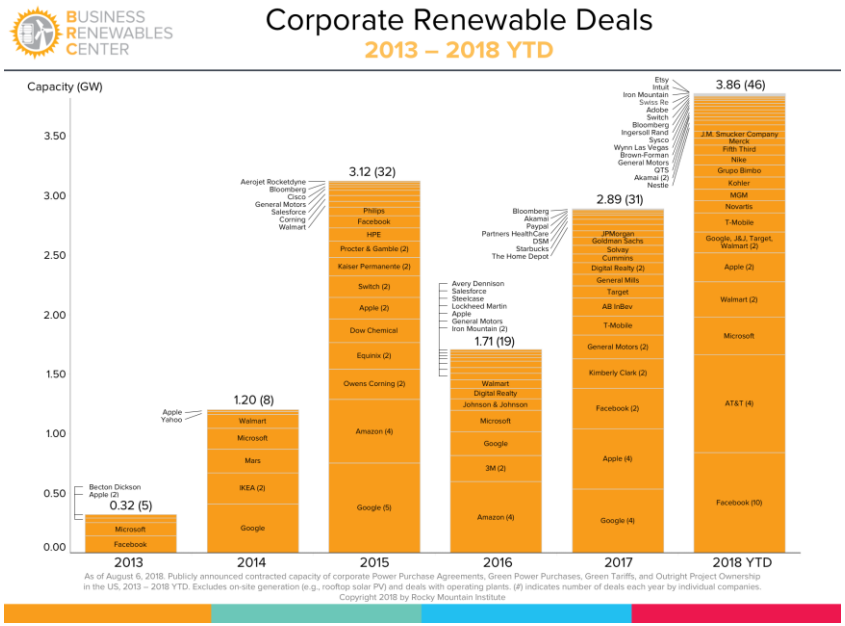
Why Are We Doing This Course?

1. **<u>Corporate renewable procurement is growing</u>** in various parts of the world, thanks to a strong economic case

Figure 1:
Landed solar tariffs vs. grid tariffs for commercial and industrial companies[6]



Source: World Business Council for Sustainable Development



Business Renewables Center

2. **<u>Policy push in India</u>**, ambitious 175GW total / 40GW rooftop target

3. **<u>Strong interest from industry and involvement of local partners (CII)</u>**

Practical Details

- **Starts**: 12 November 2018

- **Participants**: 30 from diverse occupations, including regulators

  "Senior enough to matter, junior enough to have time to participate"

- **Commitment required**: ~5 hours per week over 4 weeks

- **Outcome**: knowledge, community and Imperial College London certificate of completion

- **Cost**: Free, thanks to a grant from Children Investment Fund Foundation

- **Get in touch**:
  - **lowcarbonpowerhub@imperial.ac.uk**
  - Dr Charles Donovan, Course Leader <**c.donovan@imperial.ac.uk**>