



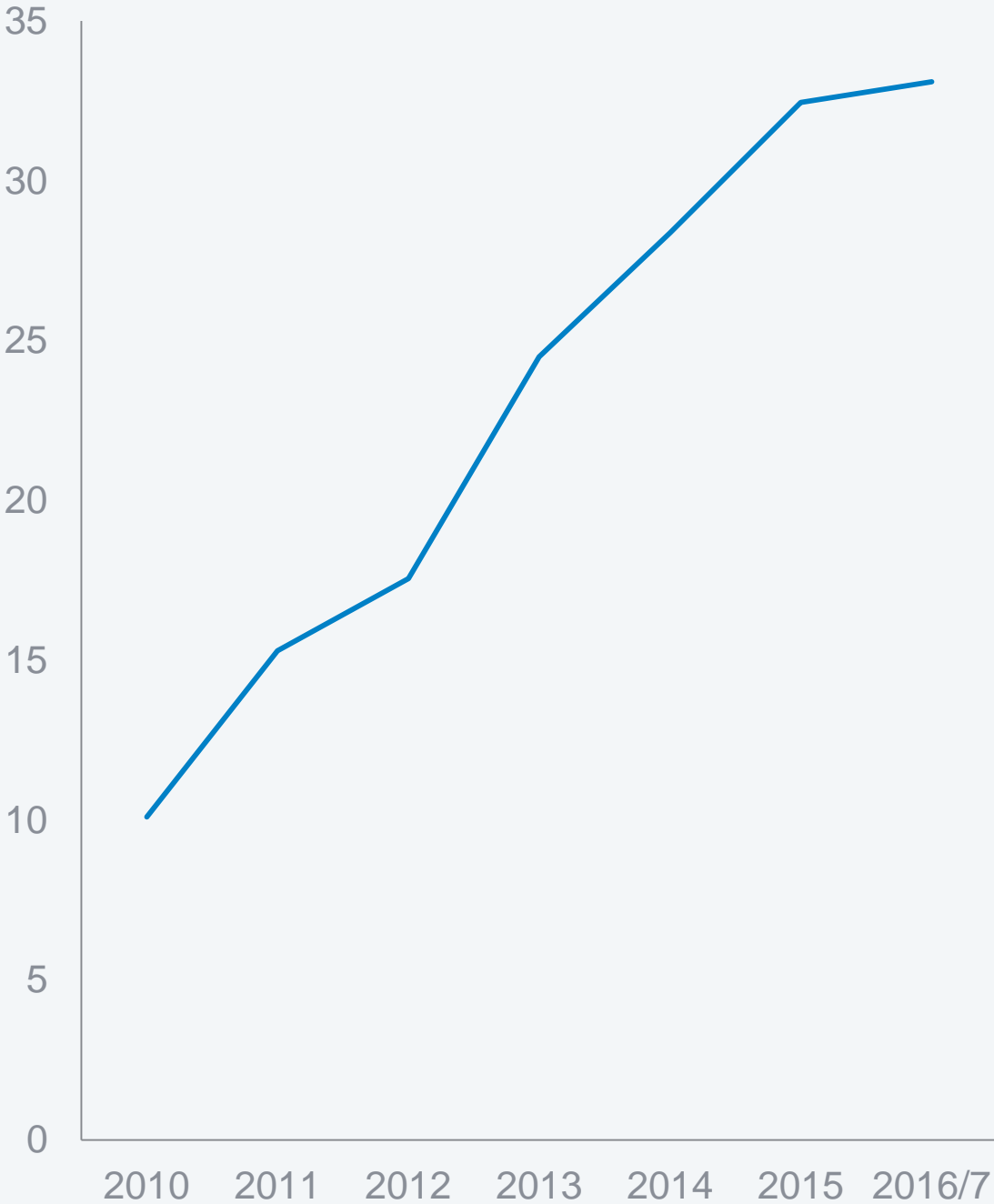
Electricity, Wind and Carbon

Professor Richard Green

Two recent trends:

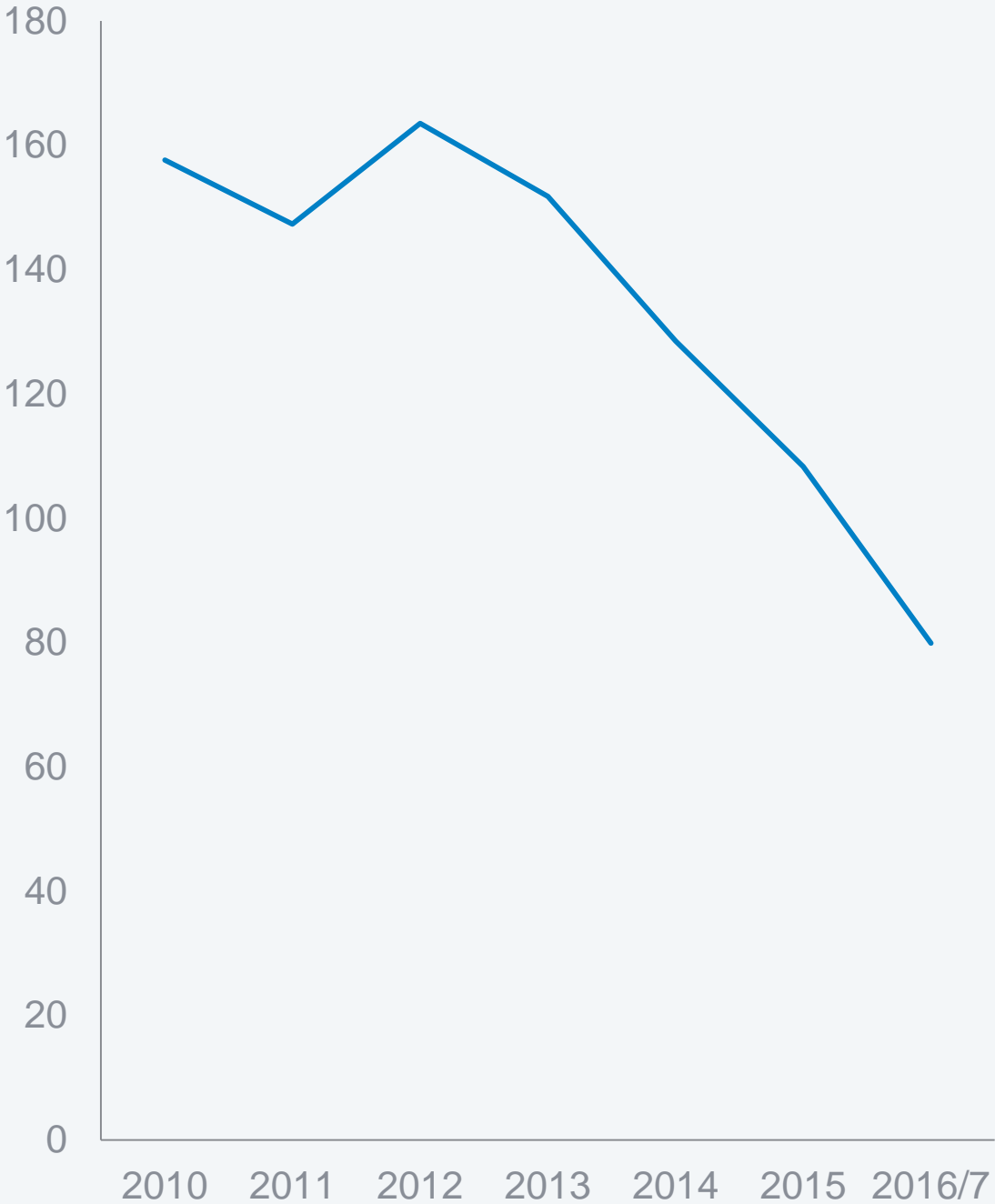
The Rise of Wind

Wind Output, TWh



The Reduction in CO₂ Emissions

Carbon Emissions, m Tonnes



Maximising the Carbon Impact of Wind Power

- 1) Improve wind output simulations based on reanalysis weather data
- 2) Estimate hourly emissions for the British power sector
- 3) Assess the impact of wind output, fuel prices, and wind forecast accuracy

Wind simulations from Renewables.Ninja

Stefan Pfenninger and Iain Staffell

The screenshot shows the Renewables.Ninja website interface. The browser address bar displays <https://www.renewables.ninja/#>. The page header includes navigation links: Help, Downloads, News, Sign up, and Login.

The main content area features a control panel on the left and a results window on the right. The control panel includes the following fields:

- Lat: 54.788, Lon: -1.567
- From: 2014-01-01, To: 2014-12-31
- Solar PV: [arrow right]
- Wind: [arrow down]
- Capacity (kW): 1
- Hub height (m): 60
- Turbine model: Vestas V80 2000
- Include raw data
- Run button

The results window displays two charts:

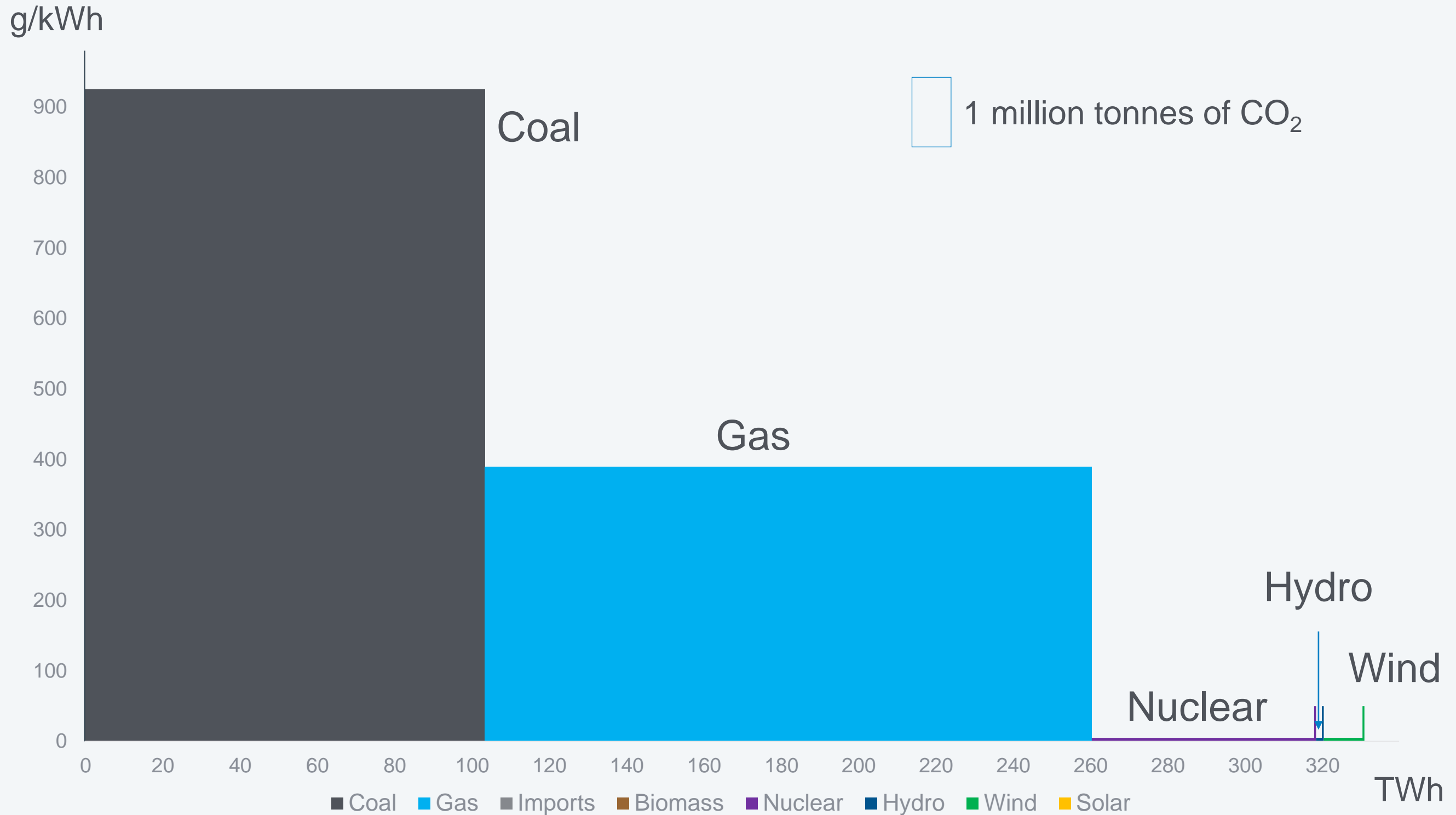
- Daily mean output:** A line graph showing the mean output in kW over time. The y-axis ranges from 0 to 1.0 kW. The x-axis shows dates from Jan 01 2014 to Oct 01 2014. The output fluctuates between approximately 0.2 kW and 0.9 kW.
- Monthly capacity factor:** A dot plot showing the capacity factor percentage for each month. The y-axis ranges from 0 to 60%. The x-axis shows months from Jan 2014 to Dec. The capacity factor is highest in February (~65%) and lowest in June (~20%).

Below the charts, the total mean capacity factor is 44.6%. A green button labeled "Save hourly output as CSV" is visible. The license information is: Creative Commons Attribution-NonCommercial, Citation: Staffell and Pfenninger (2016).

The background map shows the location in Durham, UK, with a search bar and a location pin. The bottom of the screen shows the Windows taskbar with various application icons and the system tray displaying the time 21:25 and date 25/04/2017.

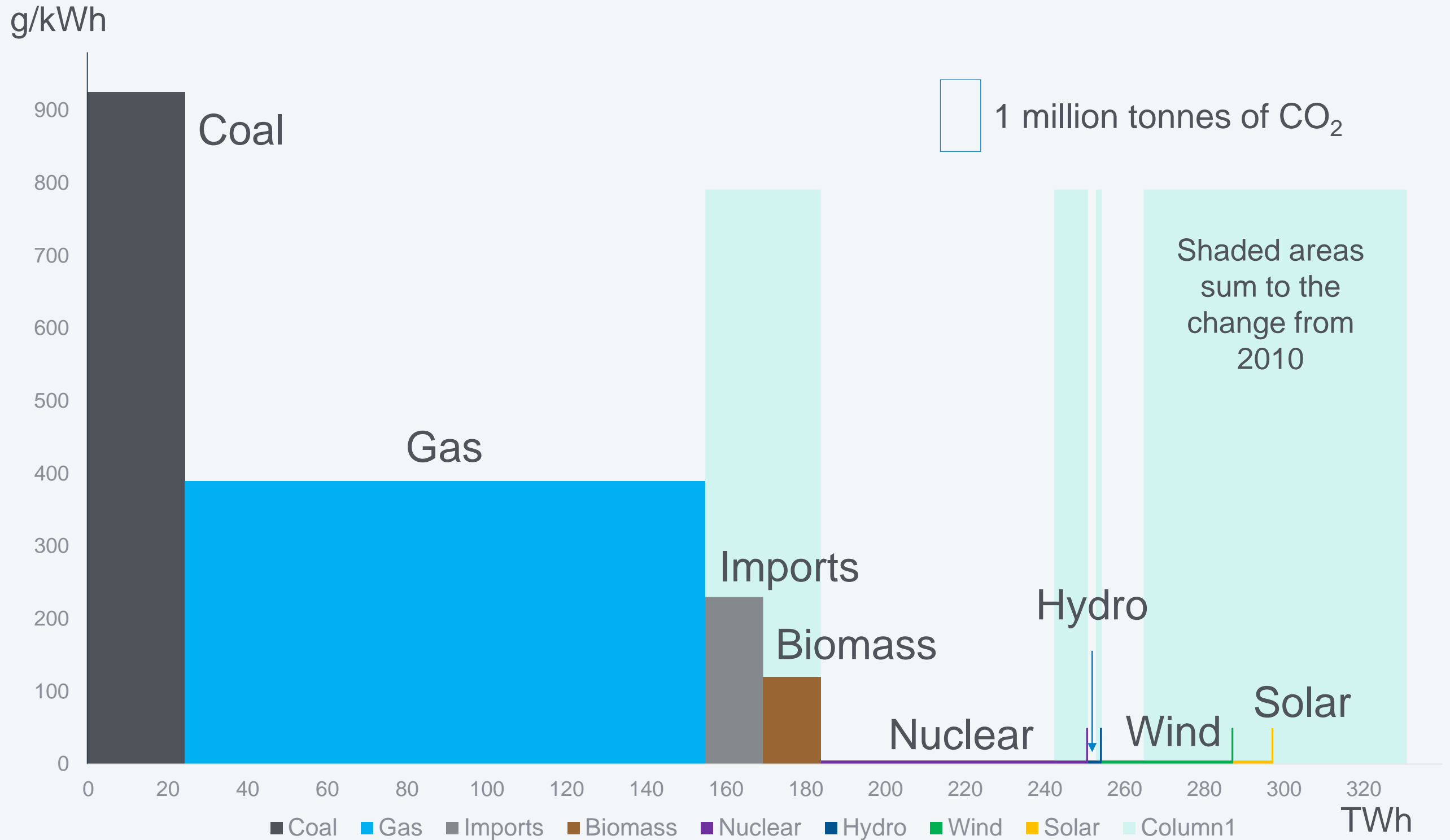
Where do the emissions come from?

Electricity Generated and CO₂ emissions in GB, 2010



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

Electricity Generated and CO₂ emissions in GB, 2016/7

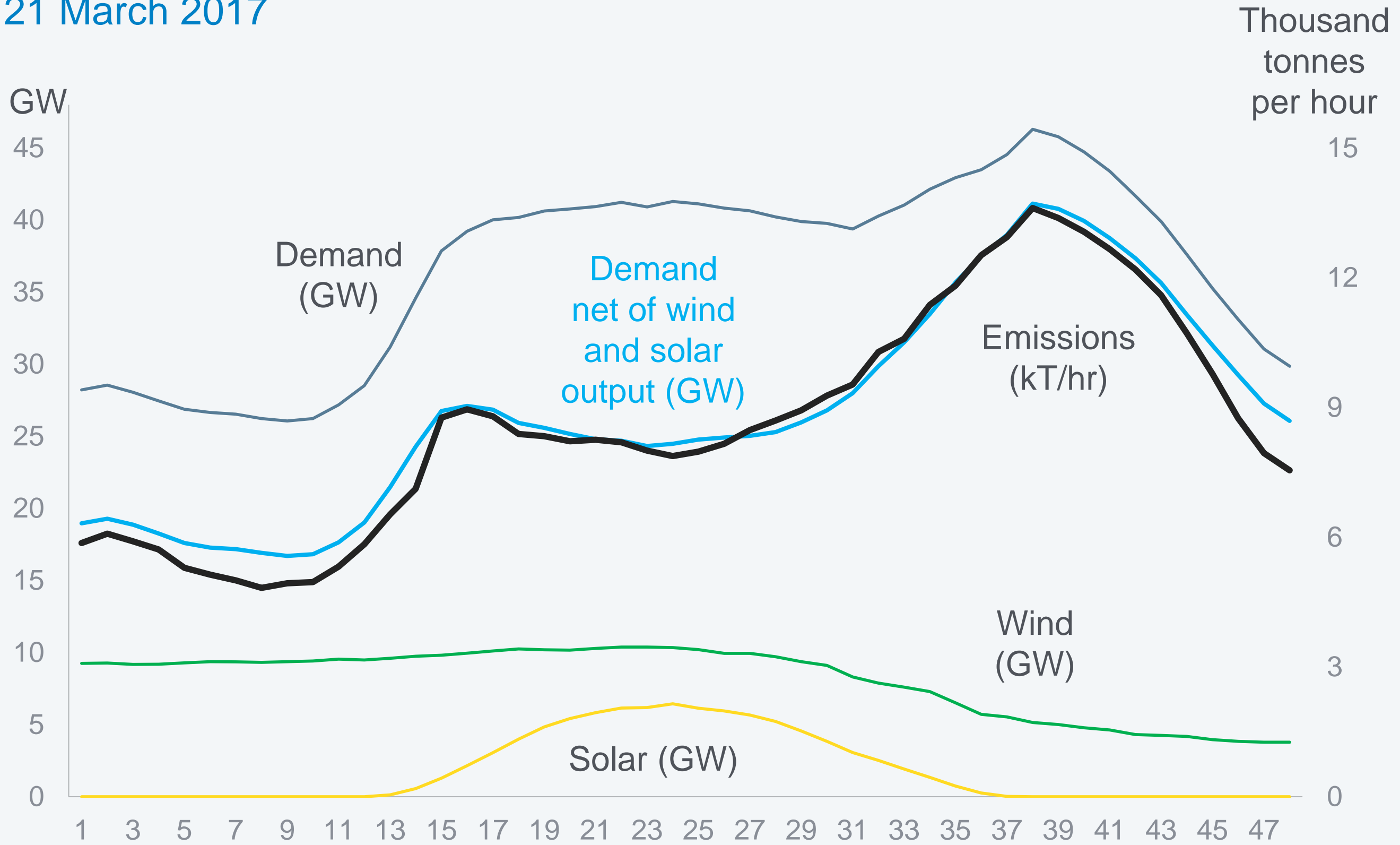


Source: www.electricinsights.co.uk (Imperial College and Drax Power)

What's behind the big picture?

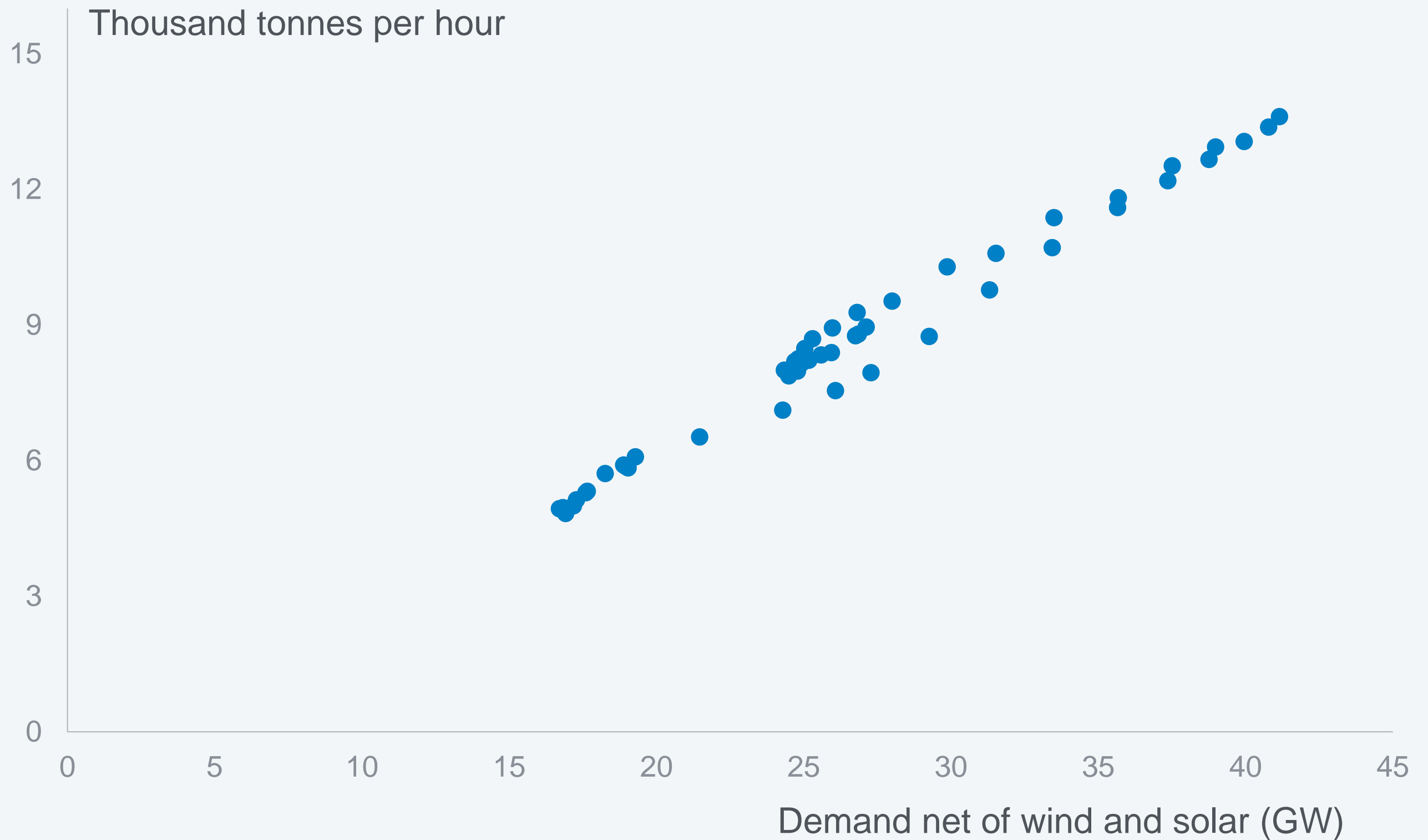
Demand and Emissions of CO₂

21 March 2017



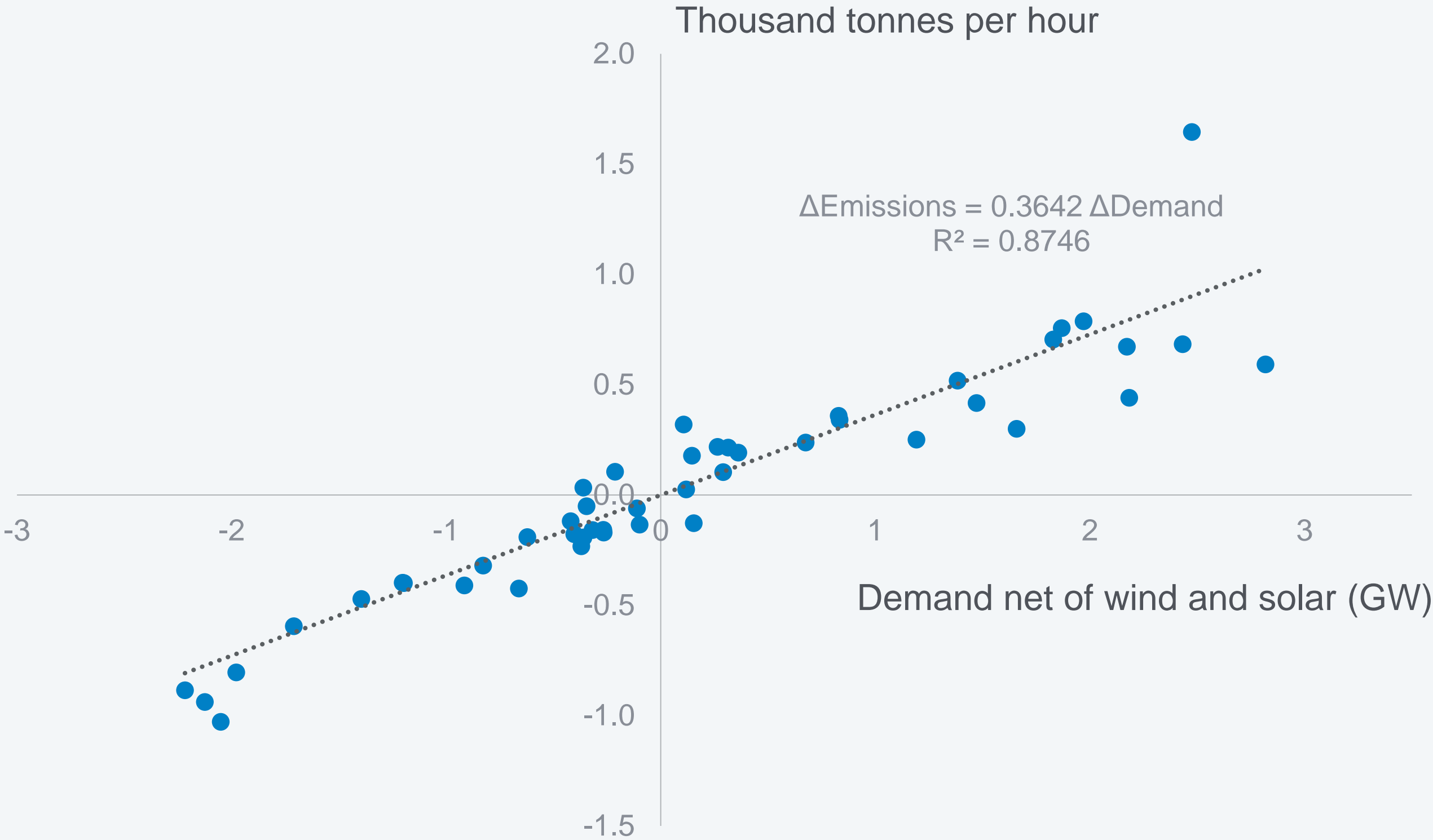
Demand and Emissions of CO₂

21 March 2017



Changes in Demand and Emissions of CO₂

21 March 2017

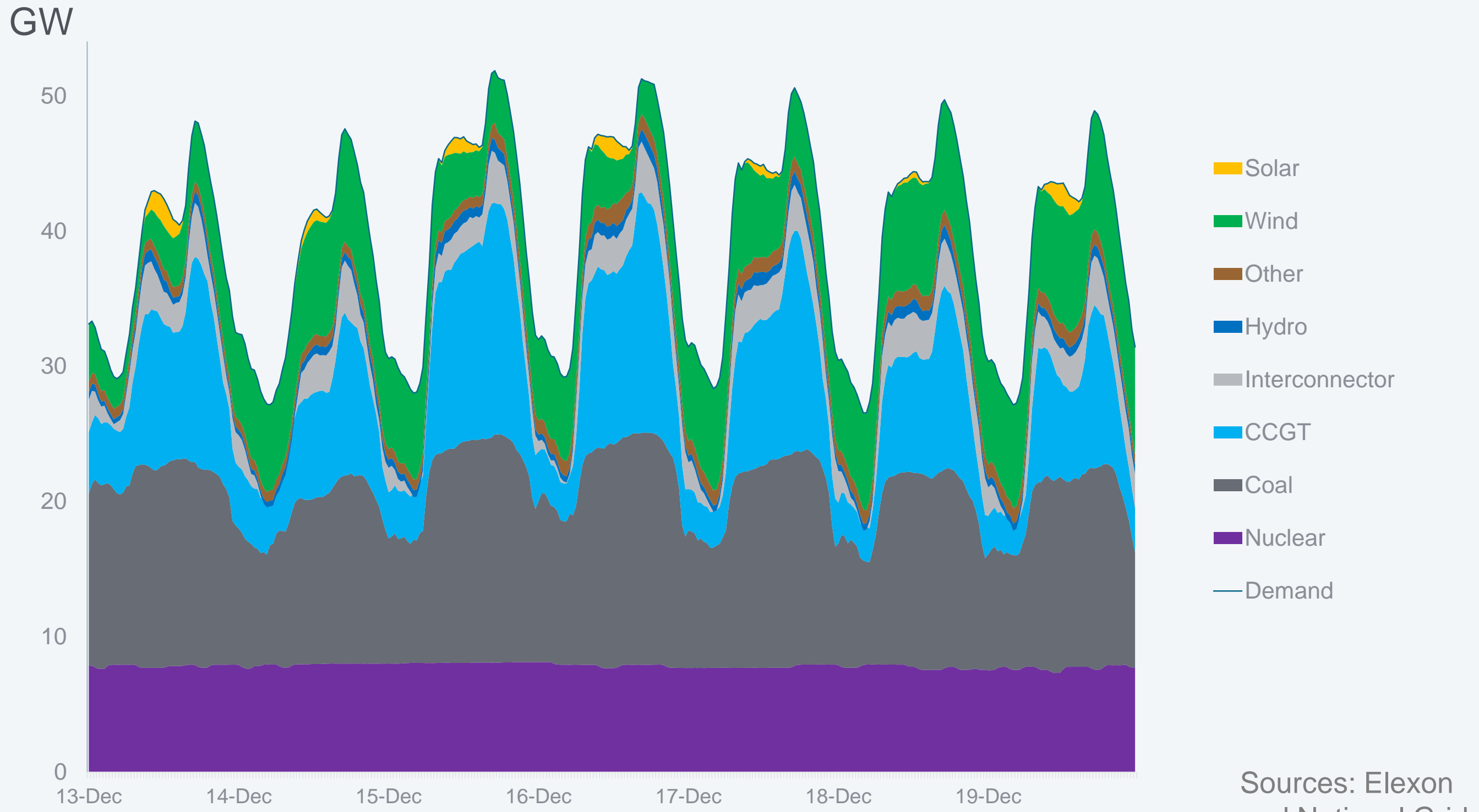


Preliminary answer?

- An extra MWh of demand raises emissions by 493 ± 1 kg
- An extra MWh of wind output cuts emissions by 462 ± 10 kg
- An extra MWh of solar output cuts emissions by 510 ± 8 kg

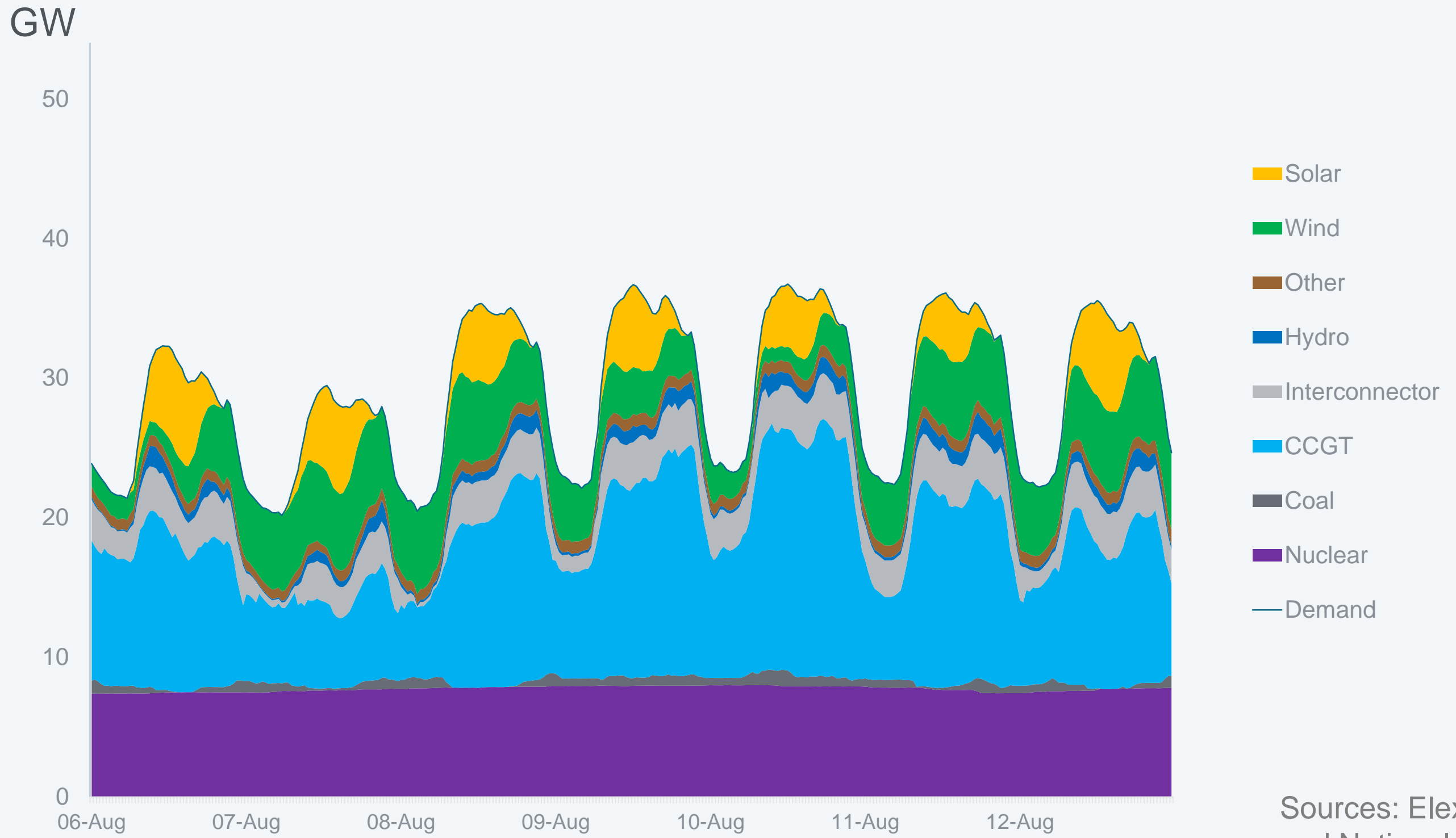
- Calculations of this kind have already been done by Hawkes AD, 2010, Estimating marginal CO2 emissions rates for national electricity systems, *Energy Policy*, Vol: 38, Pages: 5977-5987
- These are averages of marginal emissions factors that are likely to change over time, and hence VERY preliminary

Generation in Great Britain, 13-19 December 2014



Sources: Elexon and National Grid

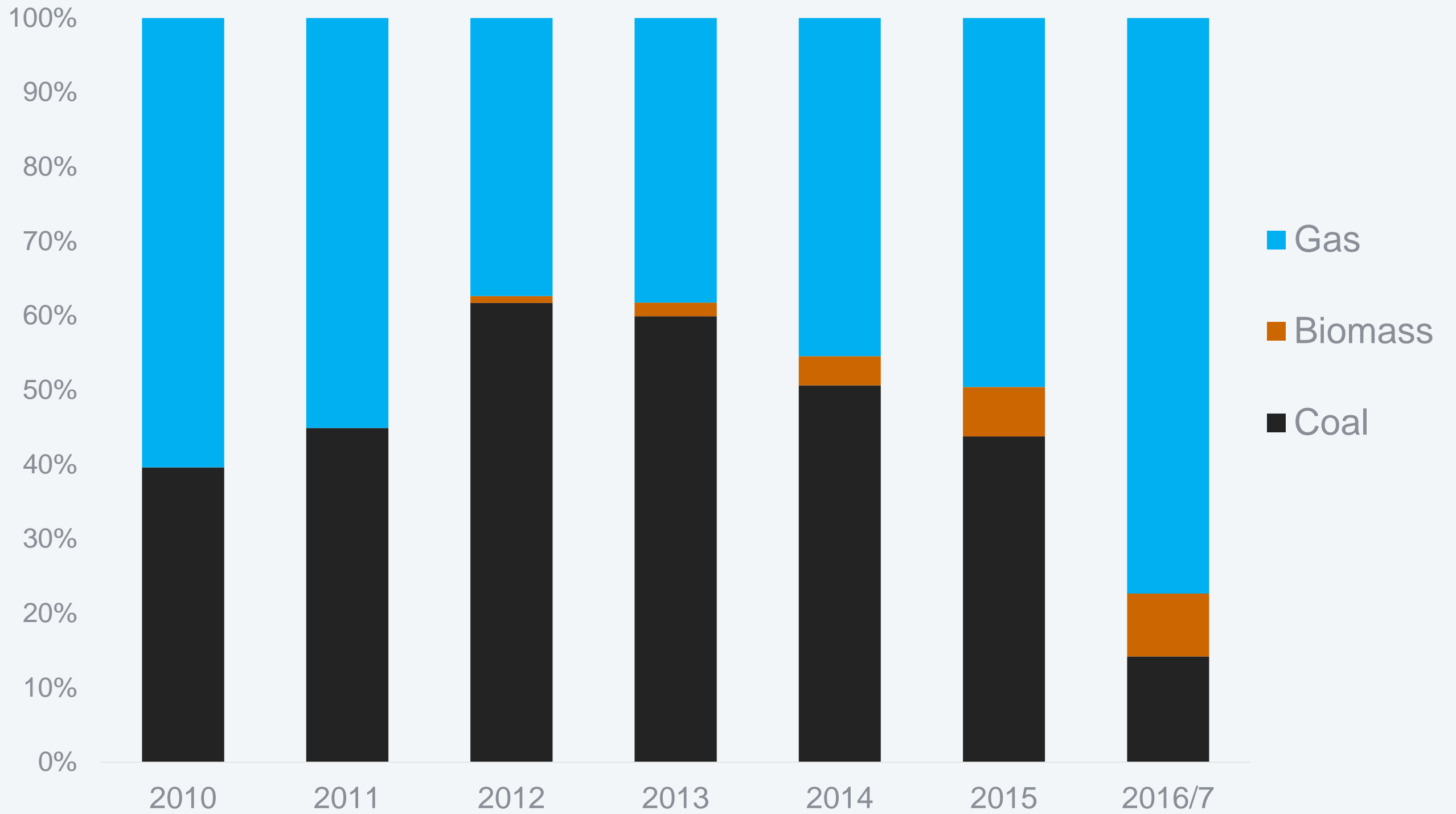
Generation in Great Britain, 6-12 August 2016



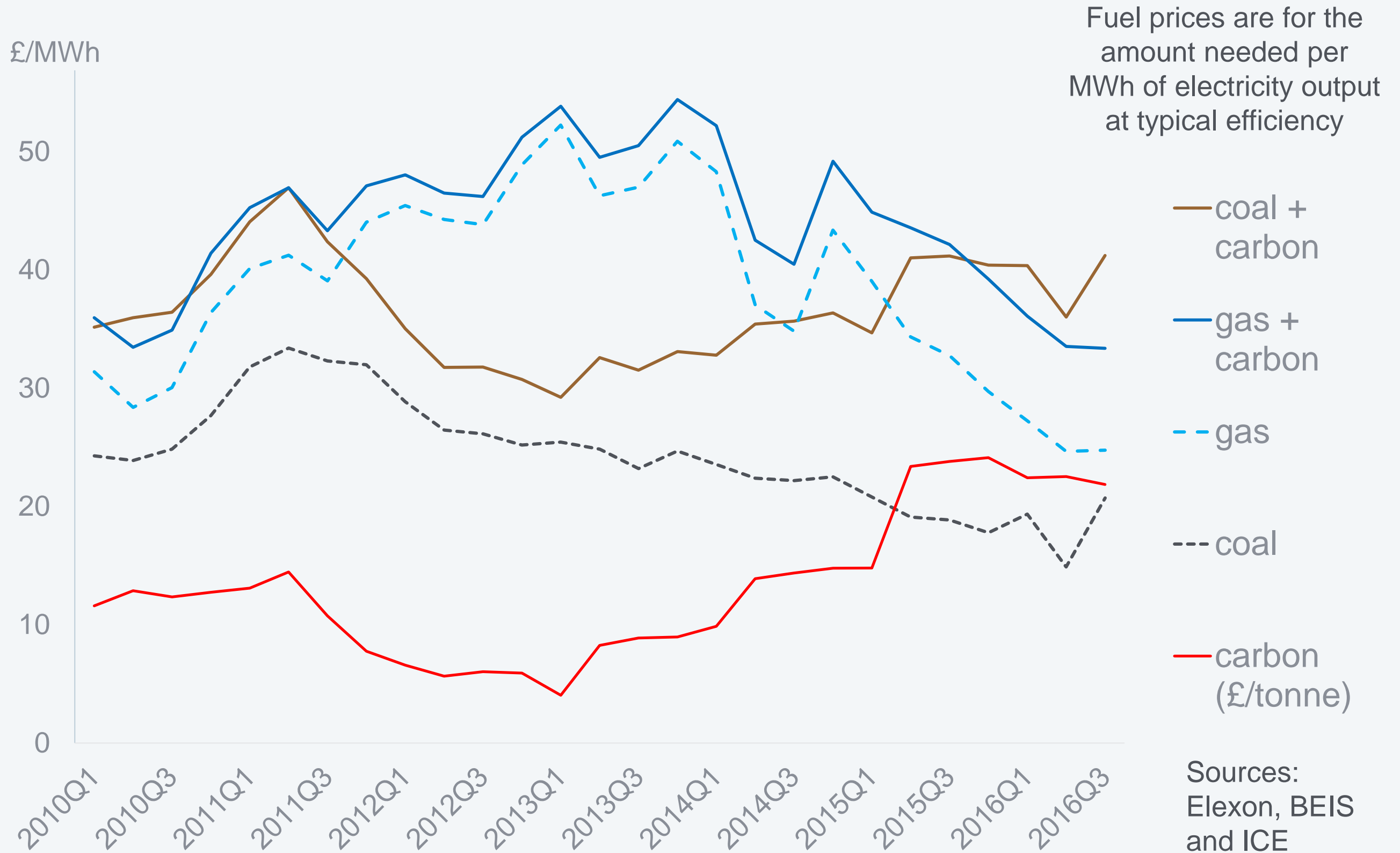
Sources: Elexon and National Grid

What caused the change?

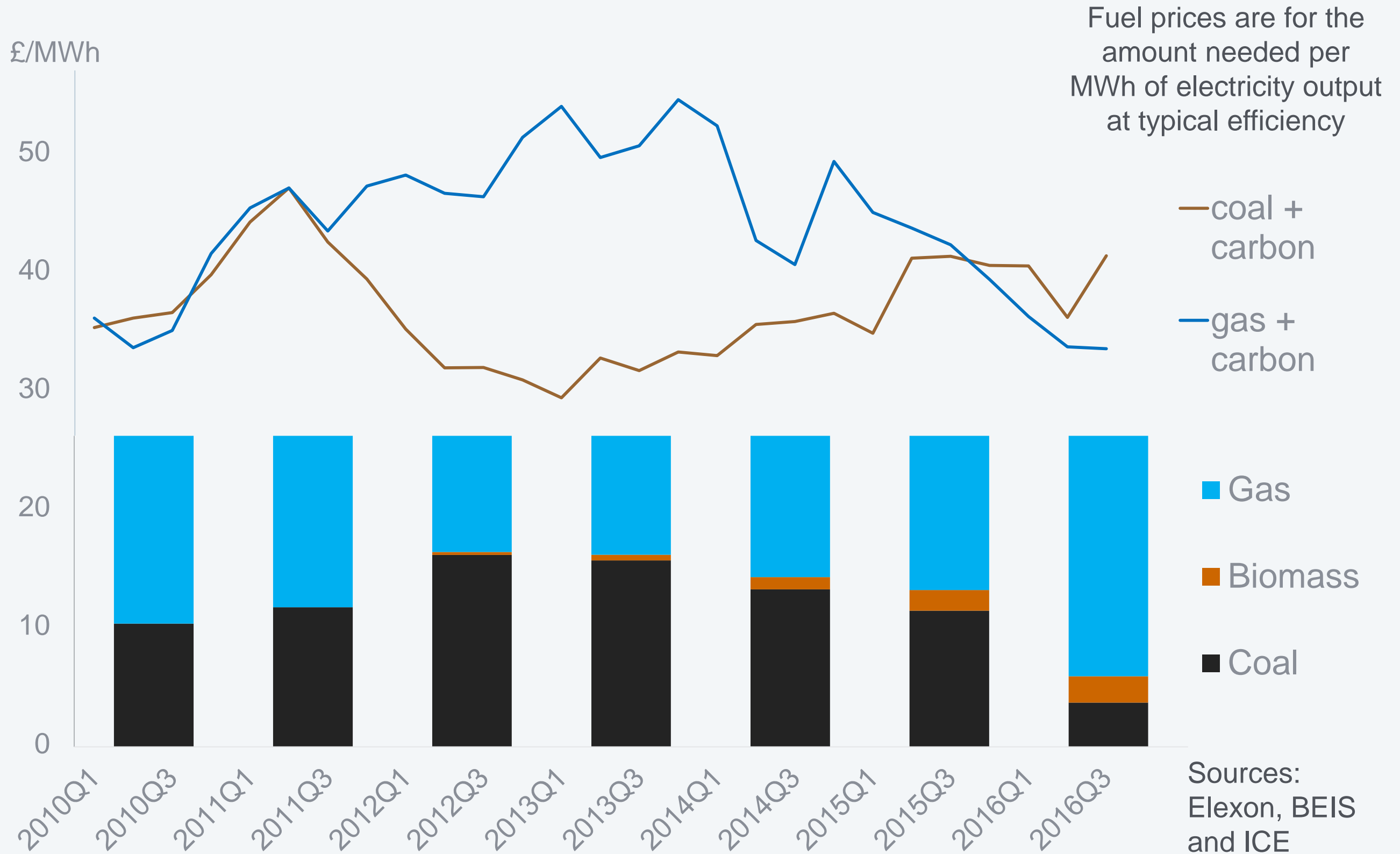
Shares of Thermal Generation



GB Fuel Prices



GB Fuel Prices



Preliminary answer?

When Coal is the marginal fuel (2009Q3 – 2011Q2, 2015Q4 – 2017Q1)

- An extra MWh of demand raises emissions by 521 ± 1 kg
- An extra MWh of wind output cuts emissions by 481 ± 15 kg
- An extra MWh of solar output cuts emissions by 526 ± 11 kg

When Gas is the marginal fuel (2009Q1 – Q2, 2011Q3 – 2015Q3)

- An extra MWh of demand raises emissions by 468 ± 1 kg
- An extra MWh of wind output cuts emissions by 454 ± 13 kg
- An extra MWh of solar output cuts emissions by 451 ± 12 kg

More detailed calculations have already been done by Thomson, R., Harrison, G. & Chick, J.(2017) Marginal Greenhouse Gas Emissions Displacement of Wind Power in Great Britain *Energy Policy*

We will be “digging deeper” into the causal factors

Maximising the Carbon Impact of Wind Power

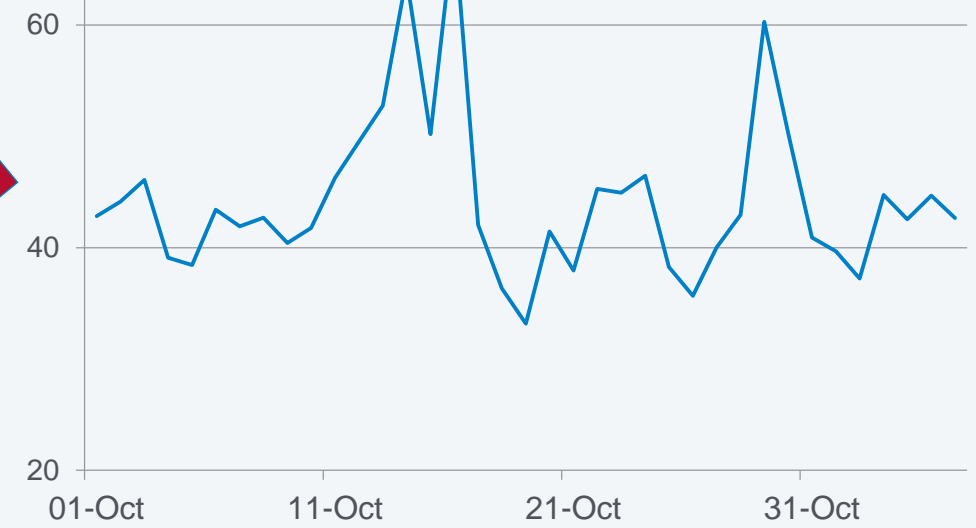
- 1) Improve wind output simulations based on reanalysis weather data
- 2) Estimate hourly emissions for the British power sector
- 3) Assess the impact of wind output, fuel prices, and wind forecast accuracy
- 4) Model future investment and operating decisions changing with wind

The MOSSI model

Merit Order Stack with Step Investment

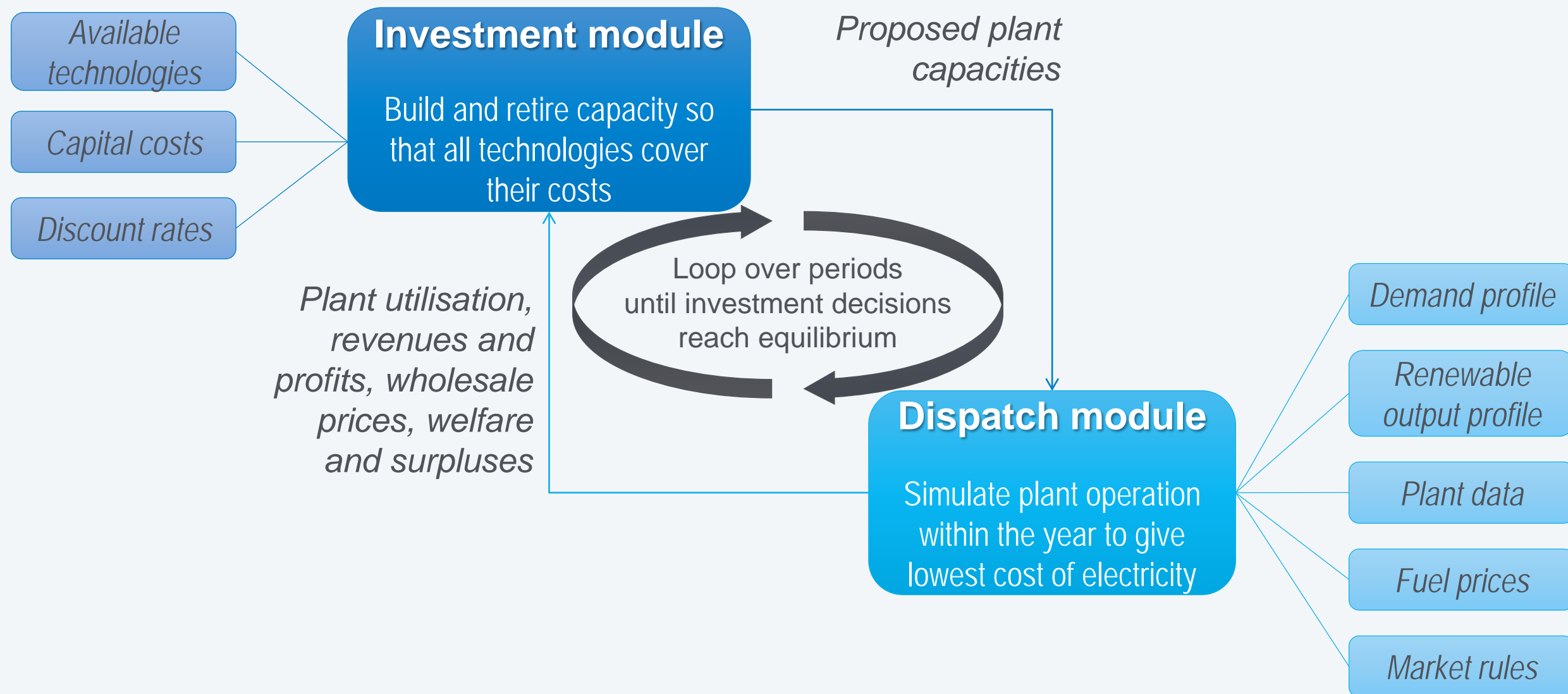


£/MWh



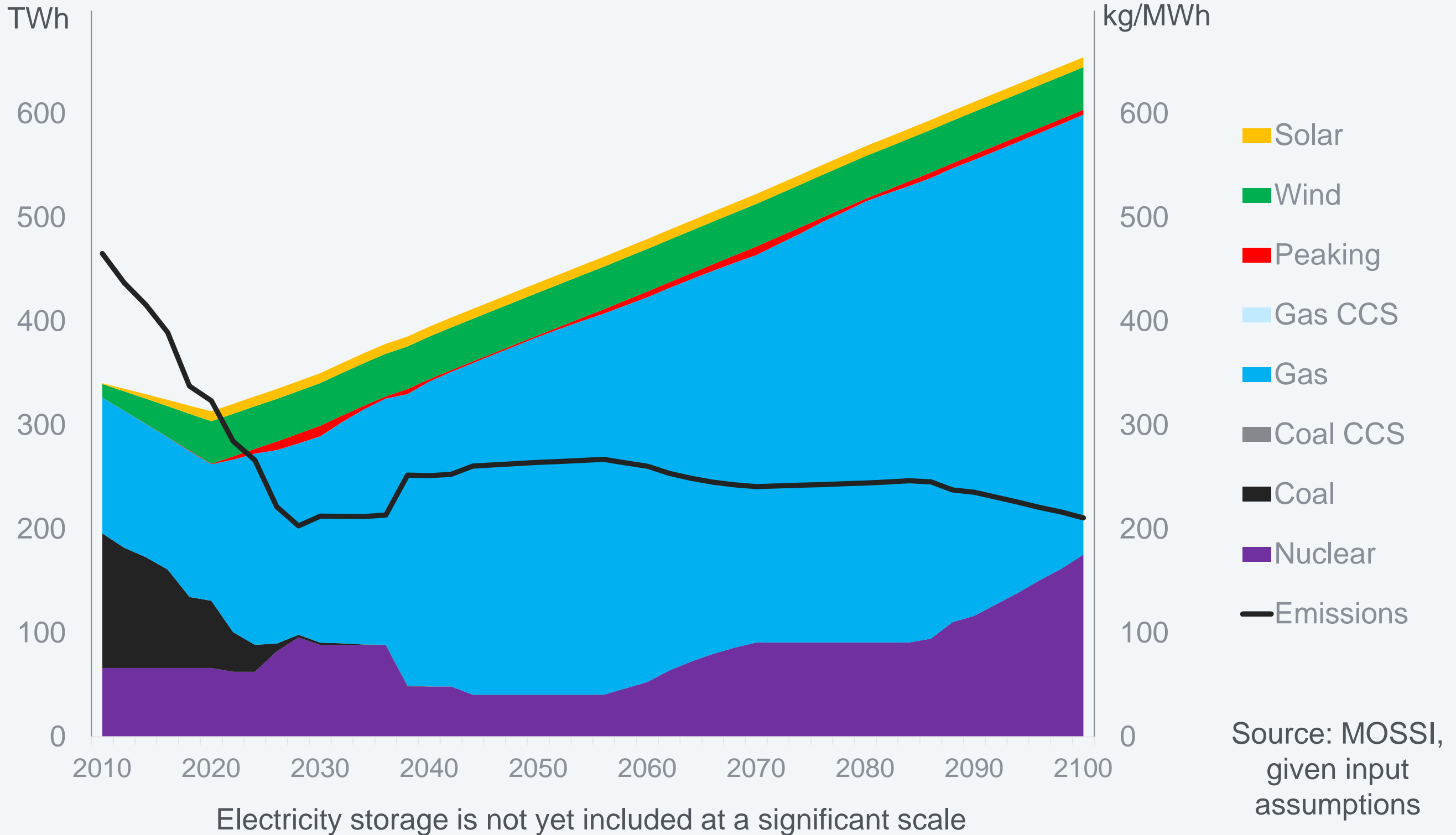
The MOSSI model

Merit Order Stack with Step Investment



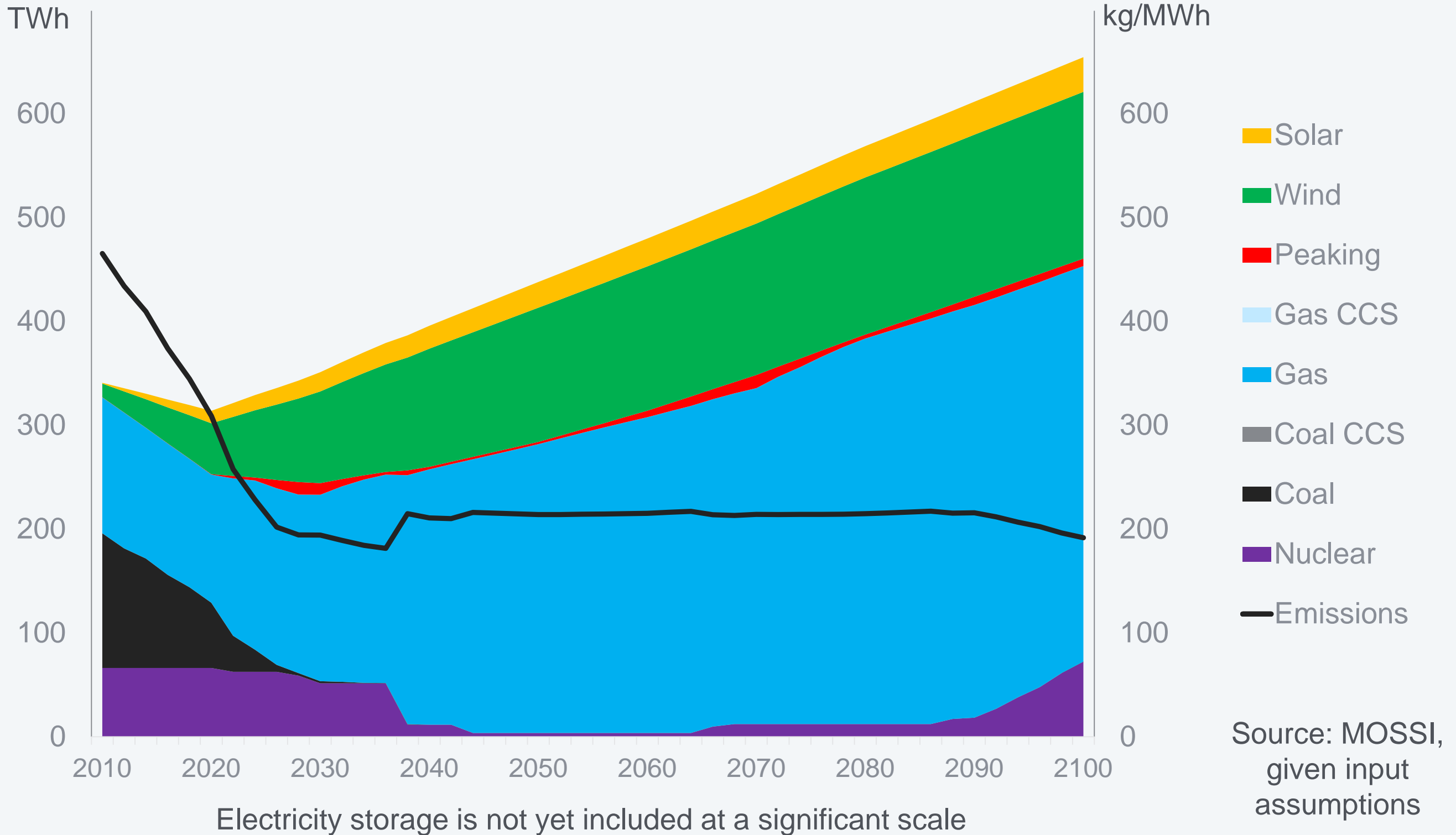
Future Electricity Output

Renewables held at 2017 levels, £50 Carbon price in 2050



Future Electricity Output

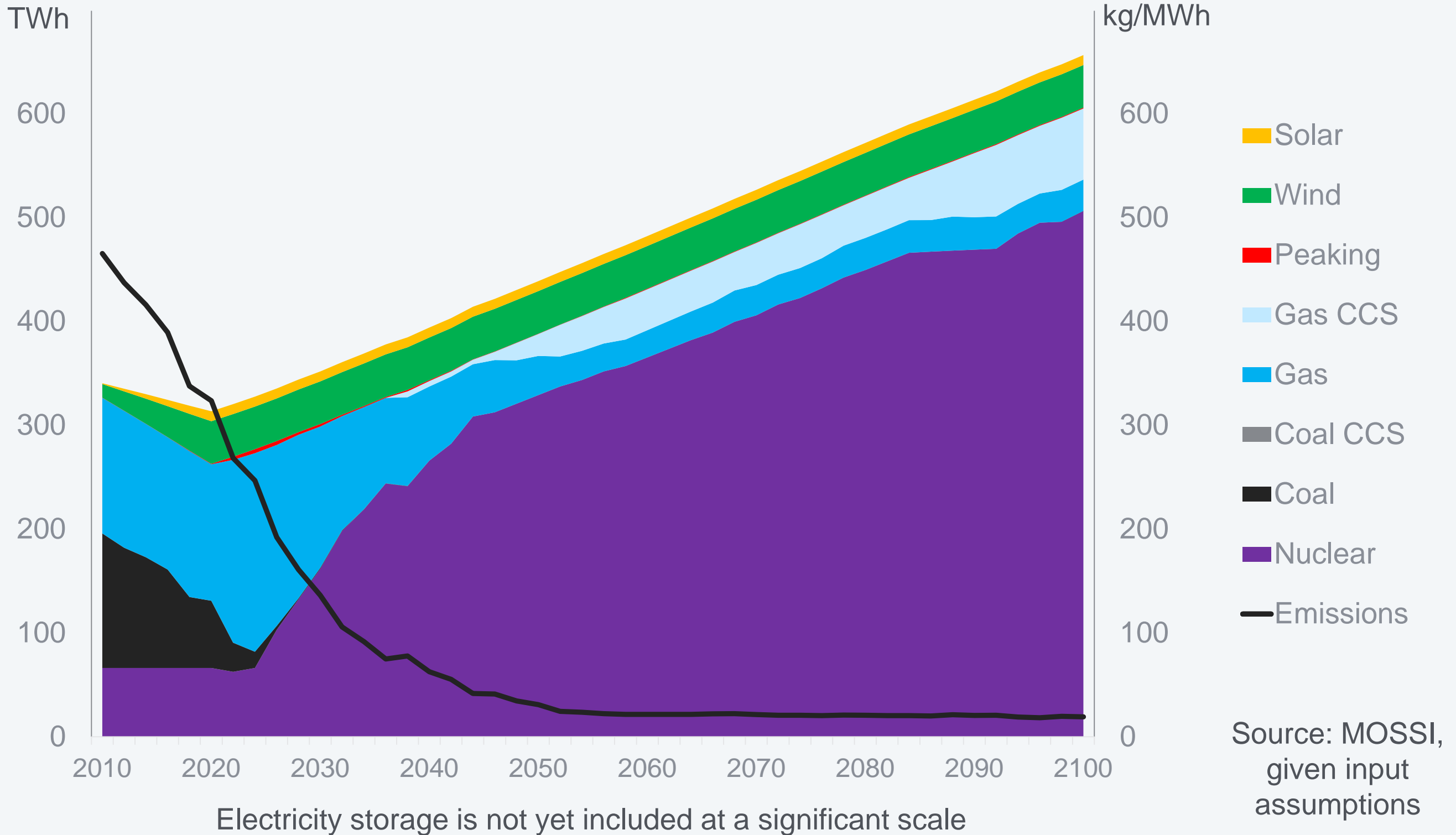
Renewables continue to grow, £50 Carbon price in 2050



Source: MOSSI, given input assumptions

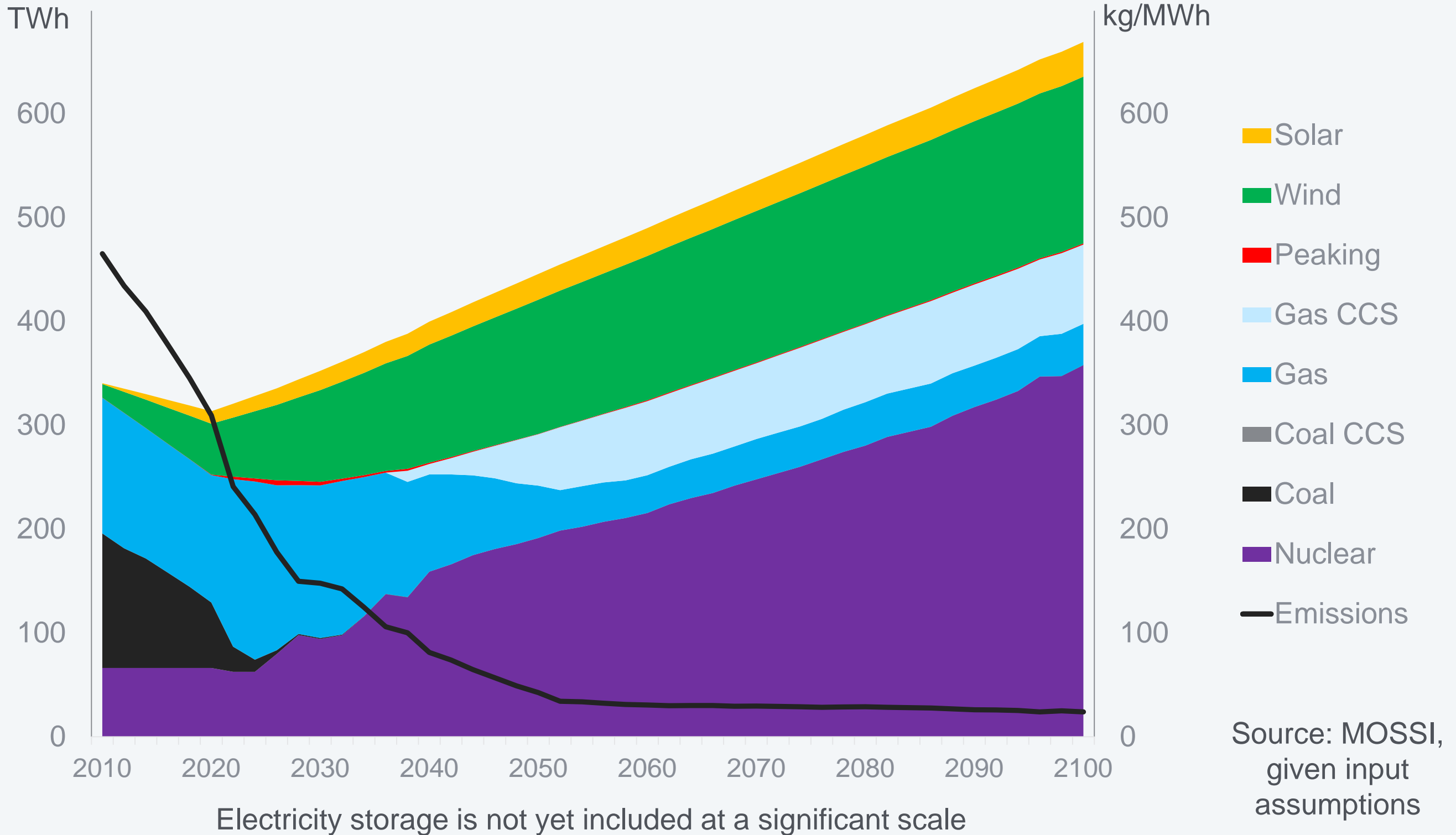
Future Electricity Output

Renewables held at 2017 levels, £250 Carbon price in 2050



Future Electricity Output

Renewables continue to grow, £250 Carbon price in 2050



Thank you

