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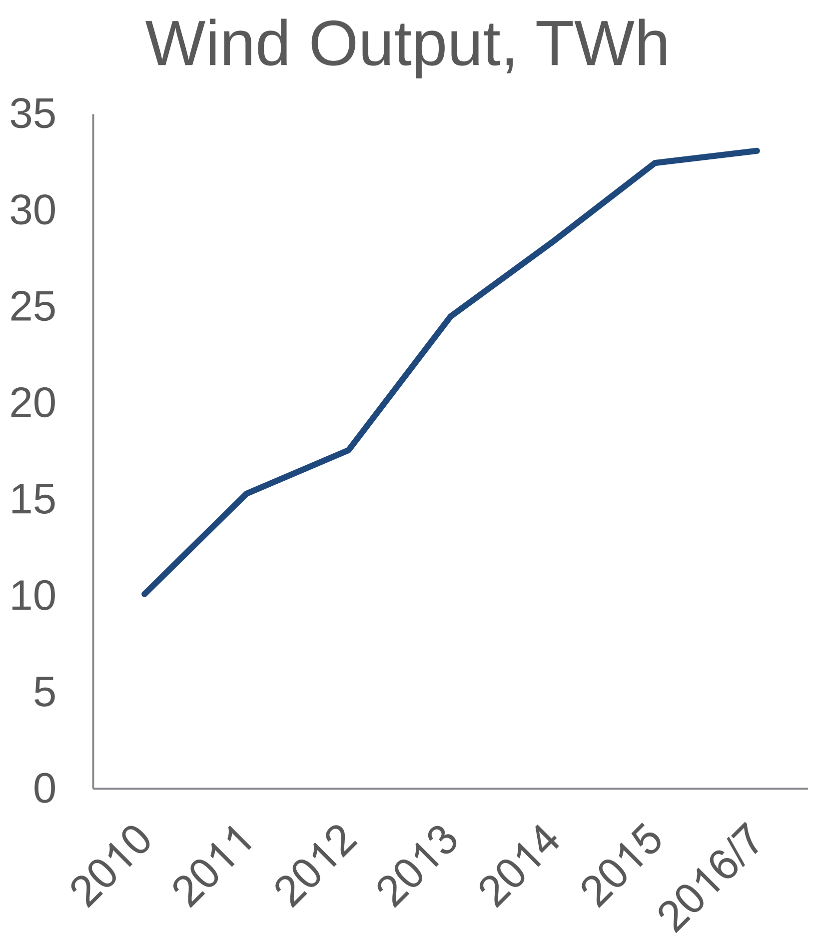
Intelligent Business

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?

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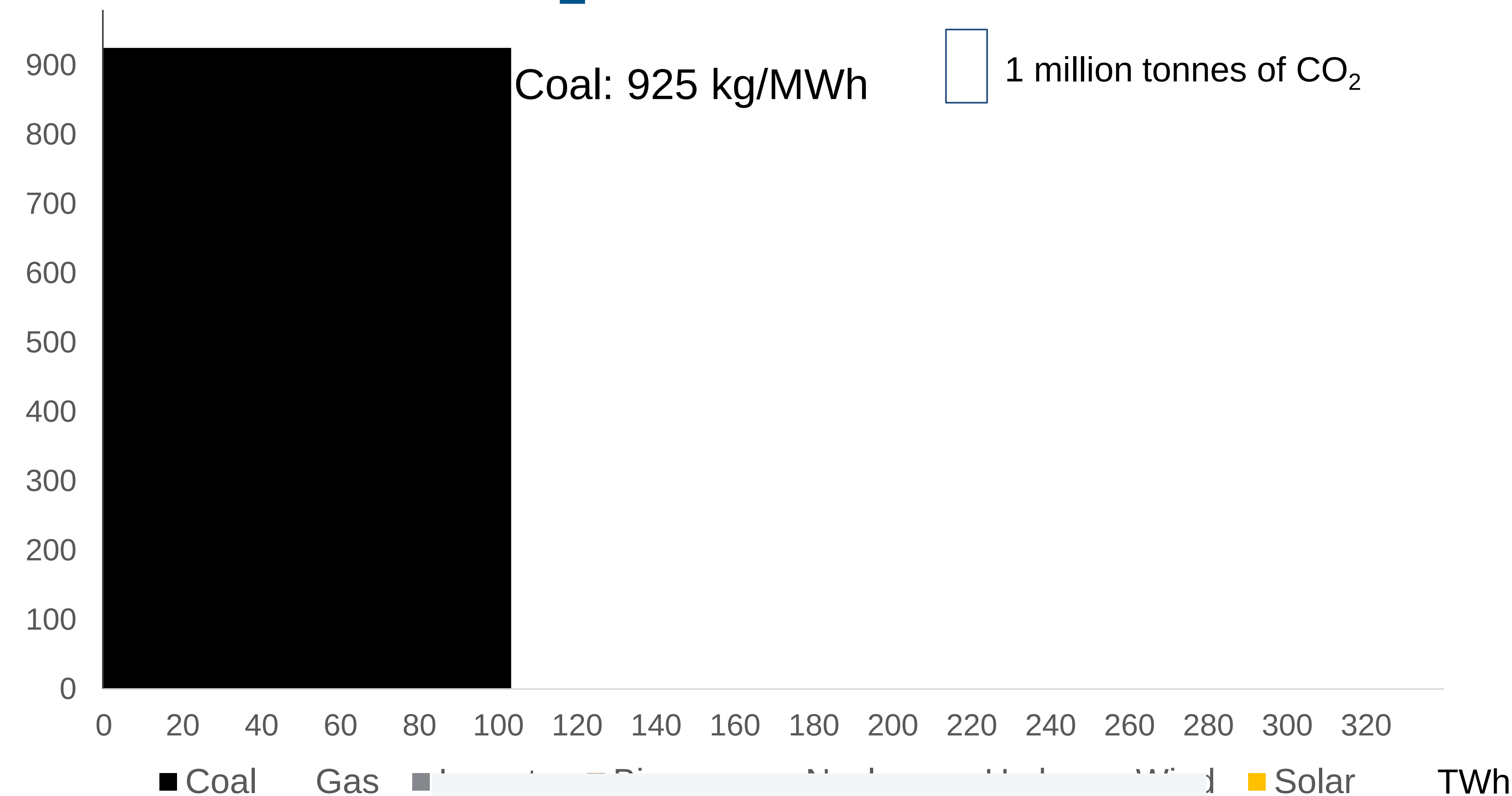
Electricity Generated and CO_2 emissions in GB, 2010



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

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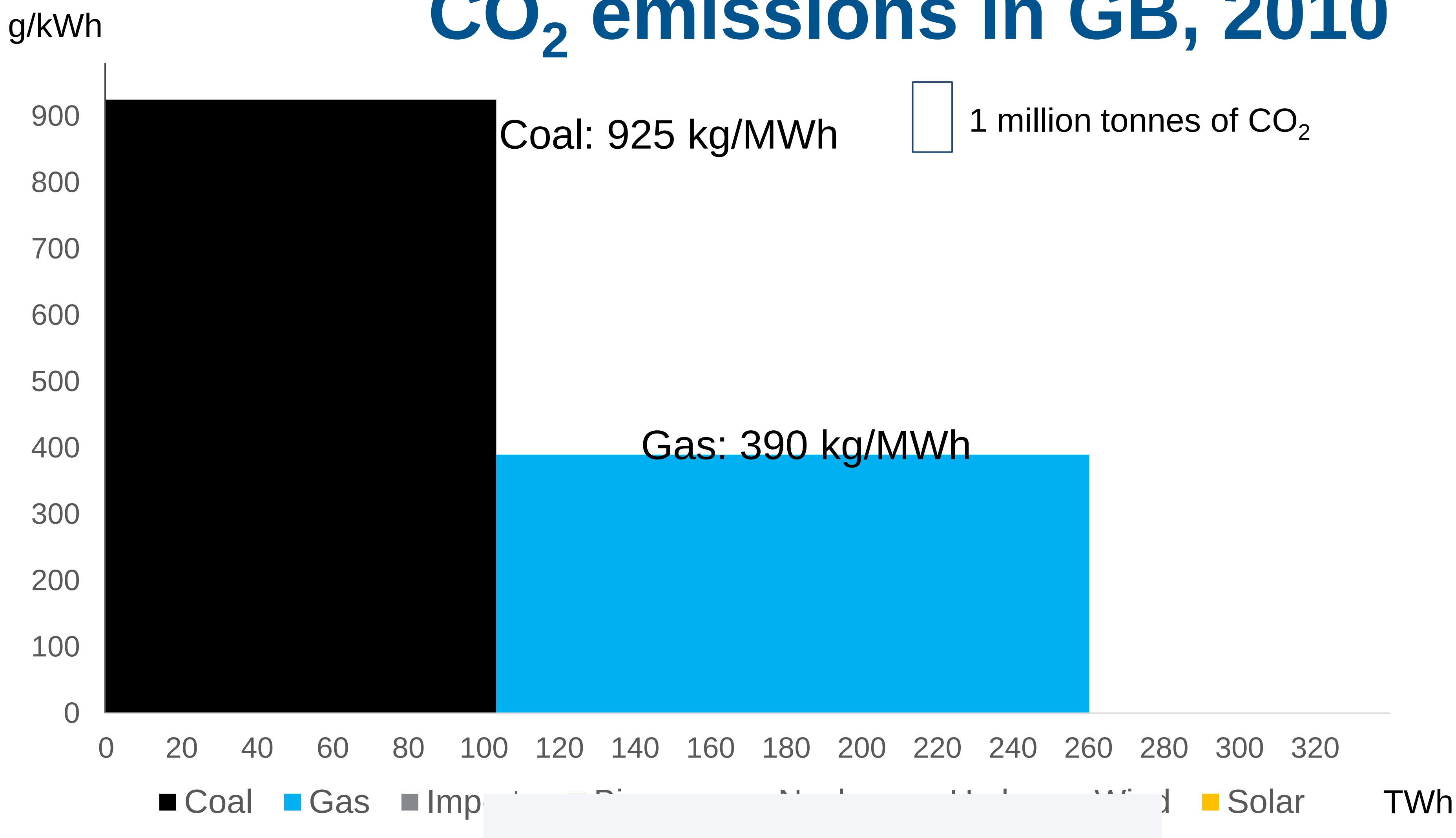

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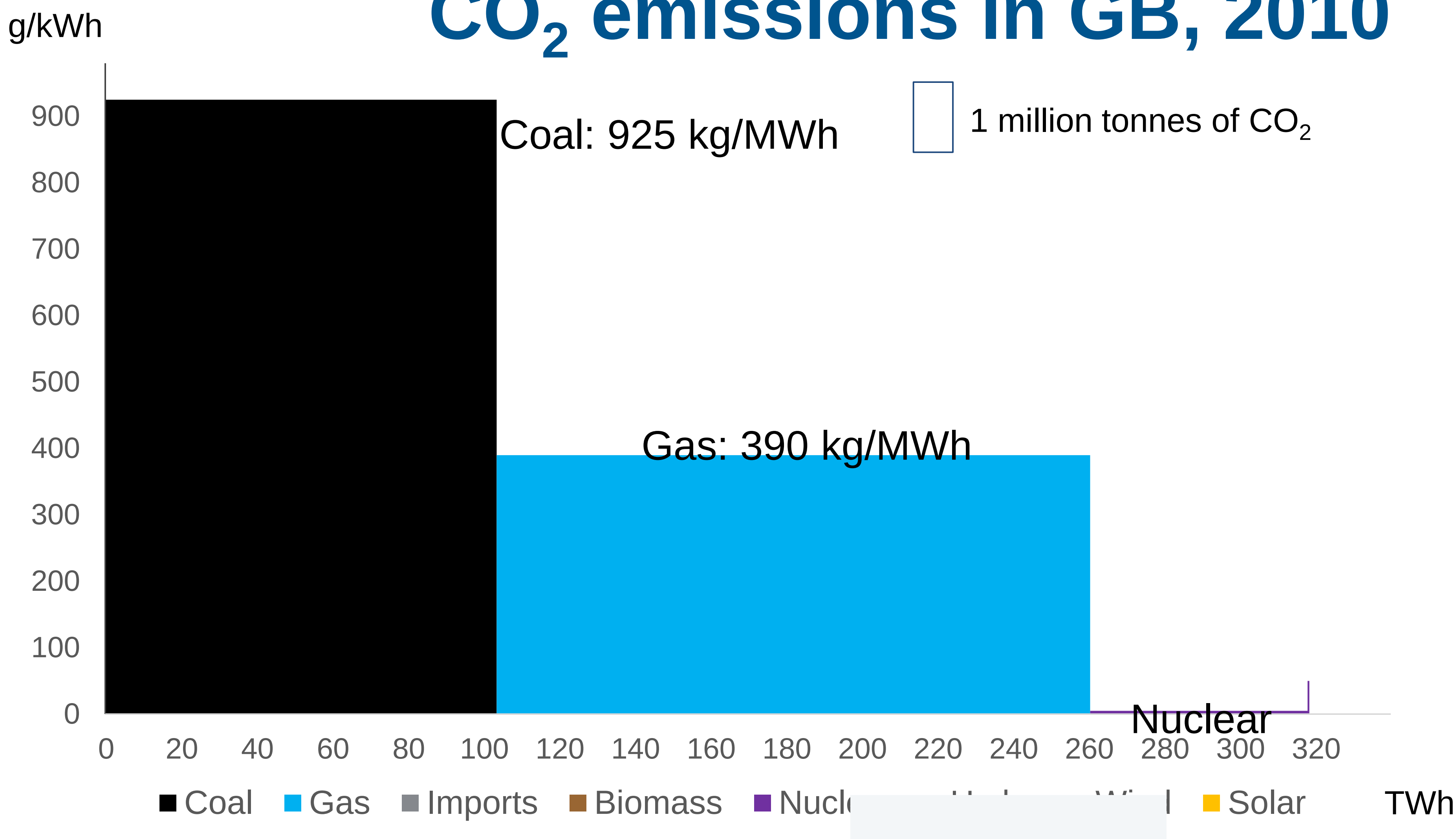

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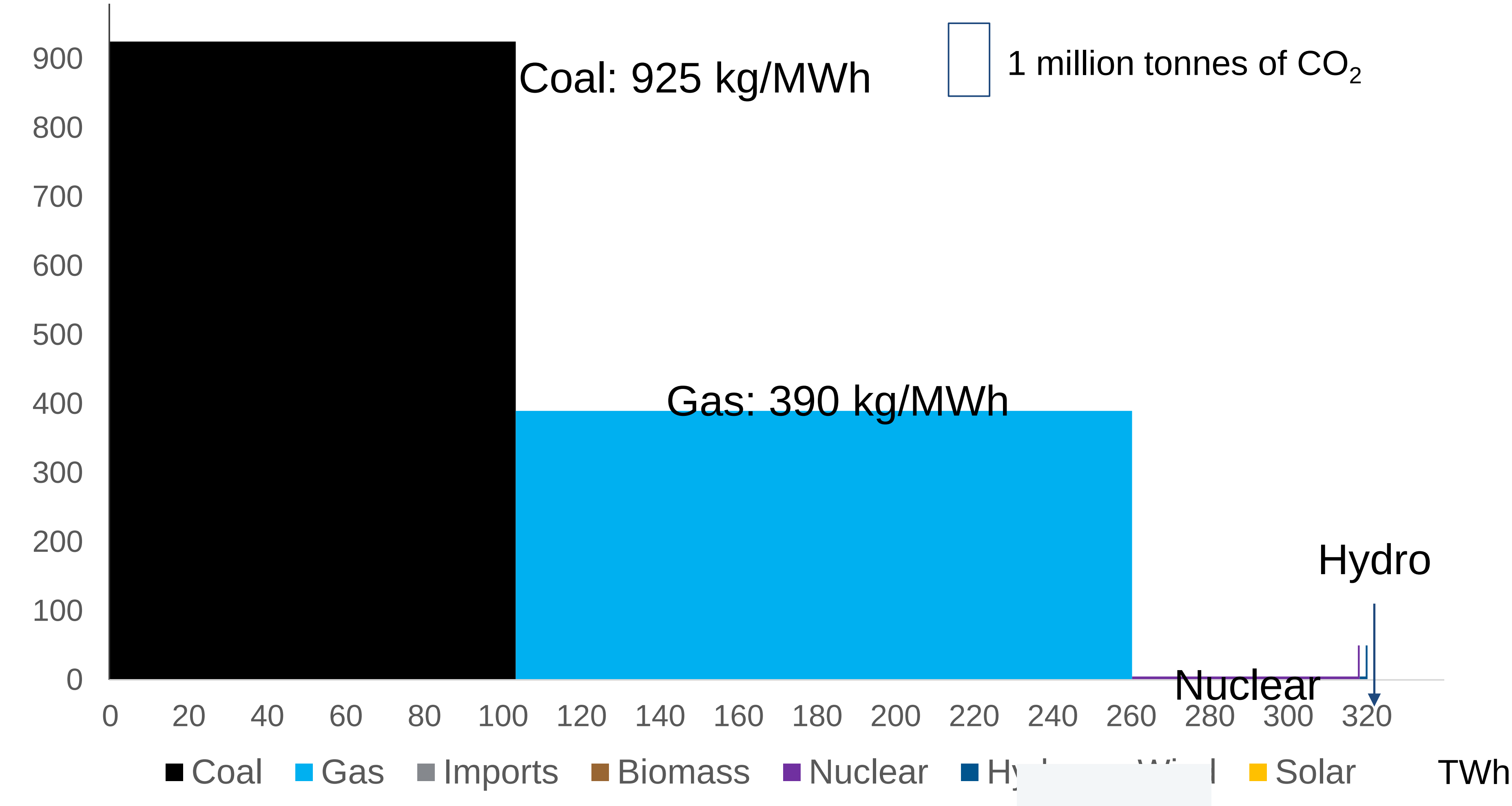

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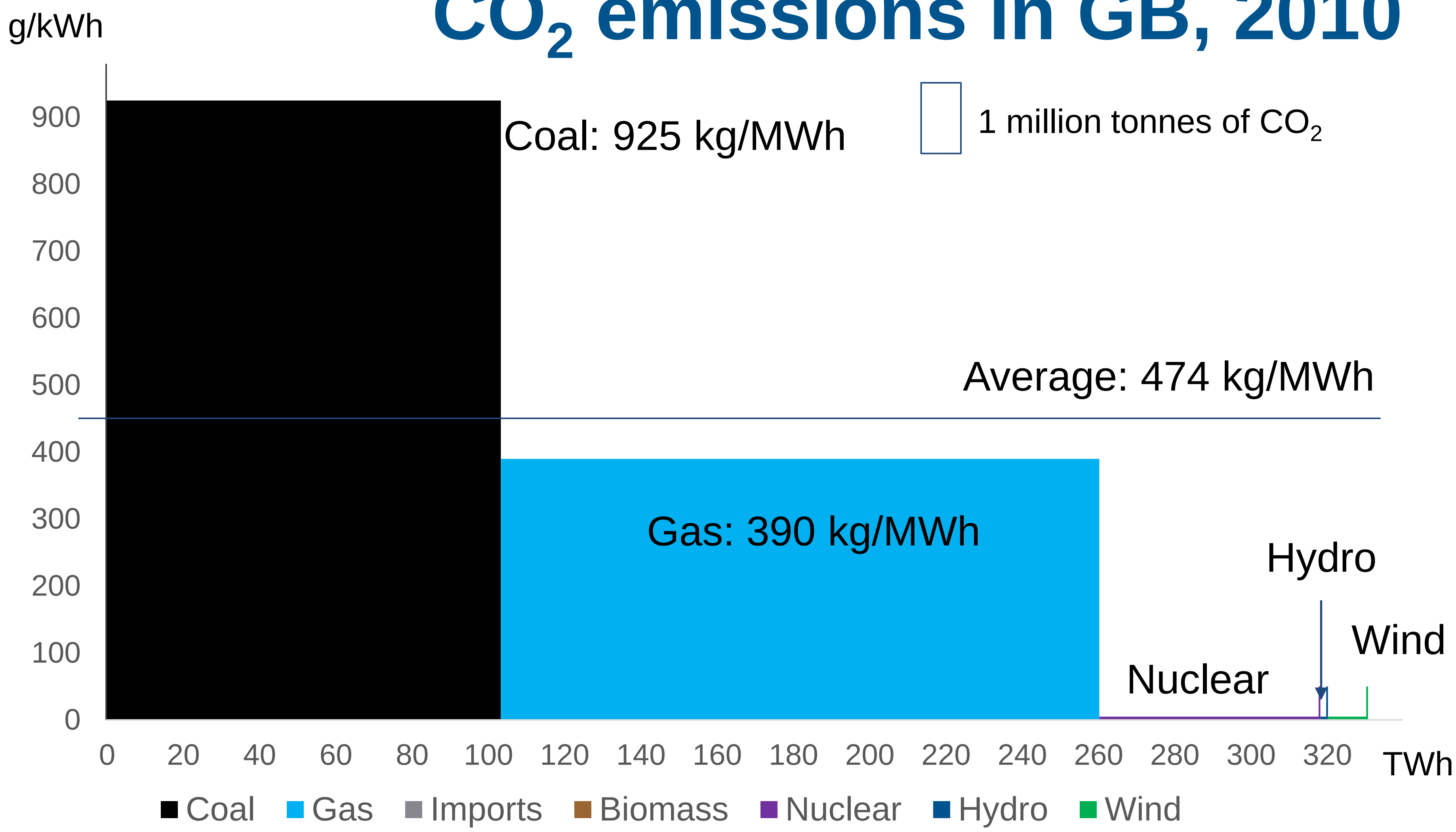

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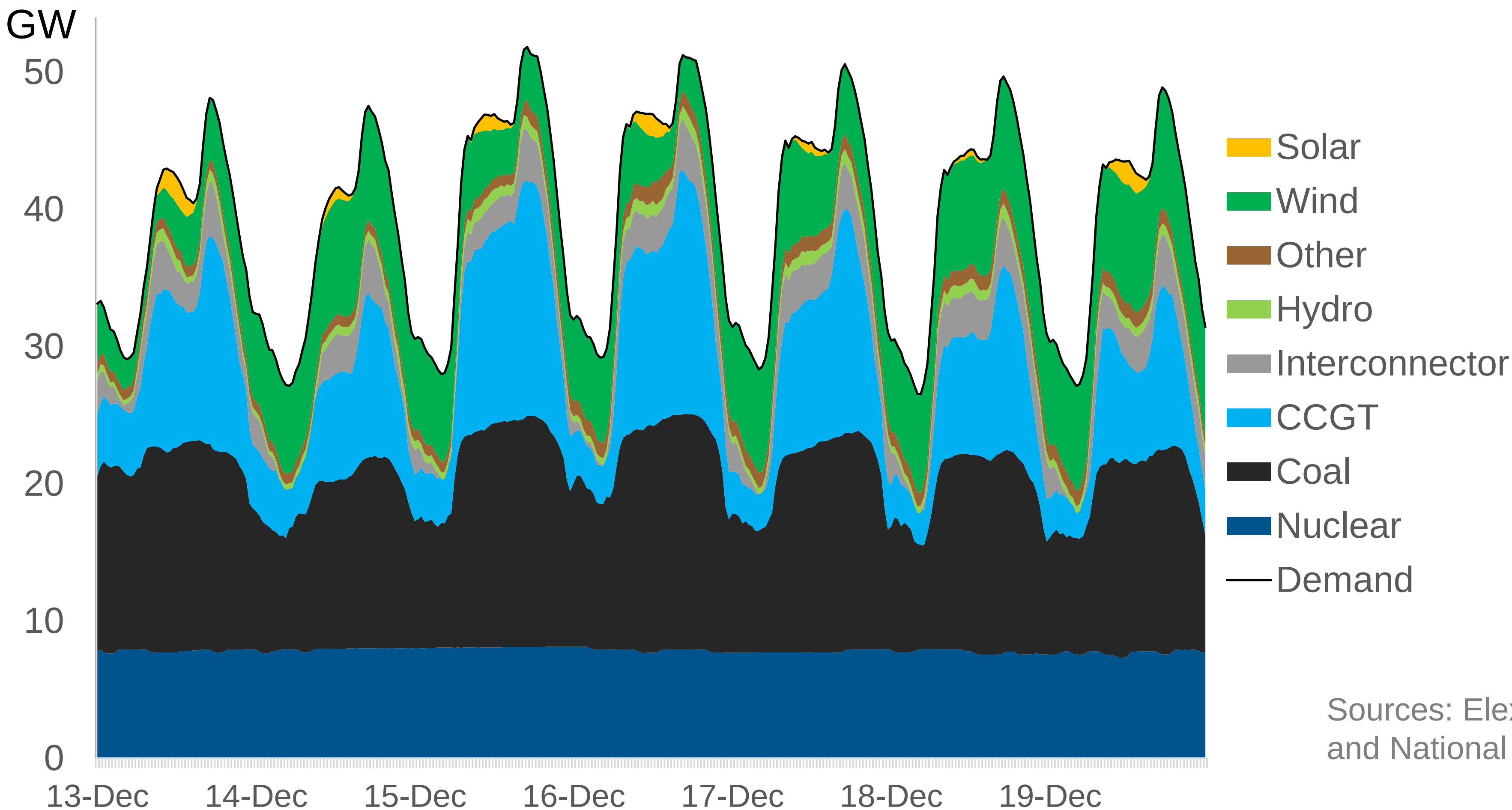
Generation in Great Britain

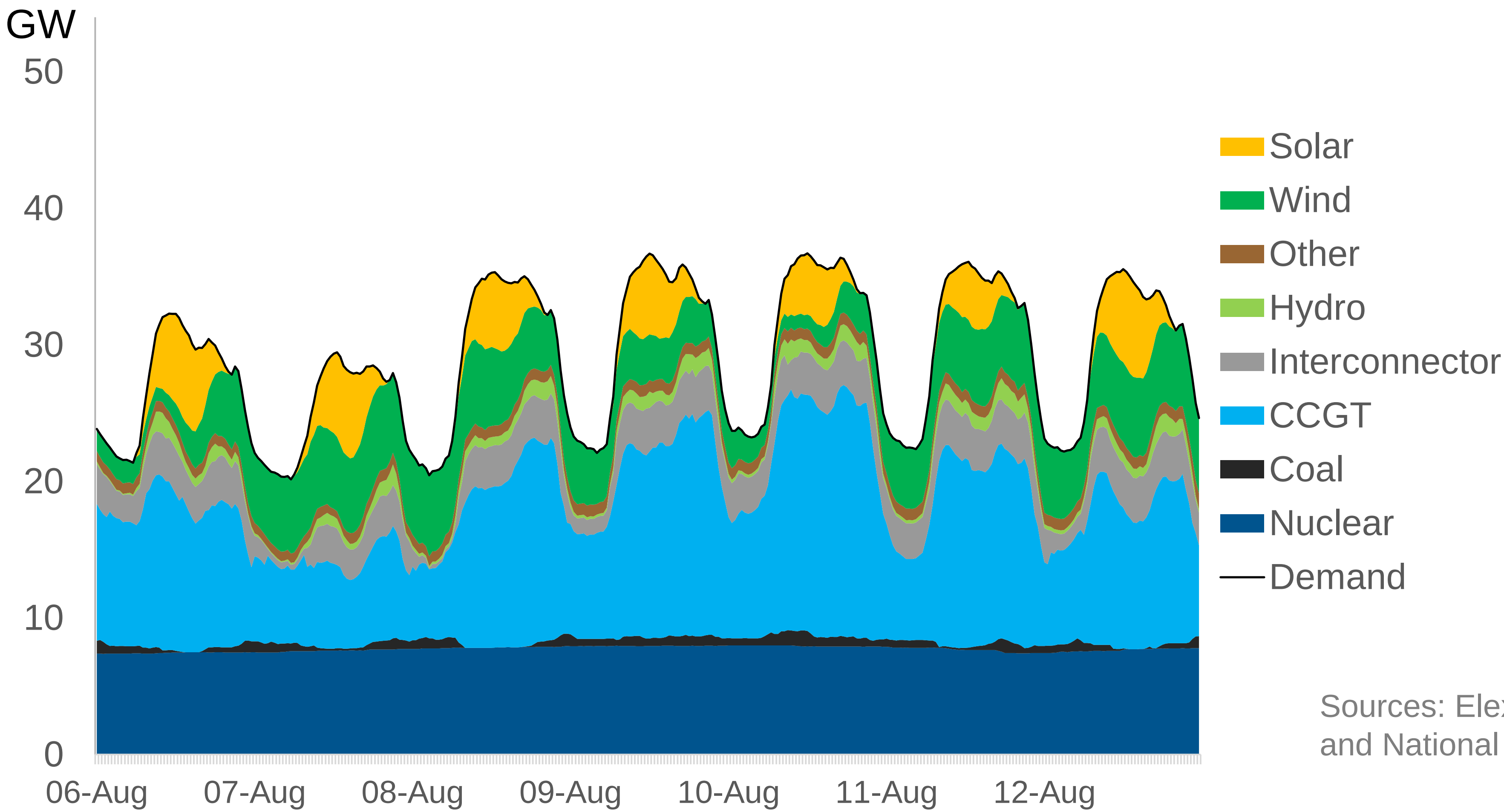
13-19 December 2014



Sources: Elexon and National Grid

Generation in Great Britain

6-12 August 2016



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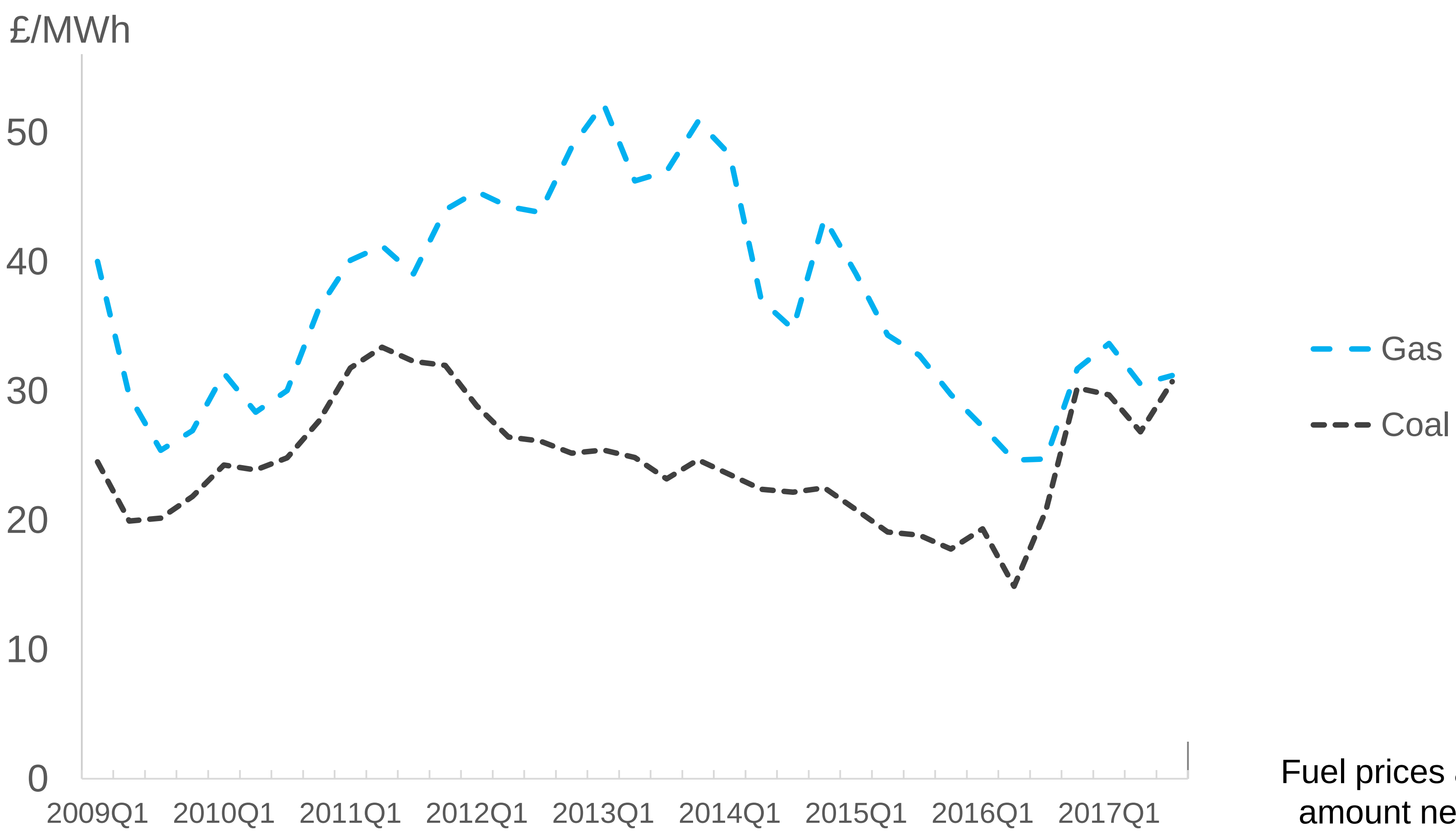
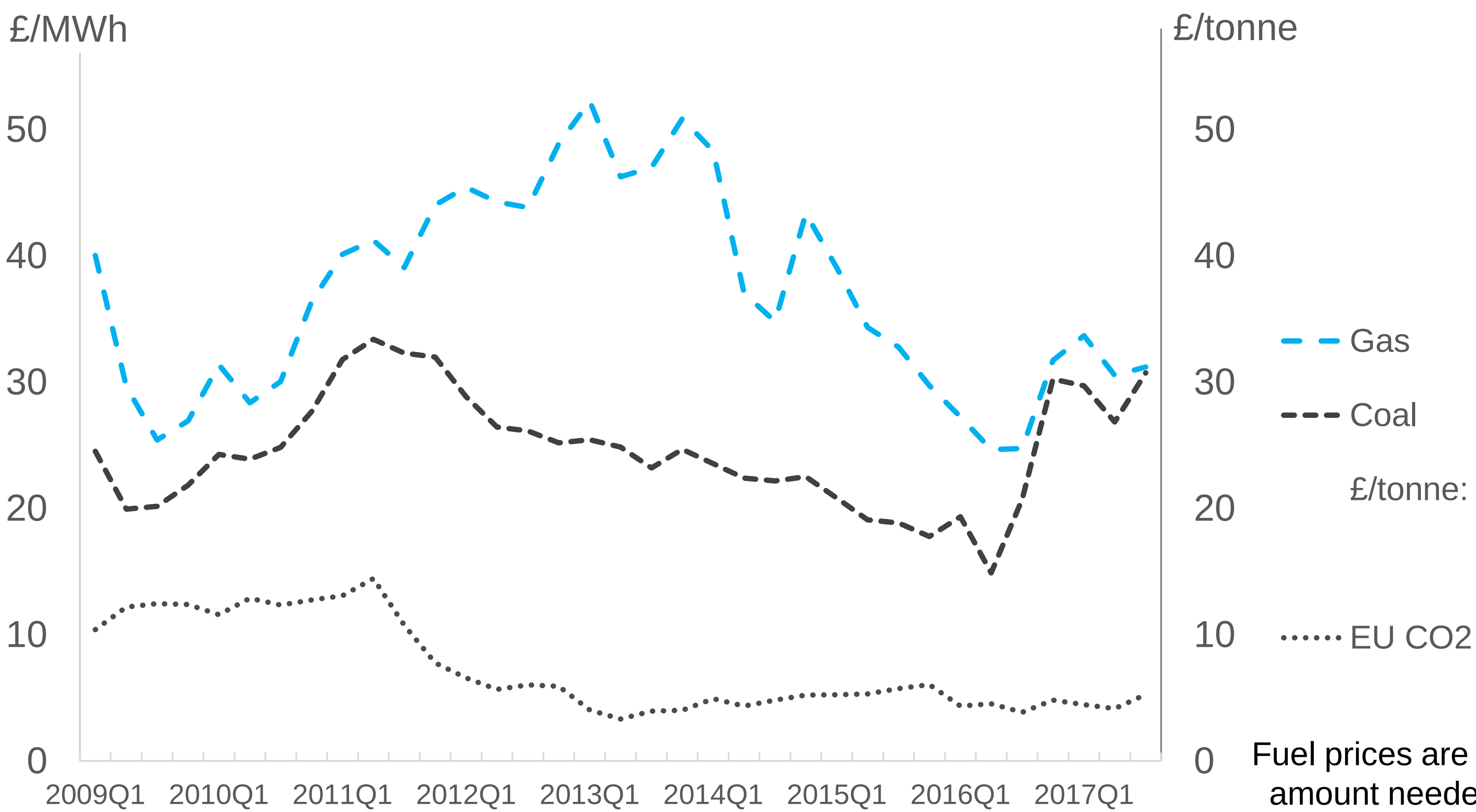
GB Fuel Prices



Fuel prices are for the amount needed per MWh of electricity output at typical efficiency

Sources: Elexon, BEIS and ICE

GB Fuel Prices



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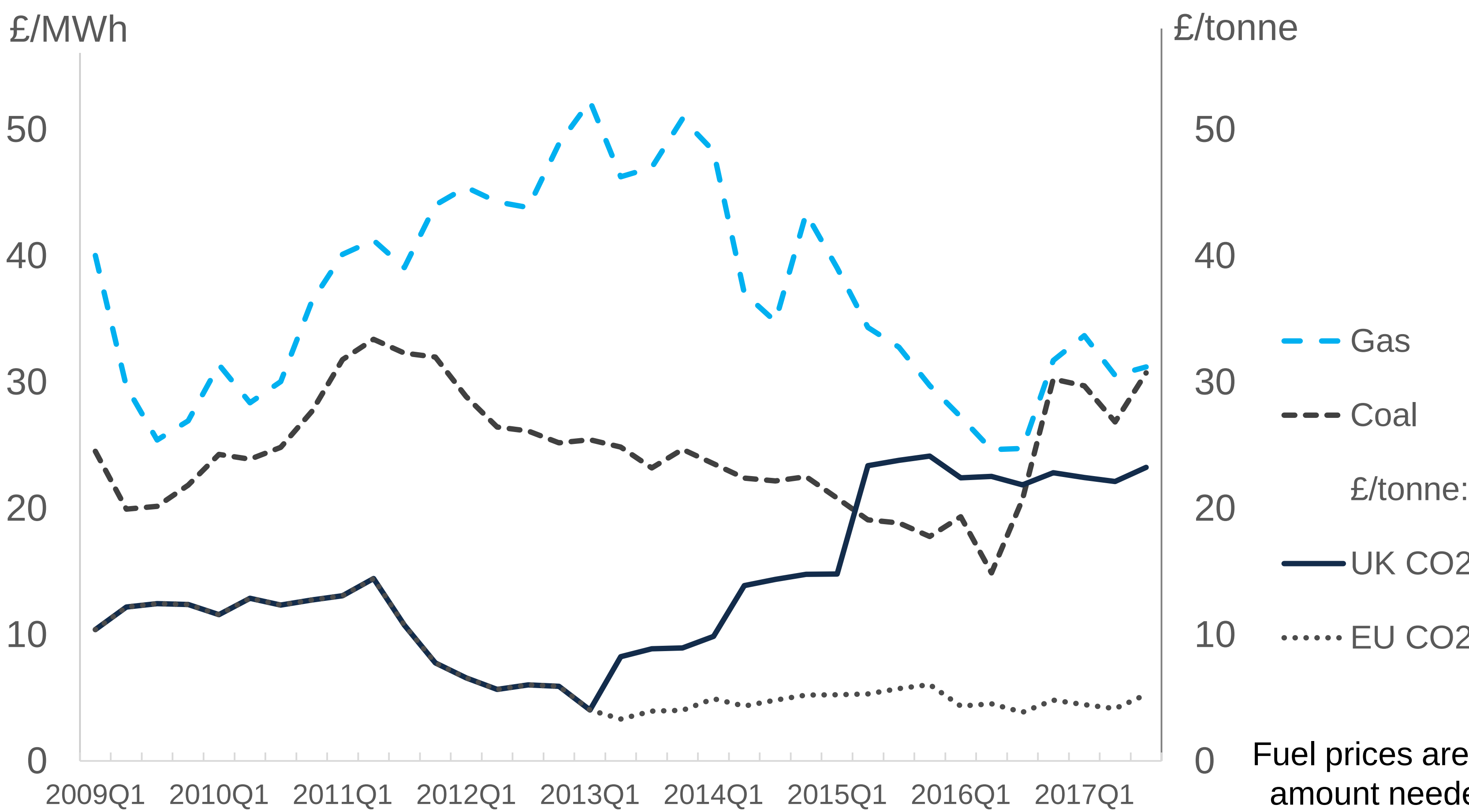

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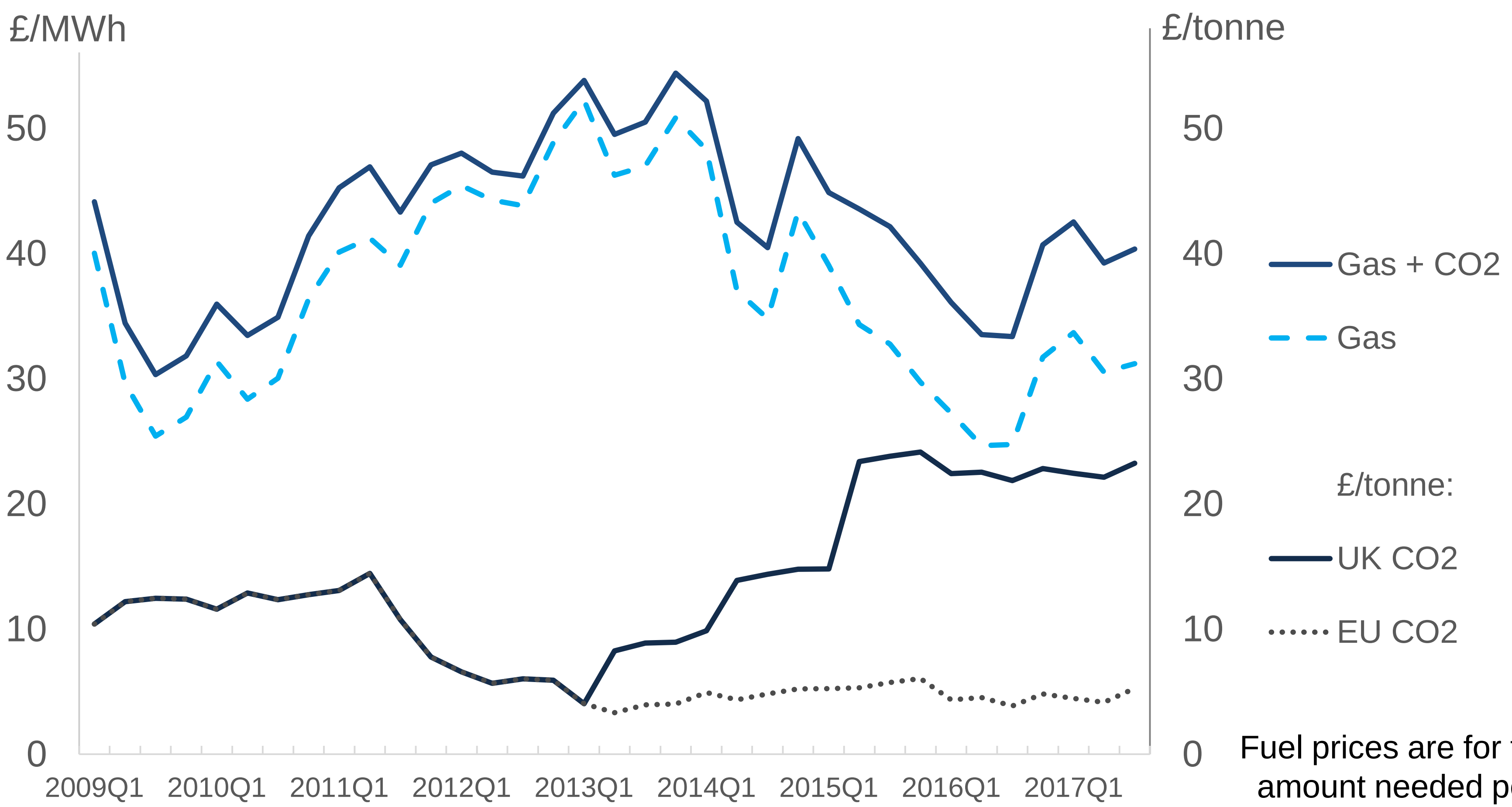

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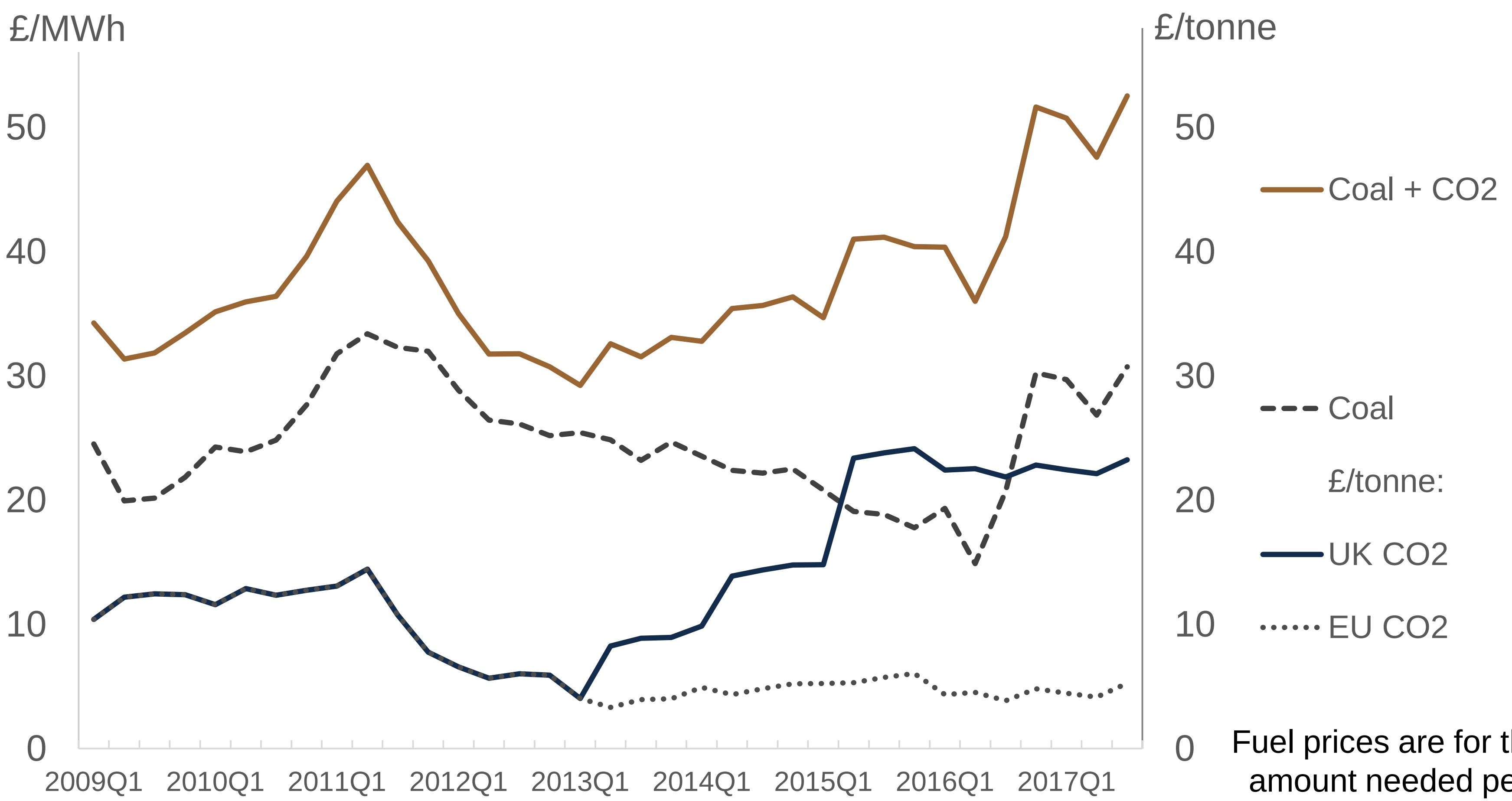

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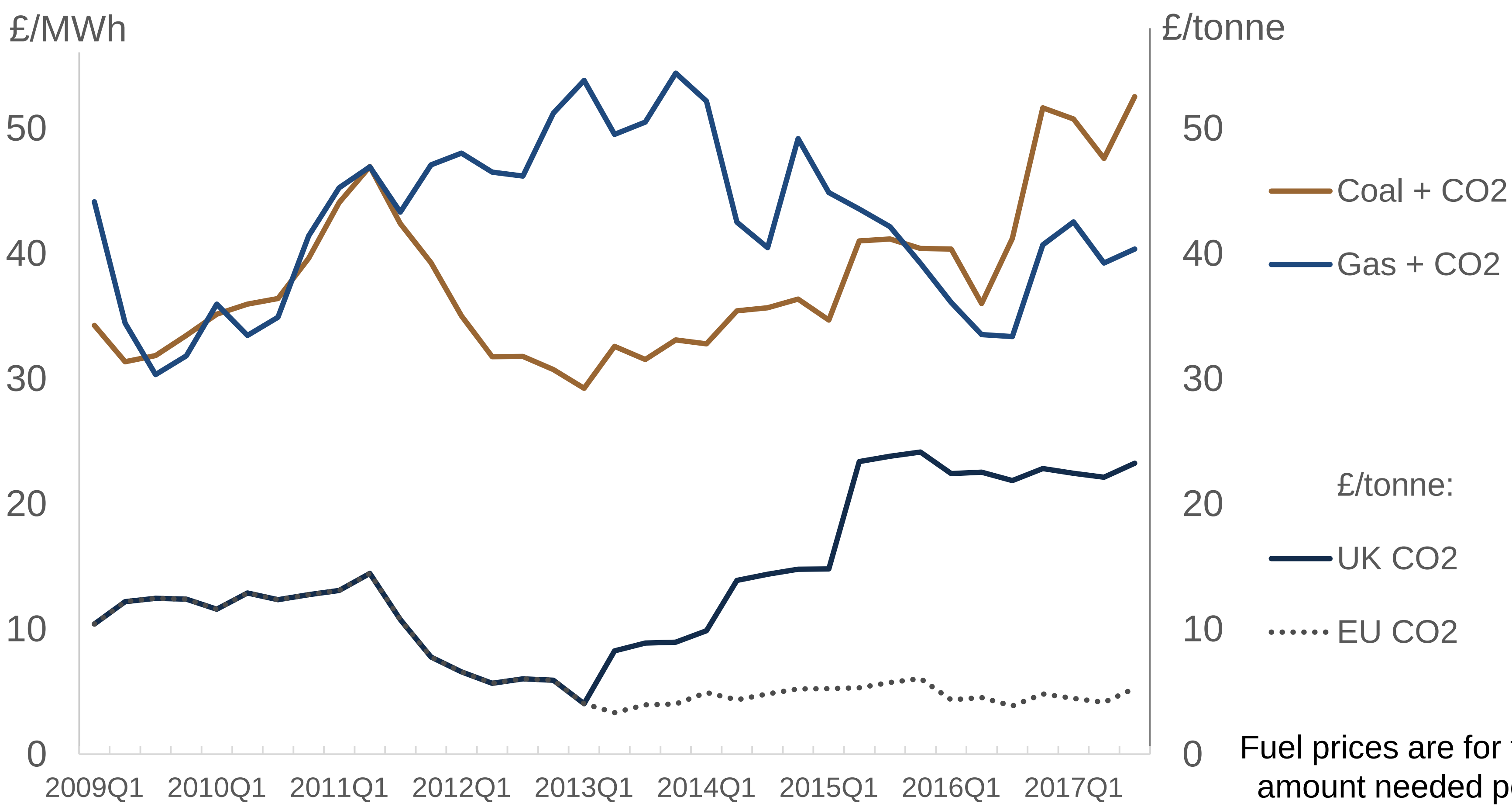
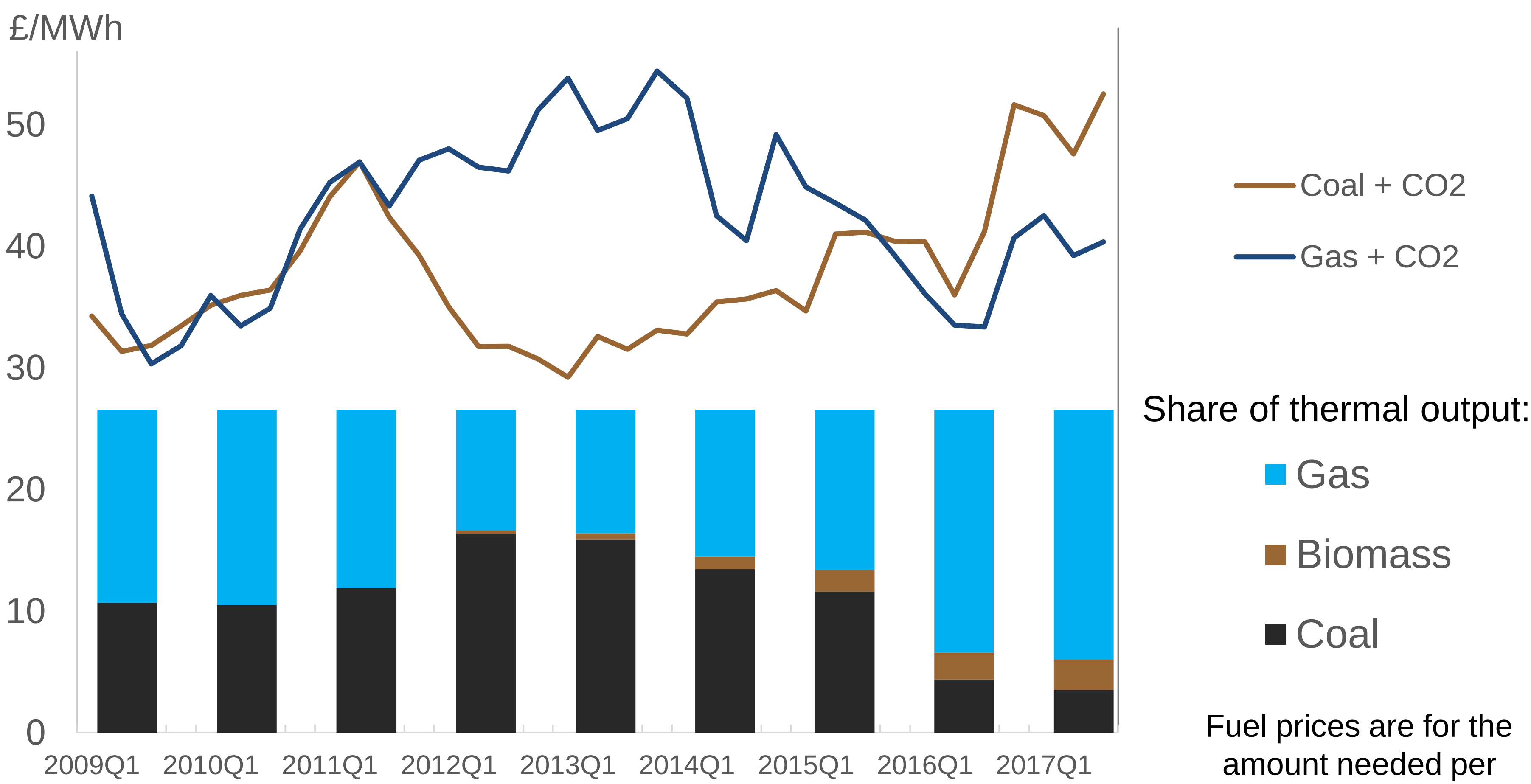
GB Fuel Prices



Fuel prices are for the amount needed per MWh of electricity output at typical efficiency

Sources: Elexon, BEIS and ICE

GB Generation & Fuel Prices



Fuel prices are for the amount needed per MWh of electricity output at typical efficiency

Sources: Elexon, BEIS and ICE

What changed from 2012 to 2016?

- Coal prices – fell 24% from £9.70 to £7.40 per MWh
- Gas prices – fell 39% from £20.70 to £12.70 per MWh
- Carbon prices – more than doubled from £6.90 to £22.60 per tonne CO_2
- Wind capacity – doubled from 7.3 to 14.7 GW
- Output rose from 17.6 to 30.6 TWh
- Solar PV capacity – grew six-fold from 1.7 to 10.4 GW
- Output rose from 1.2 to 9.6 TWh
- Biomass capacity – tripled from 0.7 to 2.1 GW
- Coal capacity – almost halved from 27.2 to 15.0 GW
- Electricity demand – fell 7% from 319 to 297 TWh

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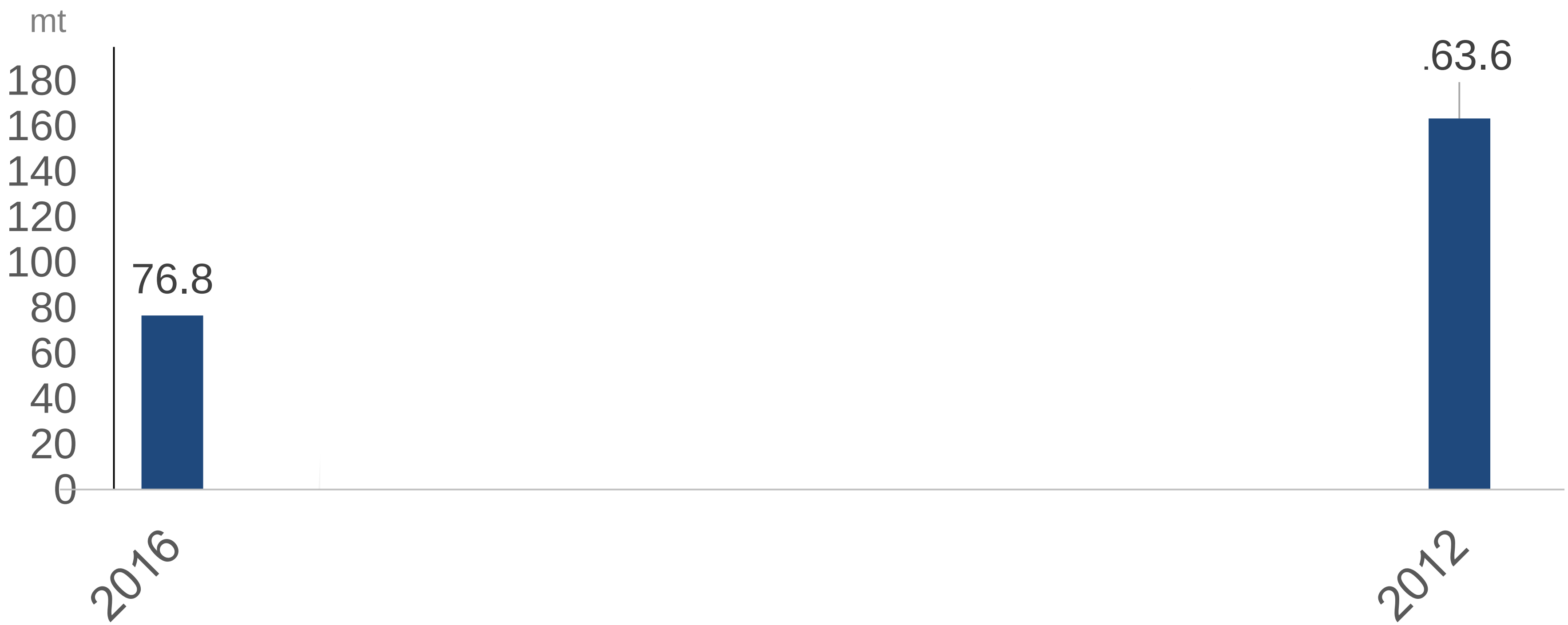
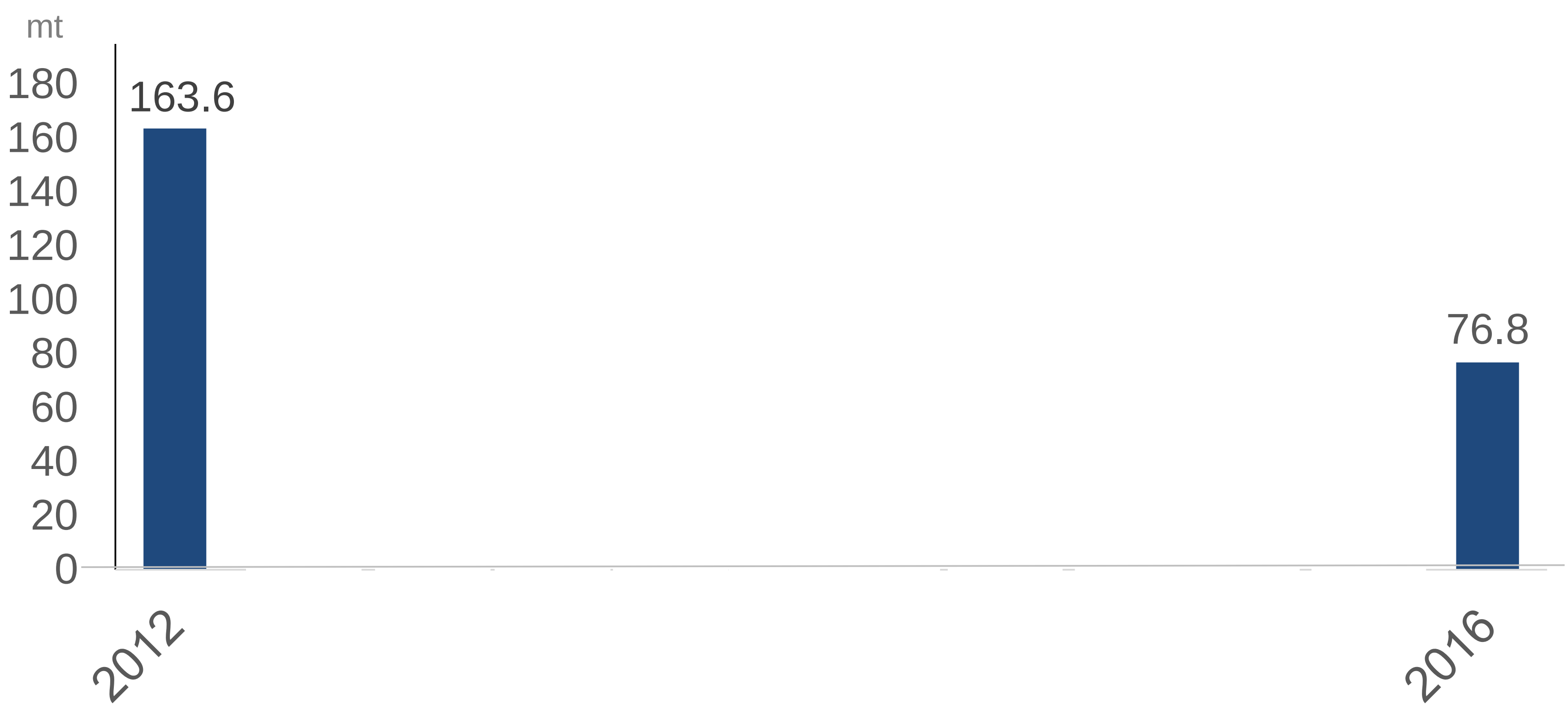
Emissions of CO_2: changes relative to 2016

What if *X* had not changed after 2012?



Emissions of CO_2: changes relative to 2012

What if *only X* had changed after 2012?



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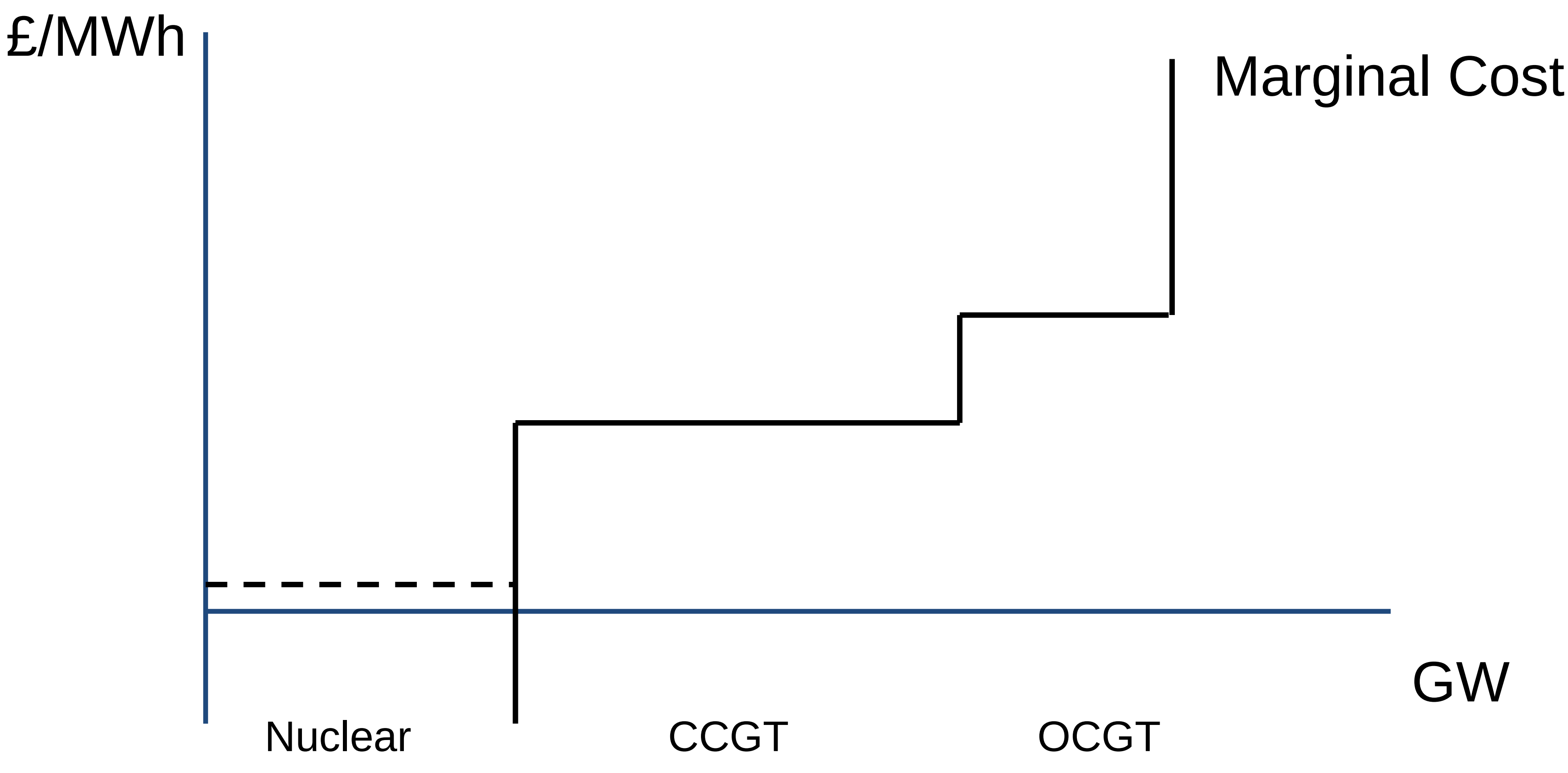
Renewables and the electricity market

Supply



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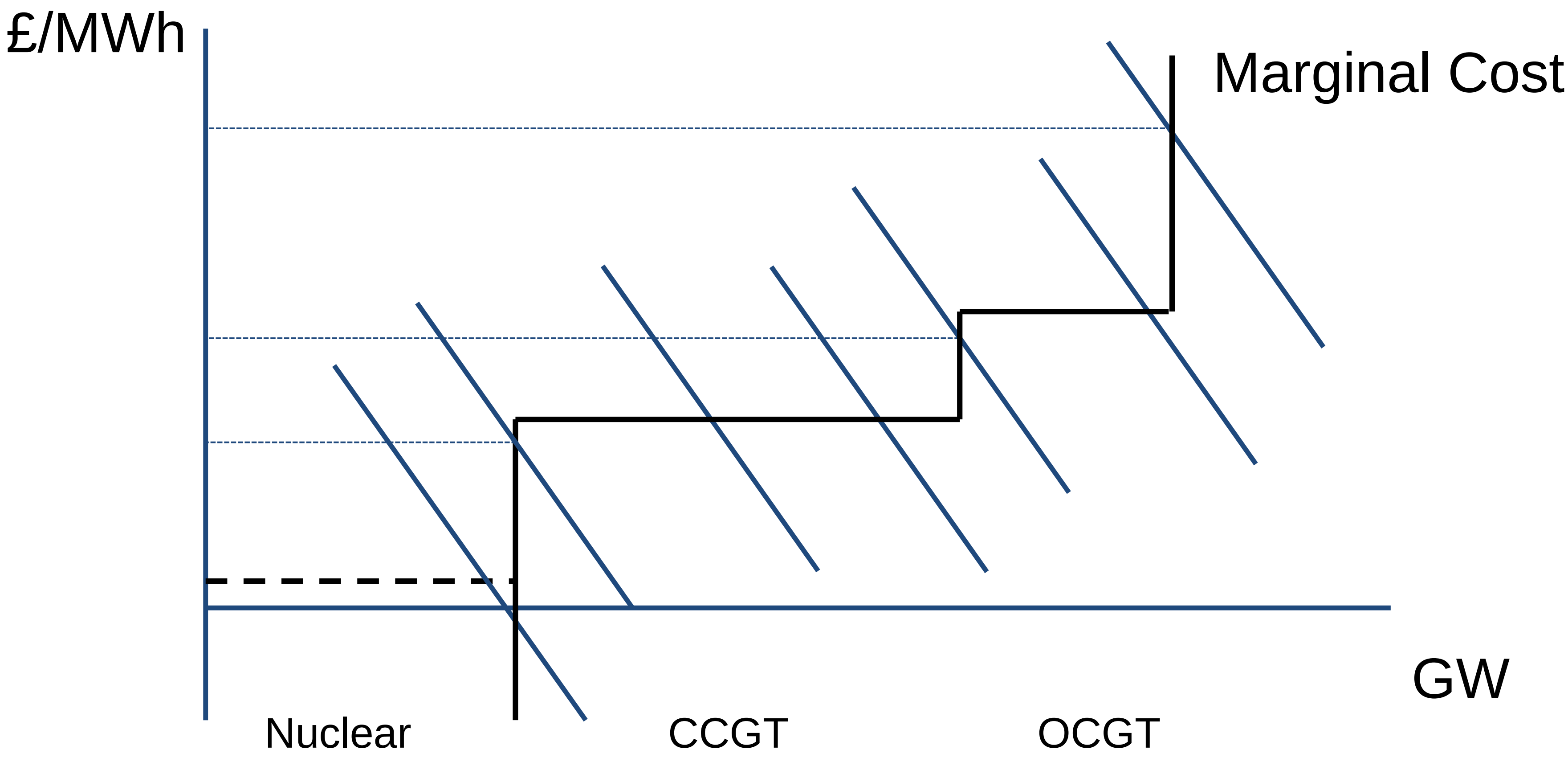
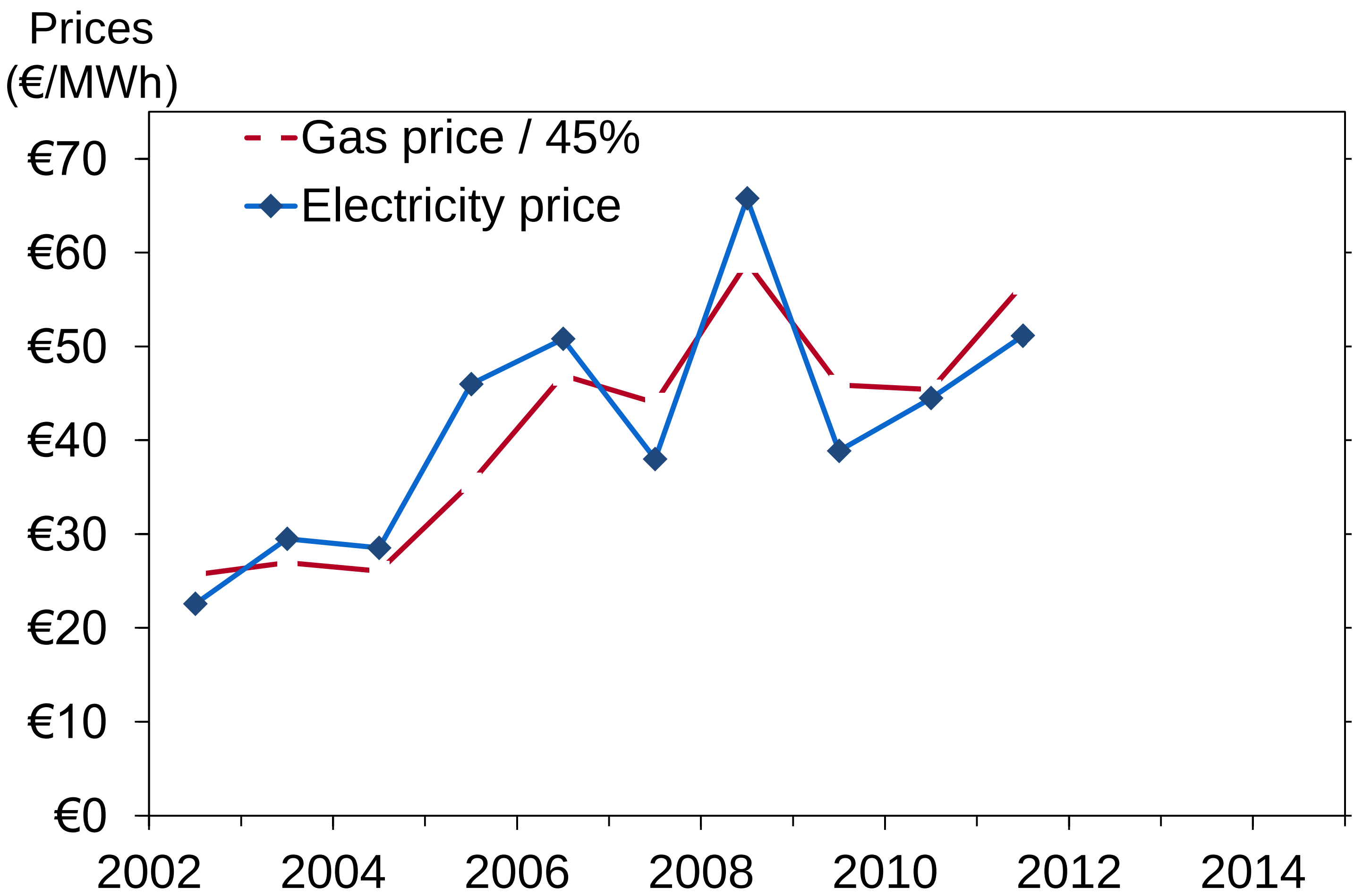
Demand and Supply

Prices reflect Marginal Costs

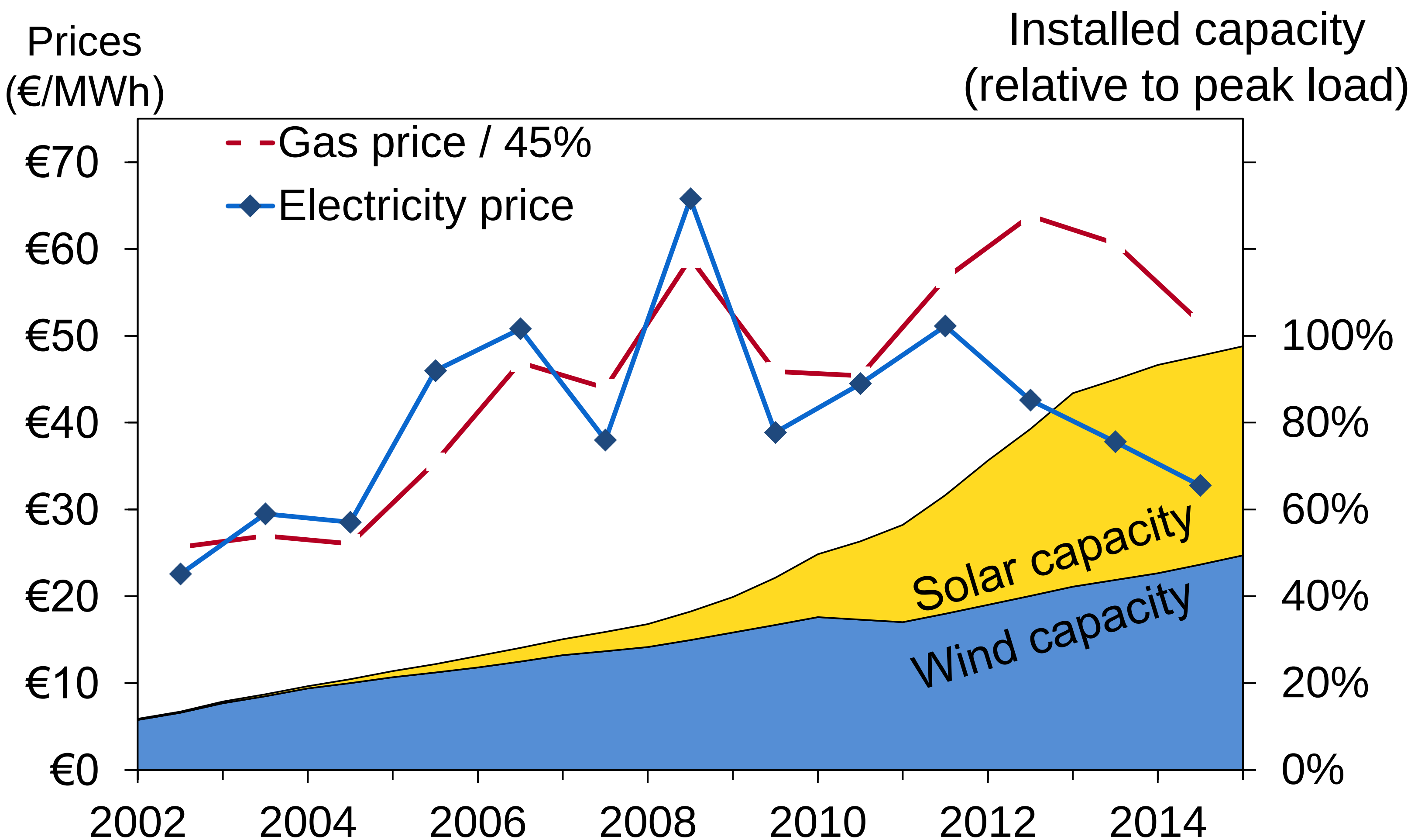


German Energy Prices: a market working well



Source: Green and Staffell, Oxrep, 2016

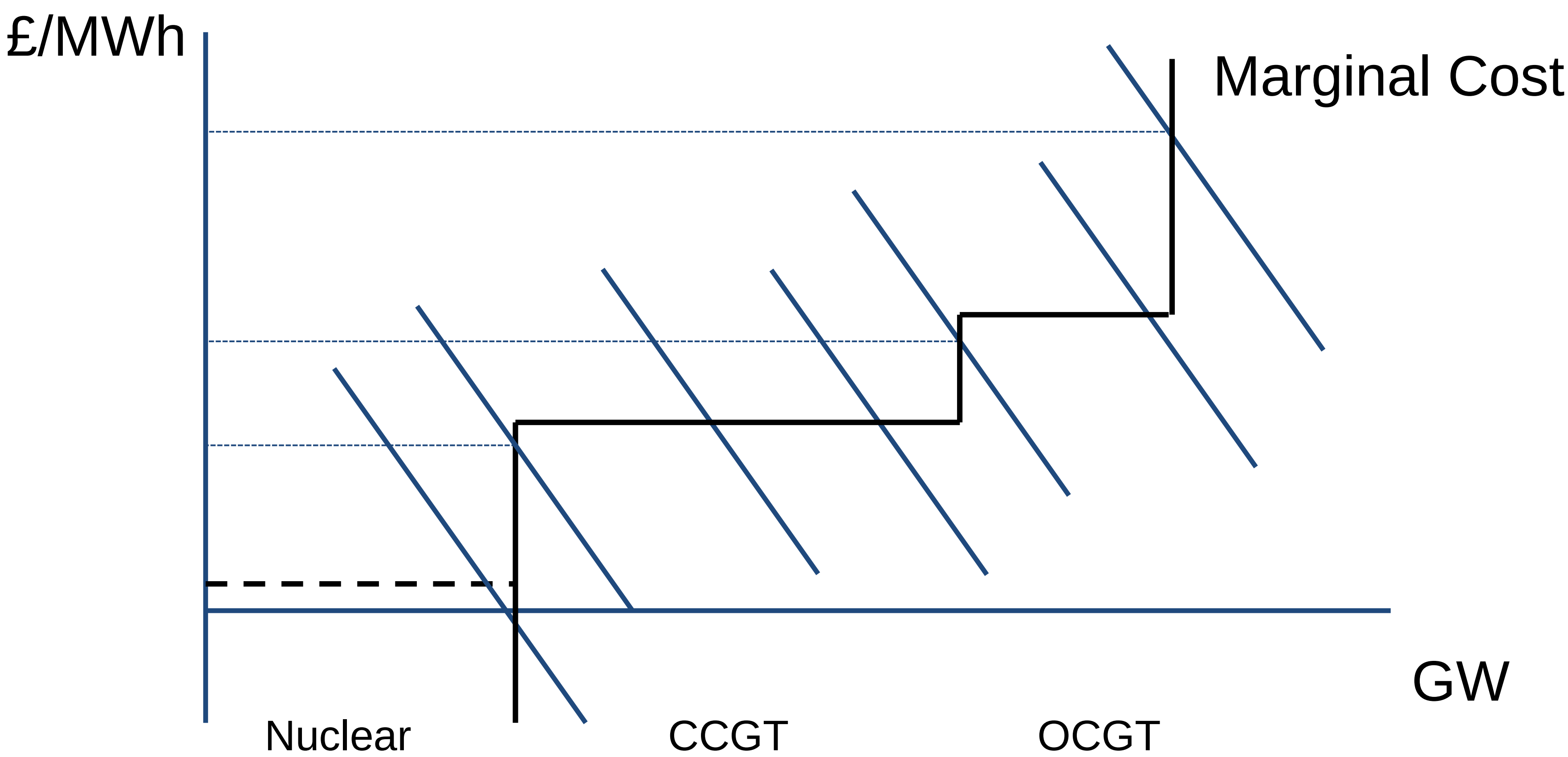
German Energy Prices: The Merit Order Effect



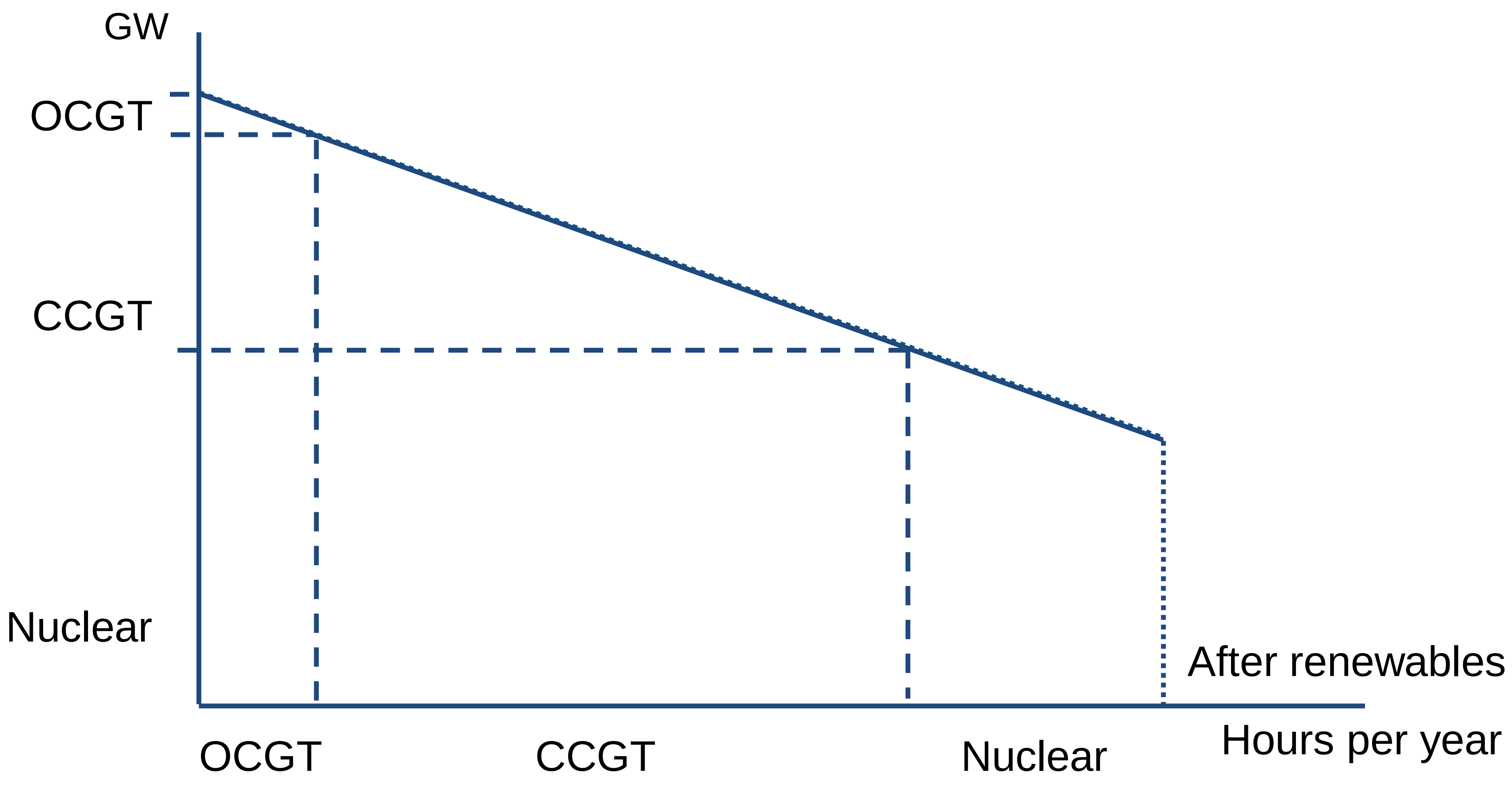
Source: Green and Staffell, Oxrep, 2016

Demand and Supply

The merit order effect



Capacity and Load



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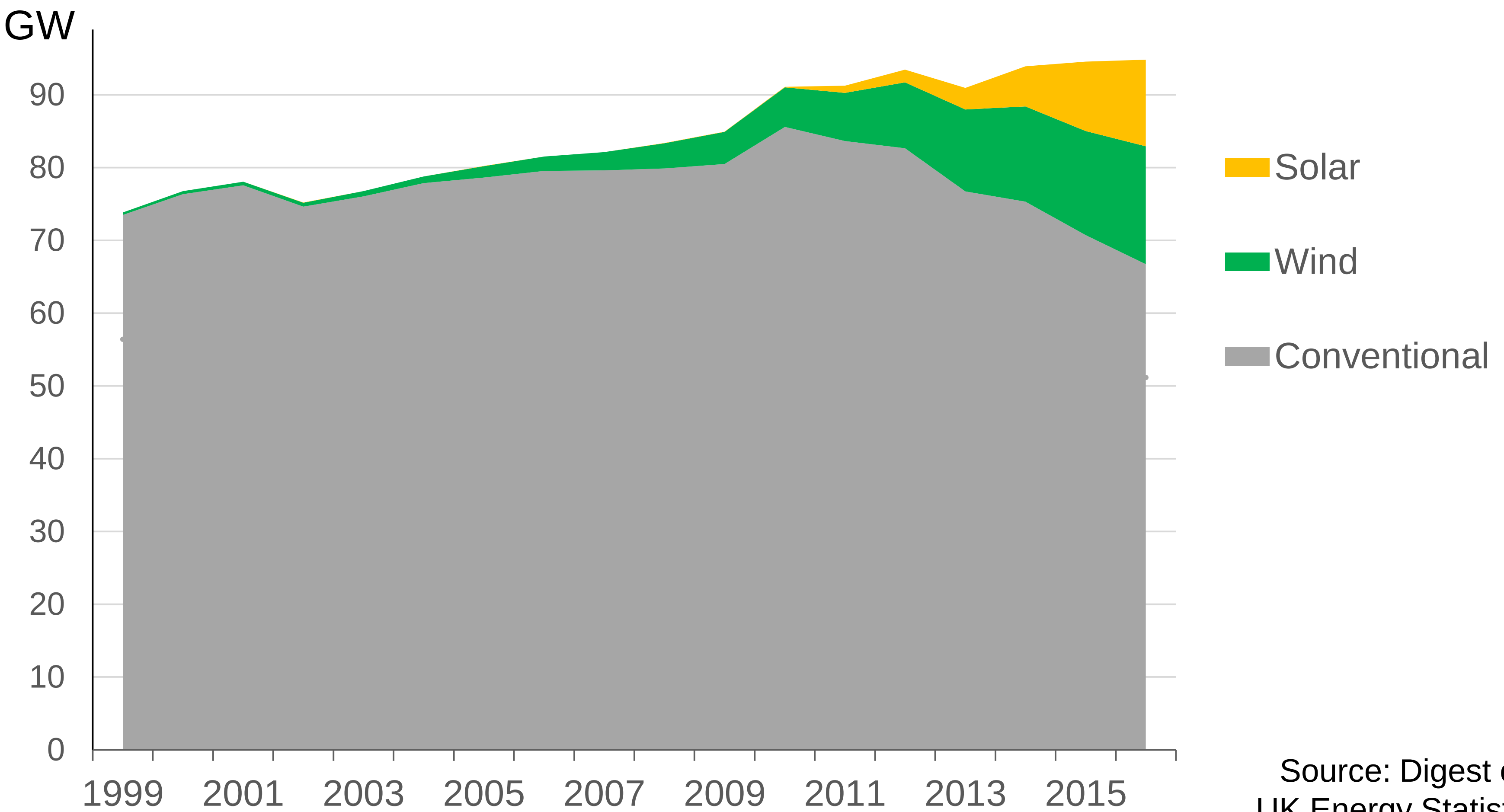
Generating Capacity

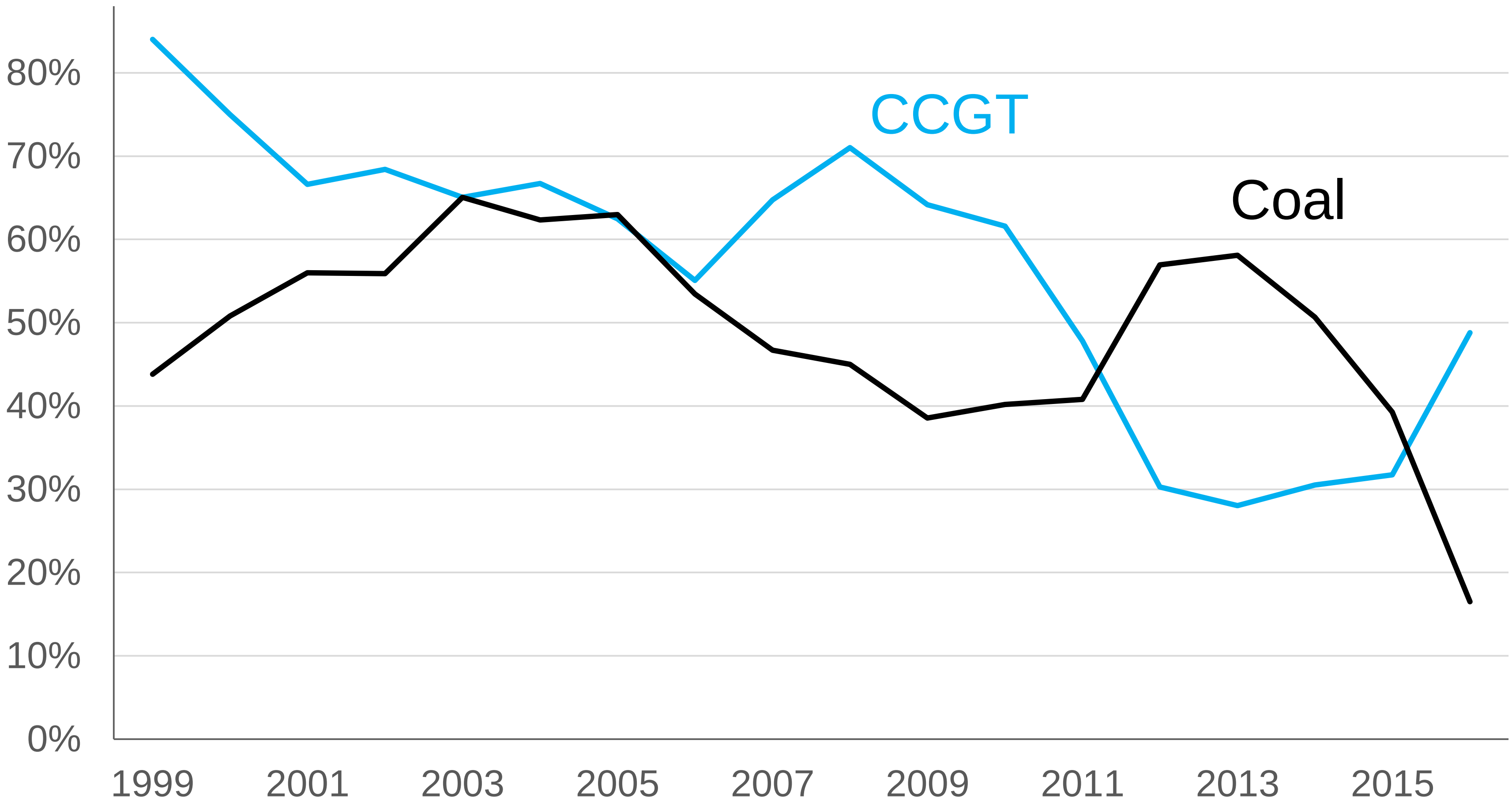
Great Britain



Source: Digest of UK Energy Statistics

Generators' Load Factors

UK-wide, including Northern Ireland



Source: Digest of UK Energy Statistics

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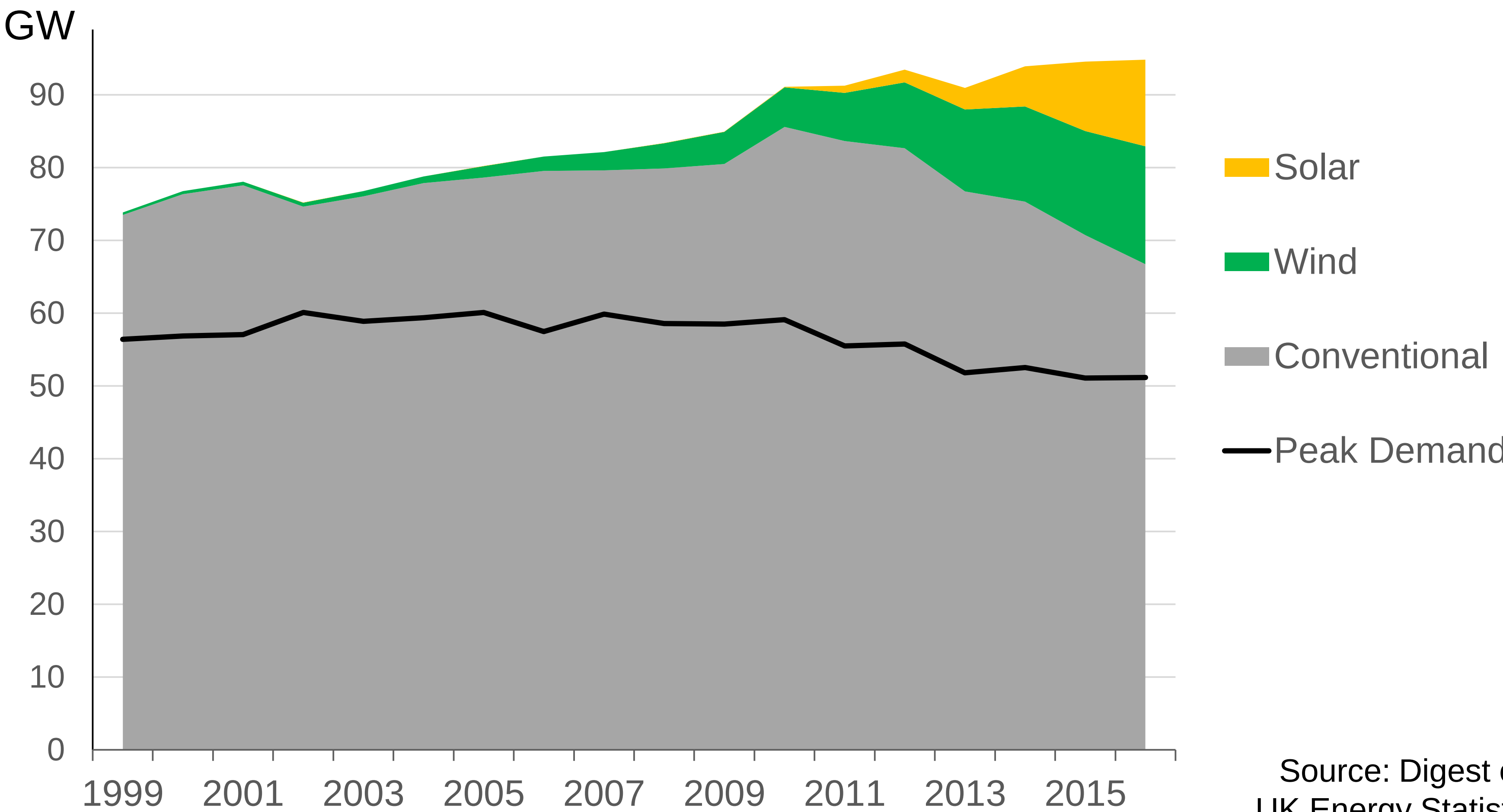
Capacity and Peak Demand

Great Britain



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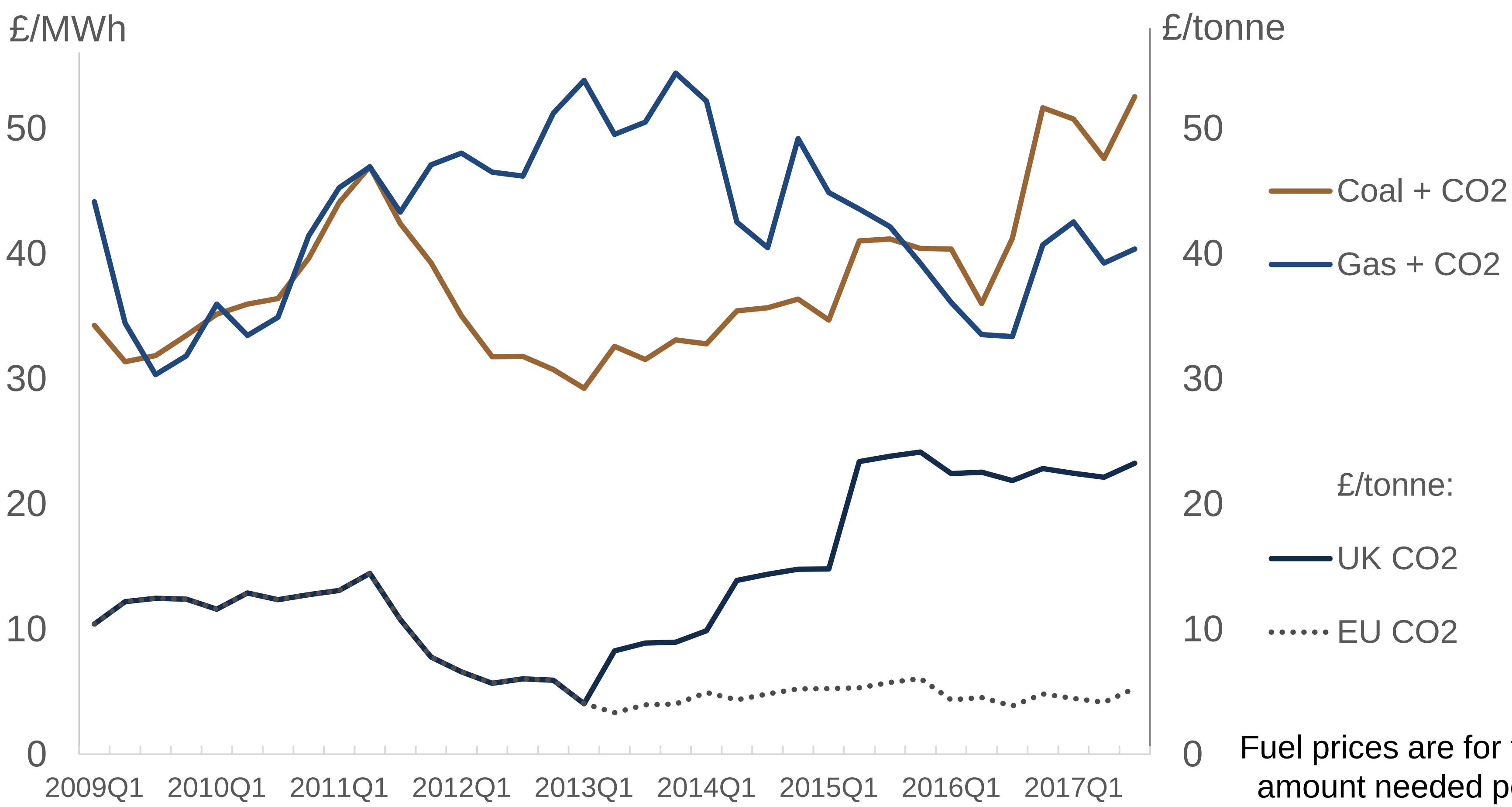
GB Fuel Prices



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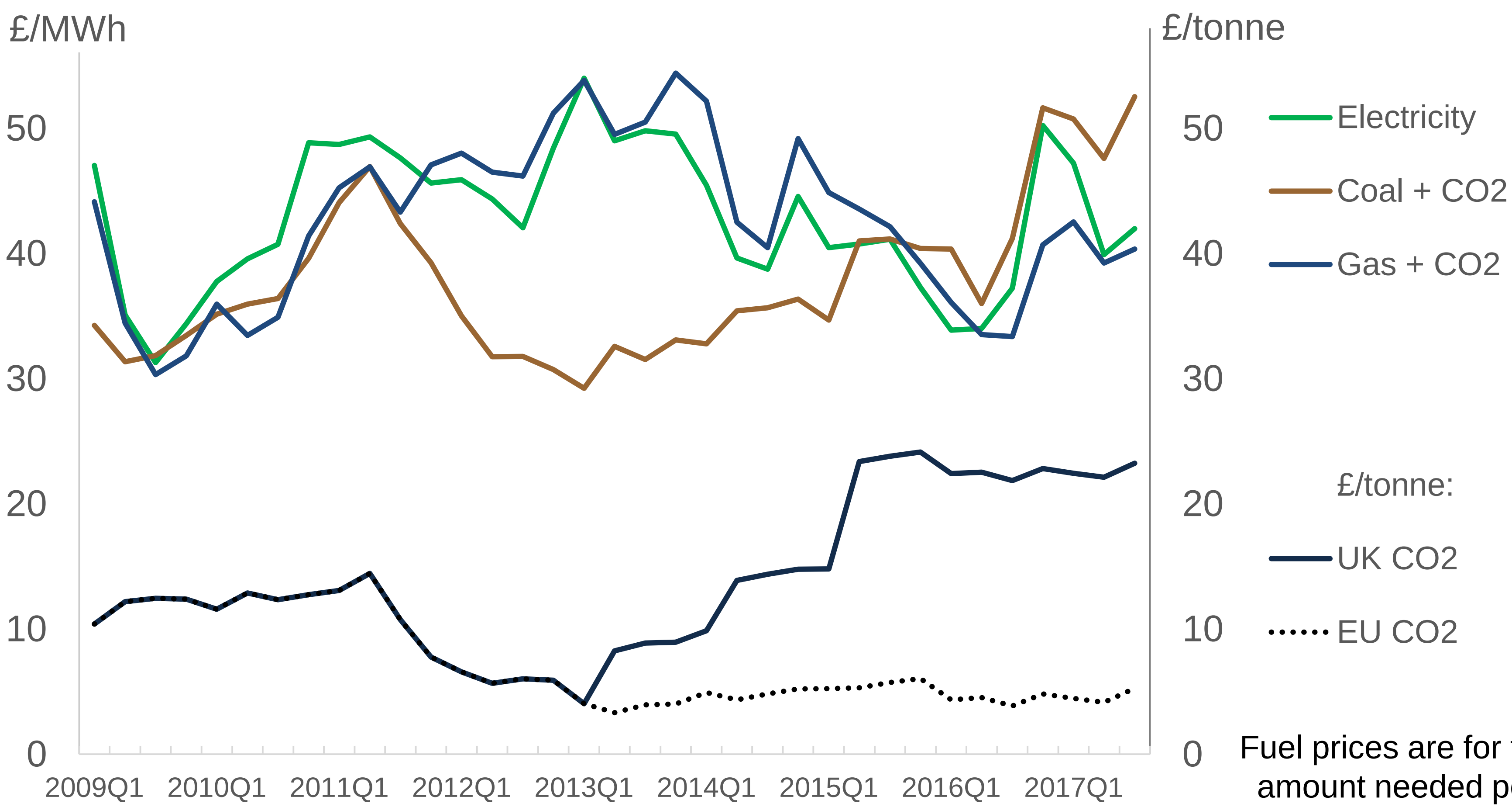
Sources: Elexon, BEIS and ICE

GB Fuel & Electricity Prices



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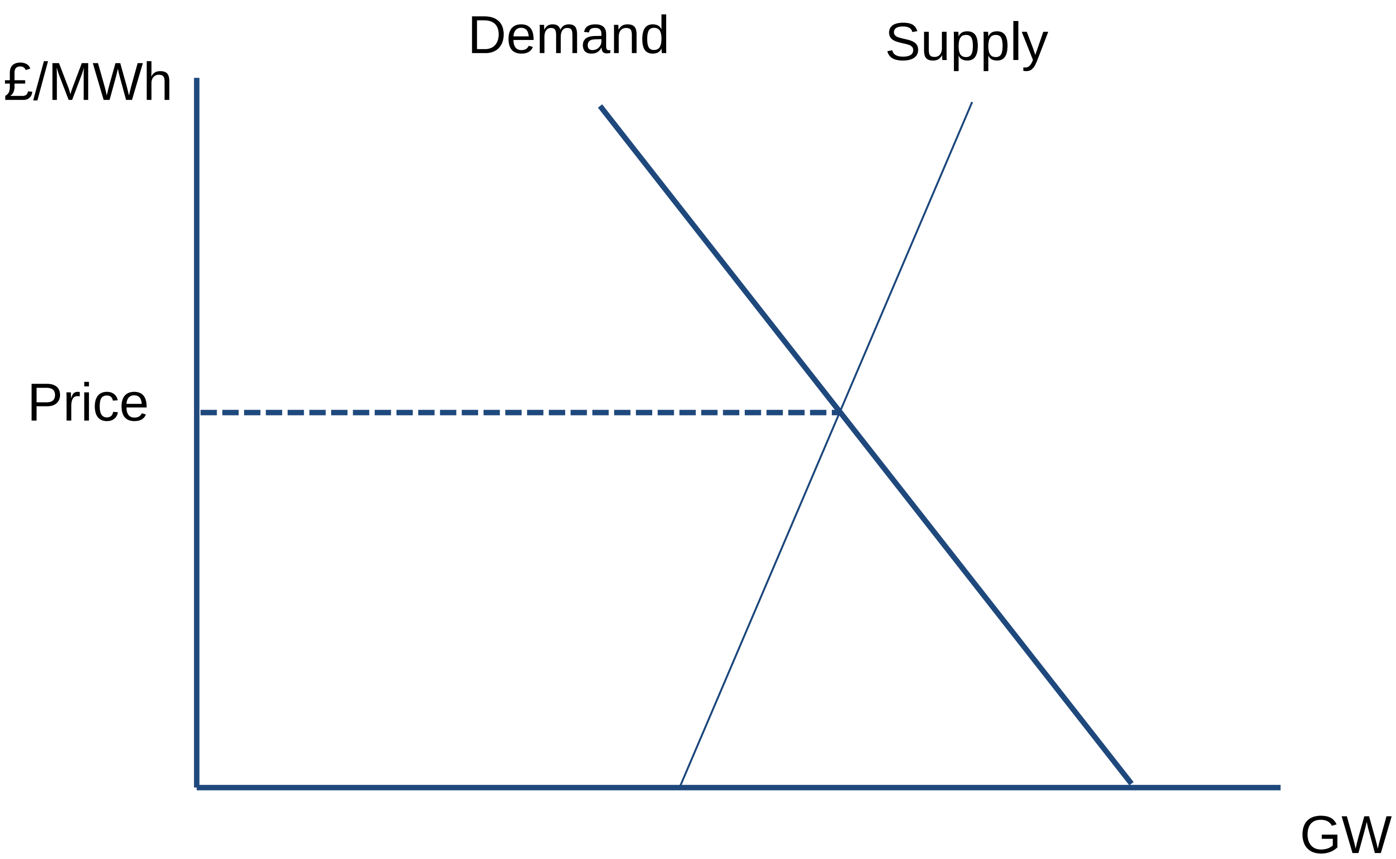
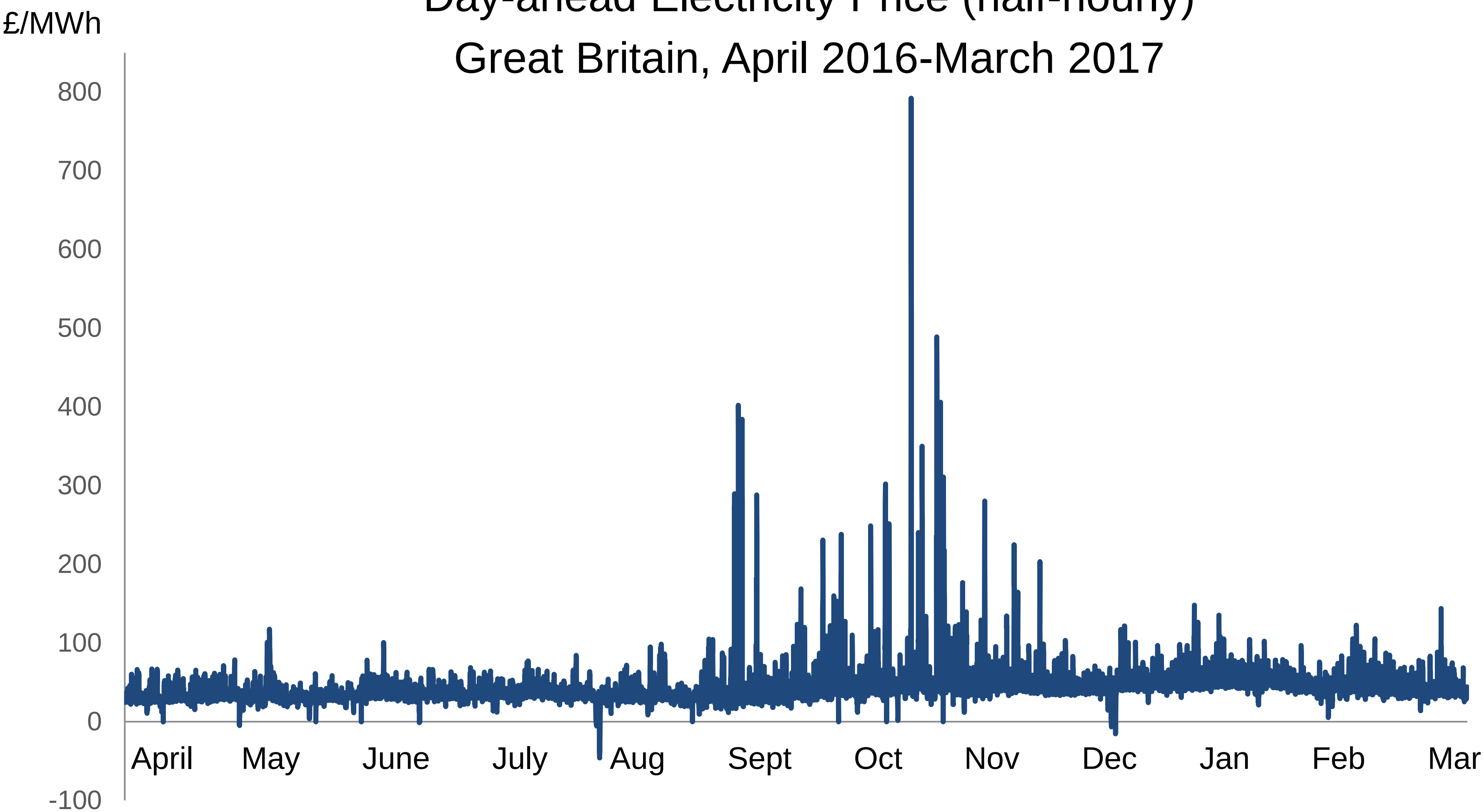
Supply and Demand



A volatile market

Day-ahead Electricity Price (half-hourly)
Great Britain, April 2016-March 2017



Source: ElectricInsights.co.uk

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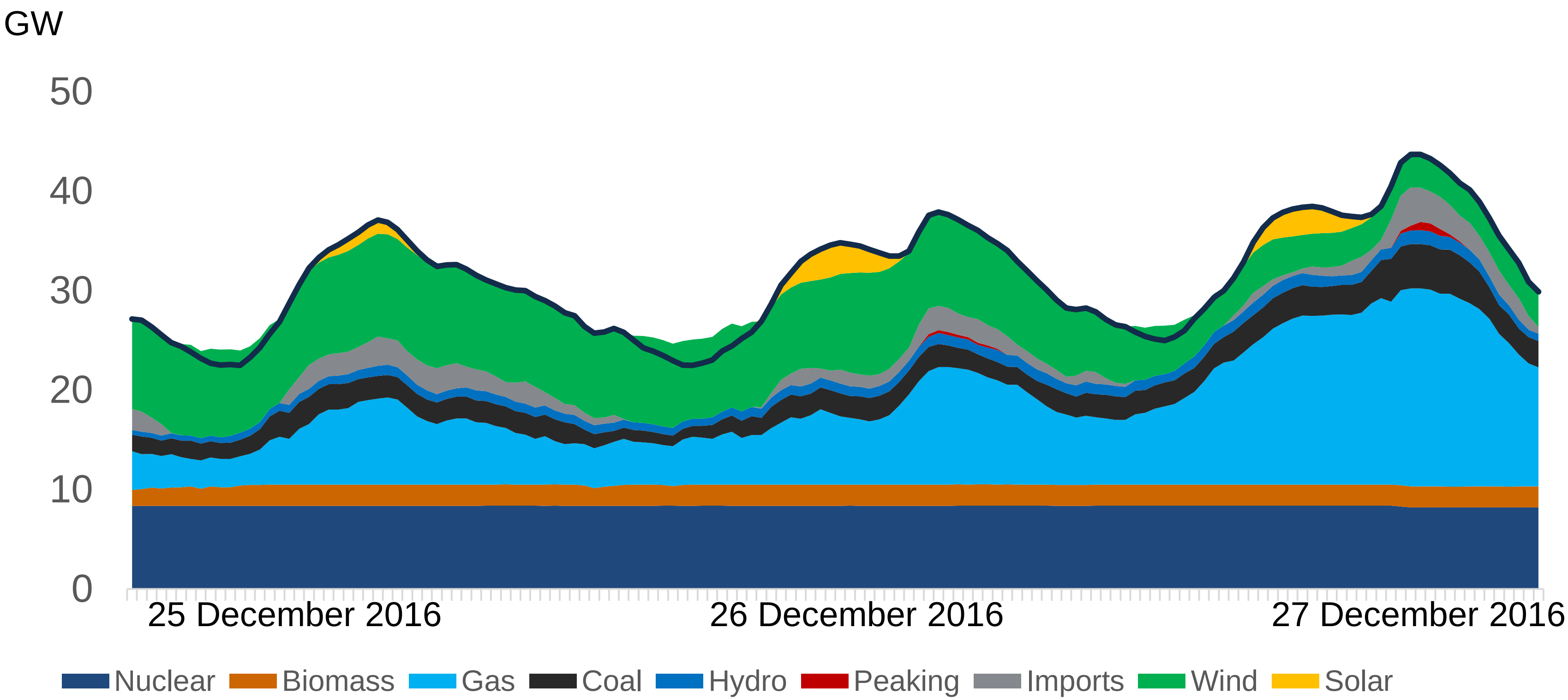
A Low-Carbon Christmas



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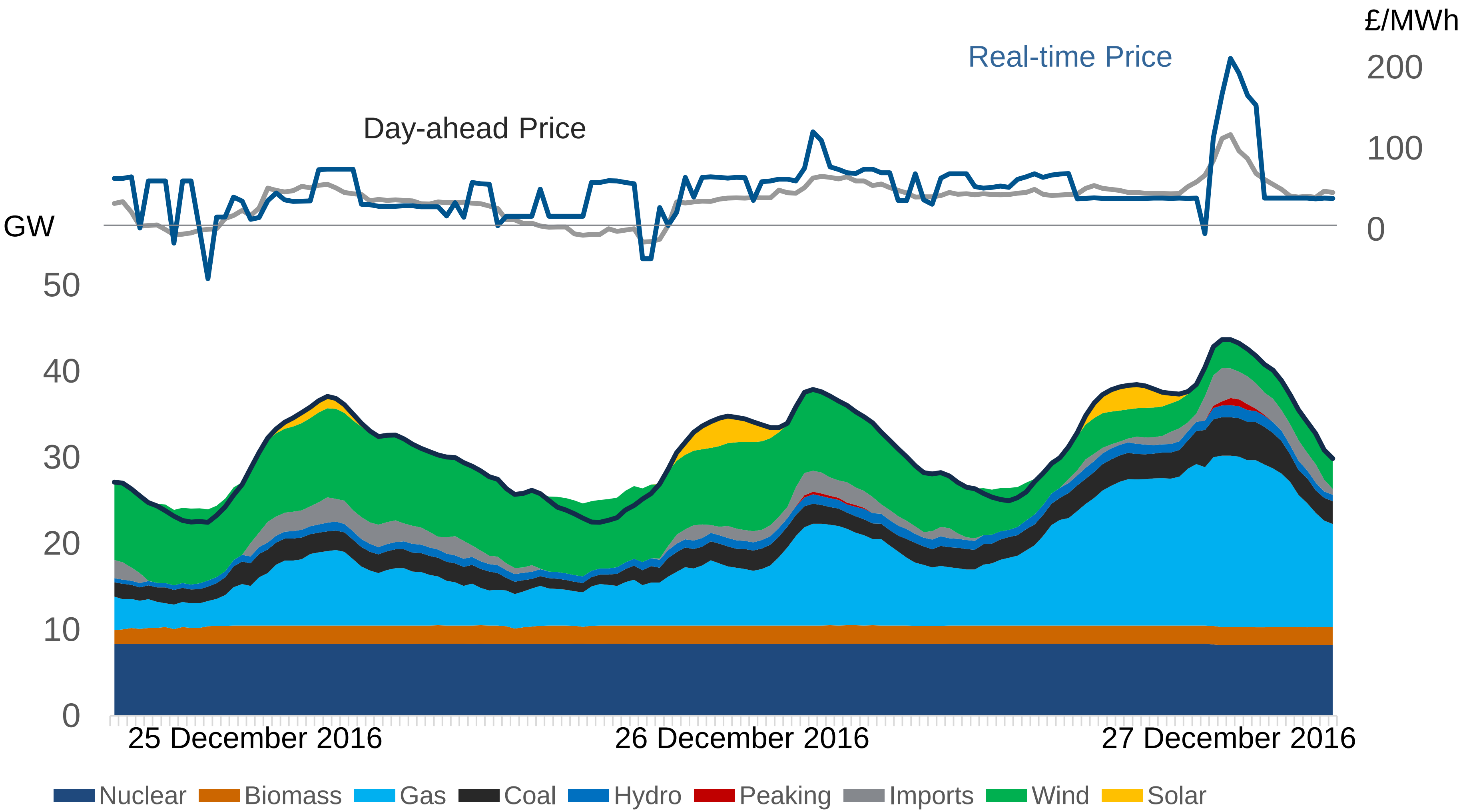

Source: ElectricInsights.co.uk

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Renewables in a Power Market

Part One: Killing your market

Load duration curve for GB

2011 demand and weather

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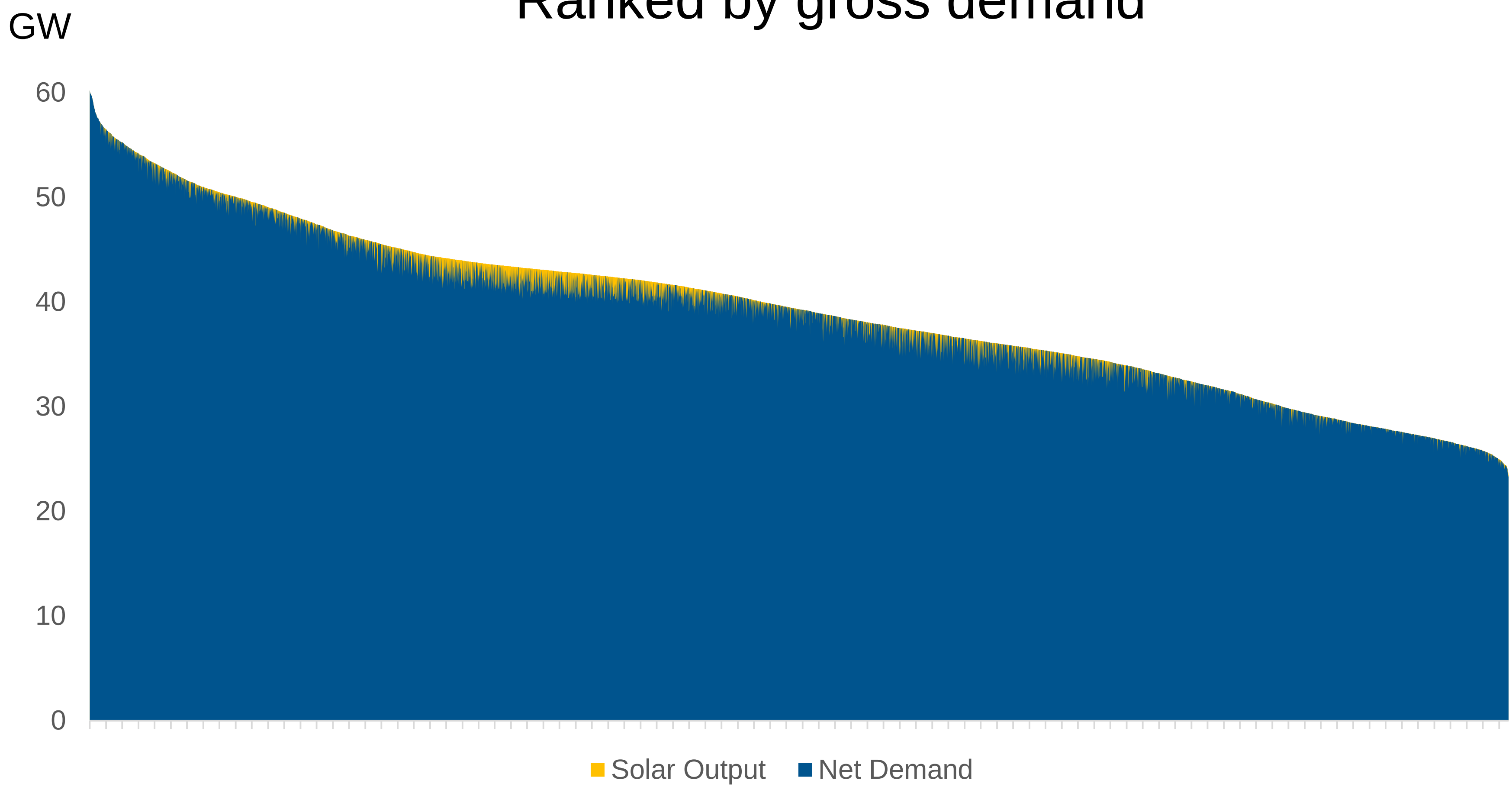
Load duration curve for GB

2011 demand and weather with 5 GW solar PV

Ranked by gross demand



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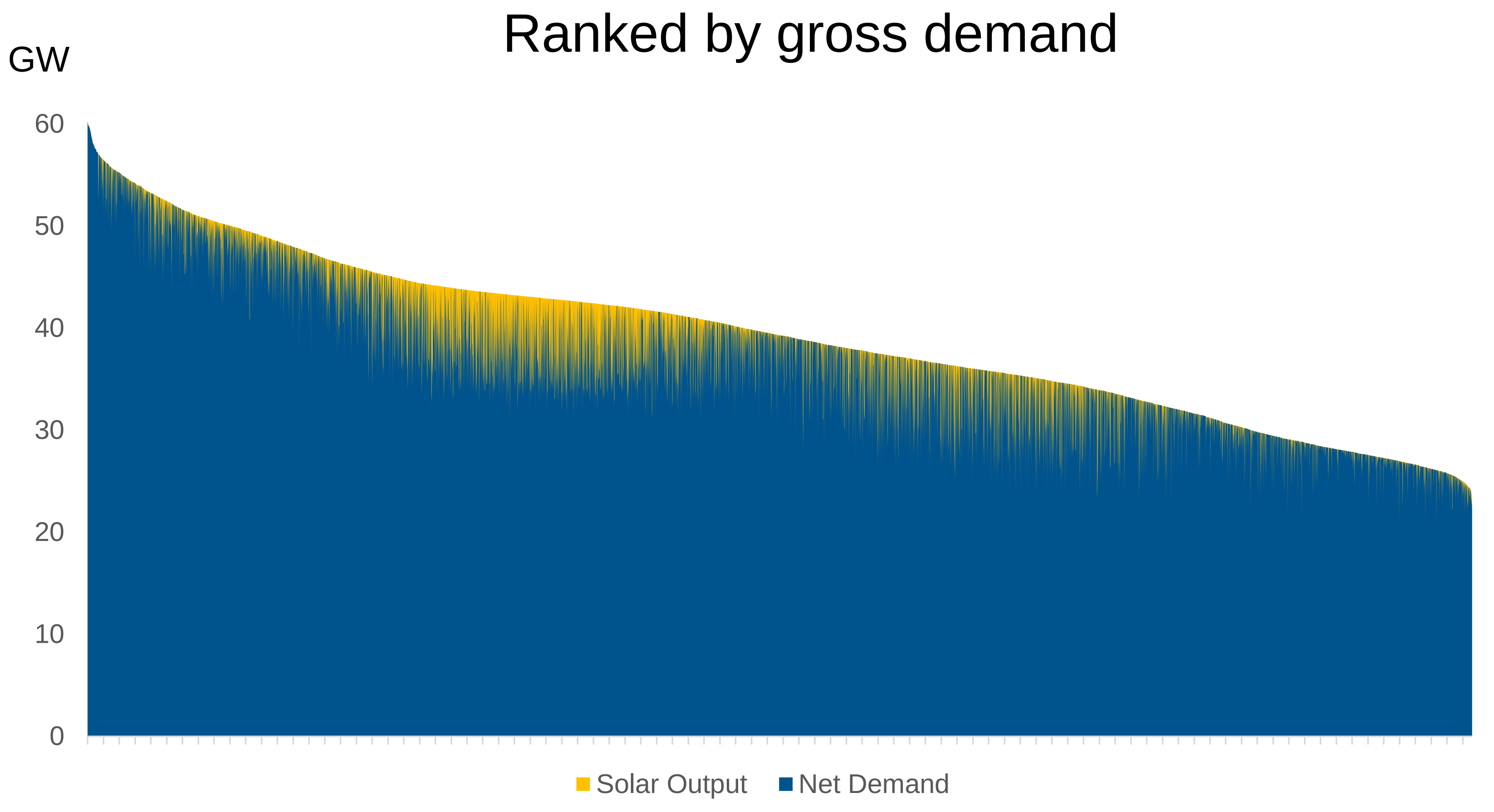
Load duration curve for GB

2011 demand and weather with 20 GW solar PV



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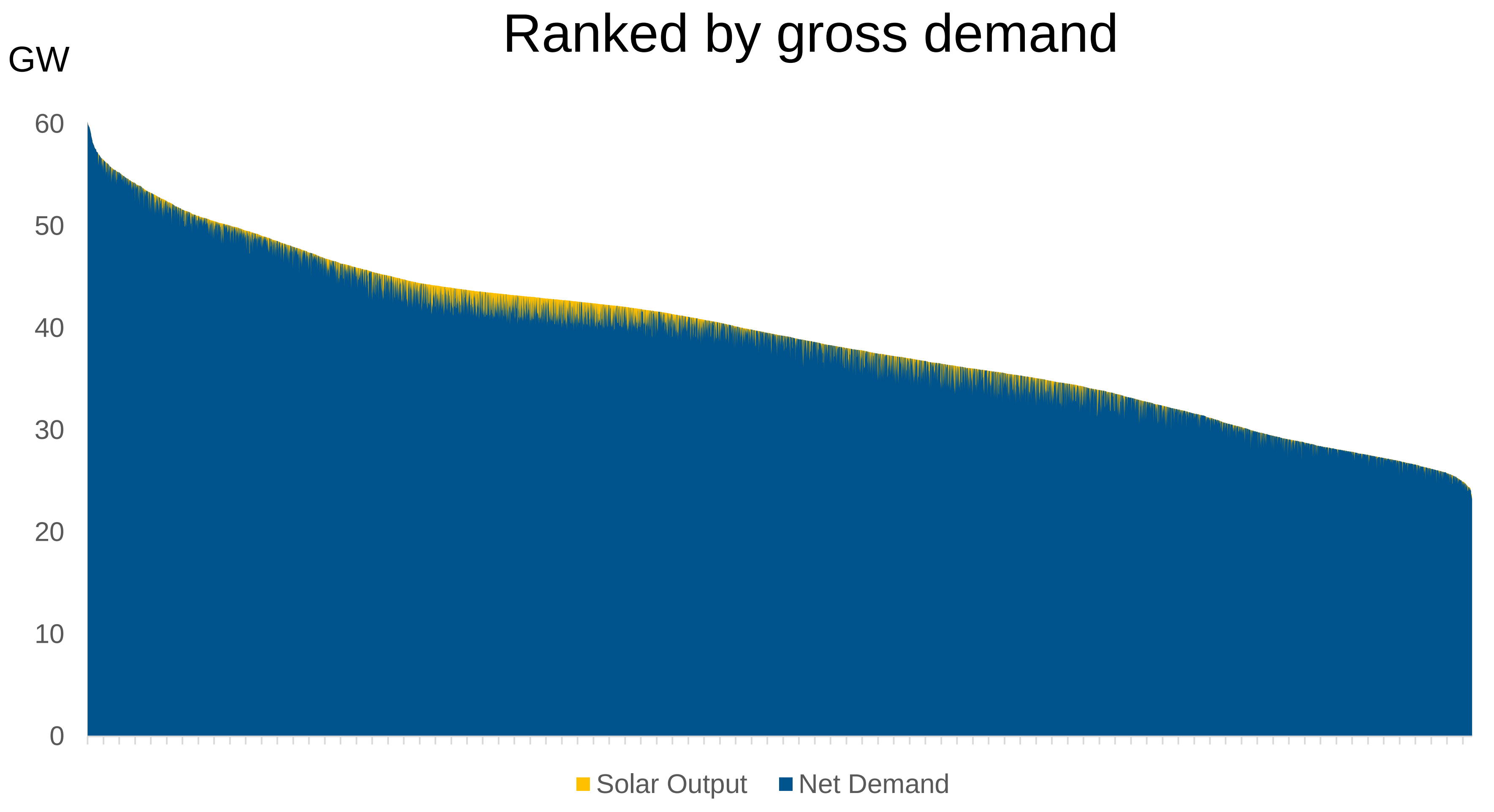
Load duration curve for GB

2011 demand and weather with 5 GW solar PV



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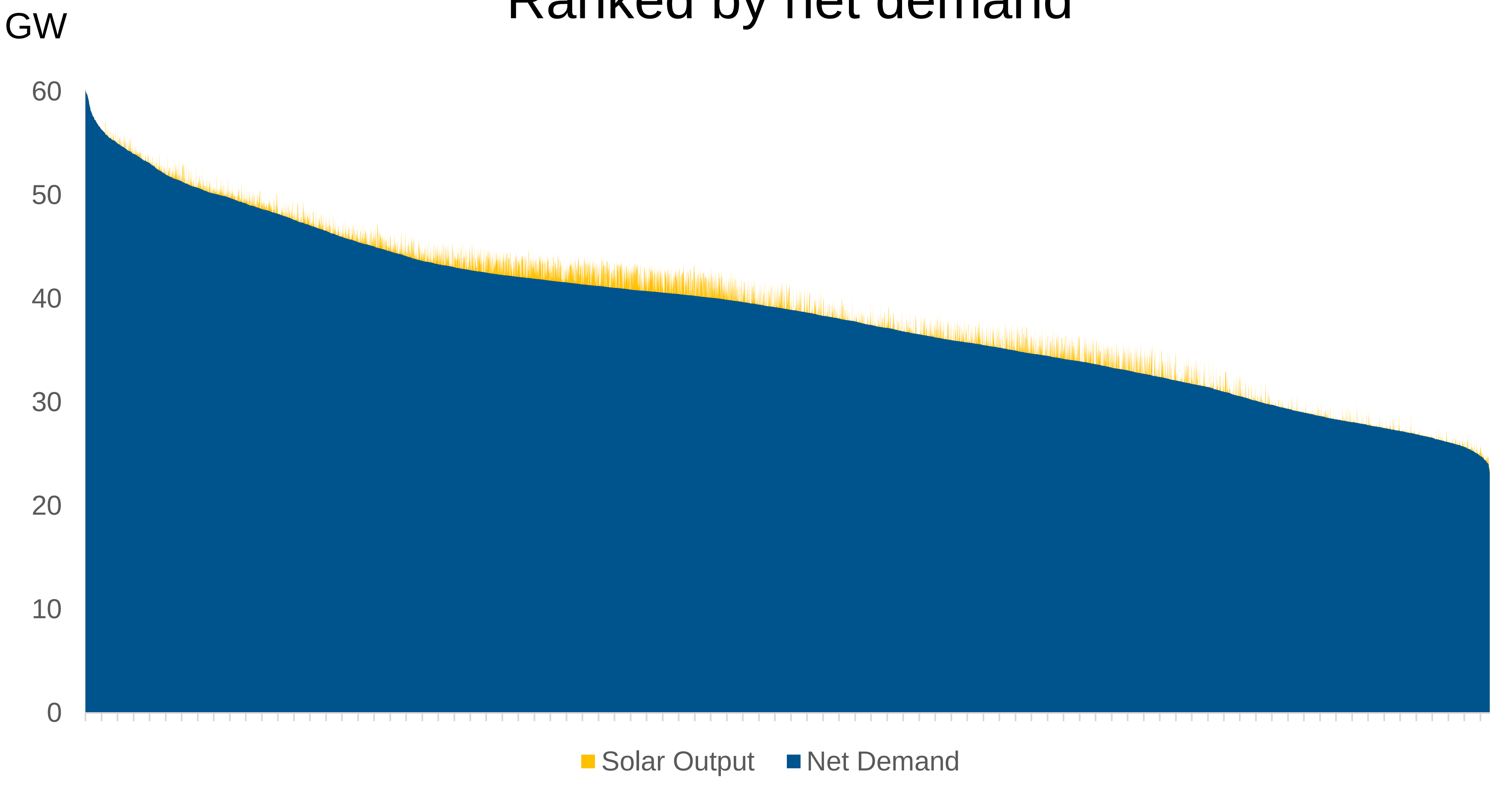
Load duration curve for GB

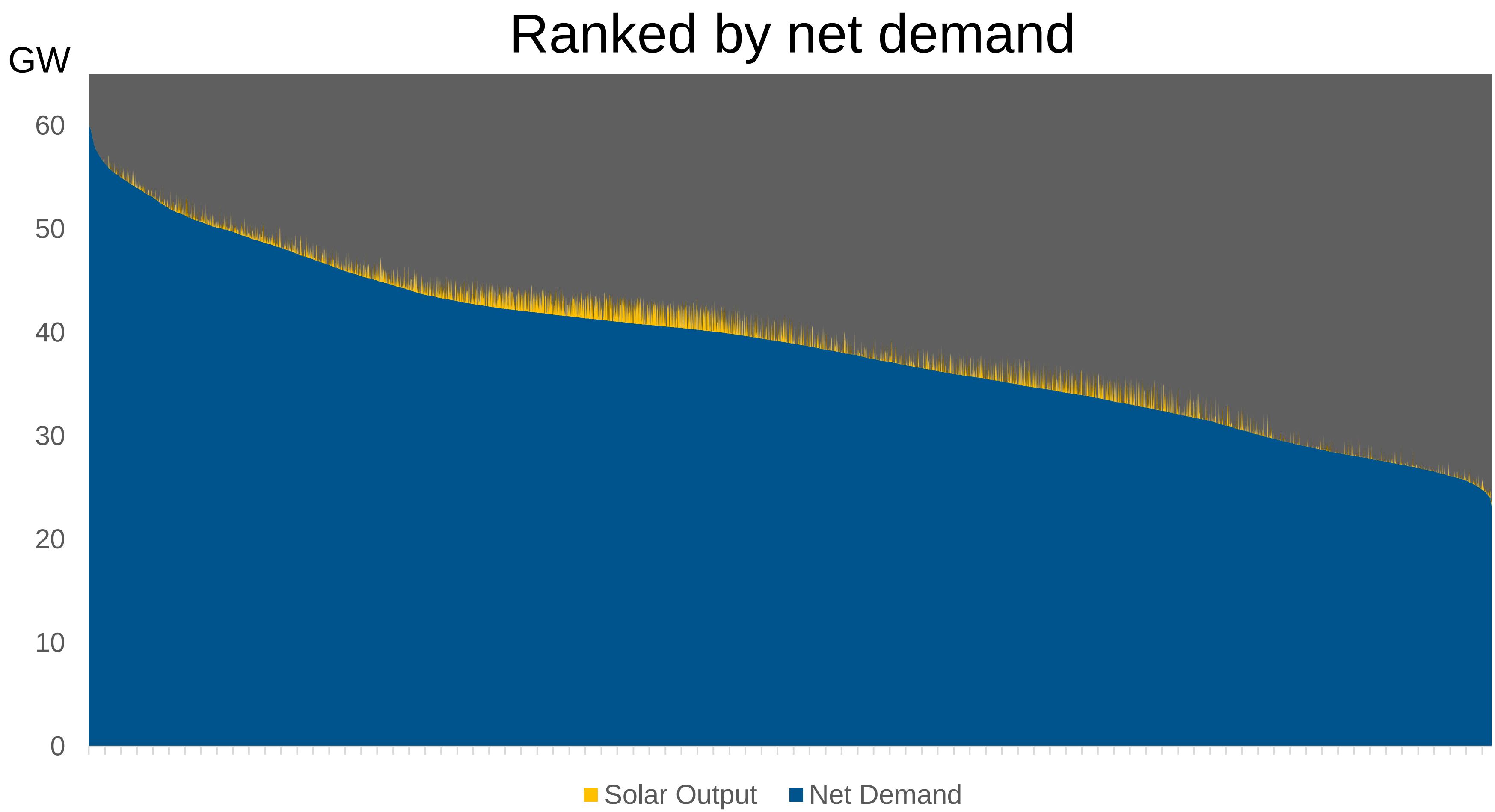
2011 demand and weather with 5 GW solar PV

Ranked by net demand



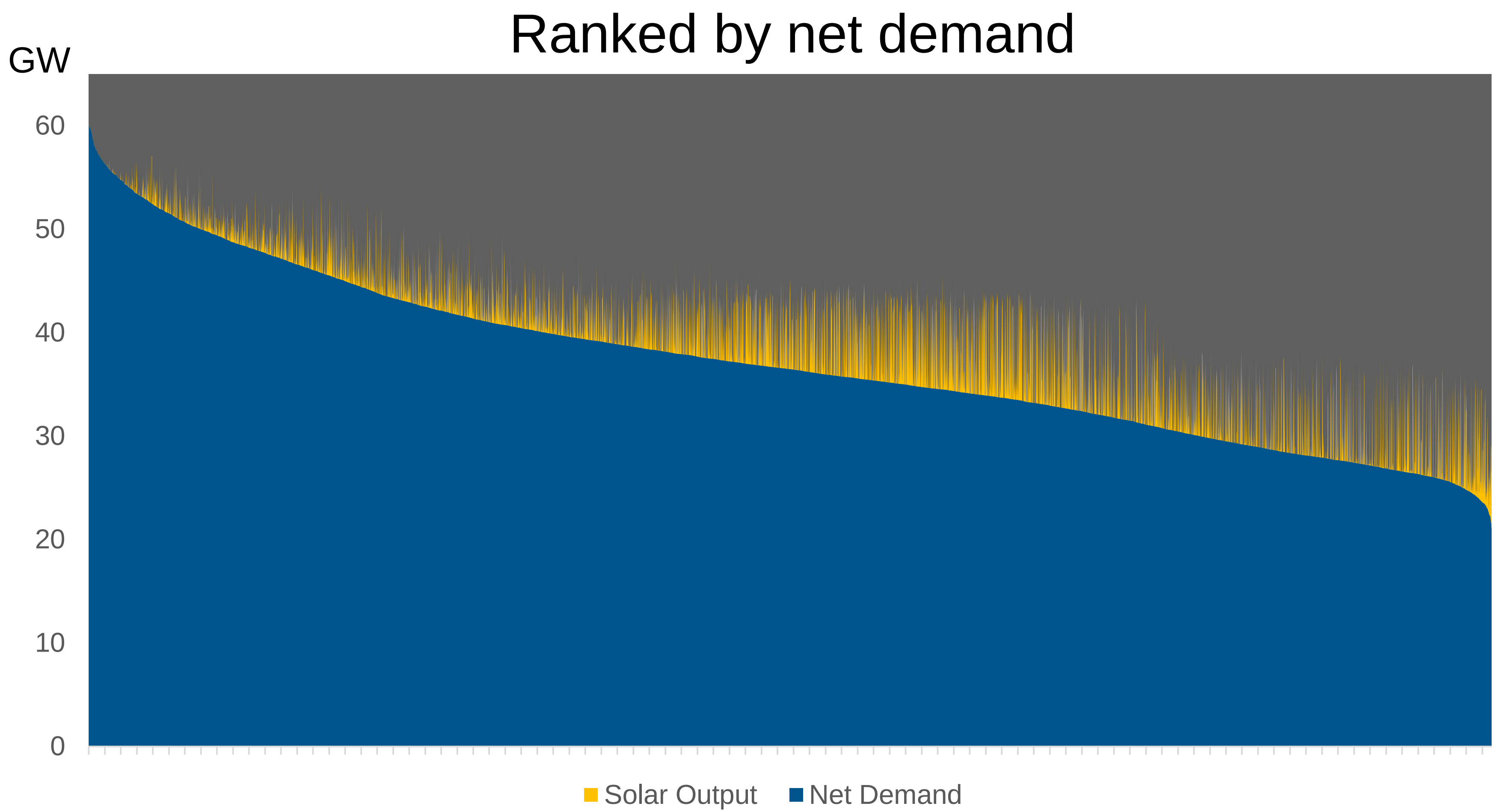
Load duration curve for GB

2011 demand and weather with 5 GW solar PV



Load duration curve for GB

2011 demand and weather with 20 GW solar PV



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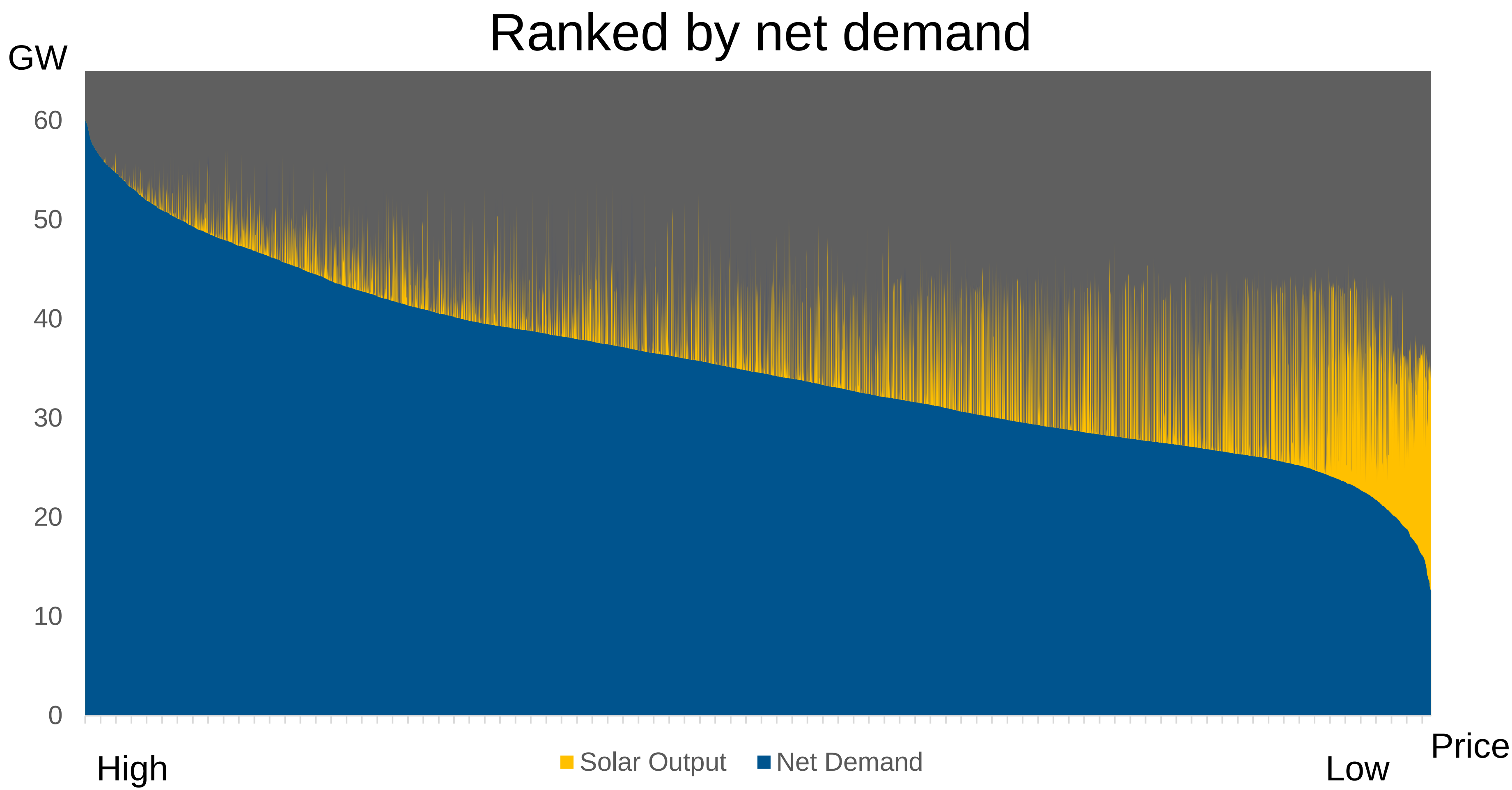
Load duration curve for GB

2011 demand and weather with 40 GW solar PV



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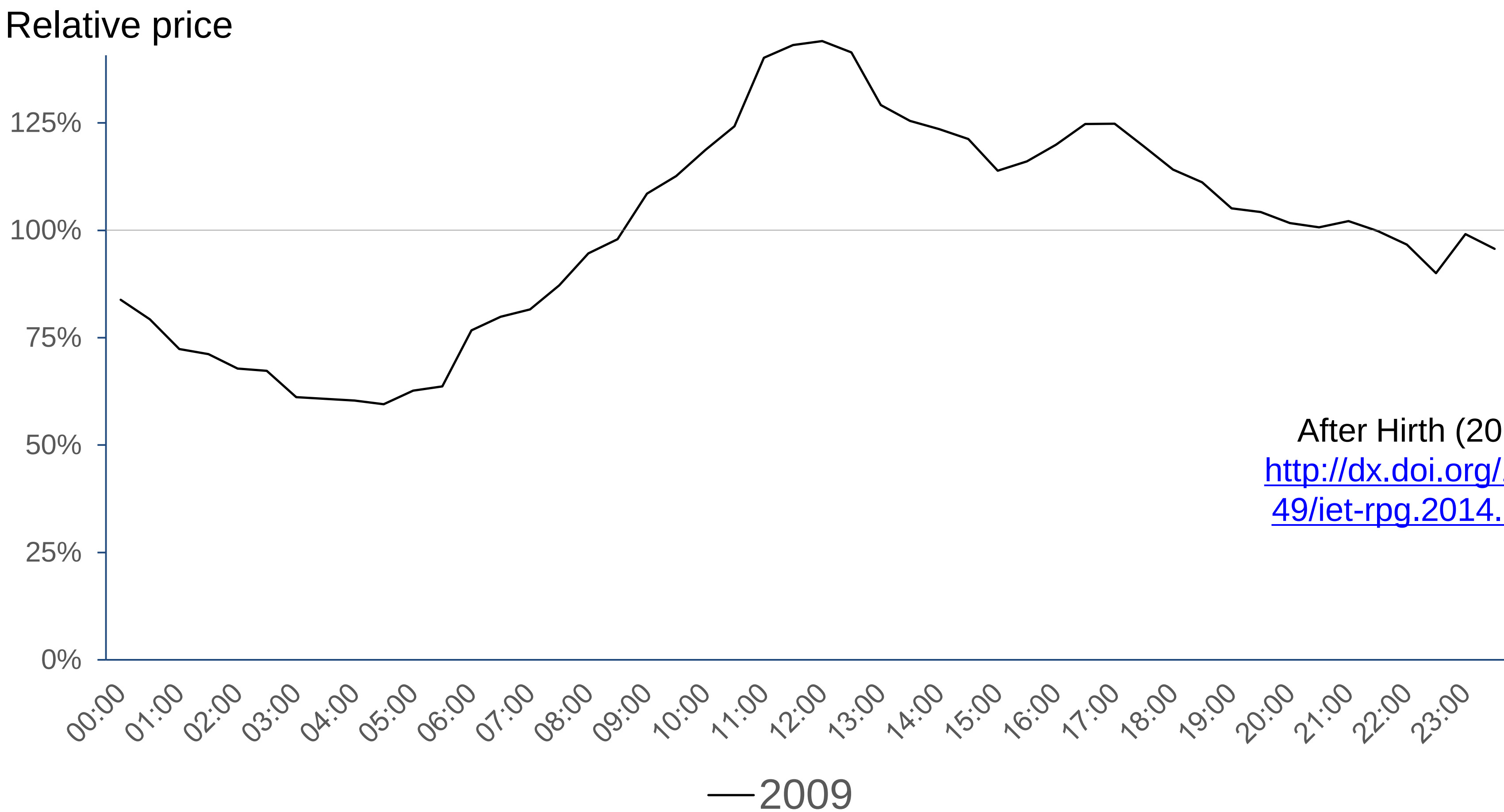
PV and Relative Prices

Great Britain, May-July



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

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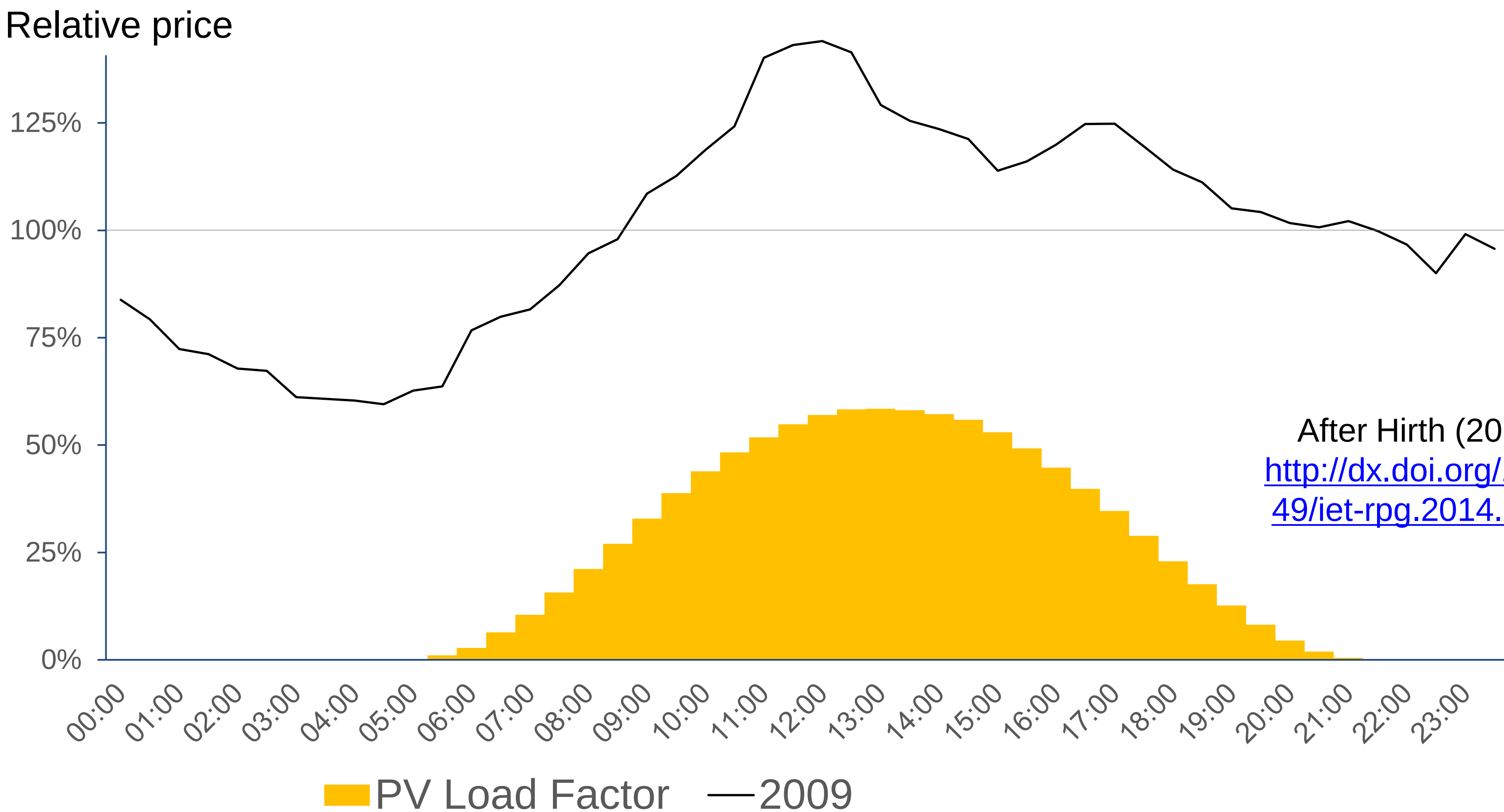

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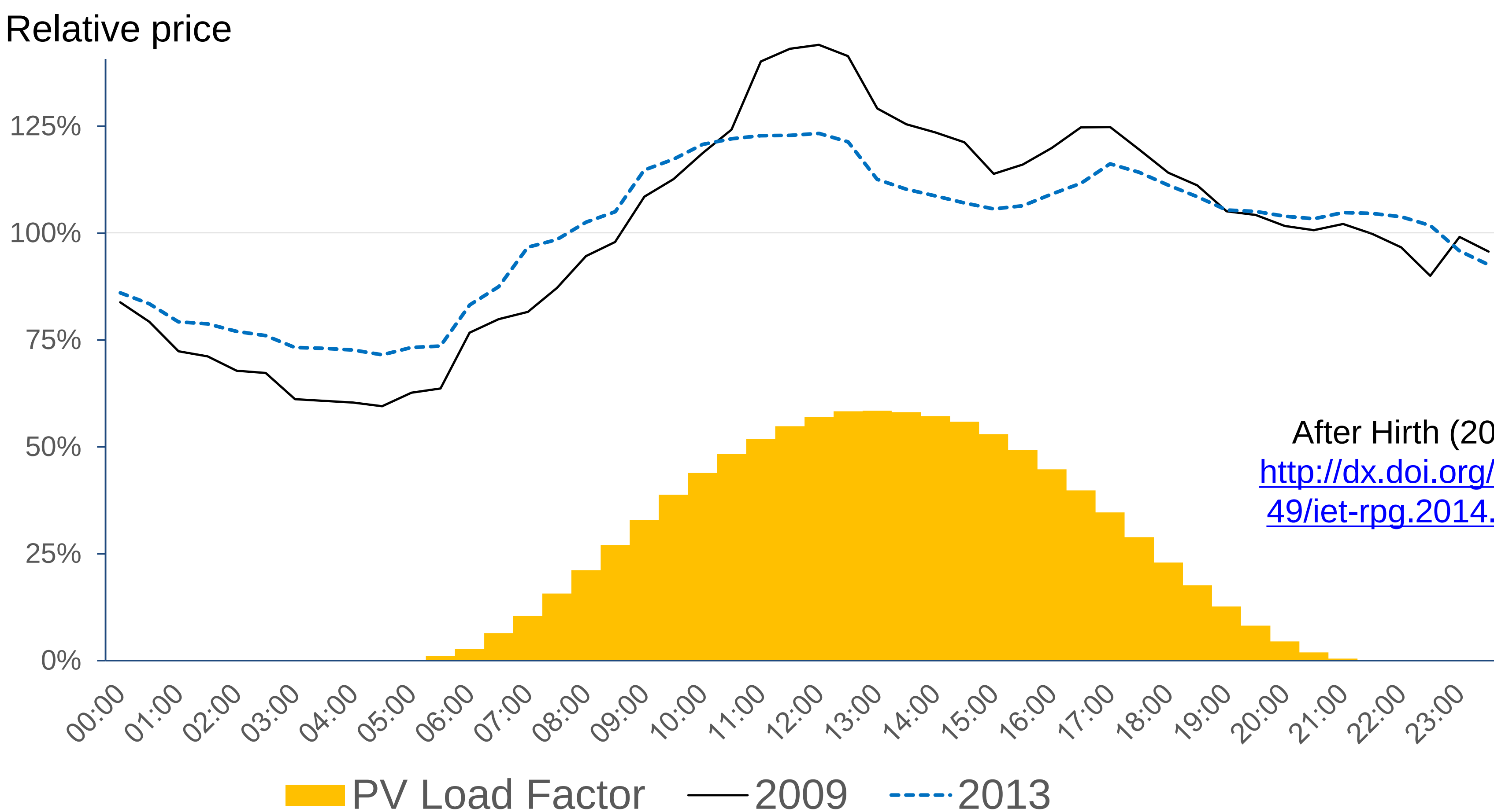

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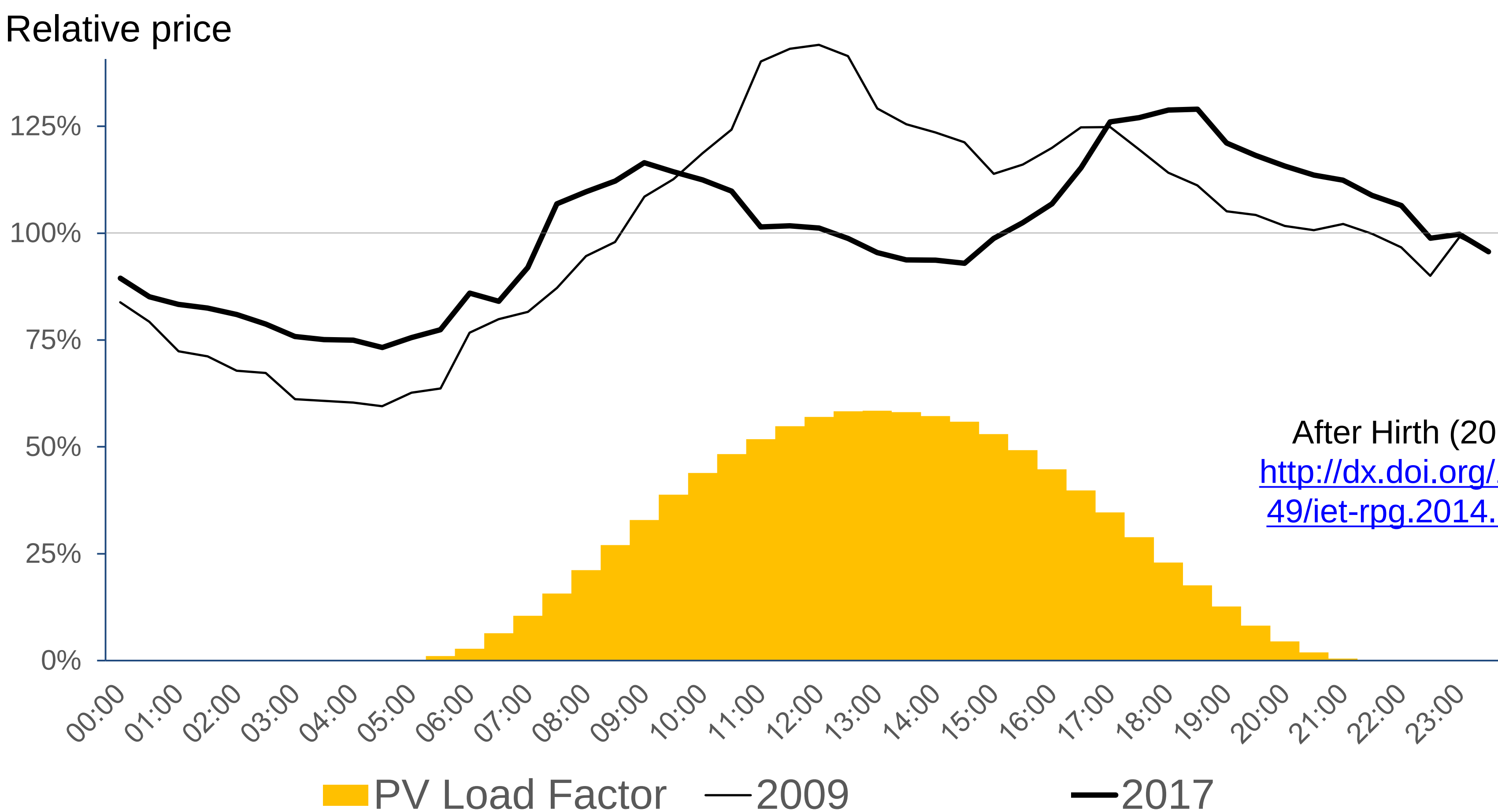

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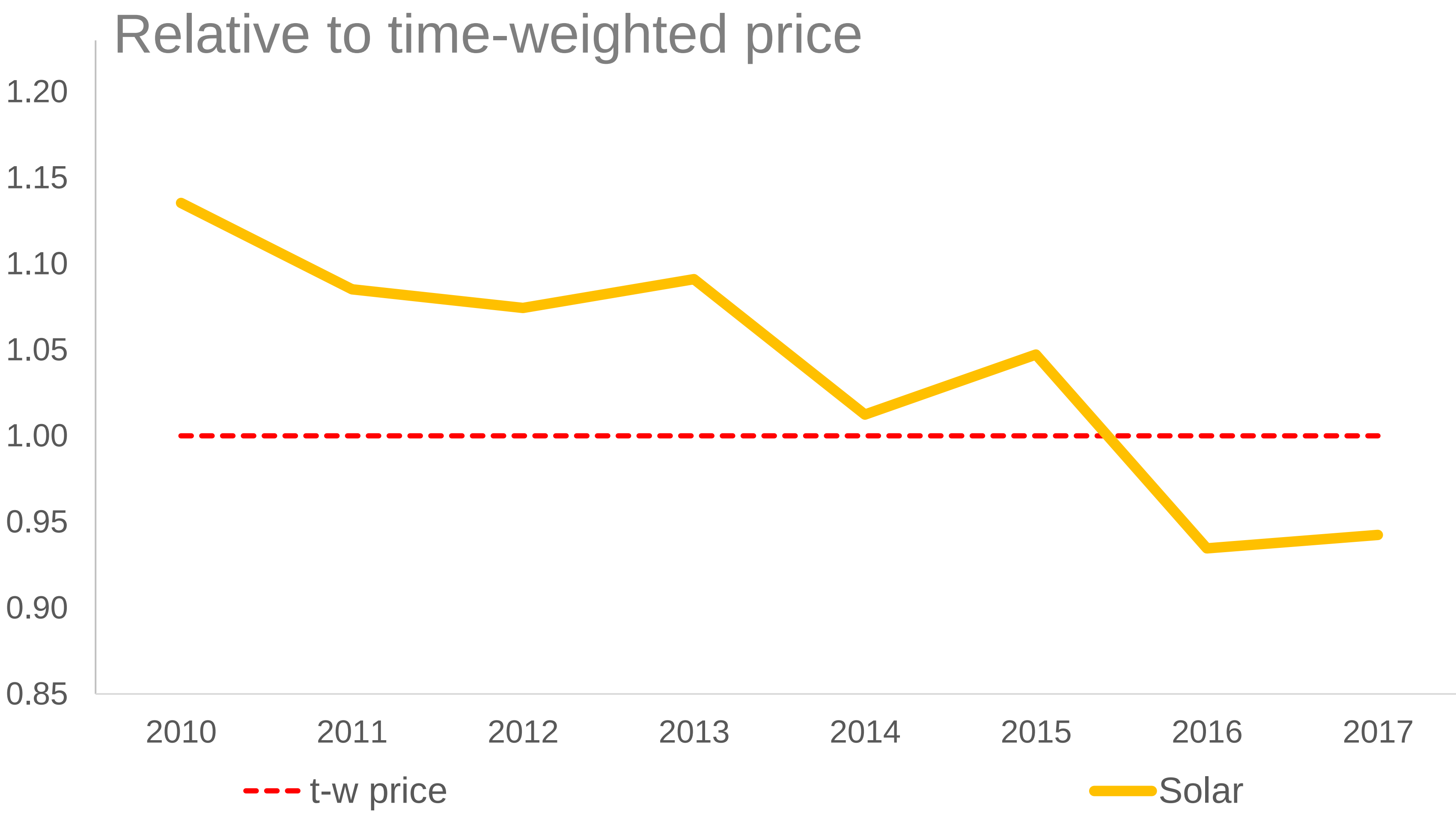
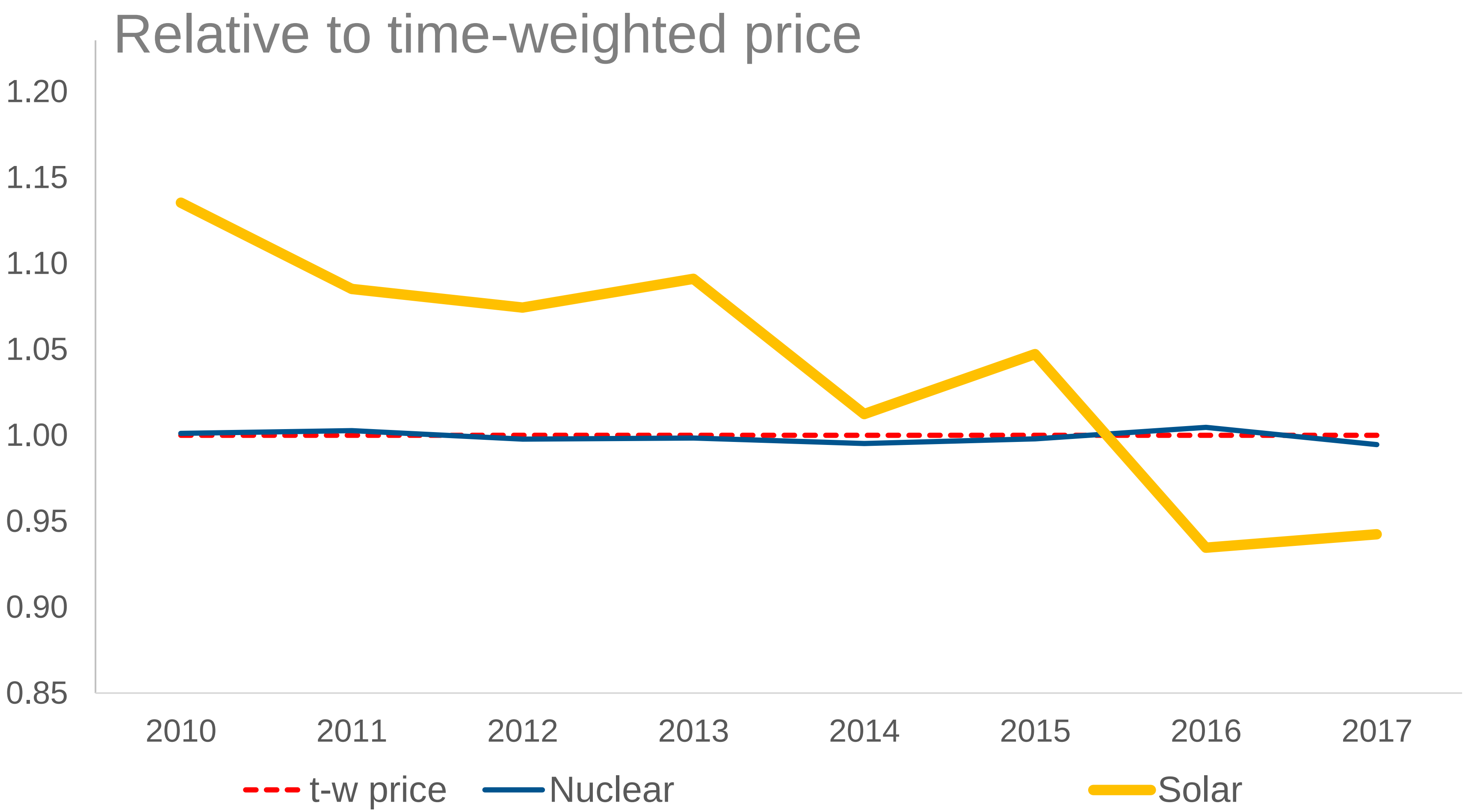
Output-weighted prices



Source: ElectricInsights.co.uk

Output-weighted prices



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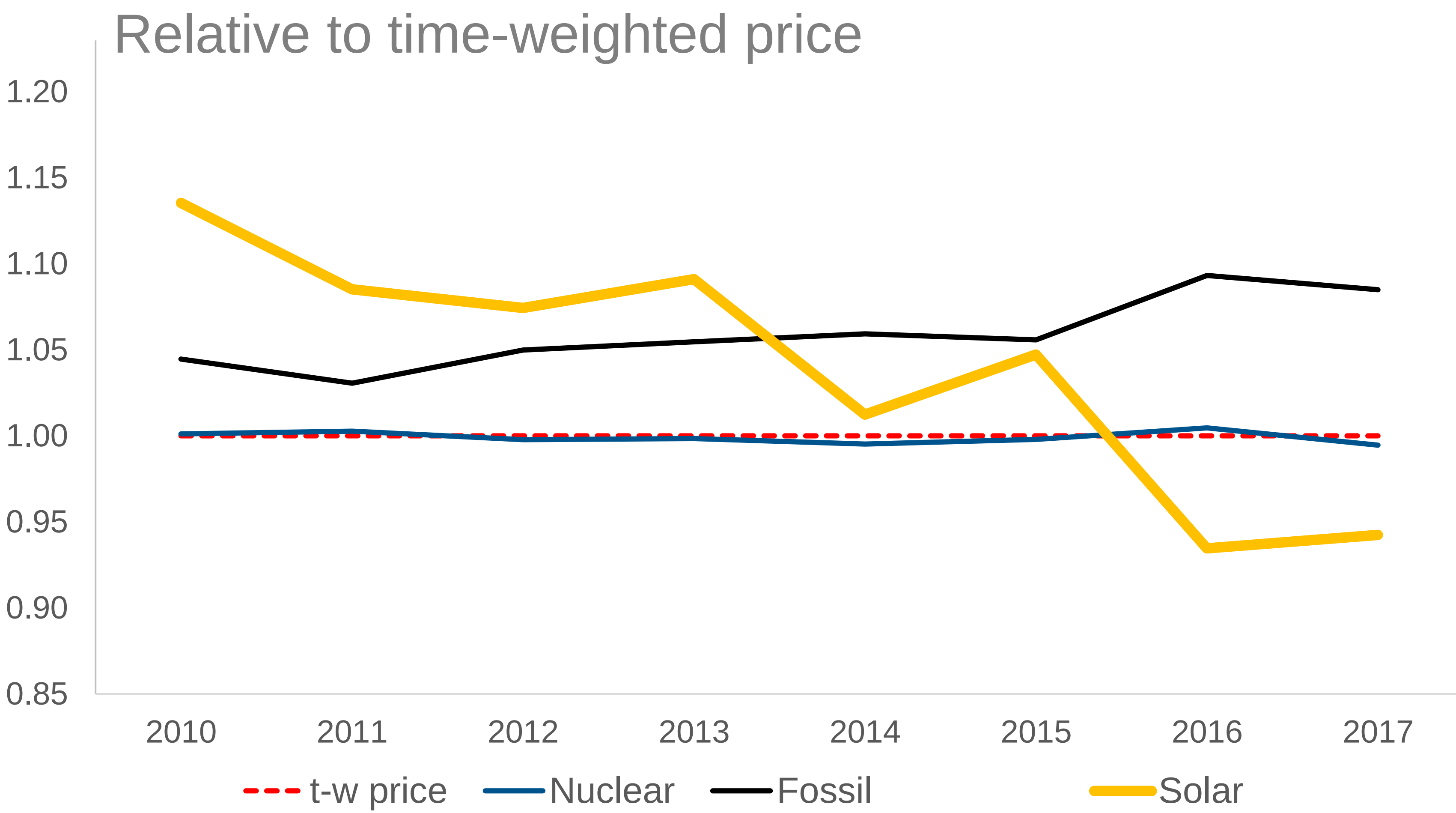

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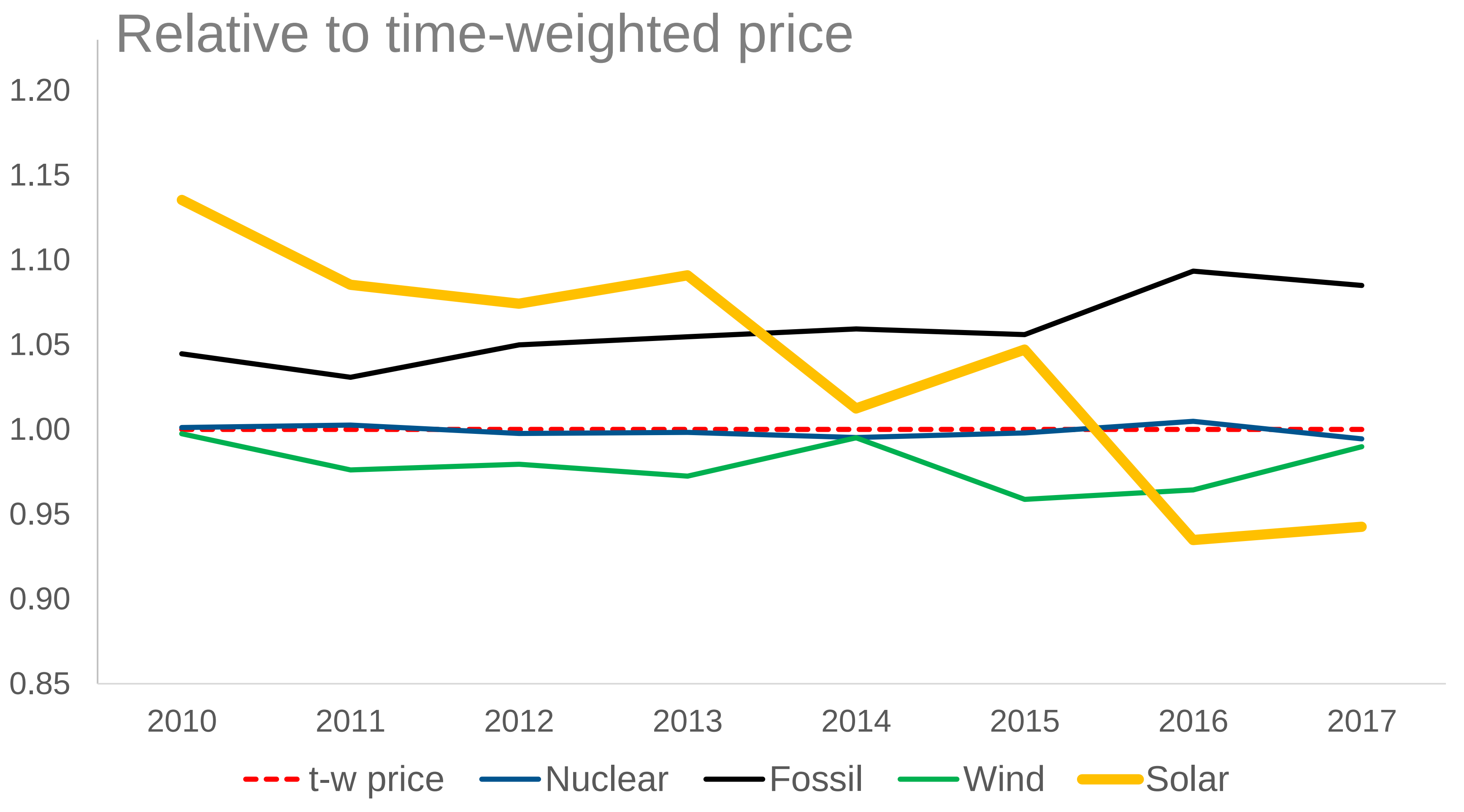

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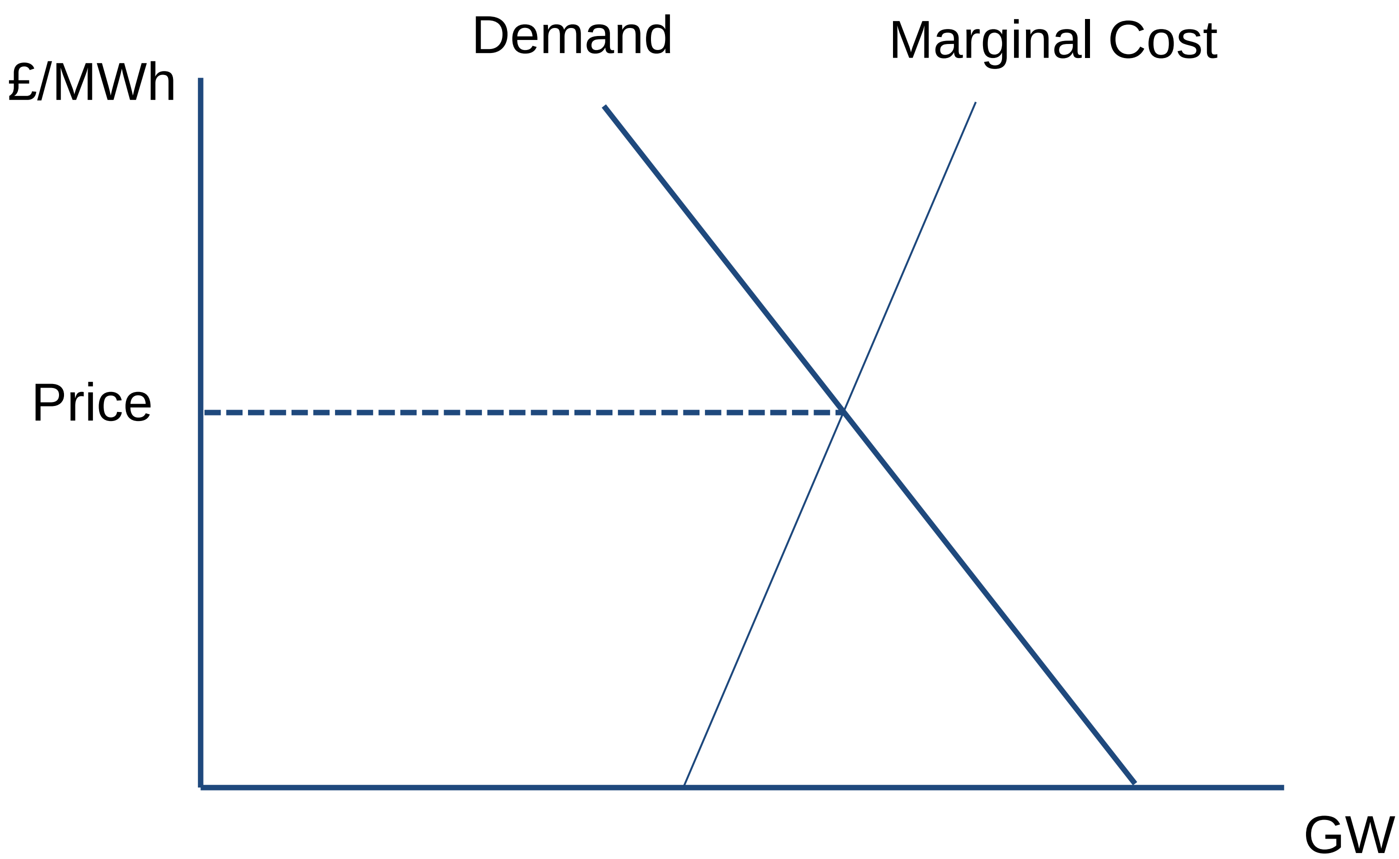
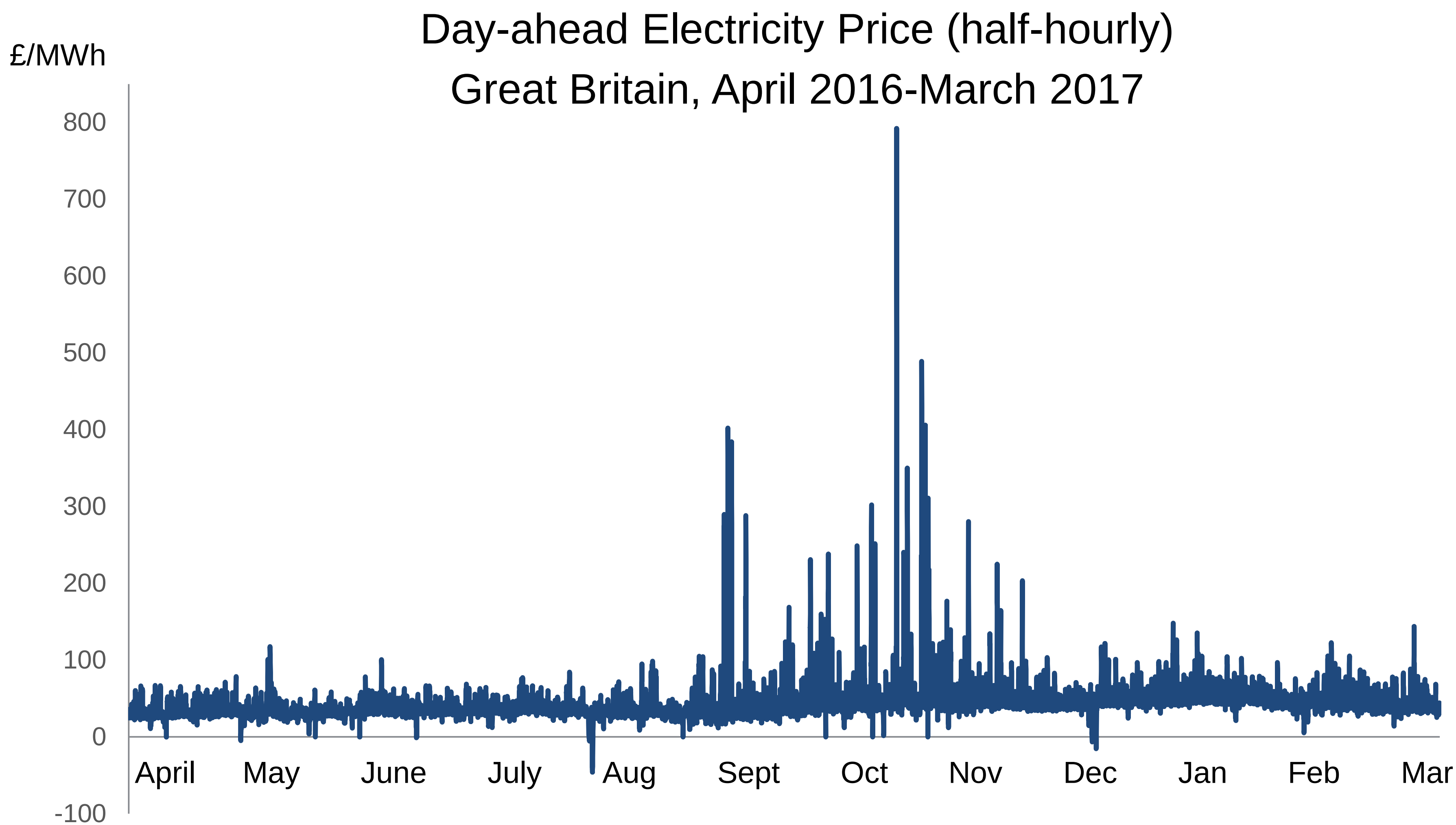
Renewables in a Power Market

Part Two: Killing the market?

Supply and Demand



A volatile market



Source: ElectricInsights.co.uk

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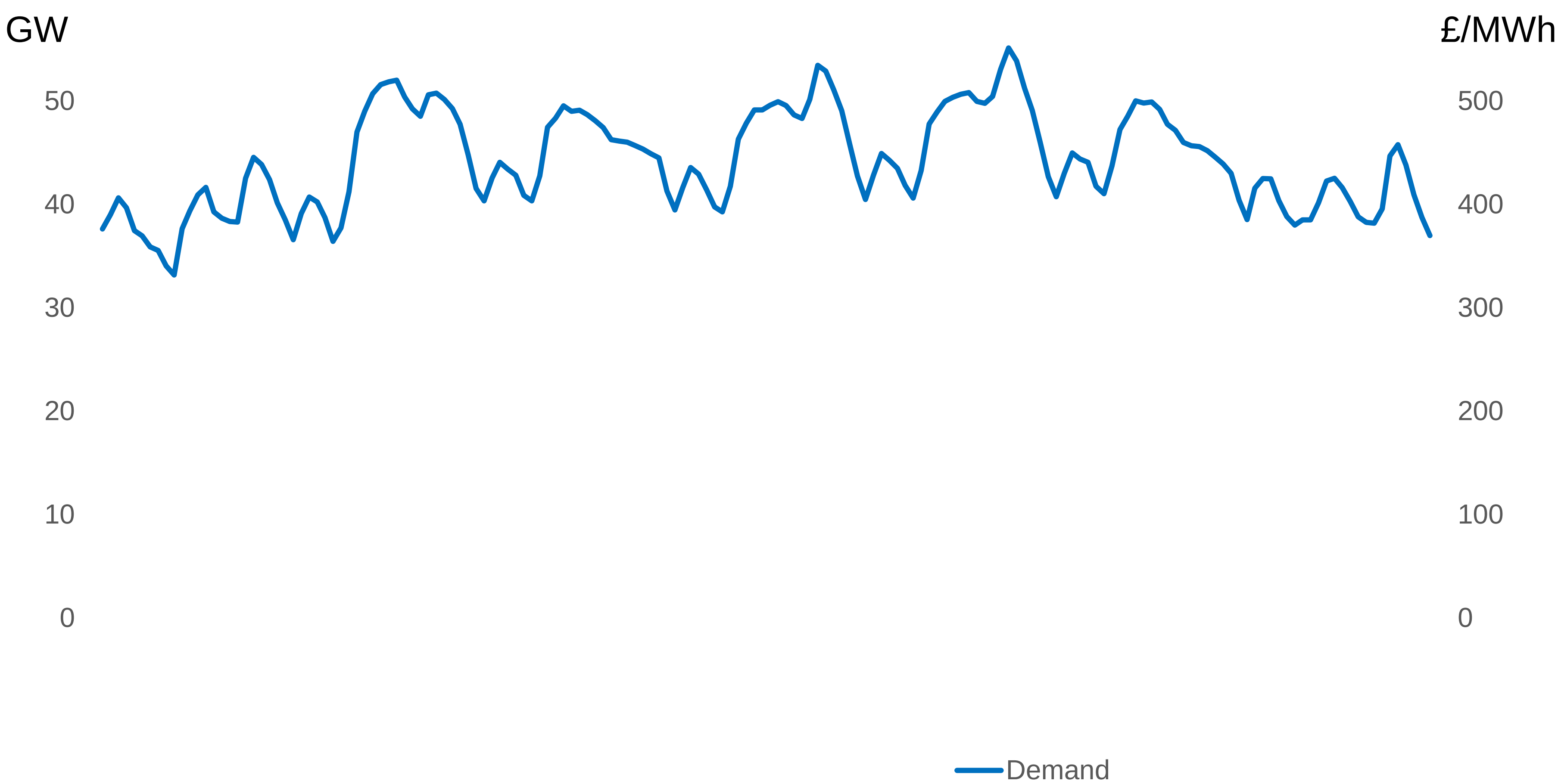
Simulating the future

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

A simulated future

Week 7 of "2010"



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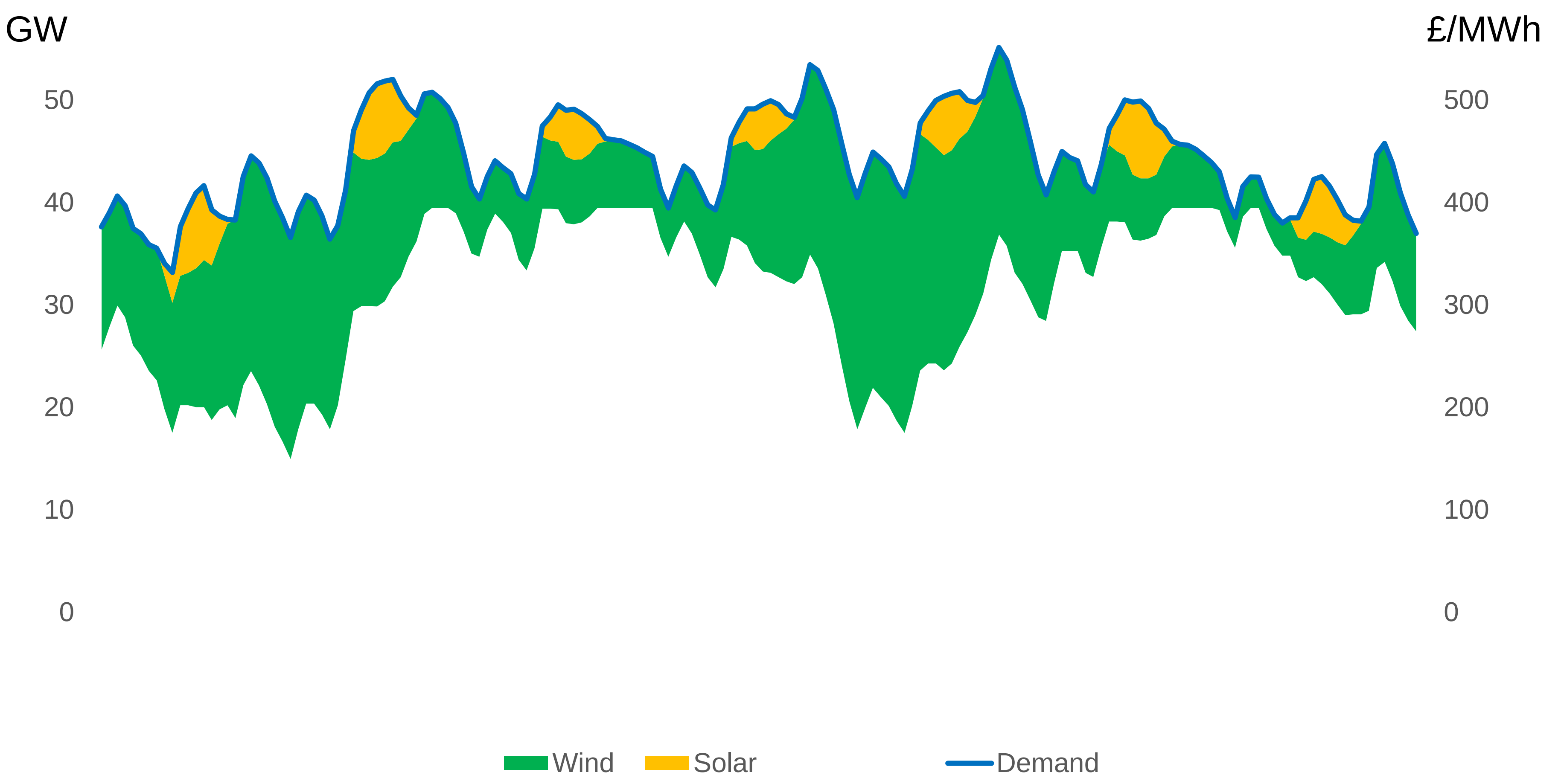
A simulated future

Week 7 of "2010"



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A simulated future

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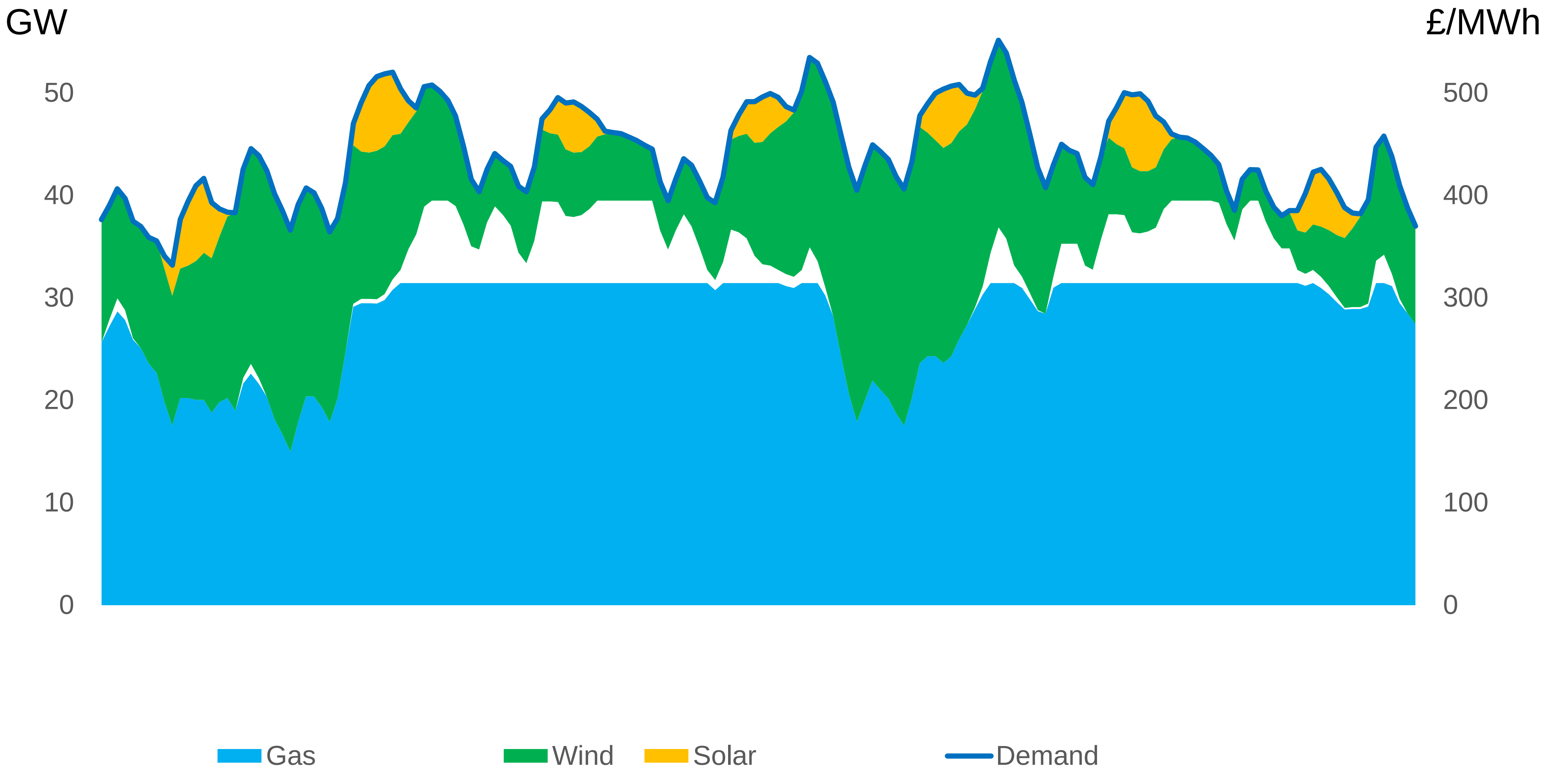

A simulated future

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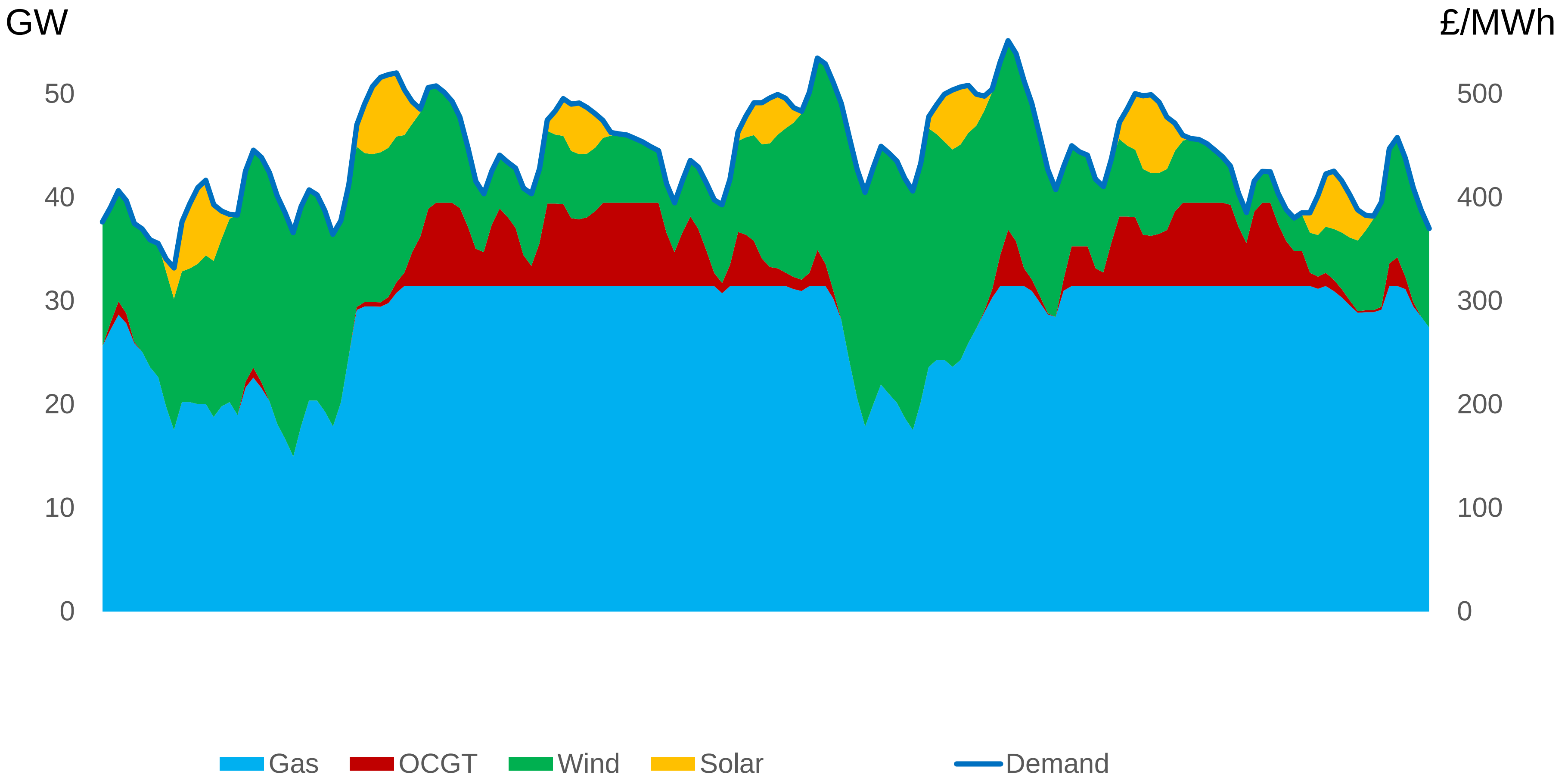
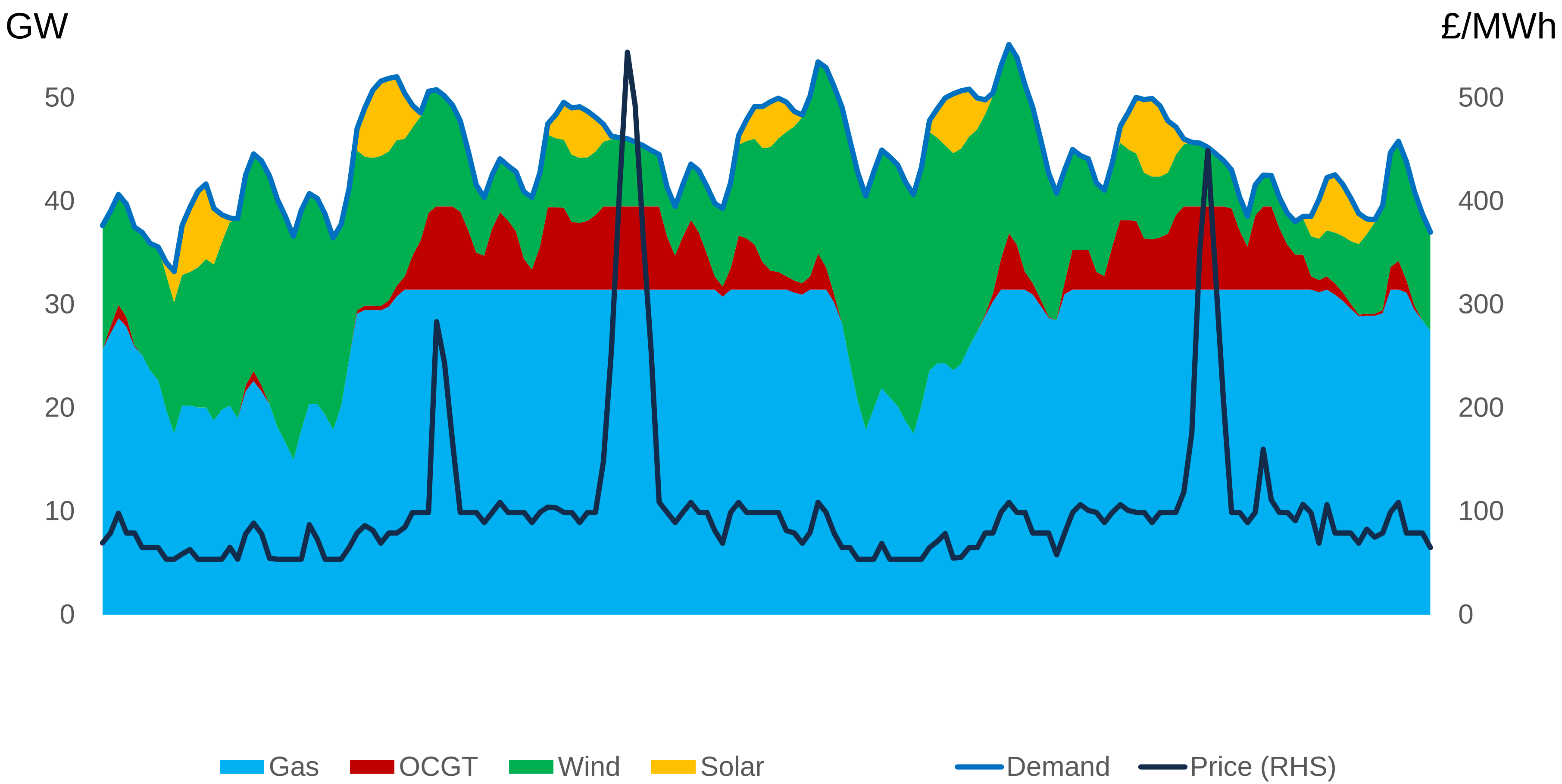


A simulated future

Week 7 of "2010"



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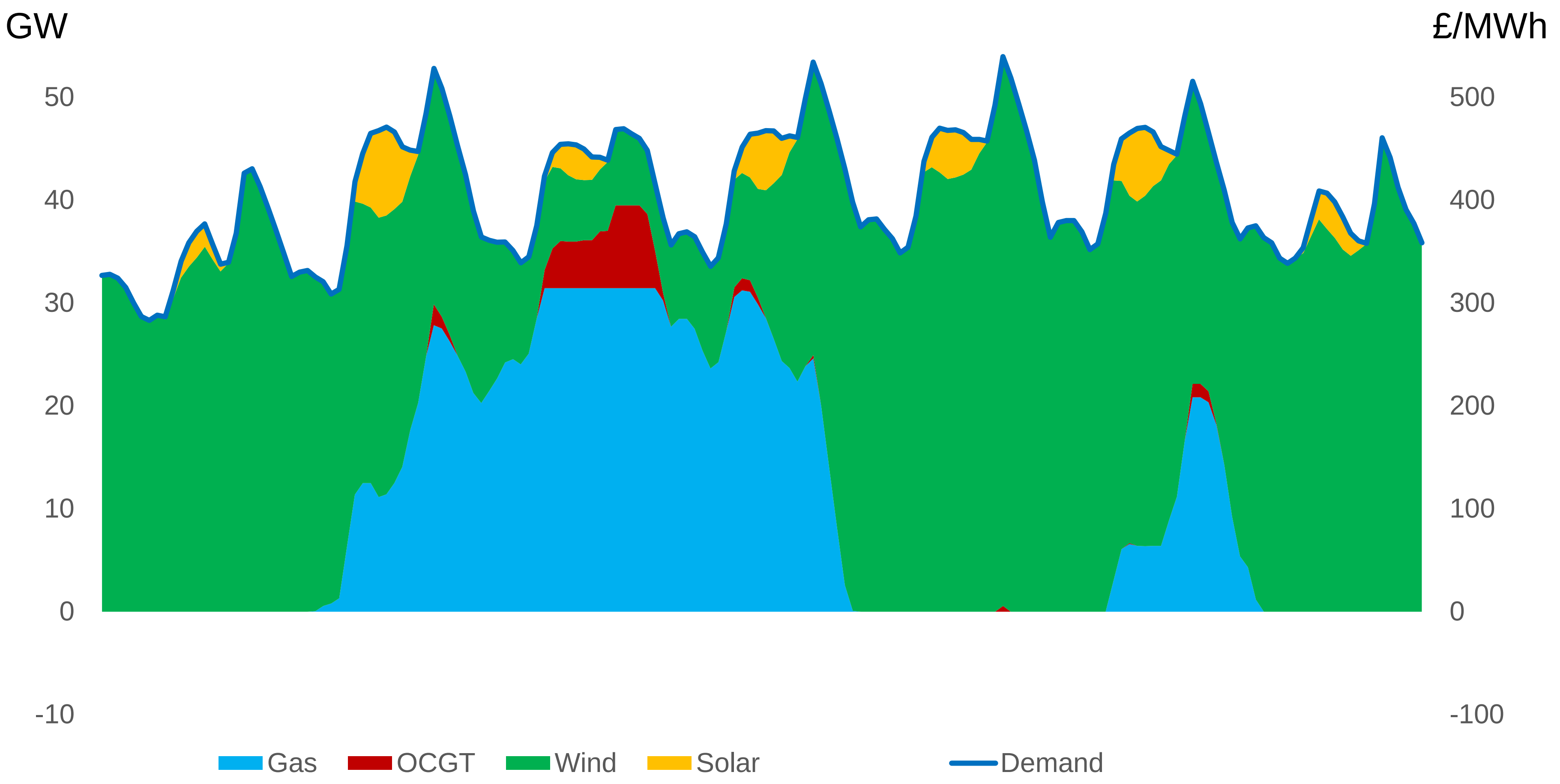
A simulated future

Week 44 of "2010"



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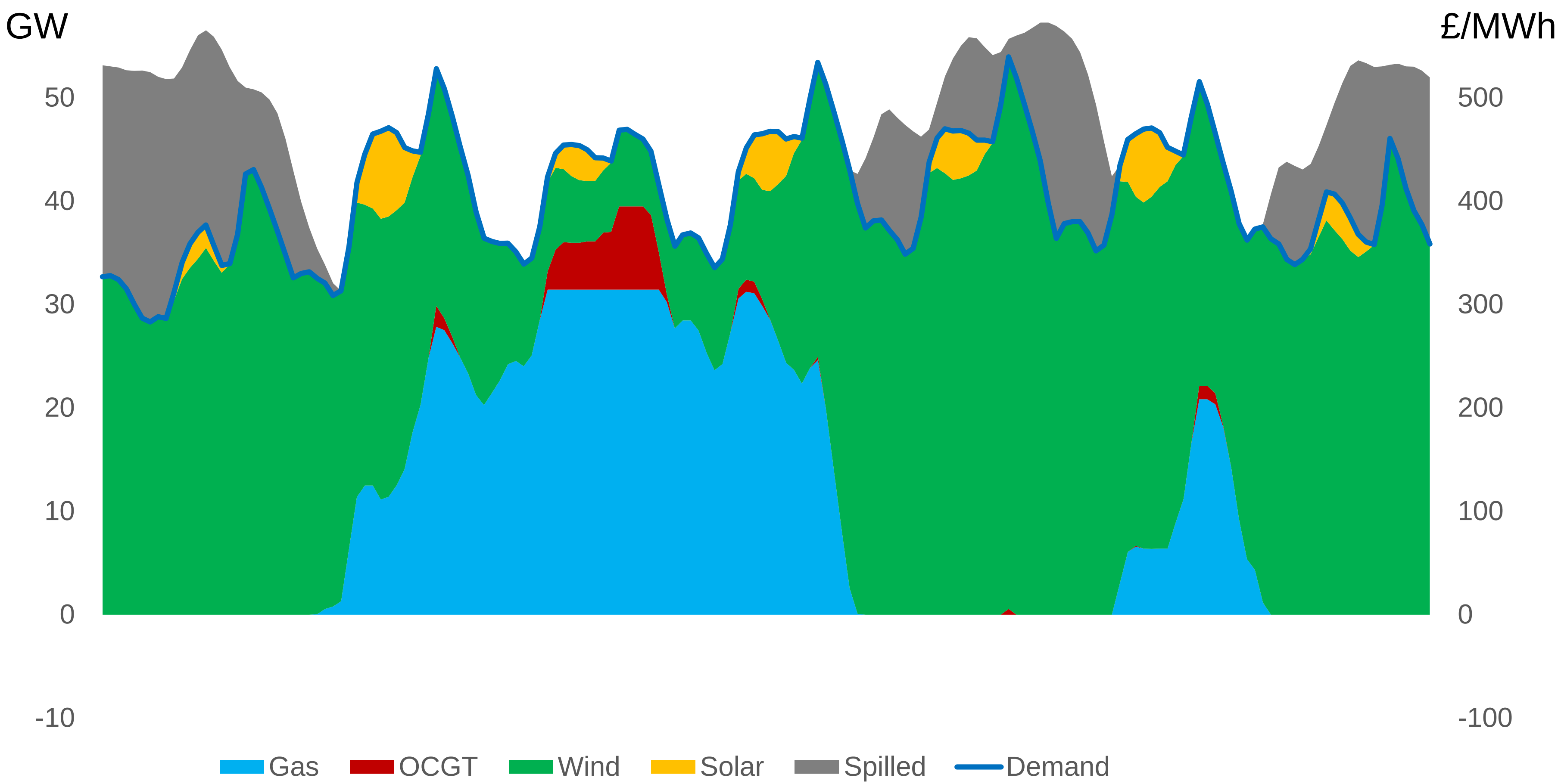
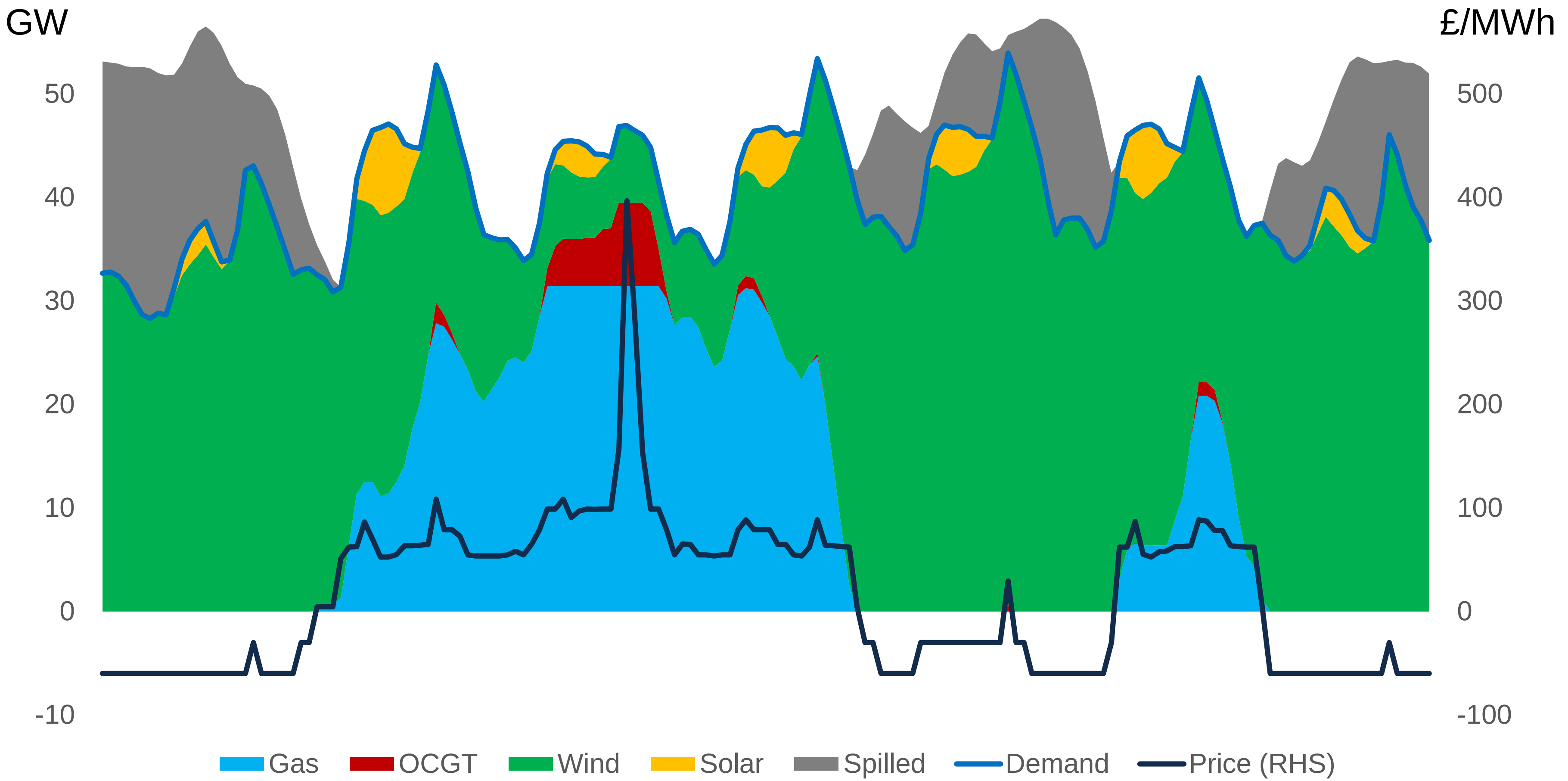
A simulated future

Week 44 of "2010"



A simulated future

Week 44 of "2010"



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A barrier to renewables?

Relative revenues by type of plant

Adding a little storage

Highest and lowest prices eliminated

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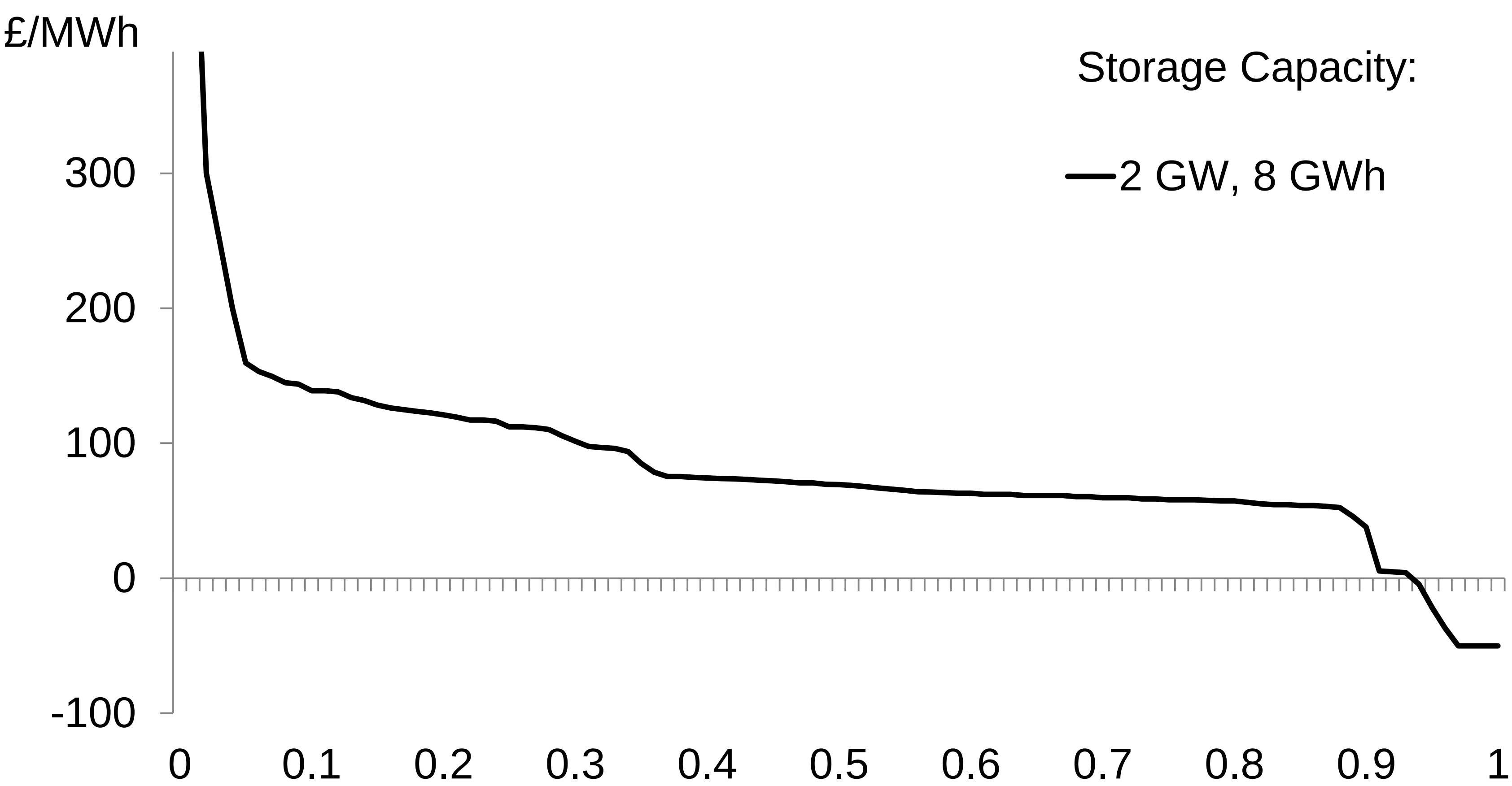
Price-duration curves

- GB, 2030 with endogenous generation capacity



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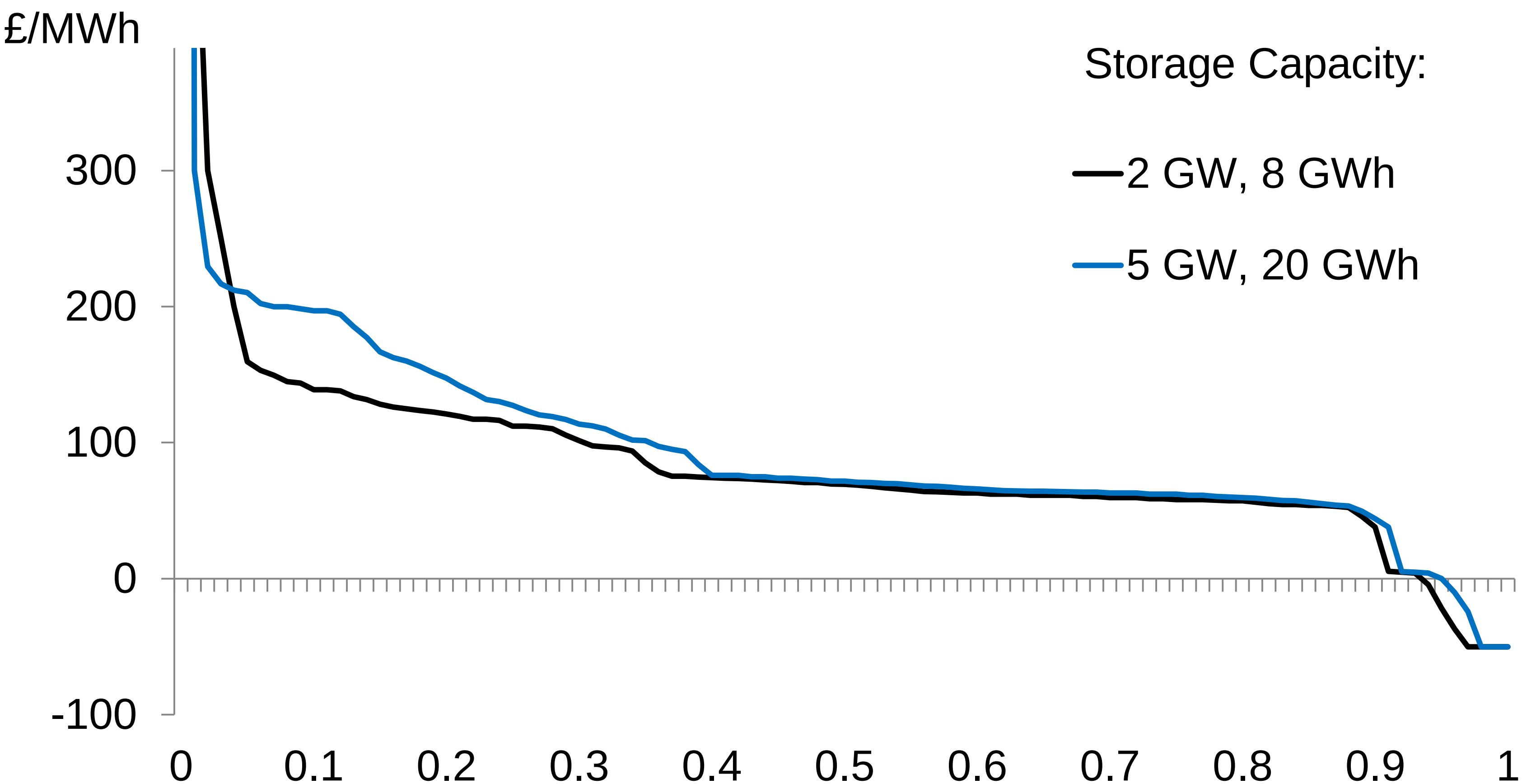
Price-duration curves

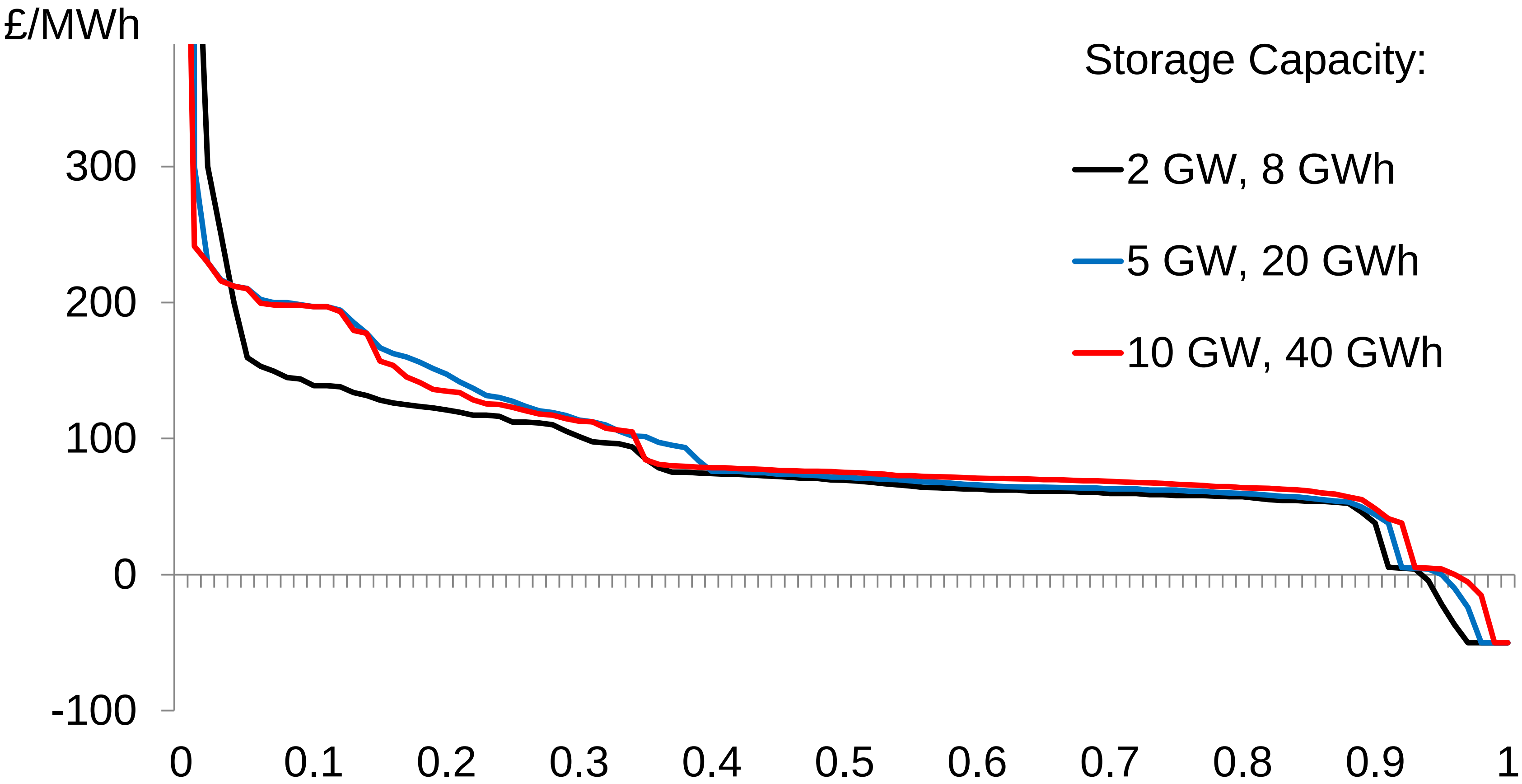
- GB, 2030 with endogenous generation capacity



1st International Capacity Building (ICB)"Learning from Regulatory Experiences and Market Development in Europe"

Price-duration curves

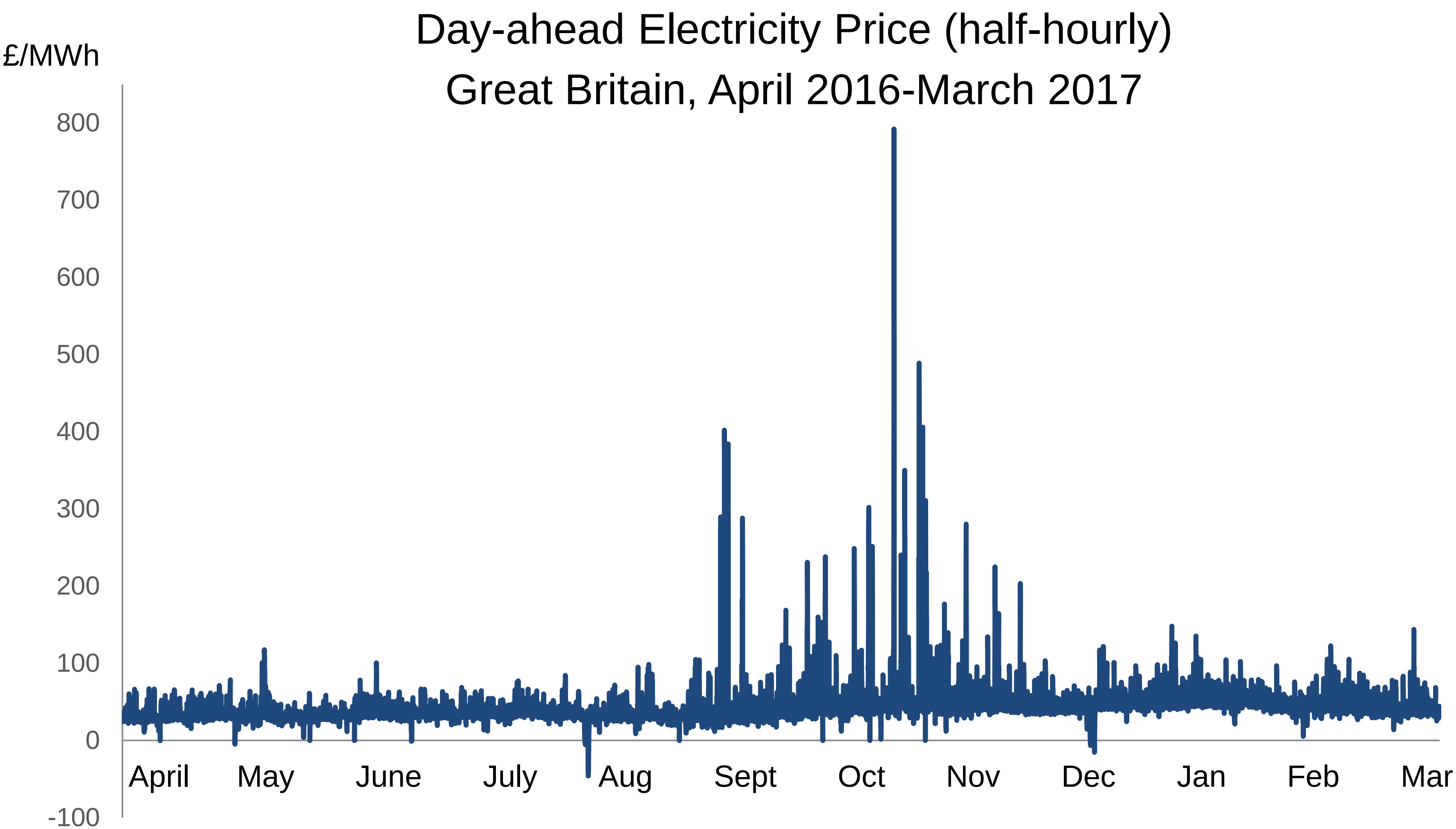
- GB, 2030 with endogenous generation capacity



Renewables in an Energy Market

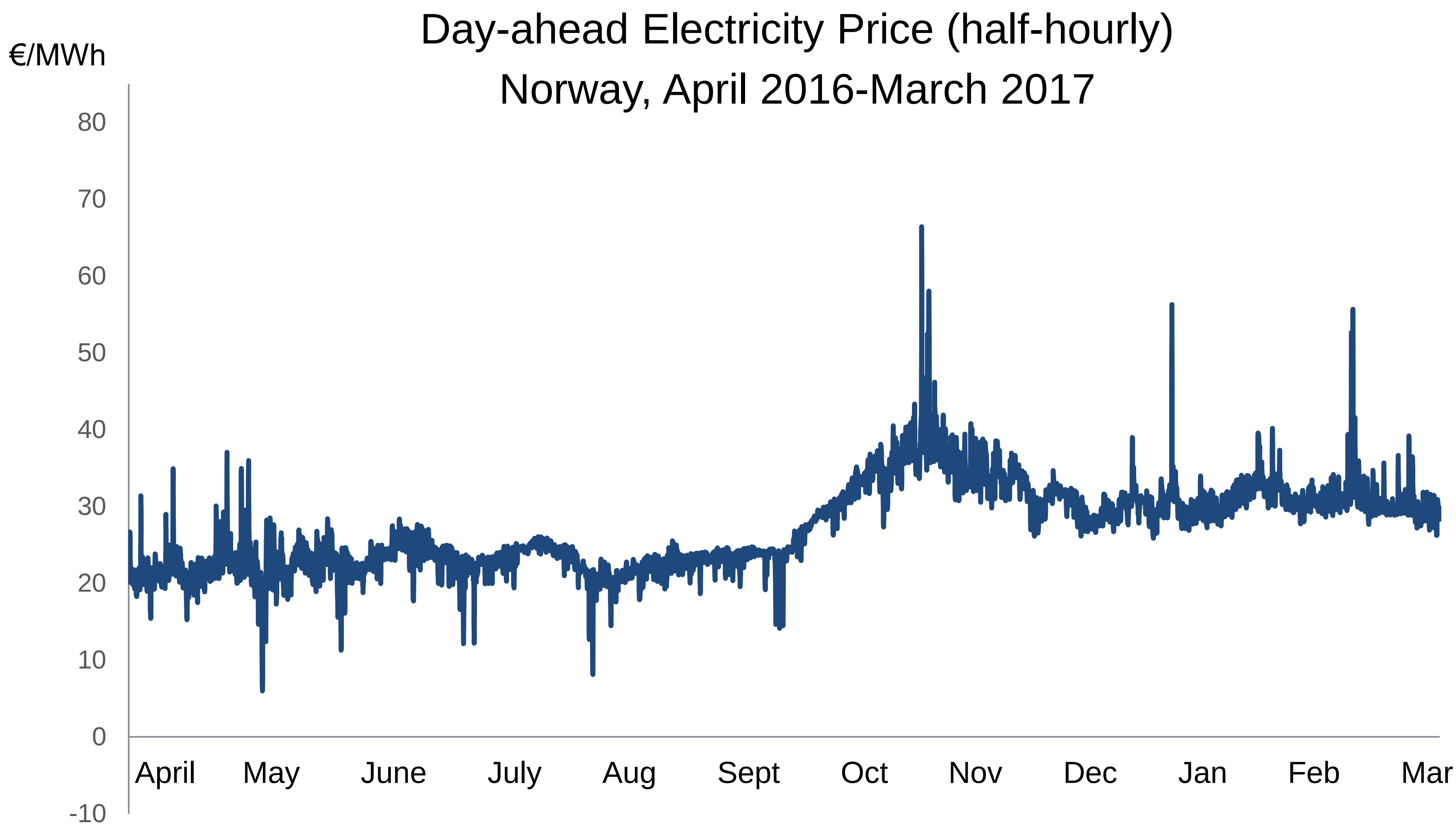
How storage changes price-setting, if there's enough of it

A volatile market



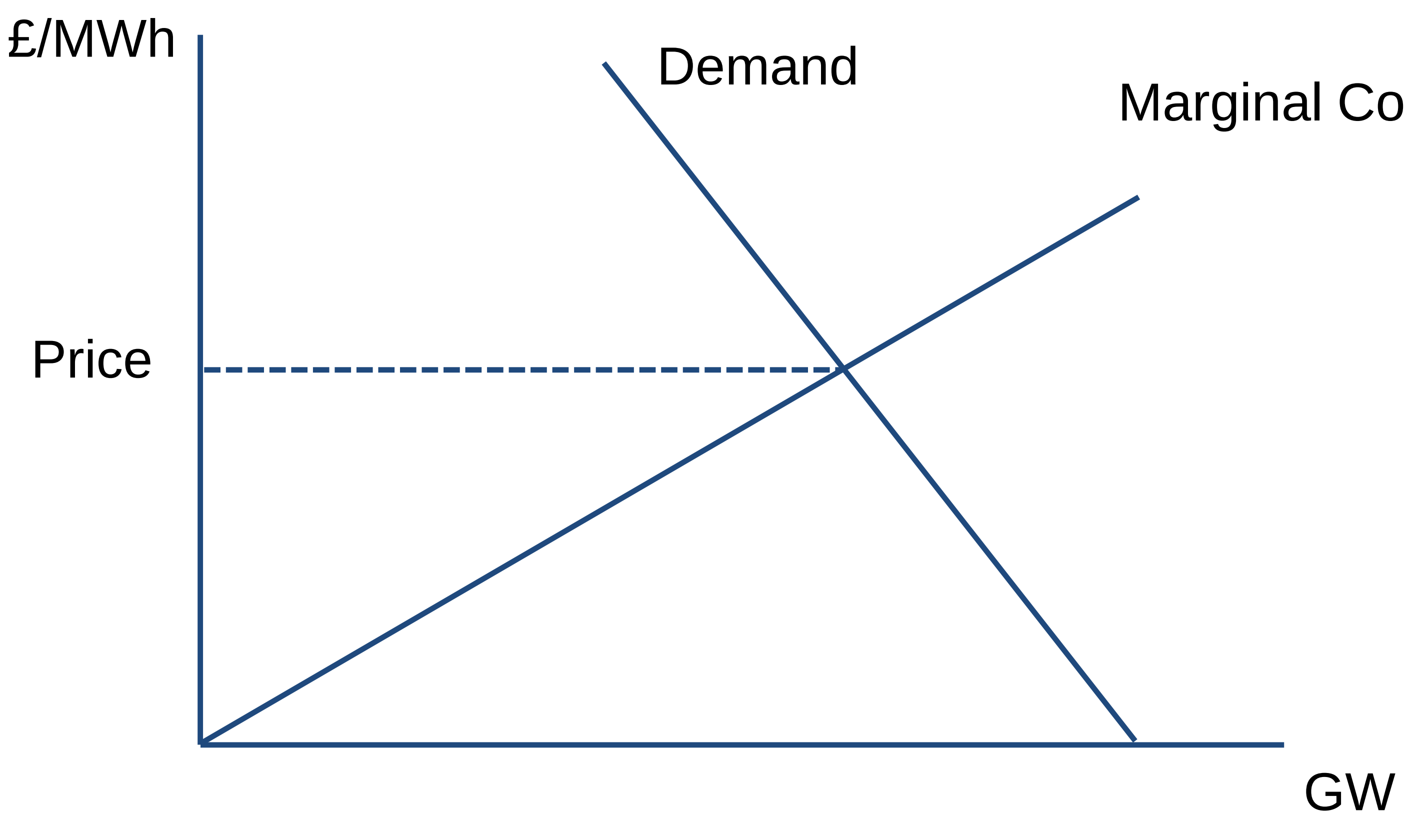
Source: ElectricInsights.co.uk

A less volatile market



Source: Energinet.dk

Supply and Demand



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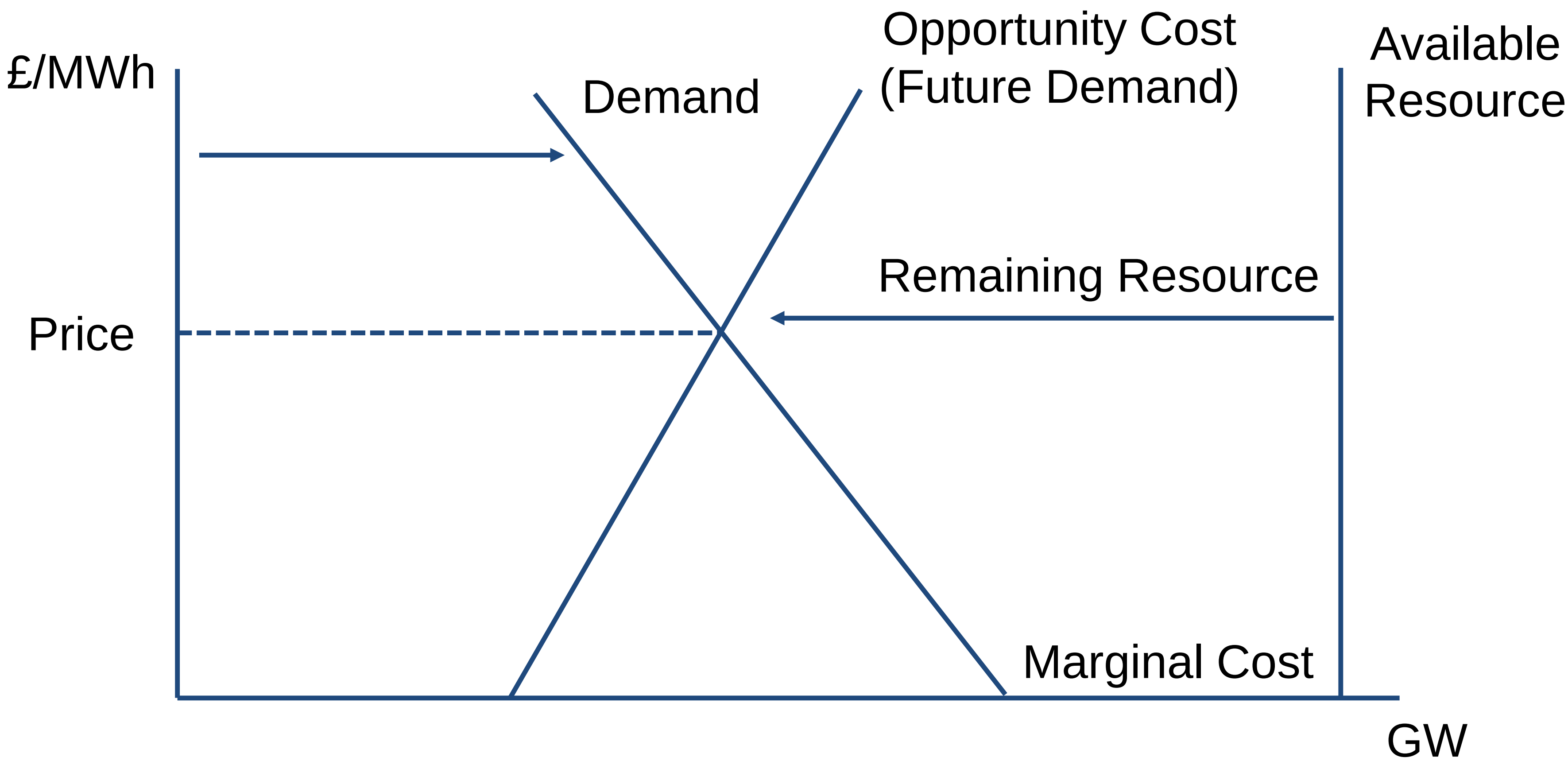
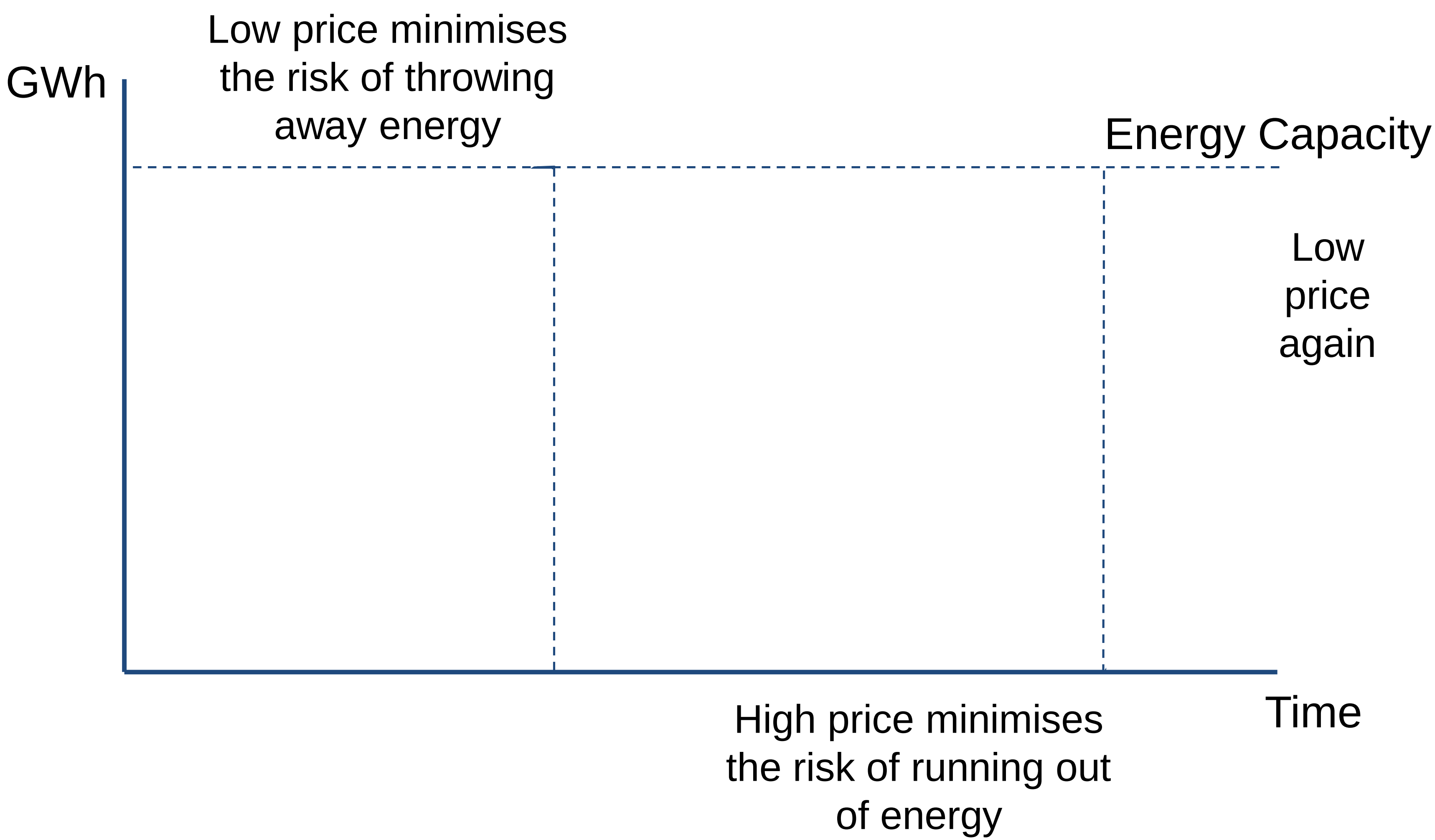
Supply and Demand



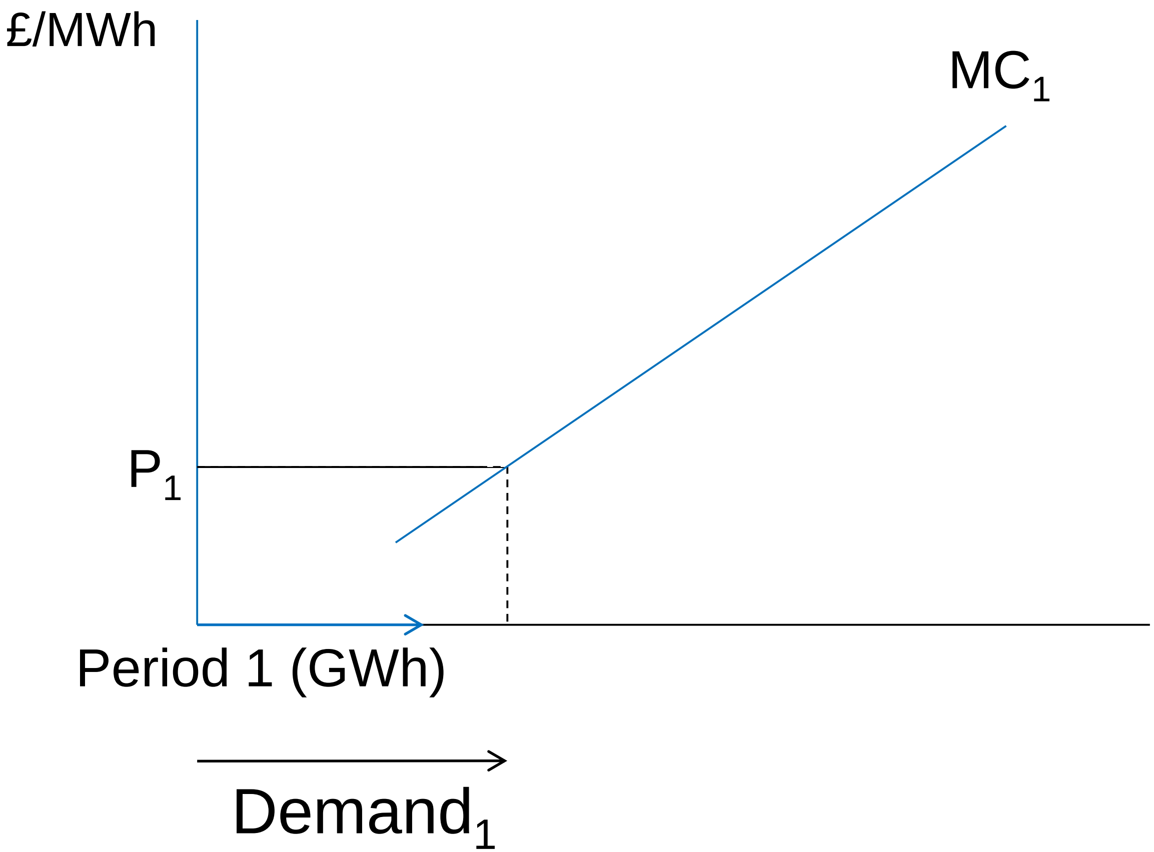
Finn's bathtub, from Forsund (2007) *Hydropower Economics,* Springer

Reservoir Levels



Richard's bath-tub

Storage with generation



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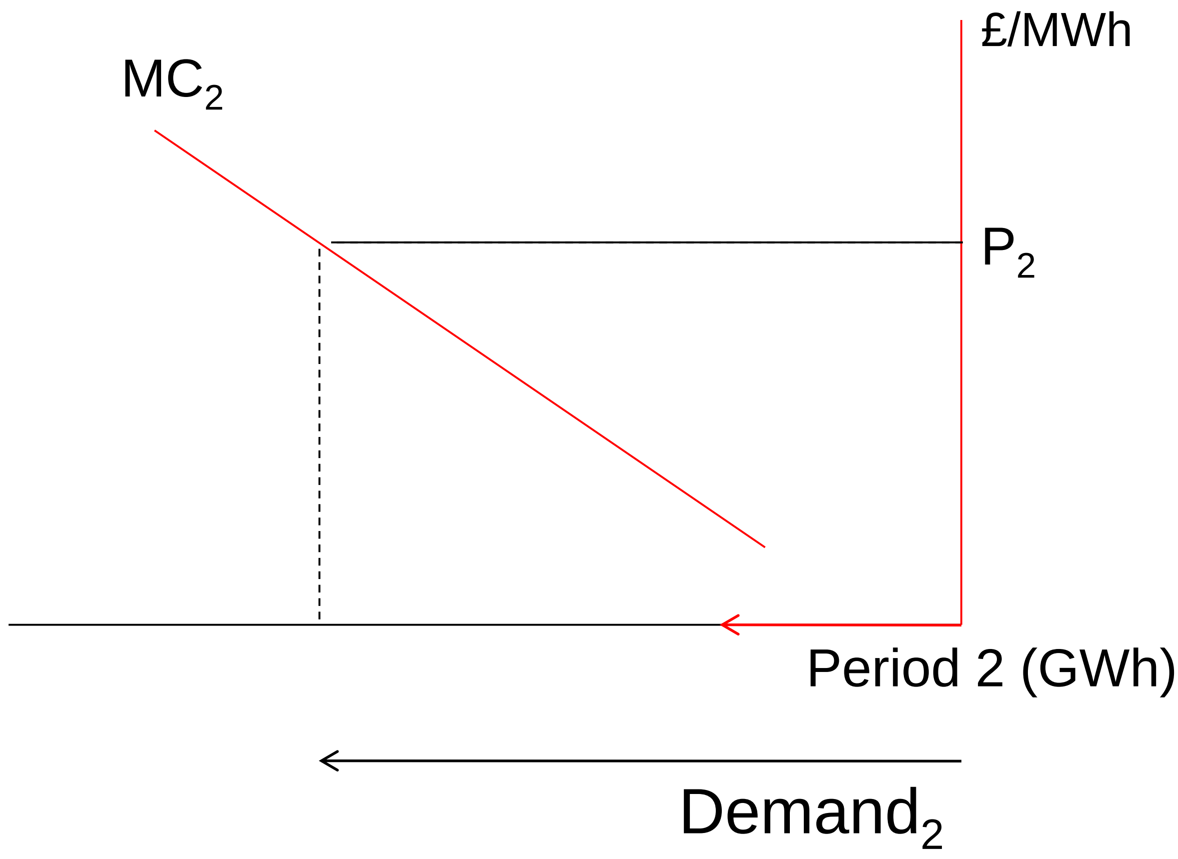

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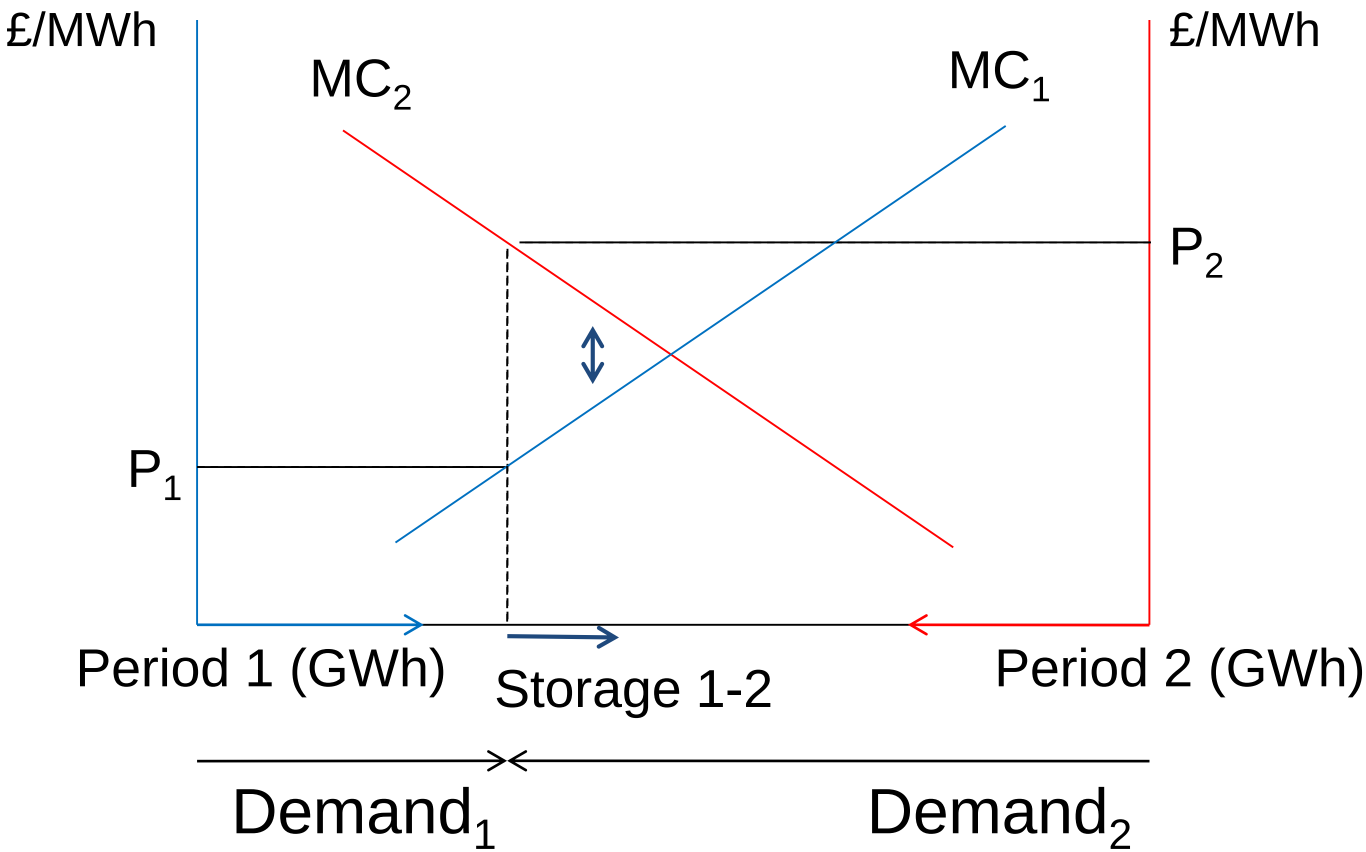
Storage with generation



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

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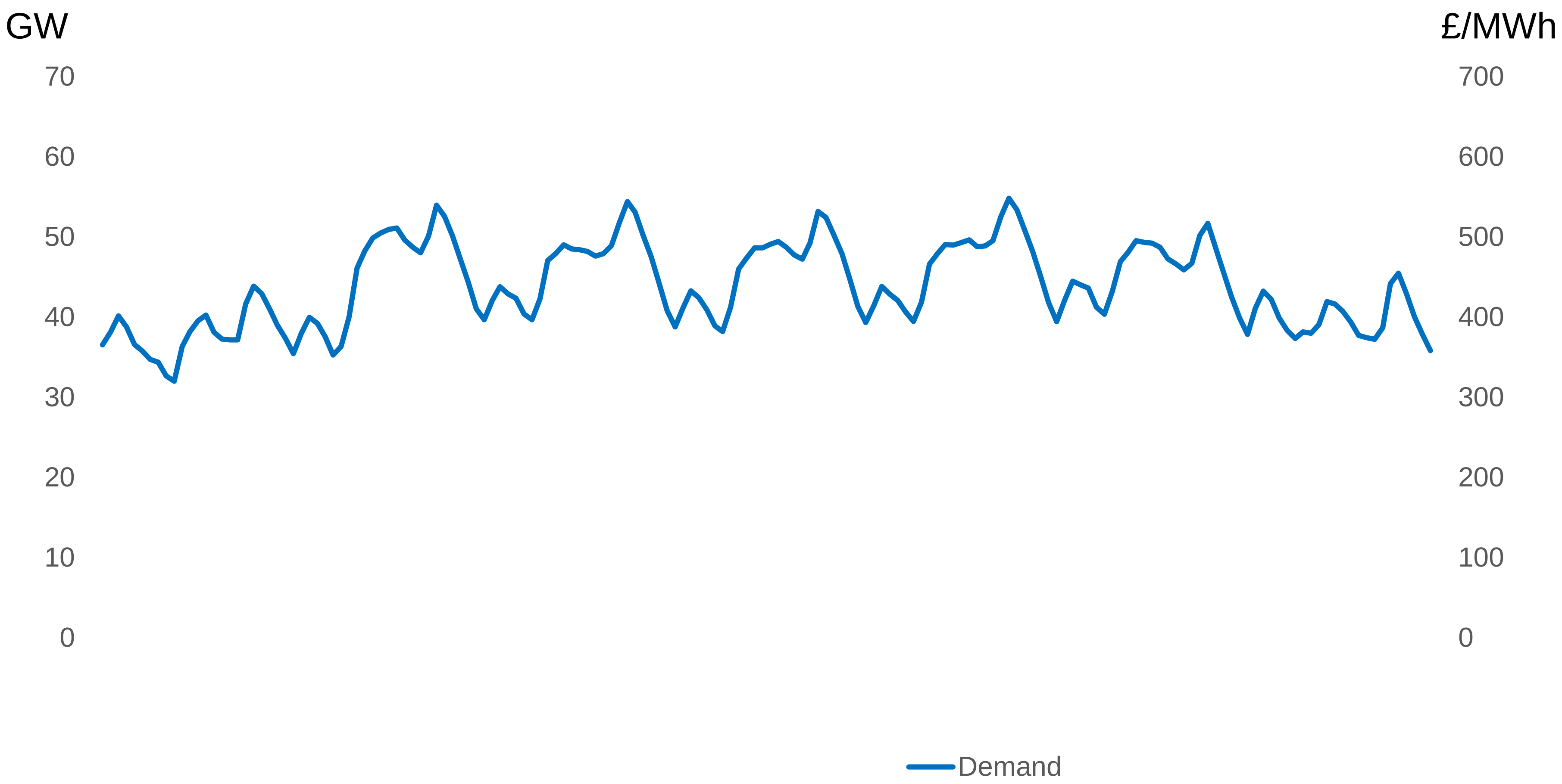
A simulated future

Energy Market: Week 7 of "2010"



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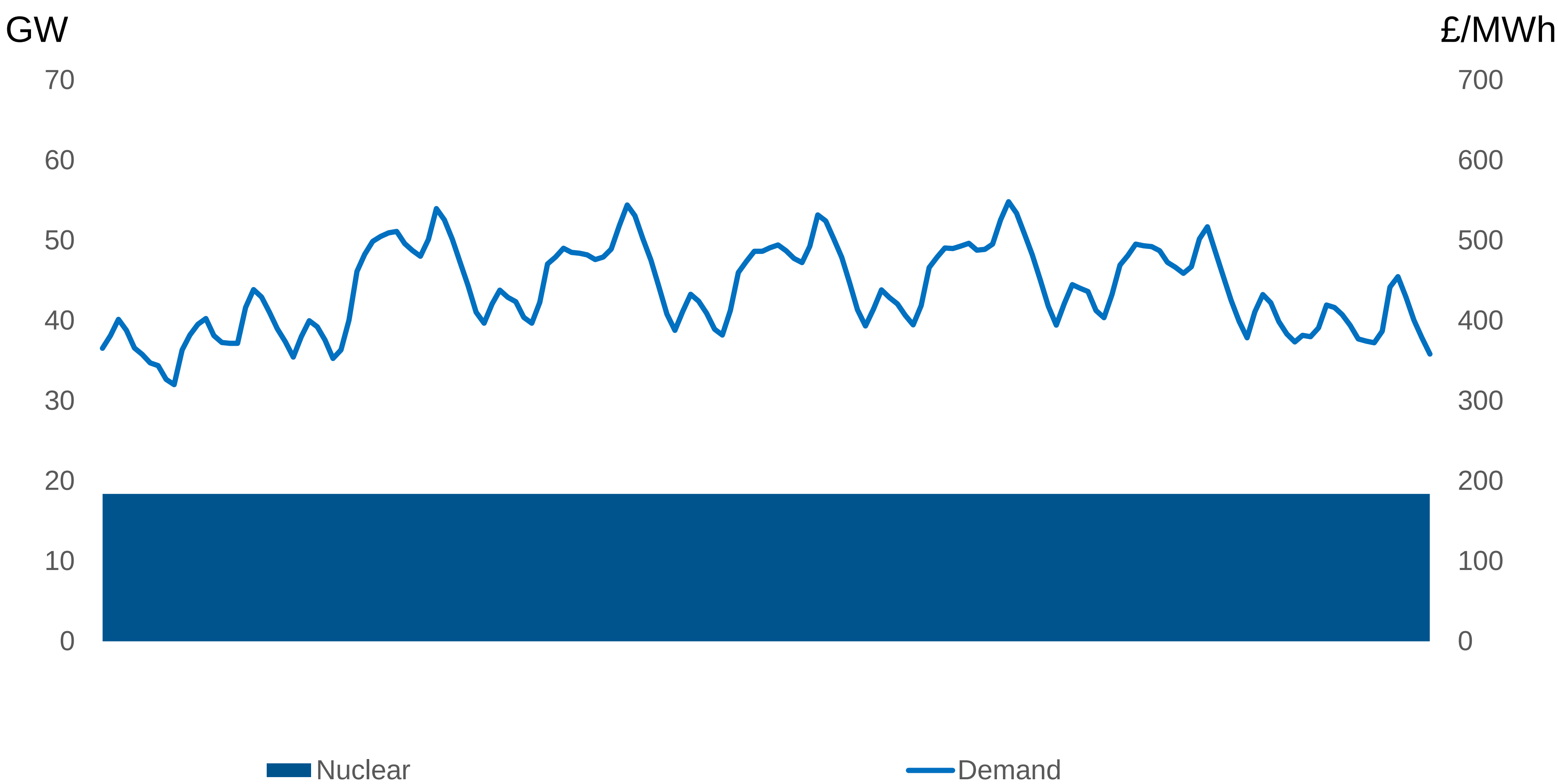

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A simulated future

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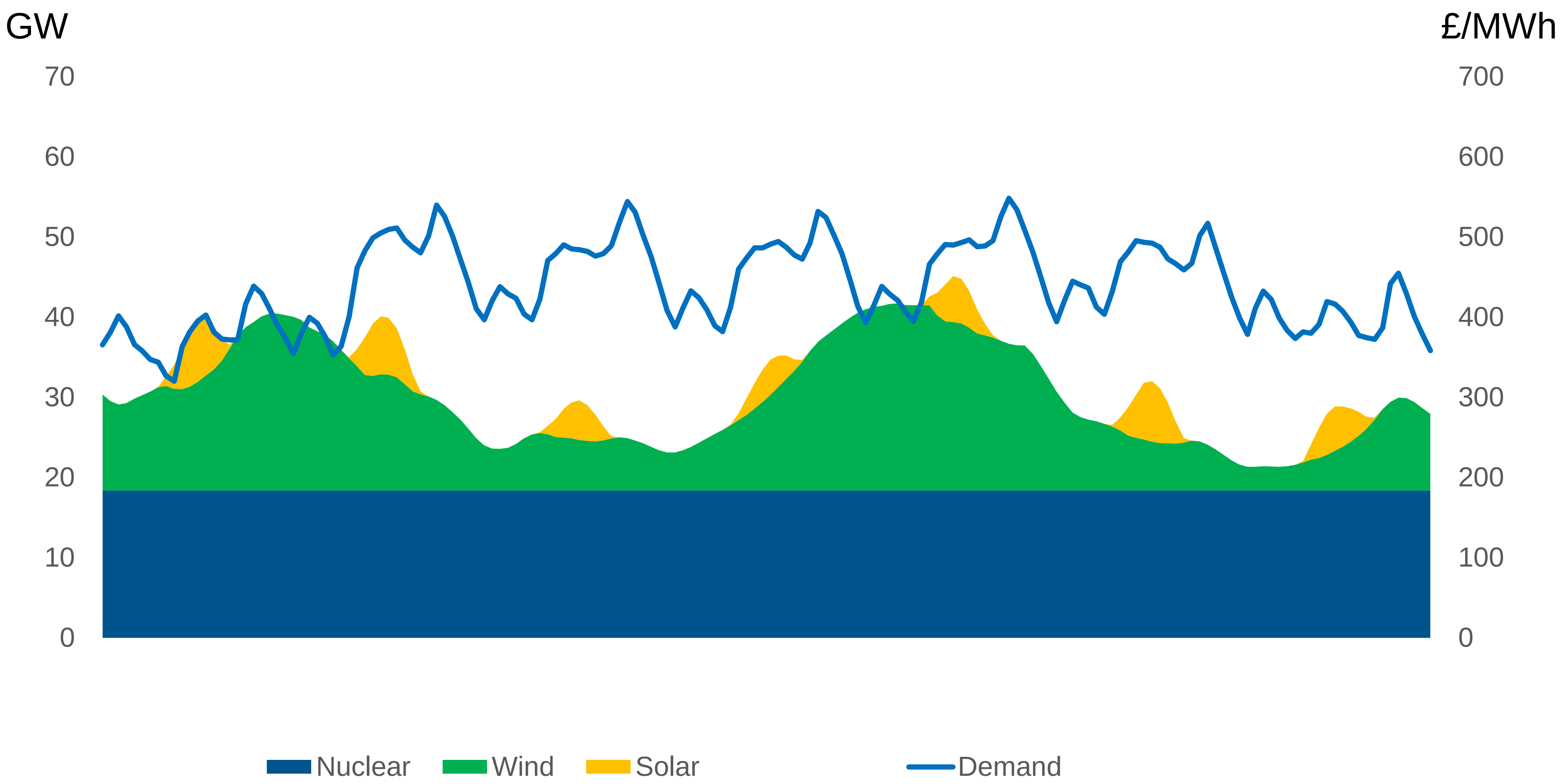

A simulated future

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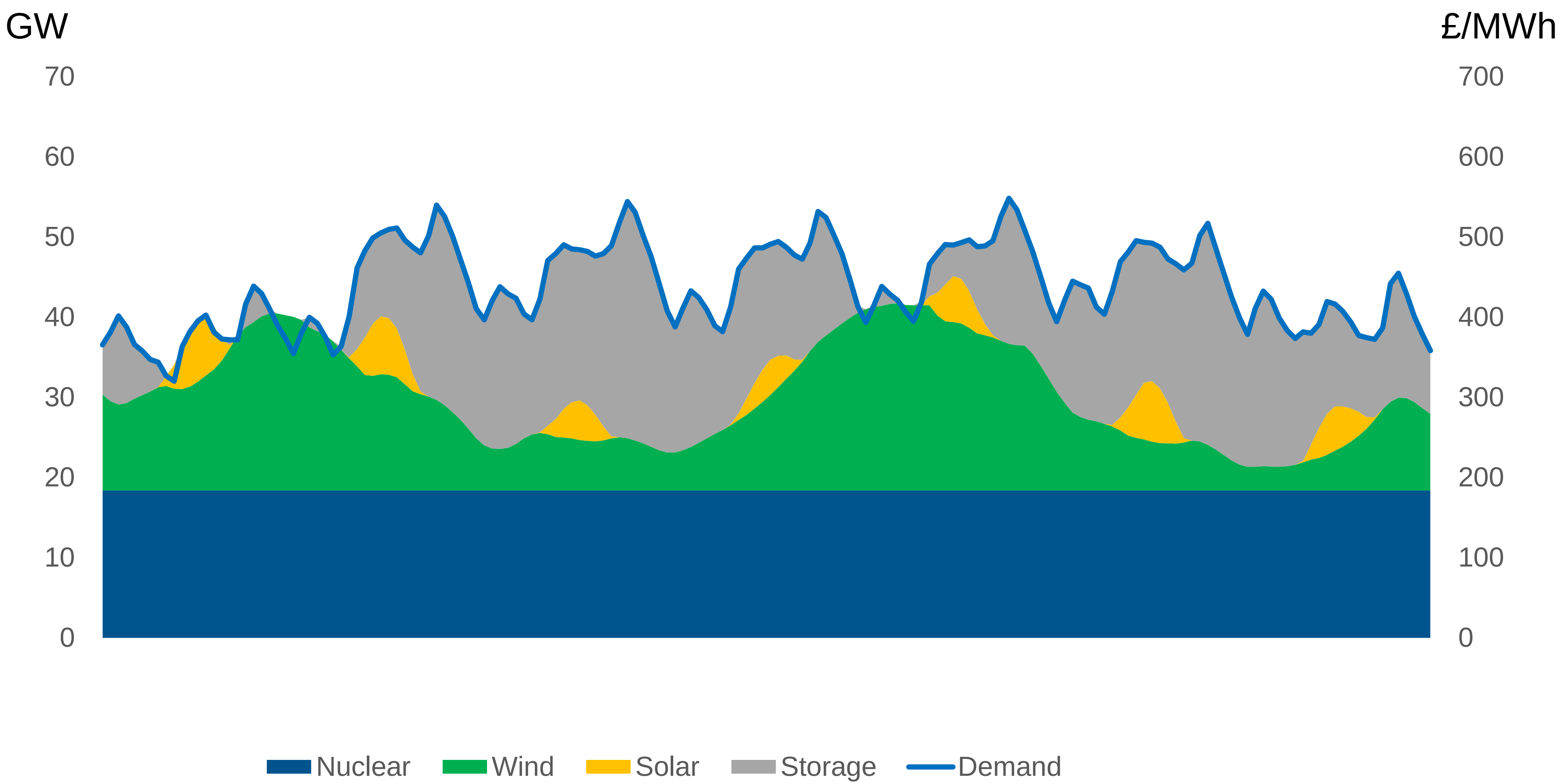

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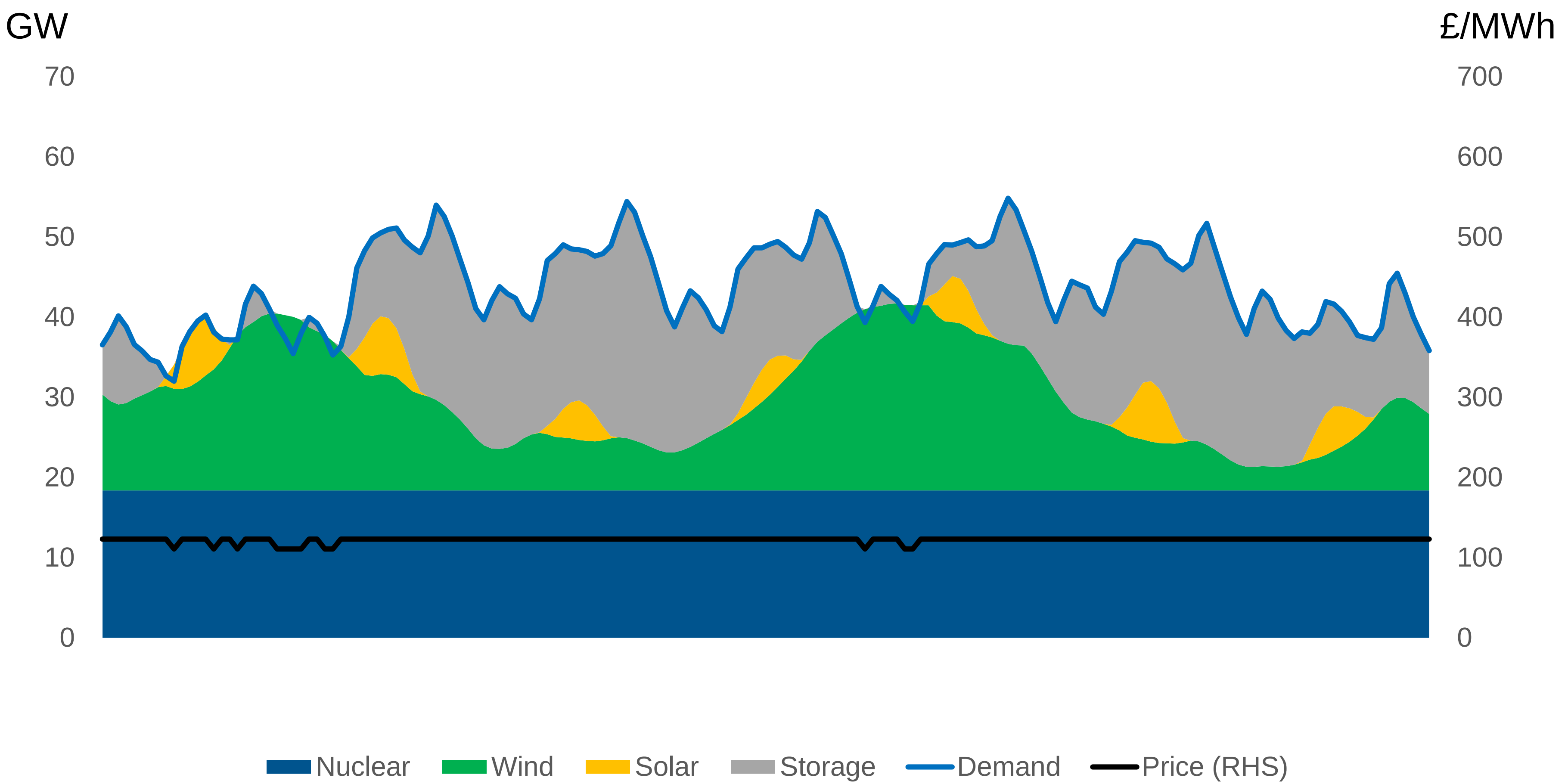
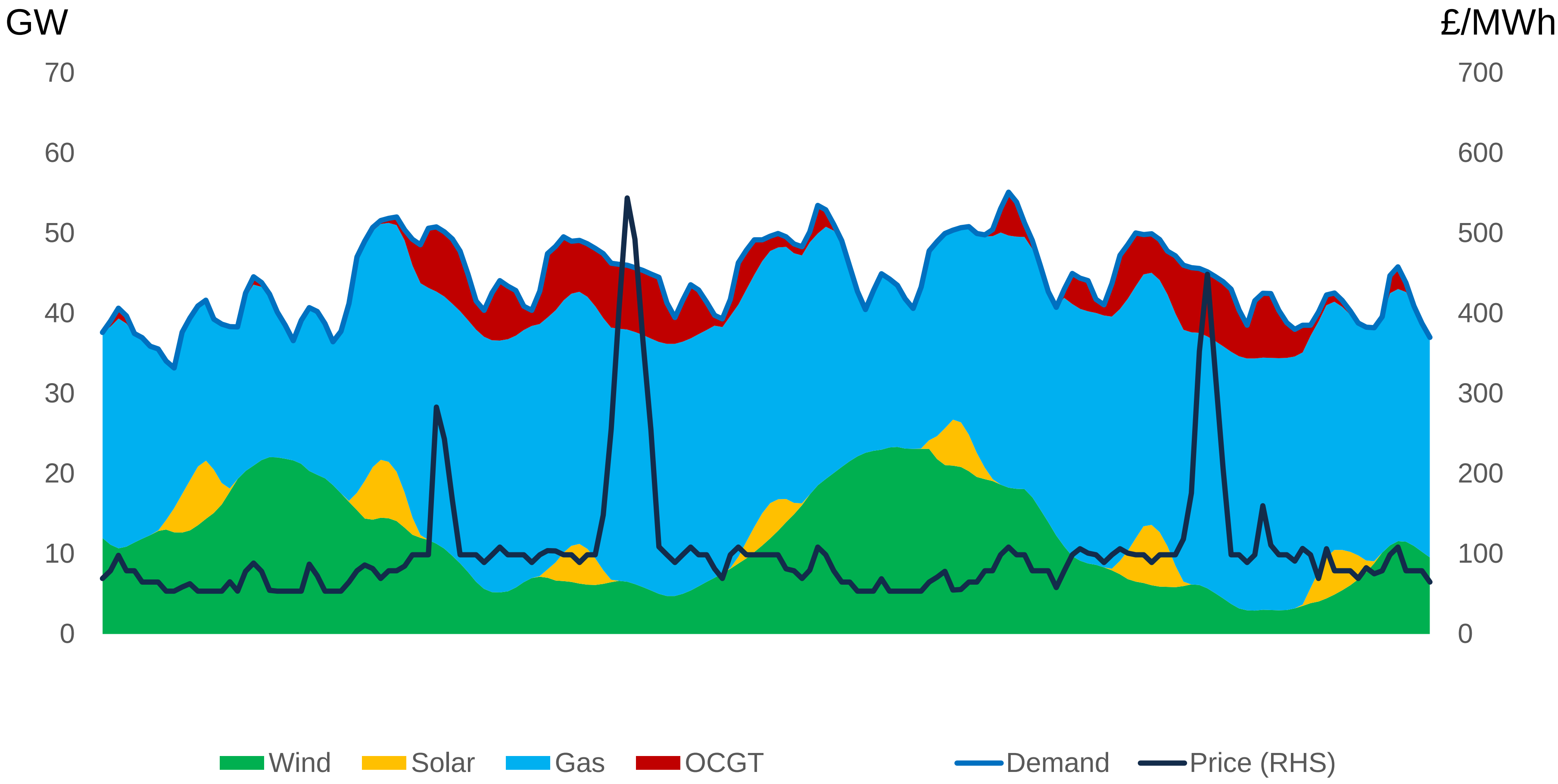
A simulated future

Energy Market: Week 7 of “2010”



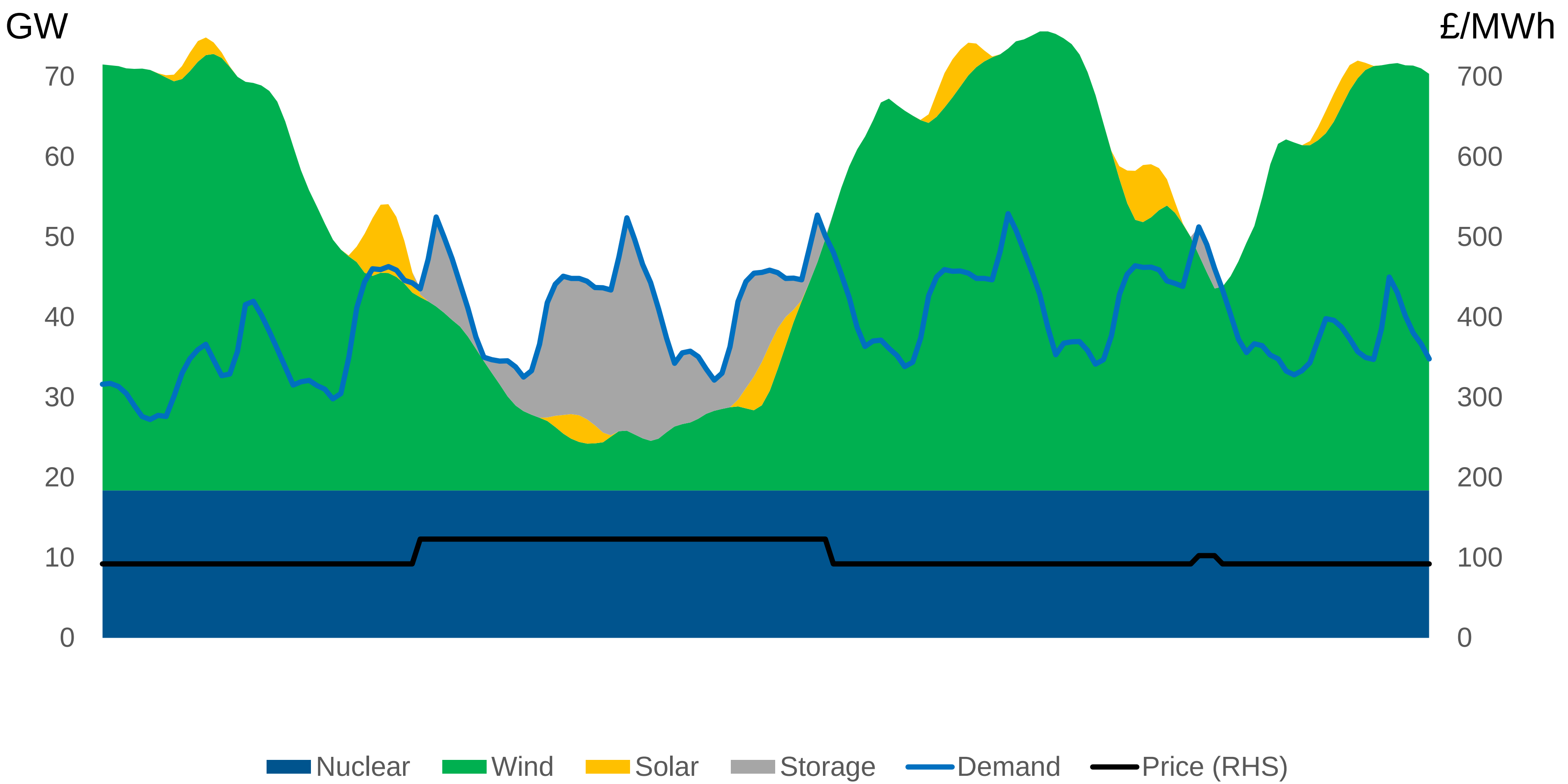
A simulated future

Power Market: Week 7 of "2010"



A simulated future

Energy Market: Week 44 of "2010"



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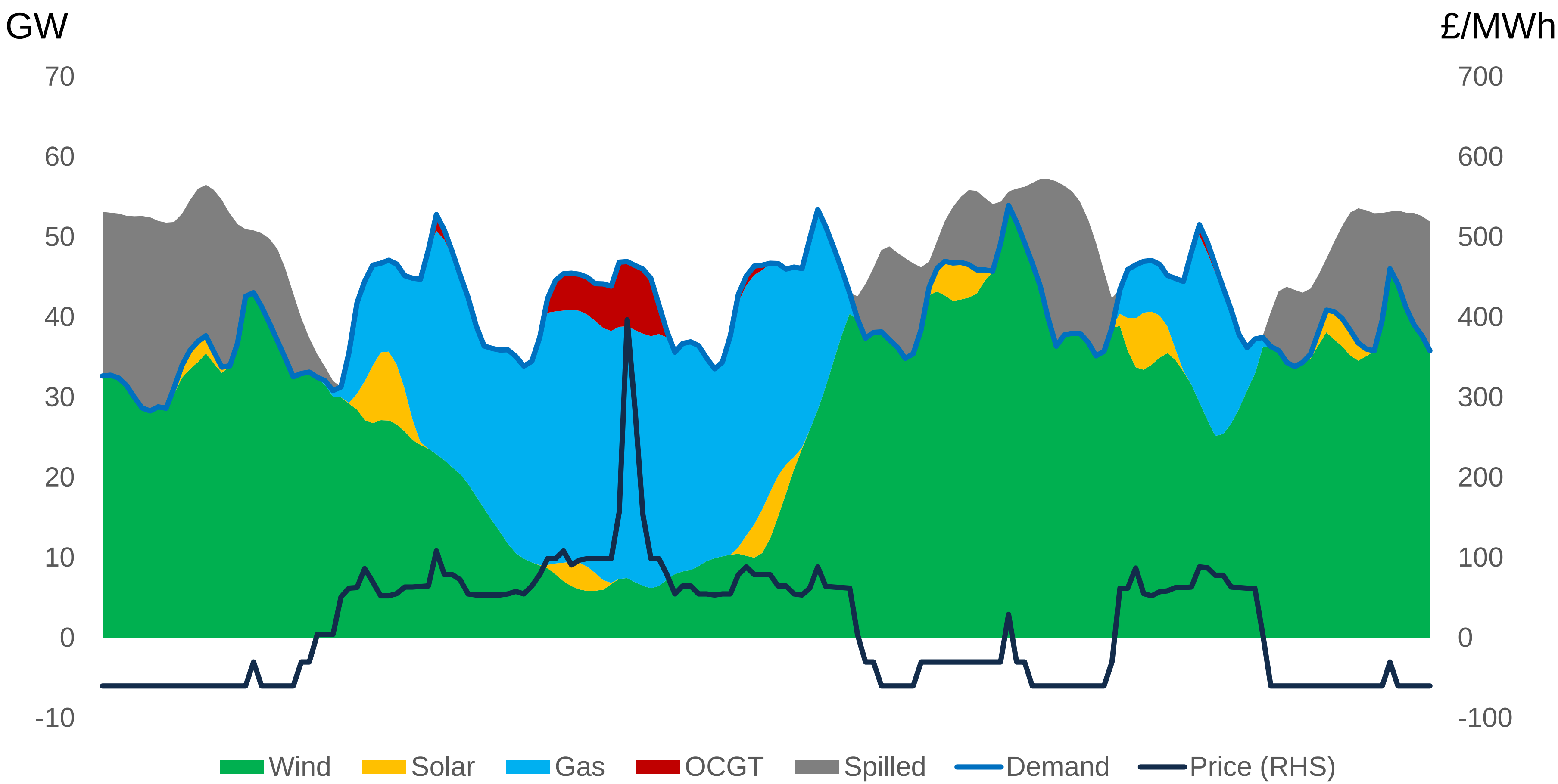
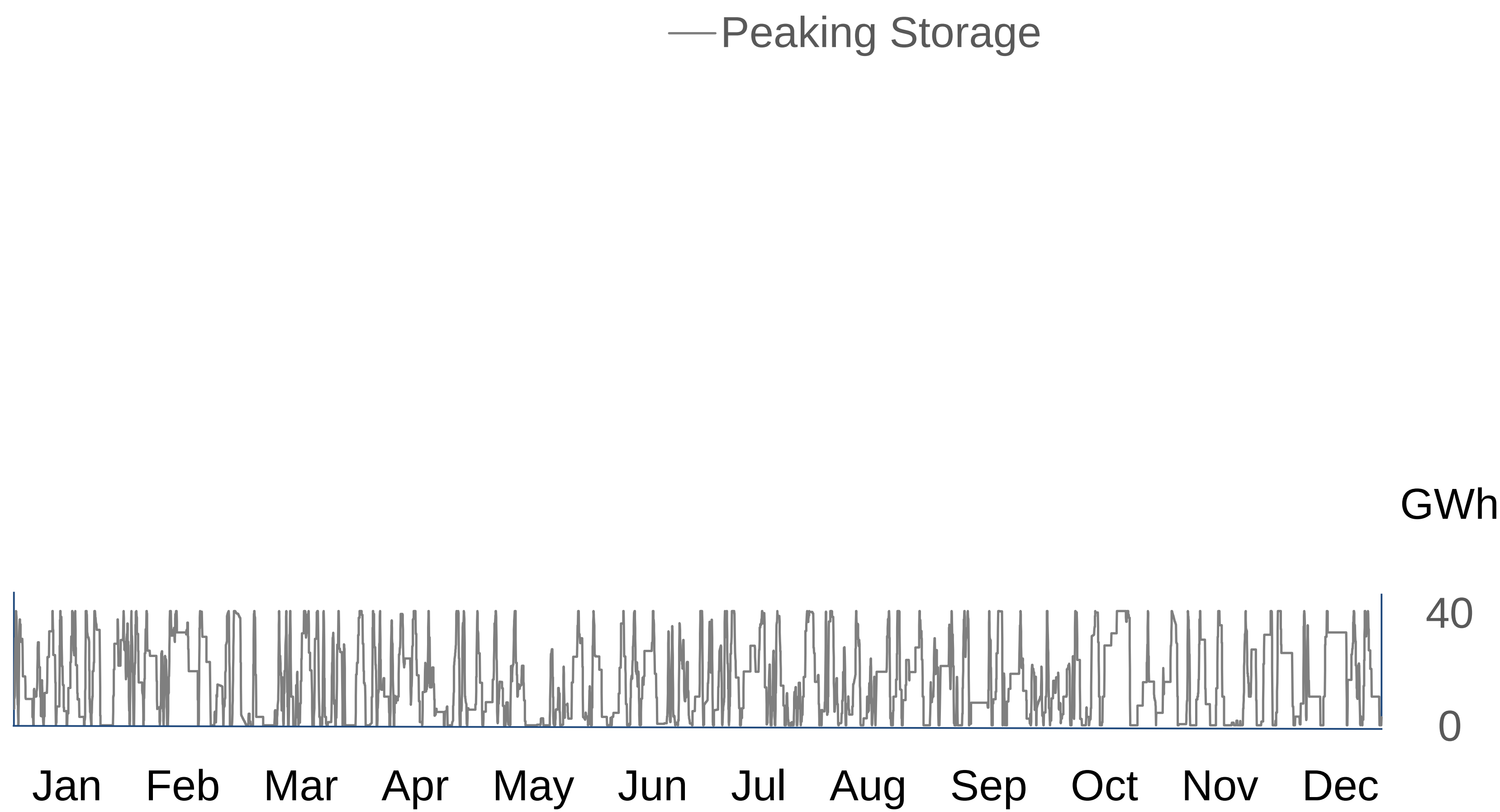
A simulated future

Power Market: Week 44 of "2010"



Stored Energy Levels

8760 hours of "2010"



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Stored Energy Levels

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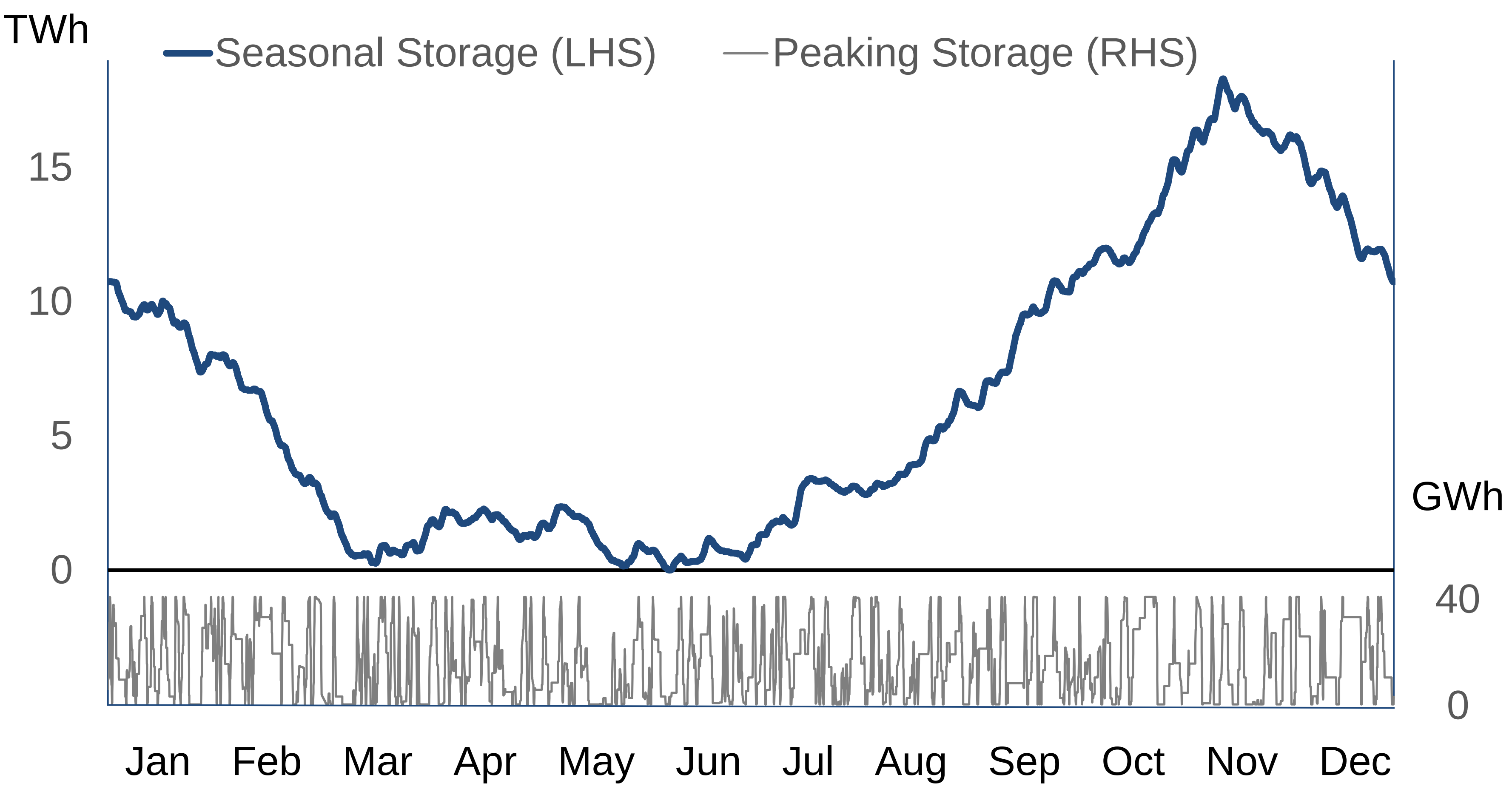

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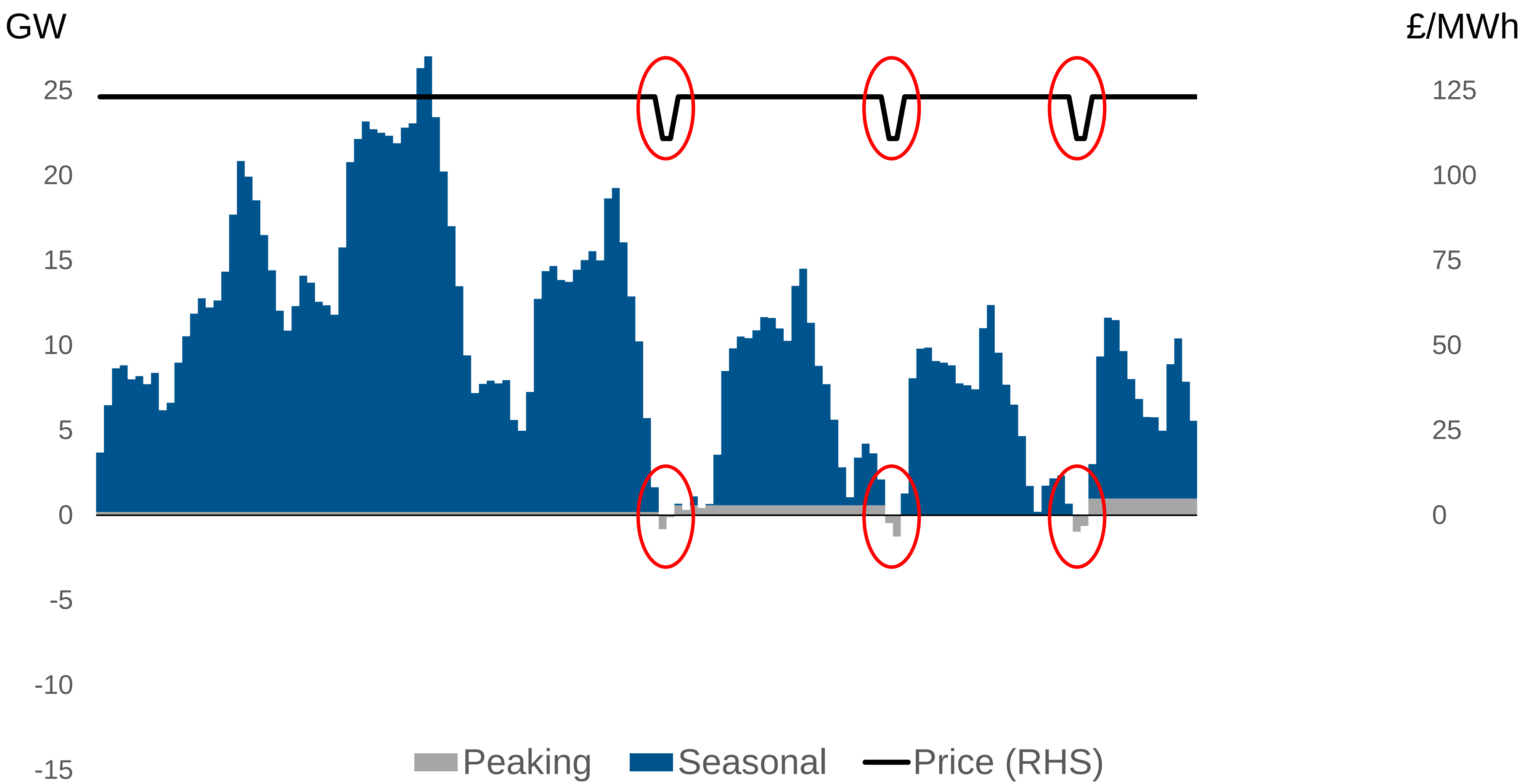
Storage flows and prices

Week 47 of "2010"



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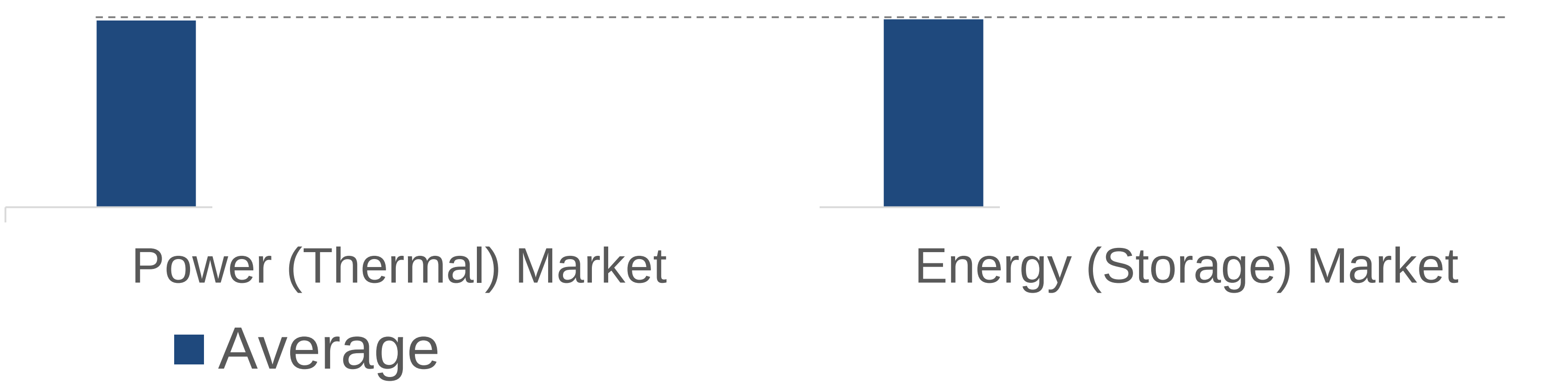
A more level playing field?

Revenues by type of plant



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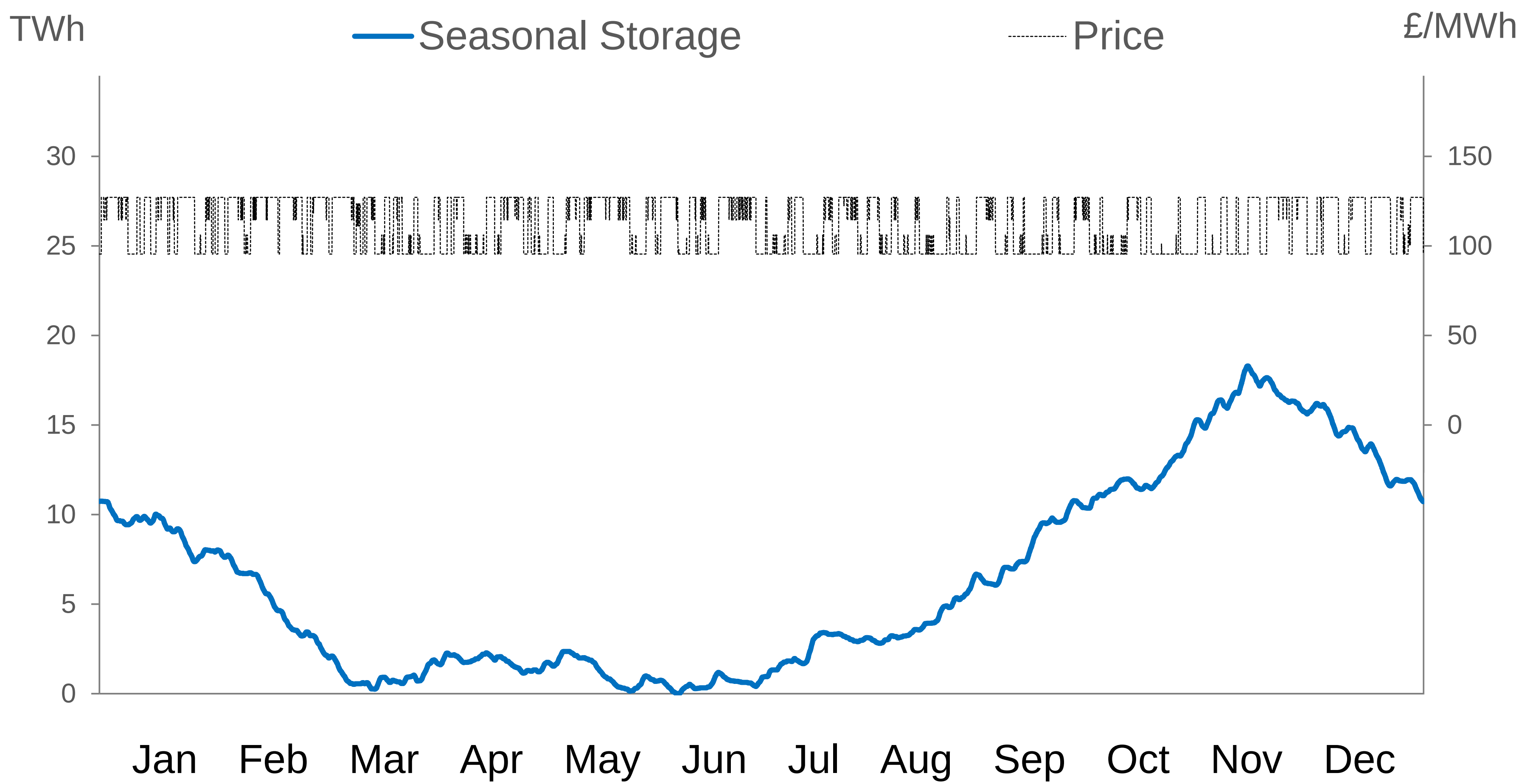
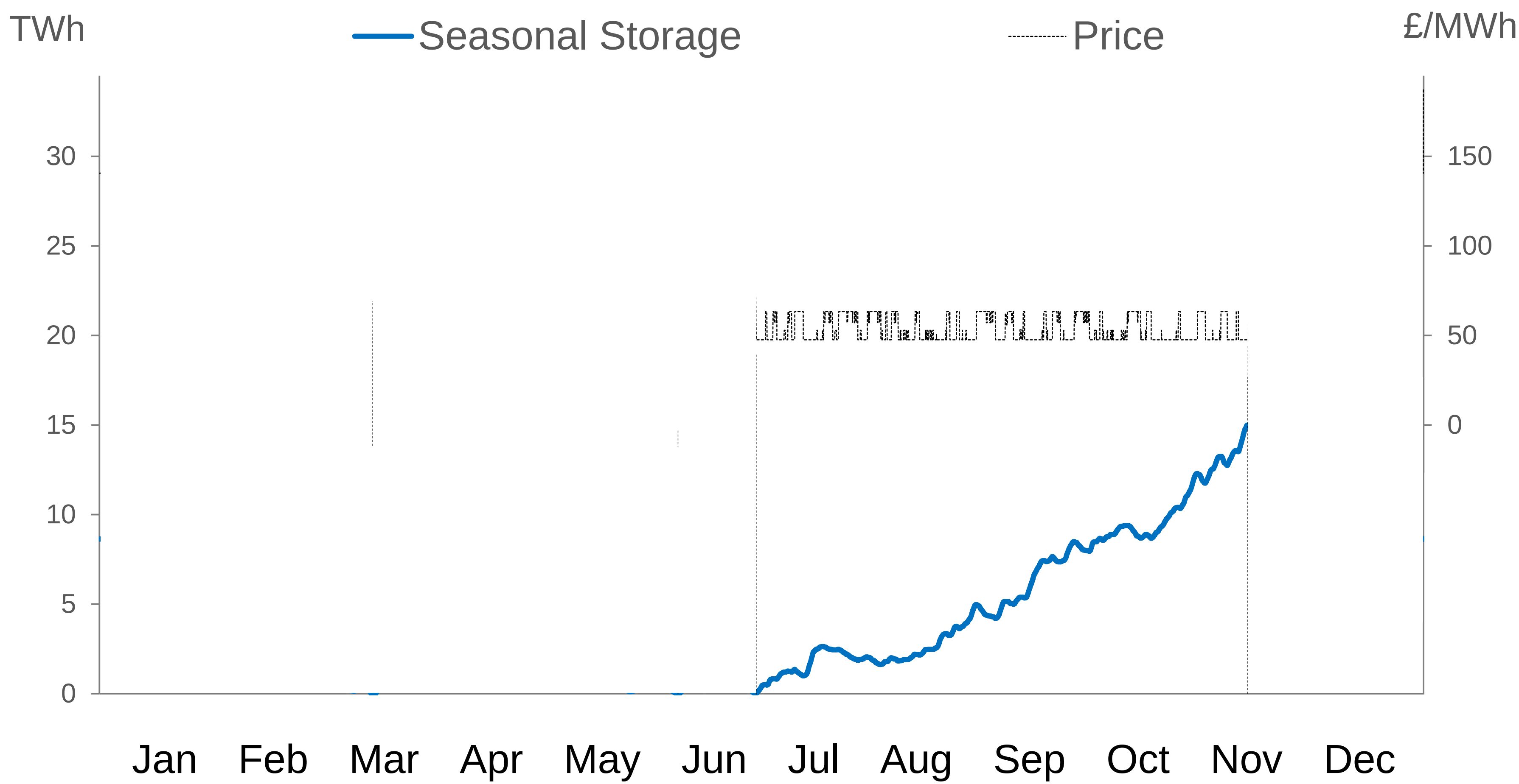
A storage-renewable market

18 TWh or more in "2010"



A storage-renewable market

15 TWh capacity in "2010"



Beyond the power market

What else can storage do?

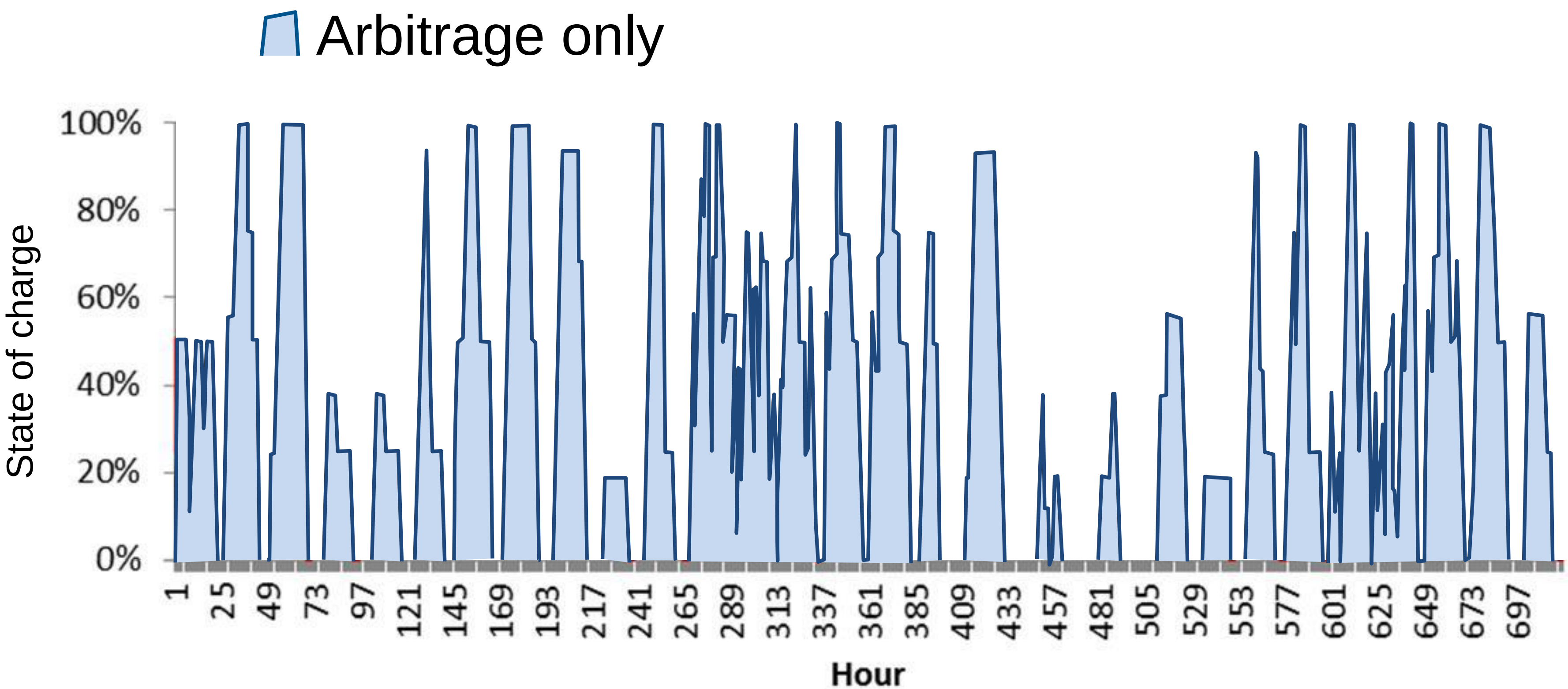
(Mostly material from Goran Strbac)

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

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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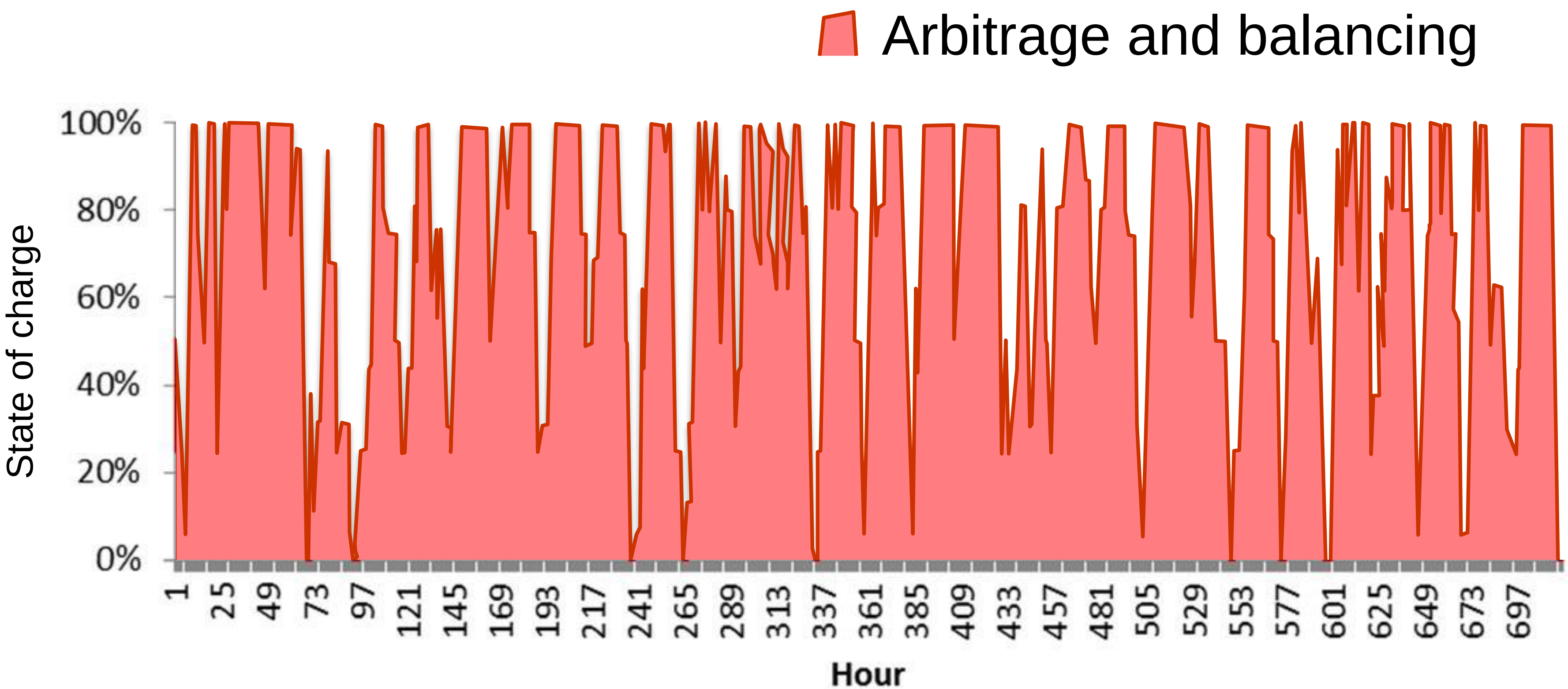

Source: Teng, F. and G. Strbac (2016), "Business Cases for energy storage with multiple service provision" *J. Mod. Power Syst. Clean Energy* DOI 10.1007/s40565-016-0244-1

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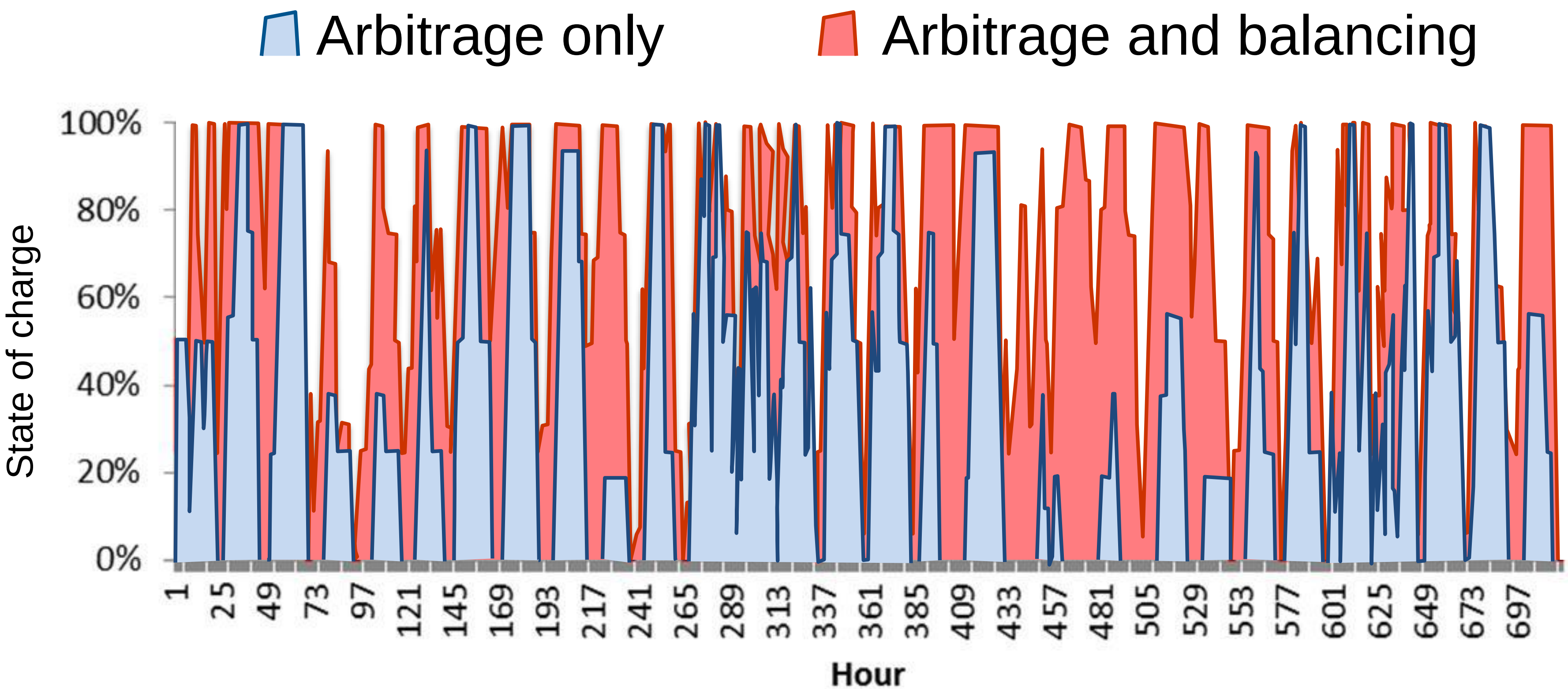

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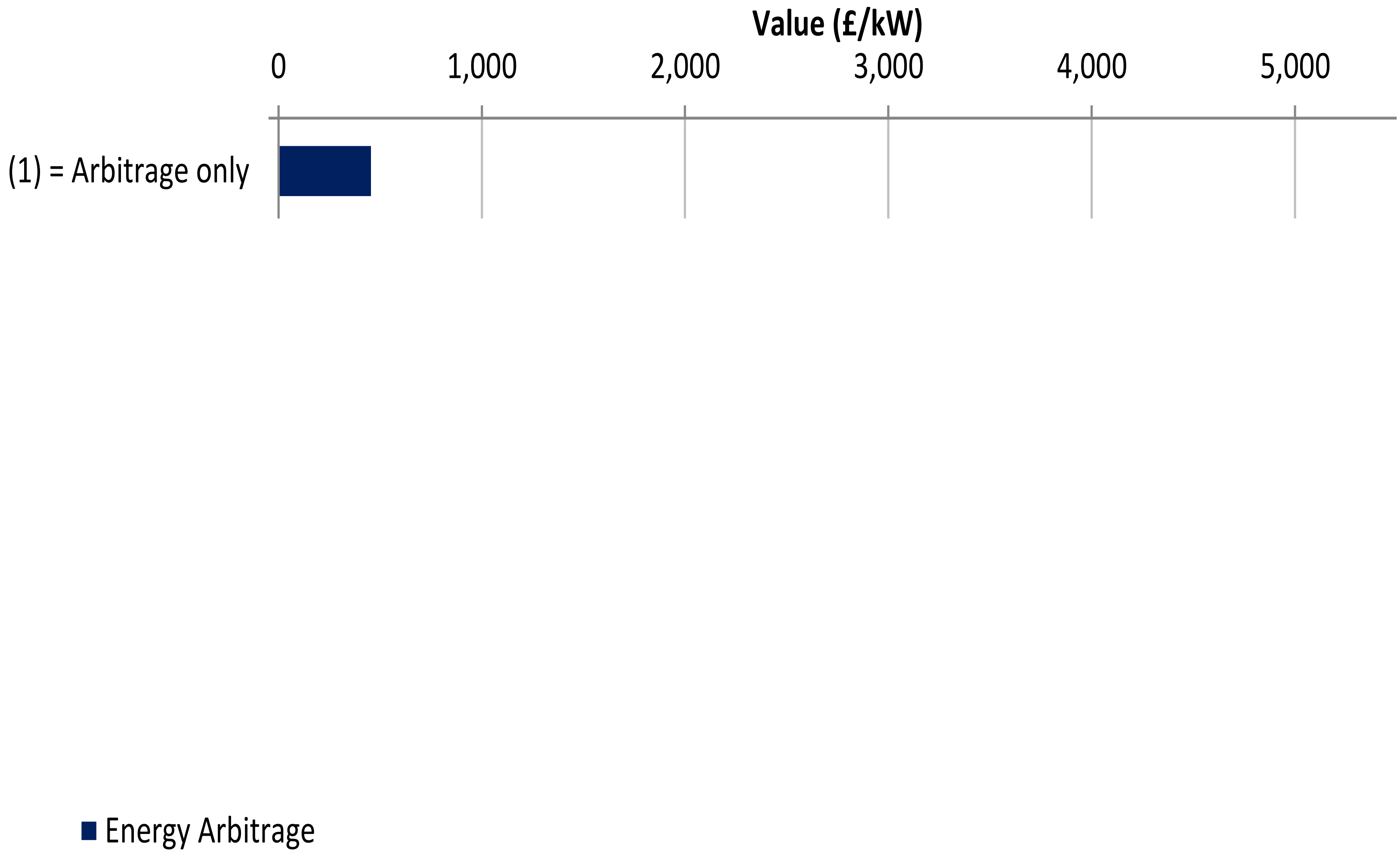
Whole-system modelling:

multi-service provision by storage

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

Whole-system value and business case for energy storage



Whole-system modelling:

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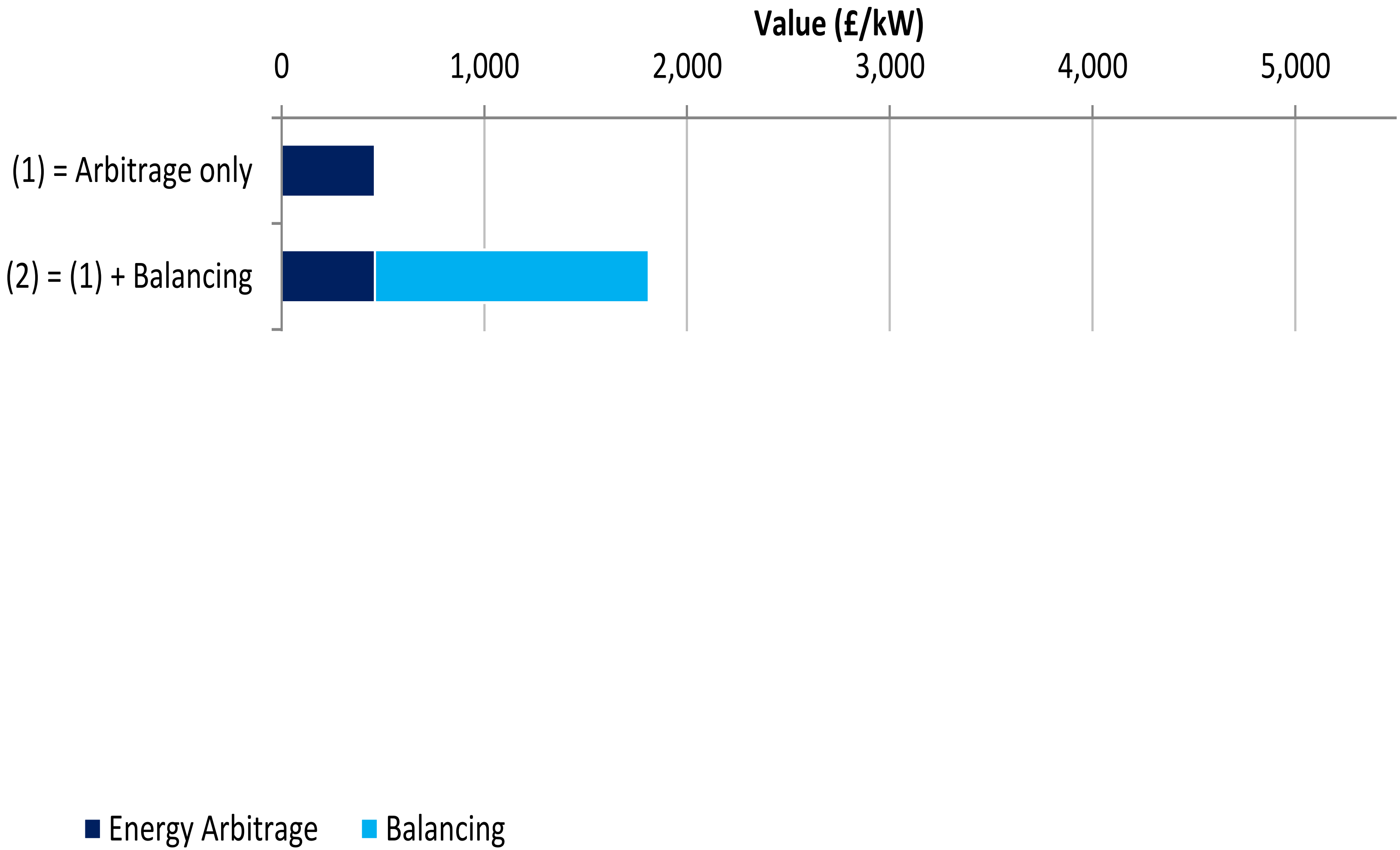
Whole-system value and business case for energy storage:

access to revenues from providing multiple services is critical



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  - ✓ Reducing need for T & D network reinforcements

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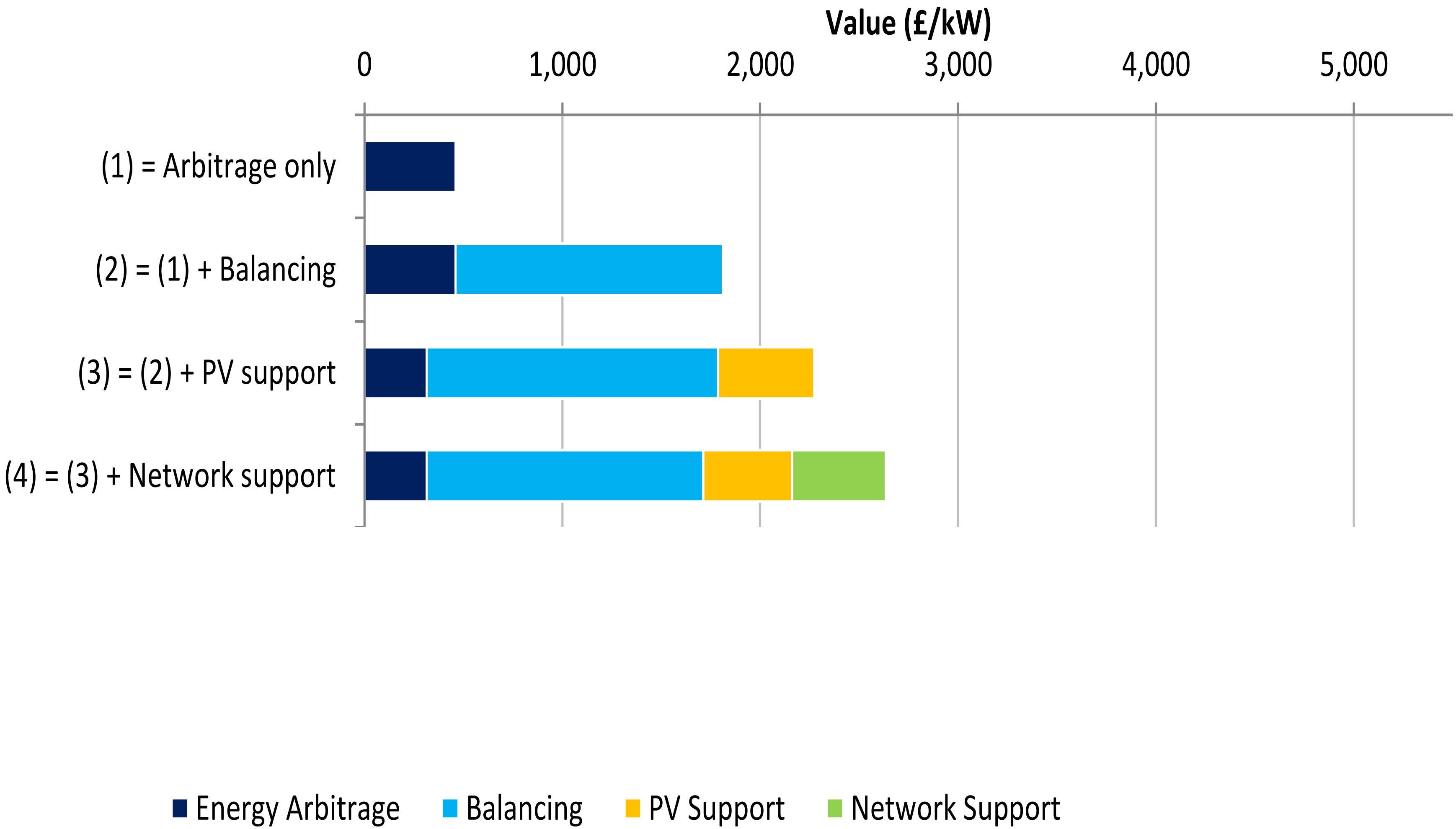

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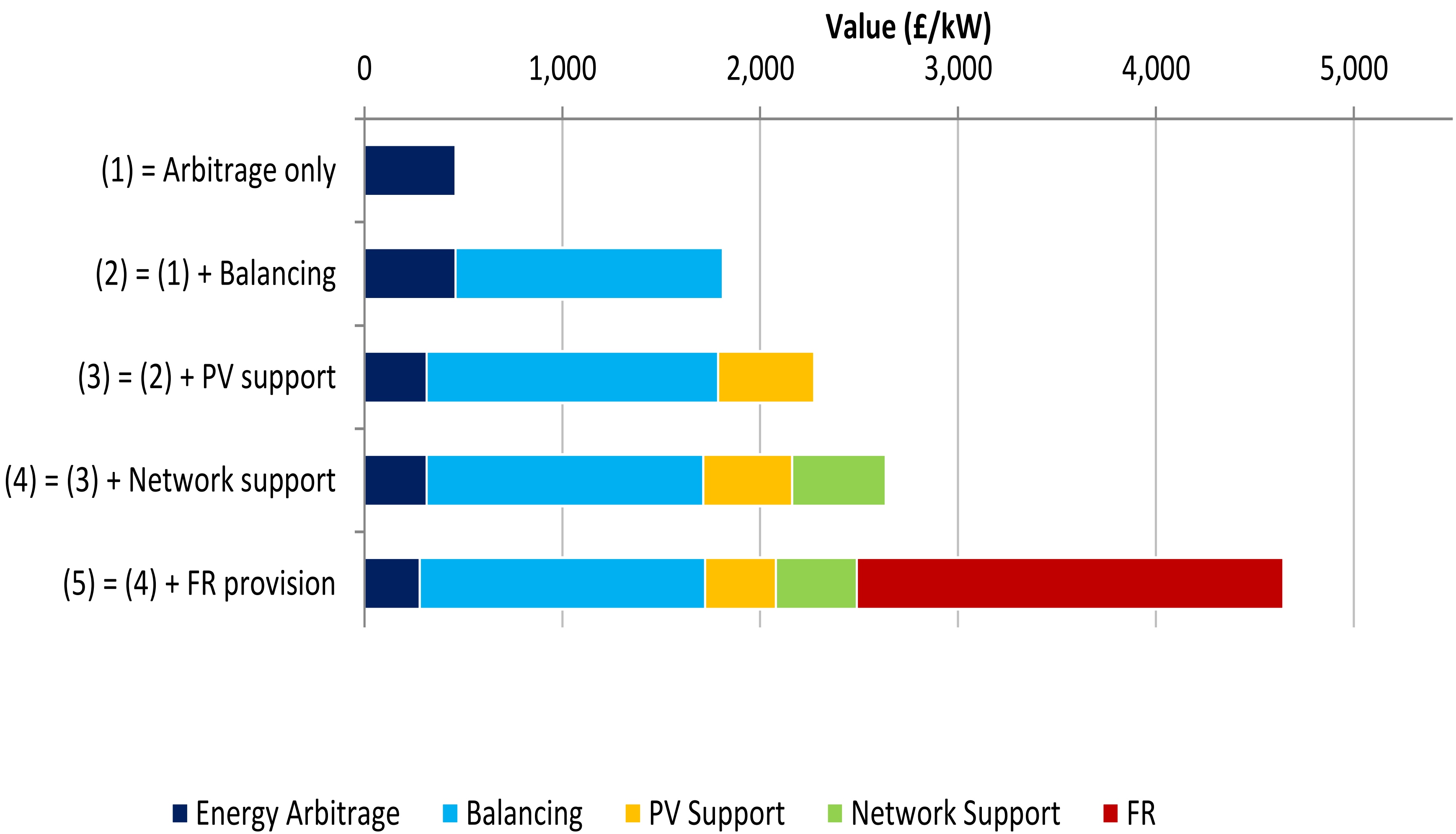

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  - ✓ Contributing to meeting peak demand, reducing need for peaking plant

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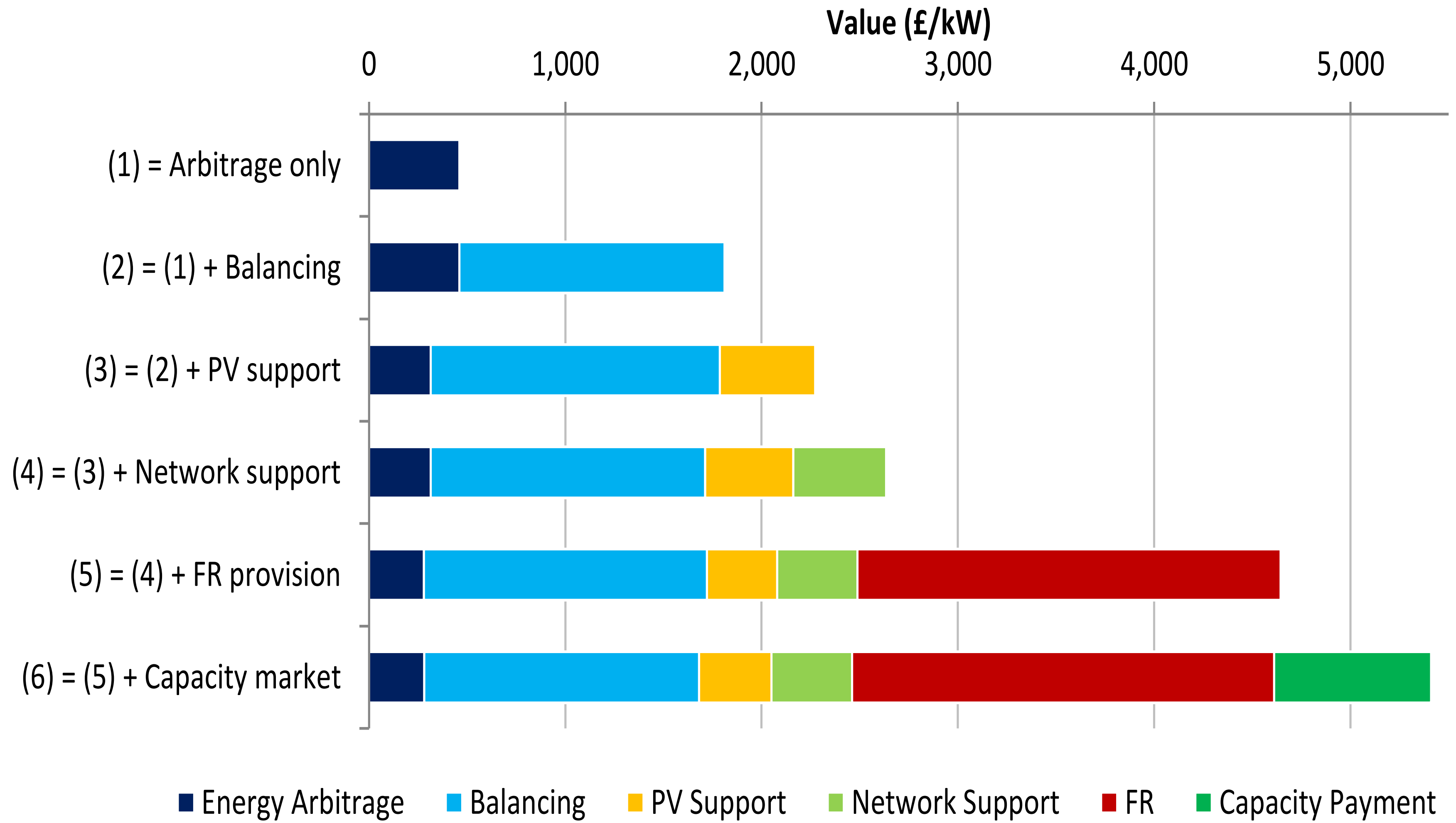

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- **Low carbon generation mix**
  - ✓ Flexibility supports meeting carbon targets while reducing investment in low carbon generation

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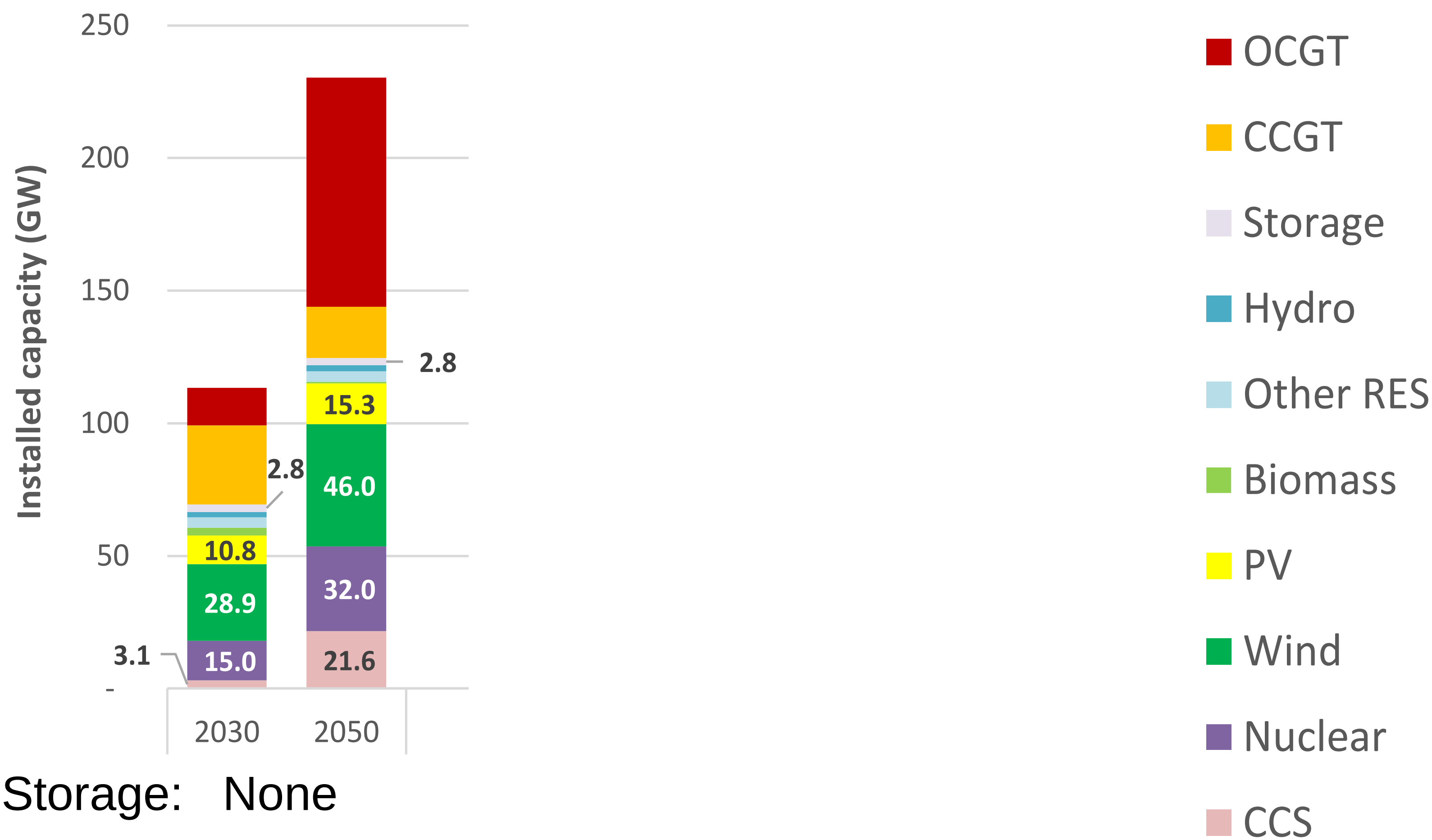
Energy Storage: *hitting CO2 targets of 100 g/kWh in 2030 and 25 g/kWh in 2050*



New Storage: None

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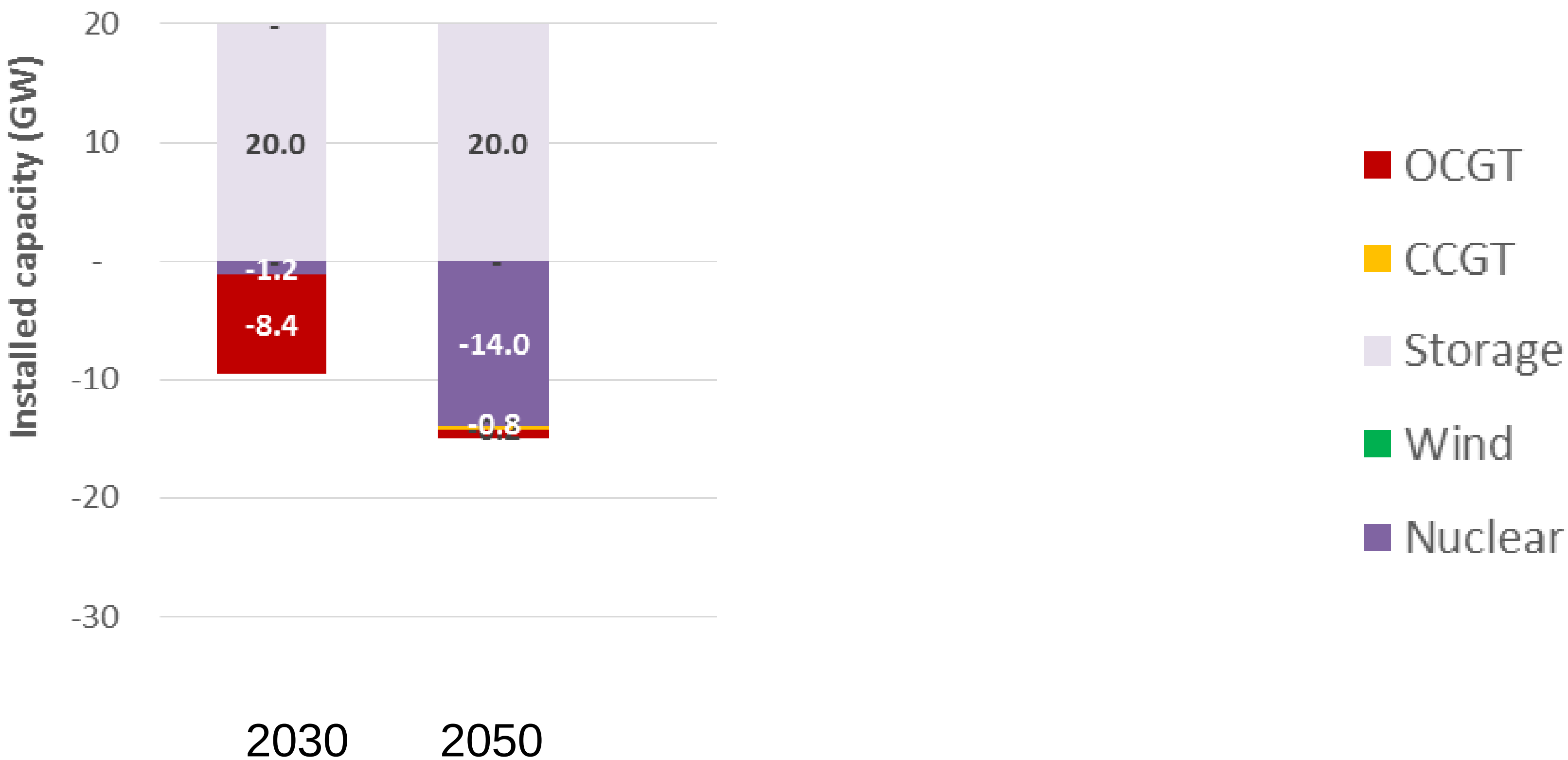
Energy Storage: *hitting CO2 targets with less investment in low carbon generation*

Change in installed capacity if 20 GW of storage added



less nuclear

Whole-system modelling:

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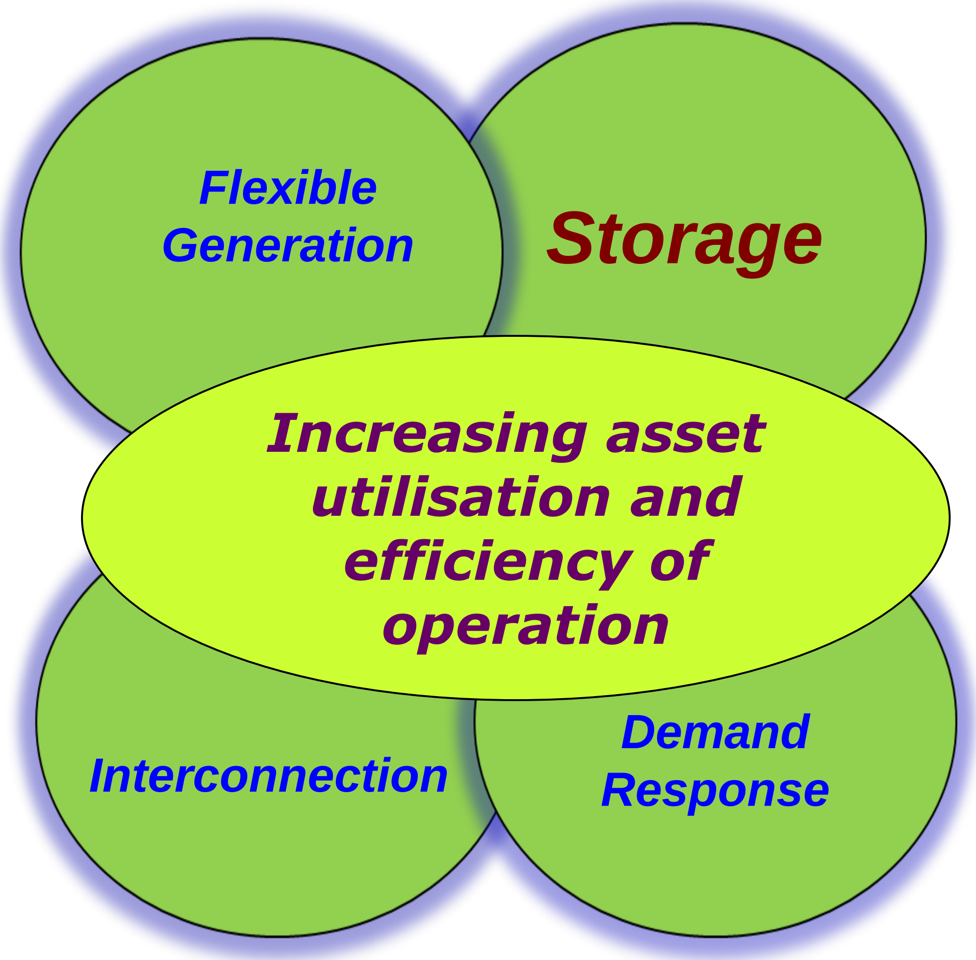
  - ✓ Flexibility supports meeting carbon targets while reducing investment in low carbon generation
- **Option value**
  - ✓ Providing flexibility to deal with uncertainty

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

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

UKERC

Thanks to:

Research Councils UK
Energy
For a Low Carbon Future

EPSRC
Engineering and Physical Sciences Research Council

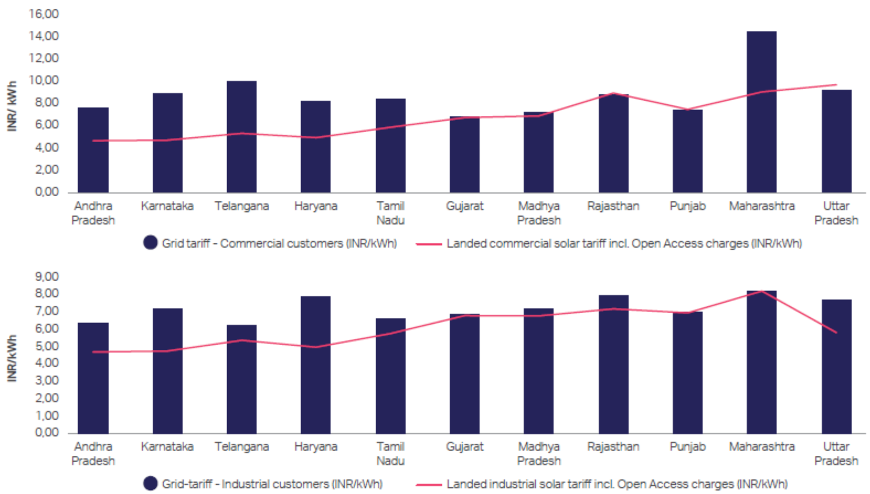
Corporate Renewable Procurement: Opportunities in India

- **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**

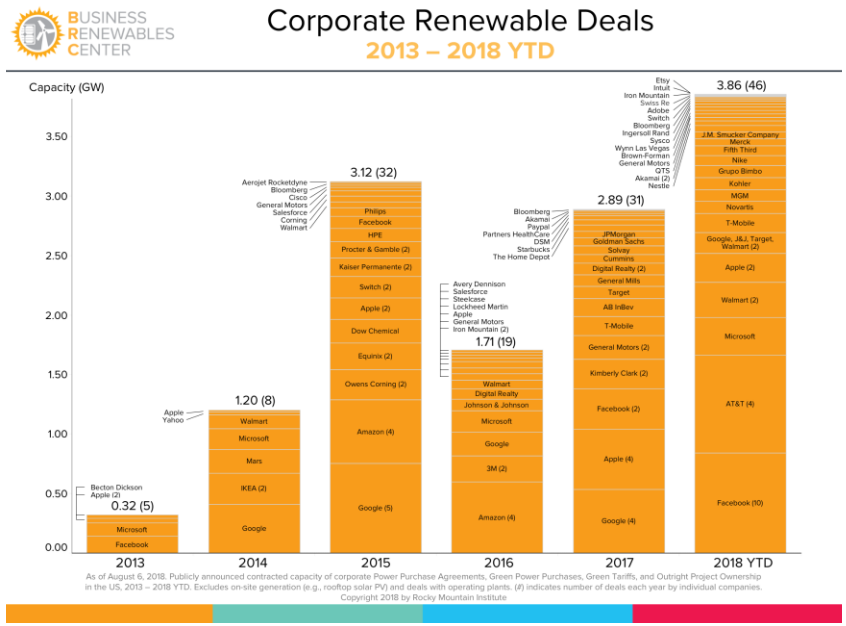
Why Are We Doing This Course?

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**>