Imperial College London

Taxes, Subsidies or Regulation: Why have Britain's CO_2 emissions from electricity halved?

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Iain Staffell, Centre for Environmental Policy

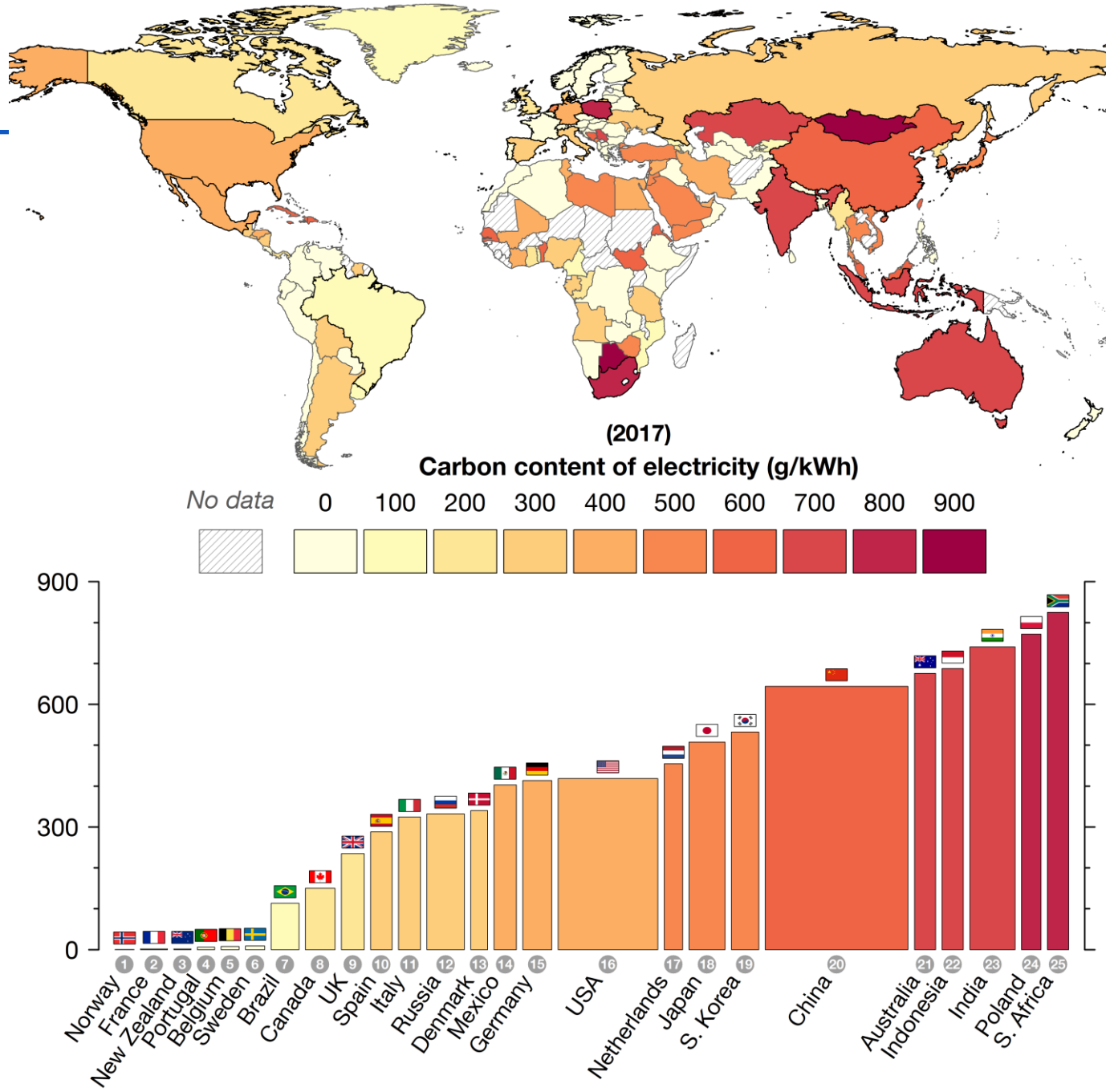
cep

Imperial College Business School

Deep Decarbonization Initiative
UC San Diego, 26 May 2021

Clean power?

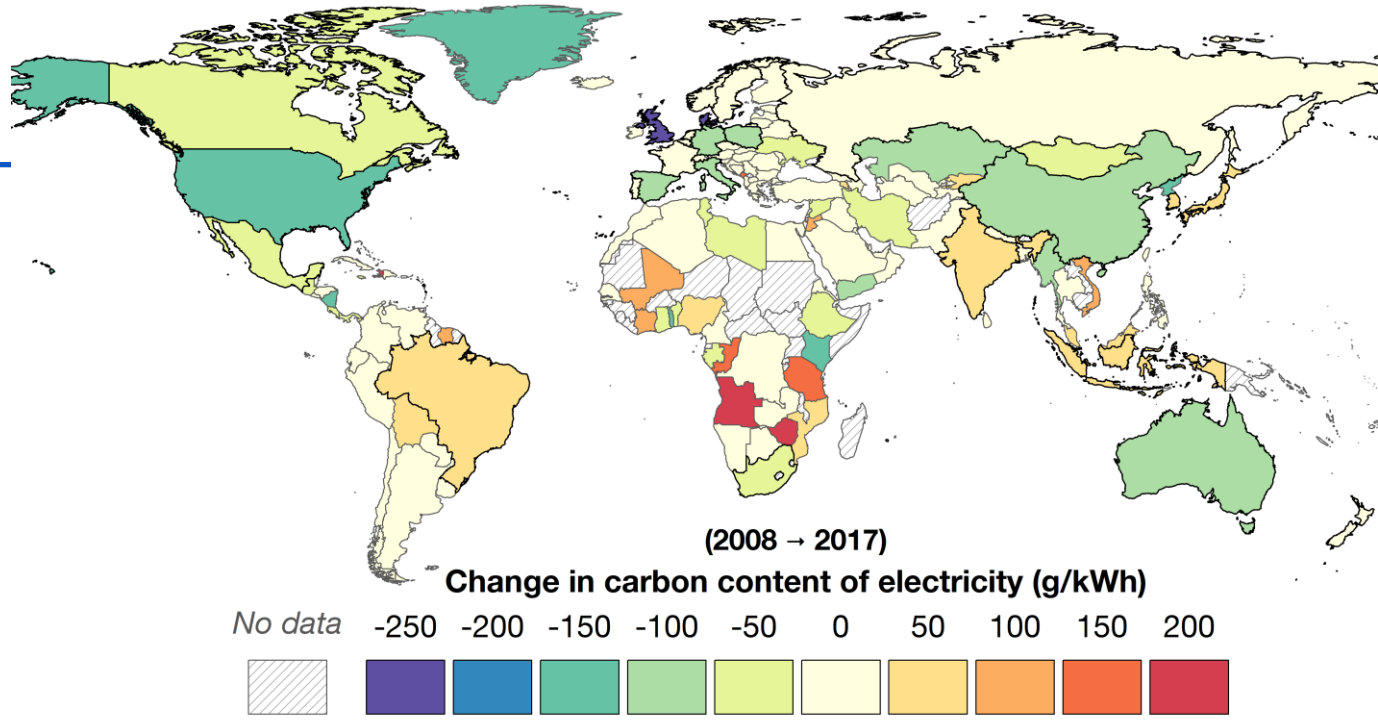
- Clean electricity is fundamental, able to drive decarbonisation of vehicles, heat and industry
- The 2017 global average carbon intensity of electricity was 440 gCO_2 per kWh consumed
- If China could reduce carbon intensity by a third to match USA, global CO_2 emissions would fall by 4%
- If China and USA could match the UK, global emissions would fall 9%

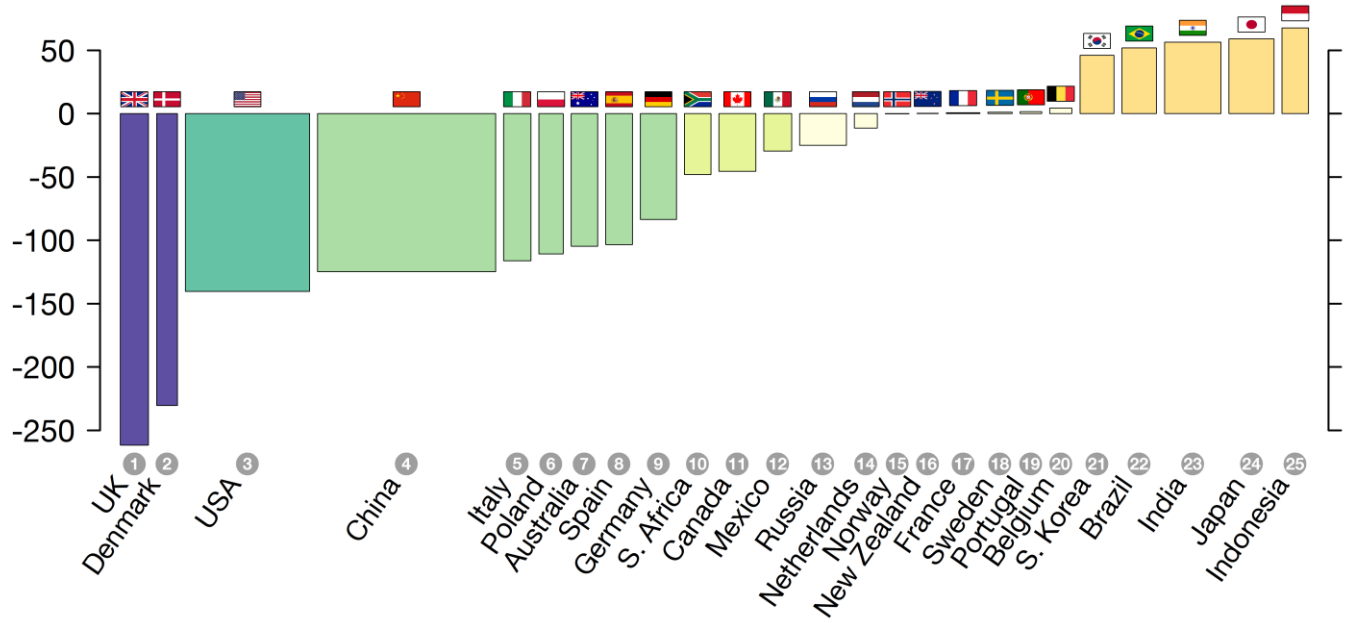


Source — Energy Revolution: A Global Outlook

Clean power?

- Global carbon intensity has only fallen by 5% over the last decade
- China and the US made big reductions, despite 'building a new coal power station every week', and trying to 'bring back coal'
- UK has seen the fastest power sector transformation over the last decade
- **Why?**





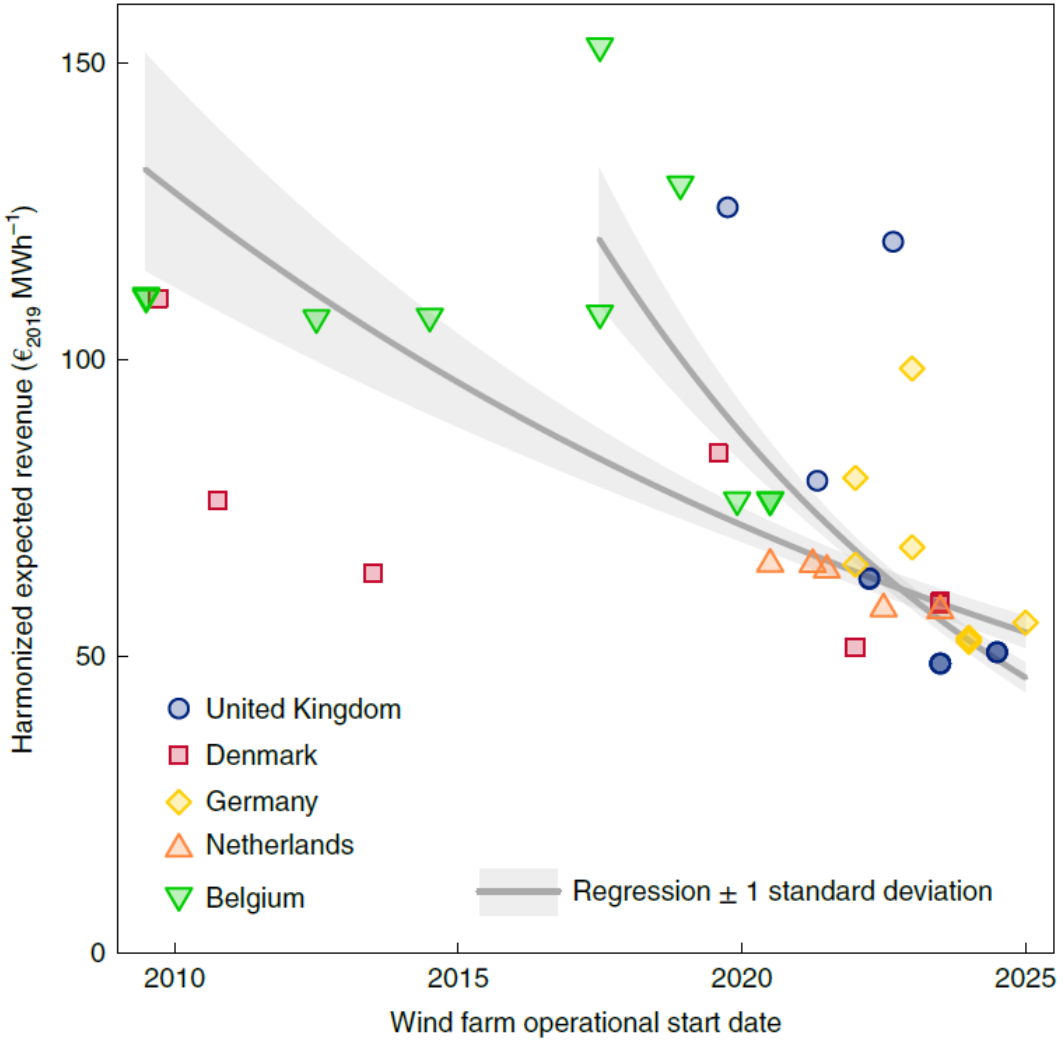
Source — Energy Revolution: A Global Outlook

Agenda

- A bit of my work
- How Britain's power system has changed
  - Past studies of emissions savings
- Our approach
  - Shapley Value to assign reductions to changes
  - Simulation modelling – the enhanced merit order stack
- Results
  - What caused the fall in emissions
  - What did this do to prices?
  - What can other countries learn from this?

Some interdisciplinary energy reserach

- *Offshore wind competitiveness in mature markets without subsidy.* Nature Energy, 5, 614–622.



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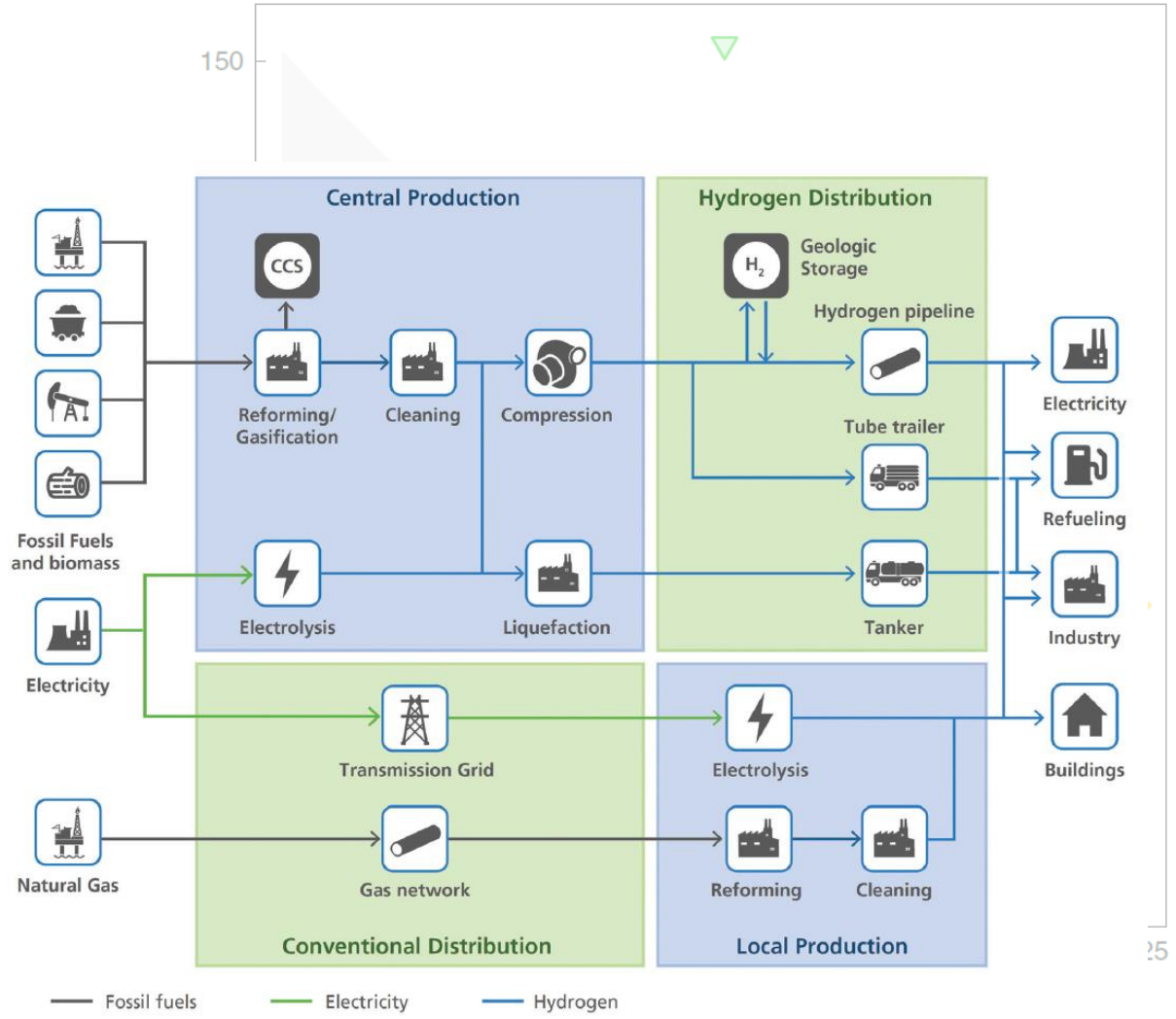

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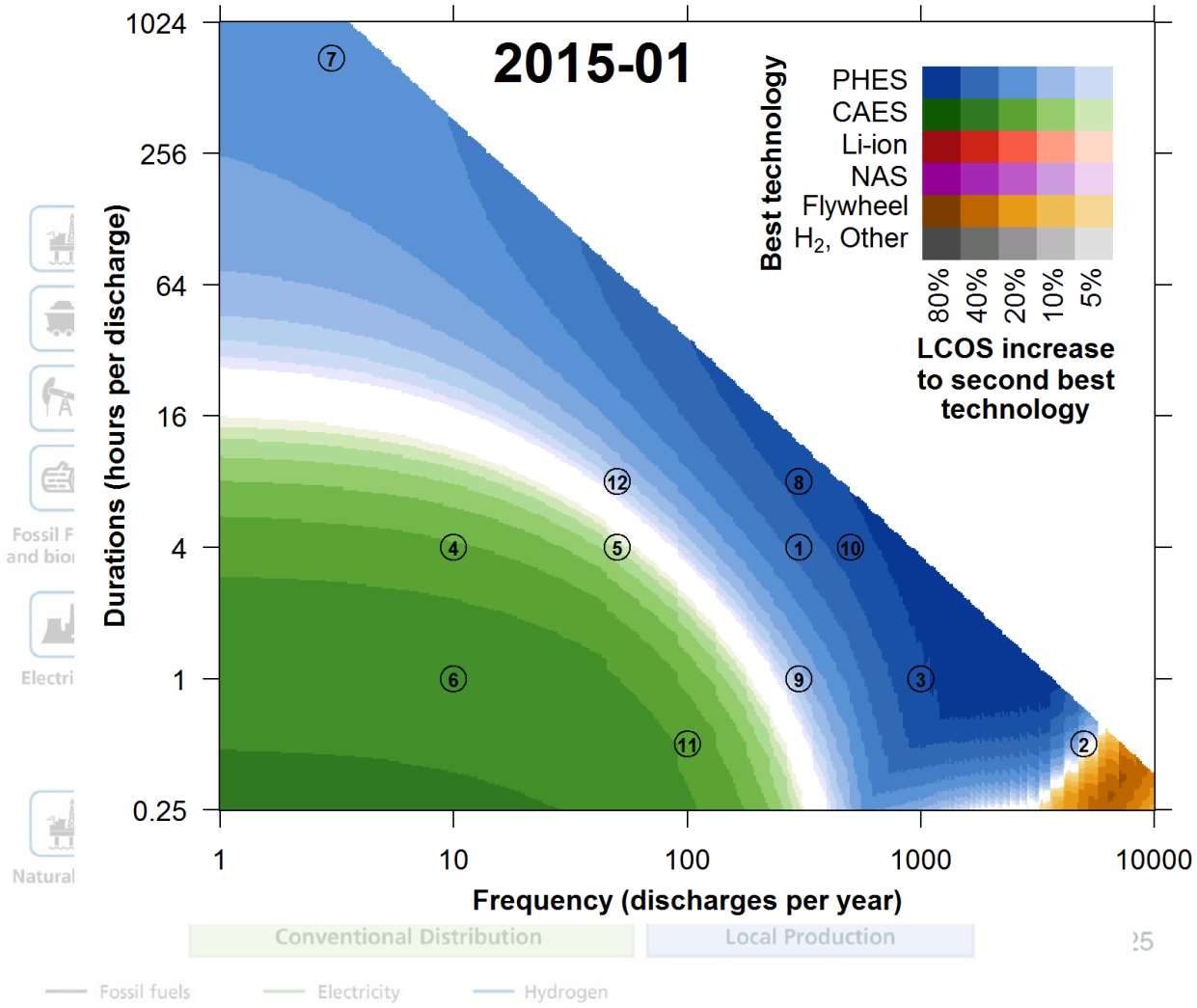

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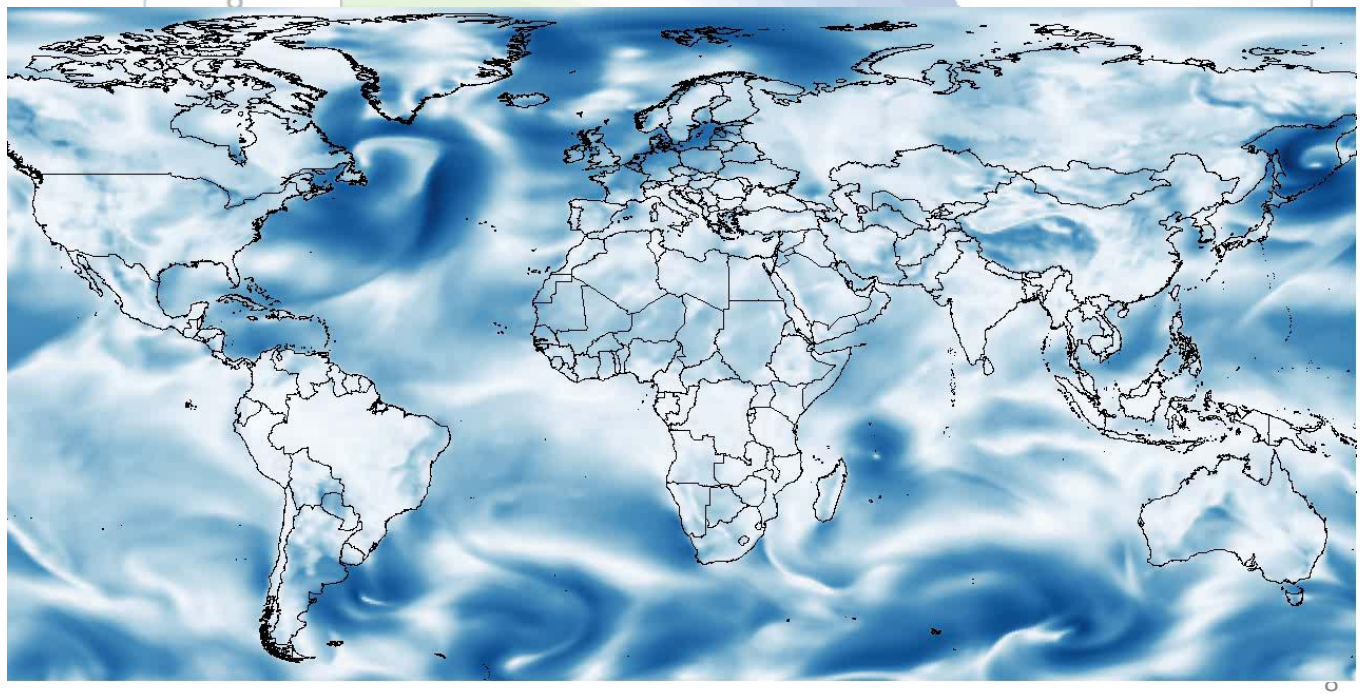

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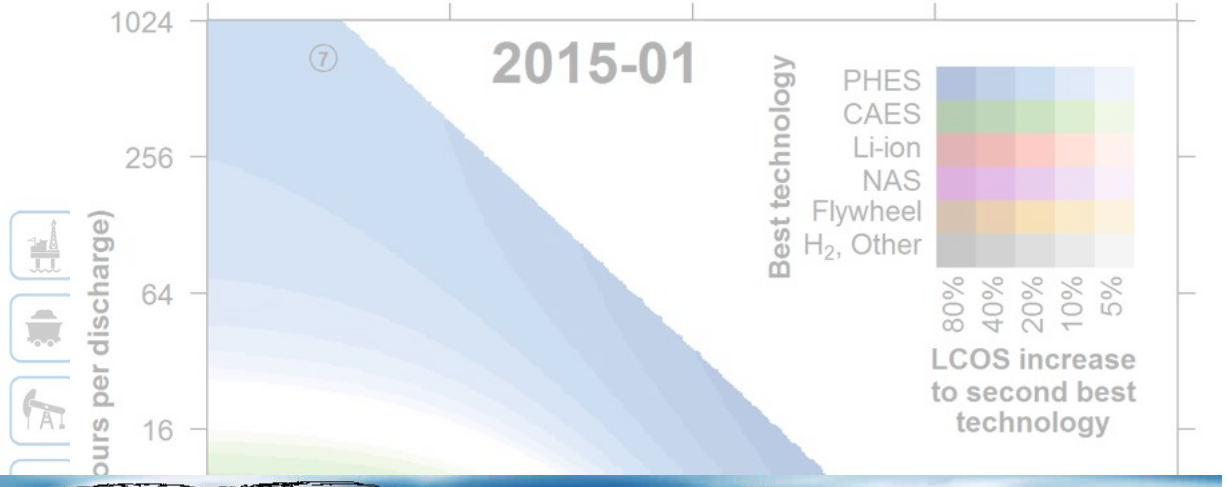
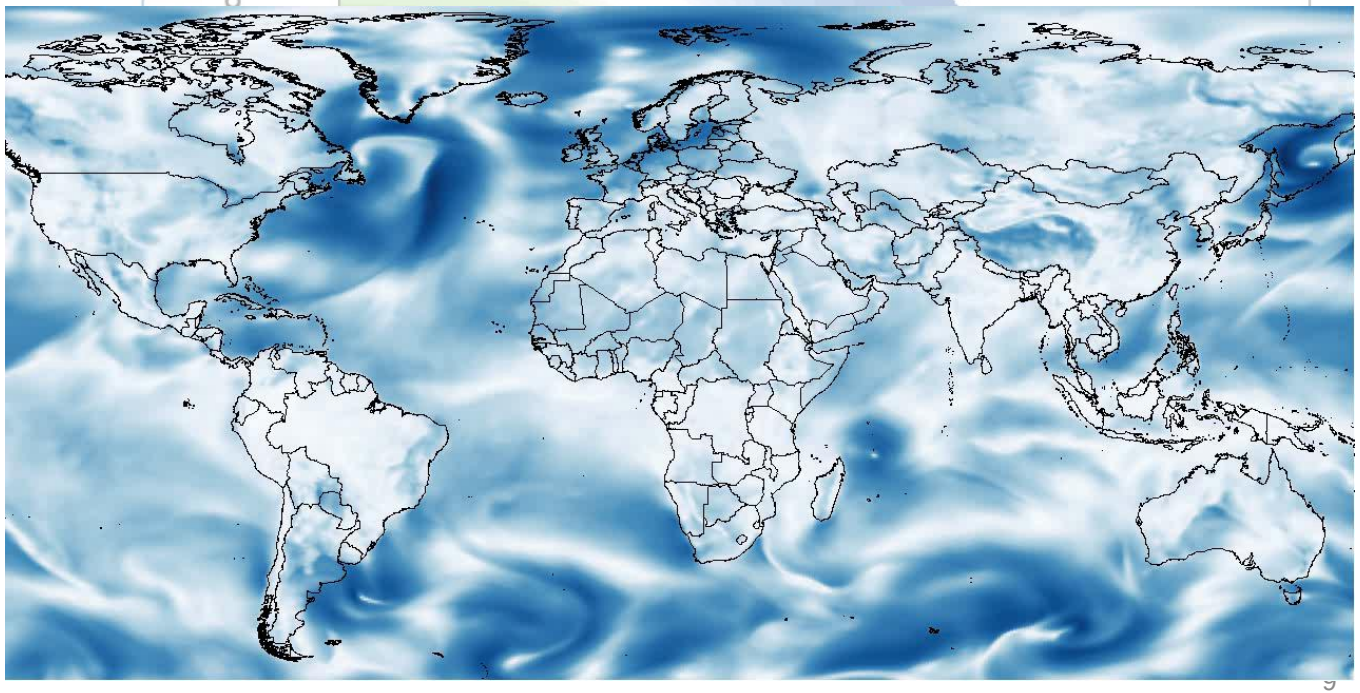
- *The importance of open data and software: is energy research lagging behind?* Energy Policy, 101, 211–215.

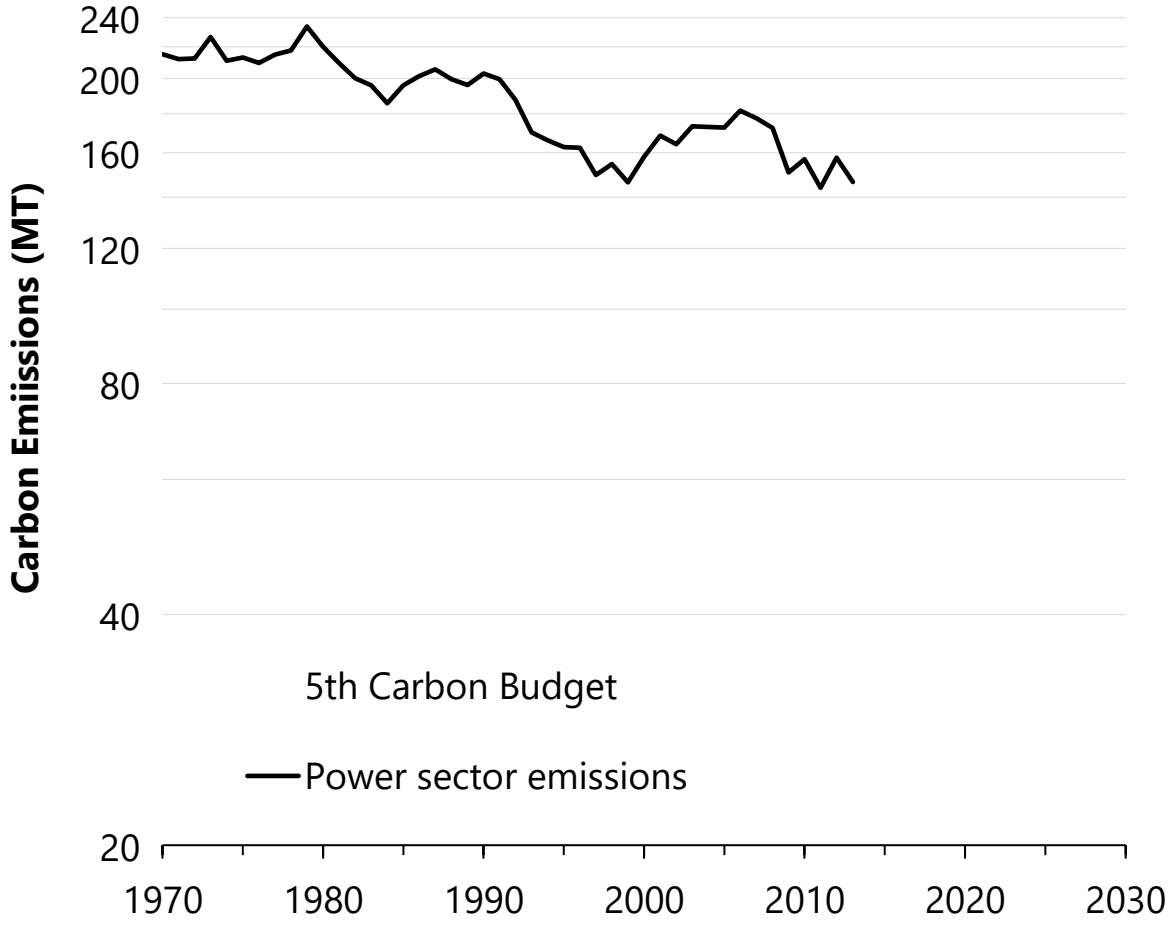




Power sector emissions

Power sector emissions

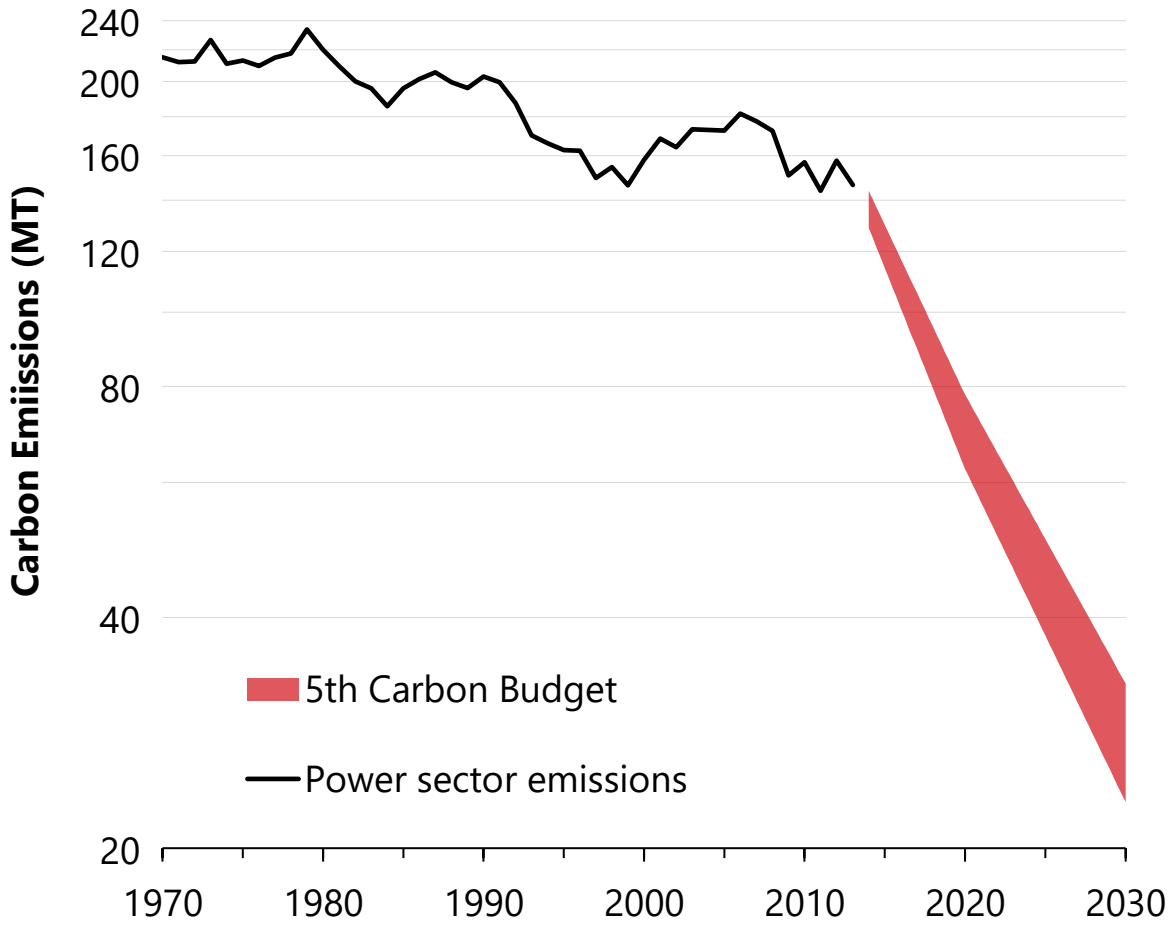
- The UK's power sector slowly decarbonised for 40 years



Source — Staffell, 2017, Energy Policy

Power sector emissions

- The UK's power sector slowly decarbonised for 40 years
- But the law required 5x faster



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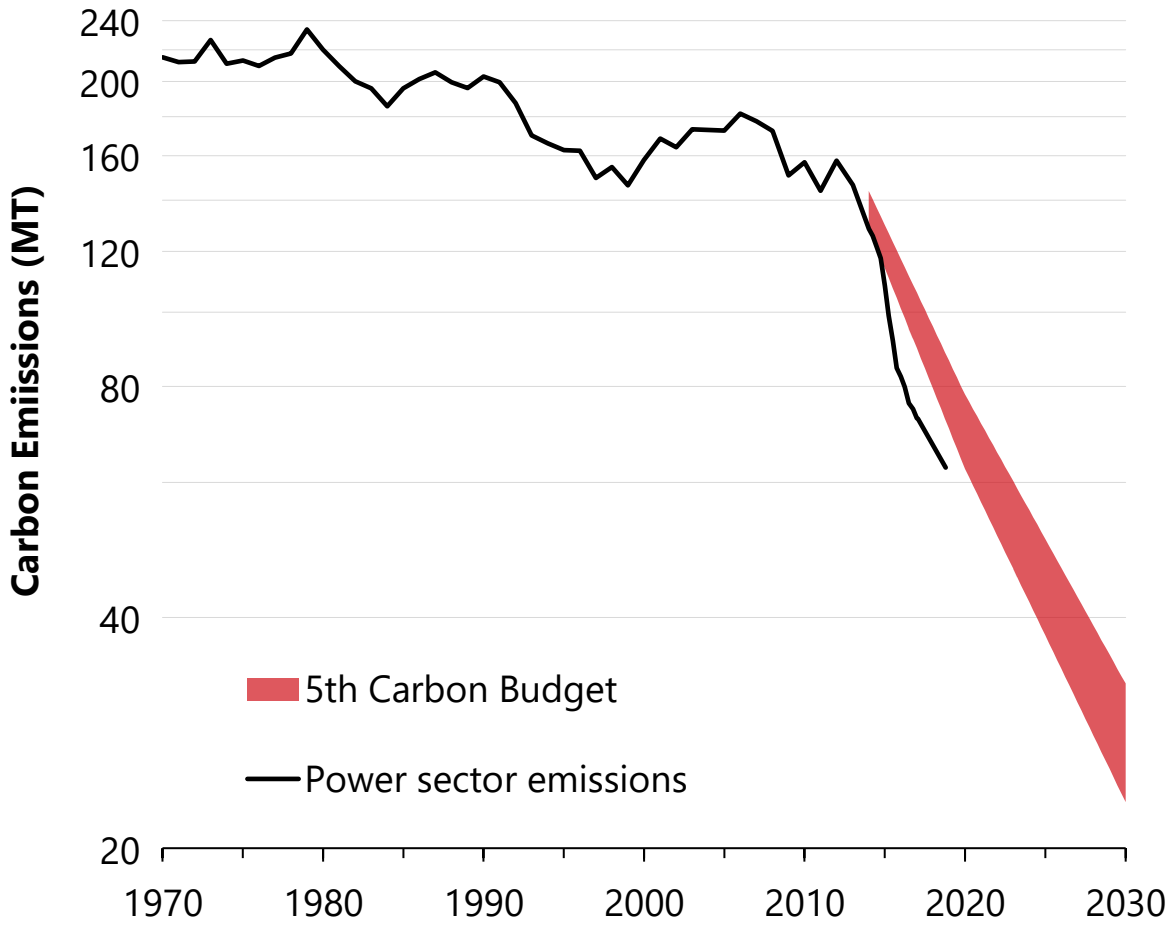
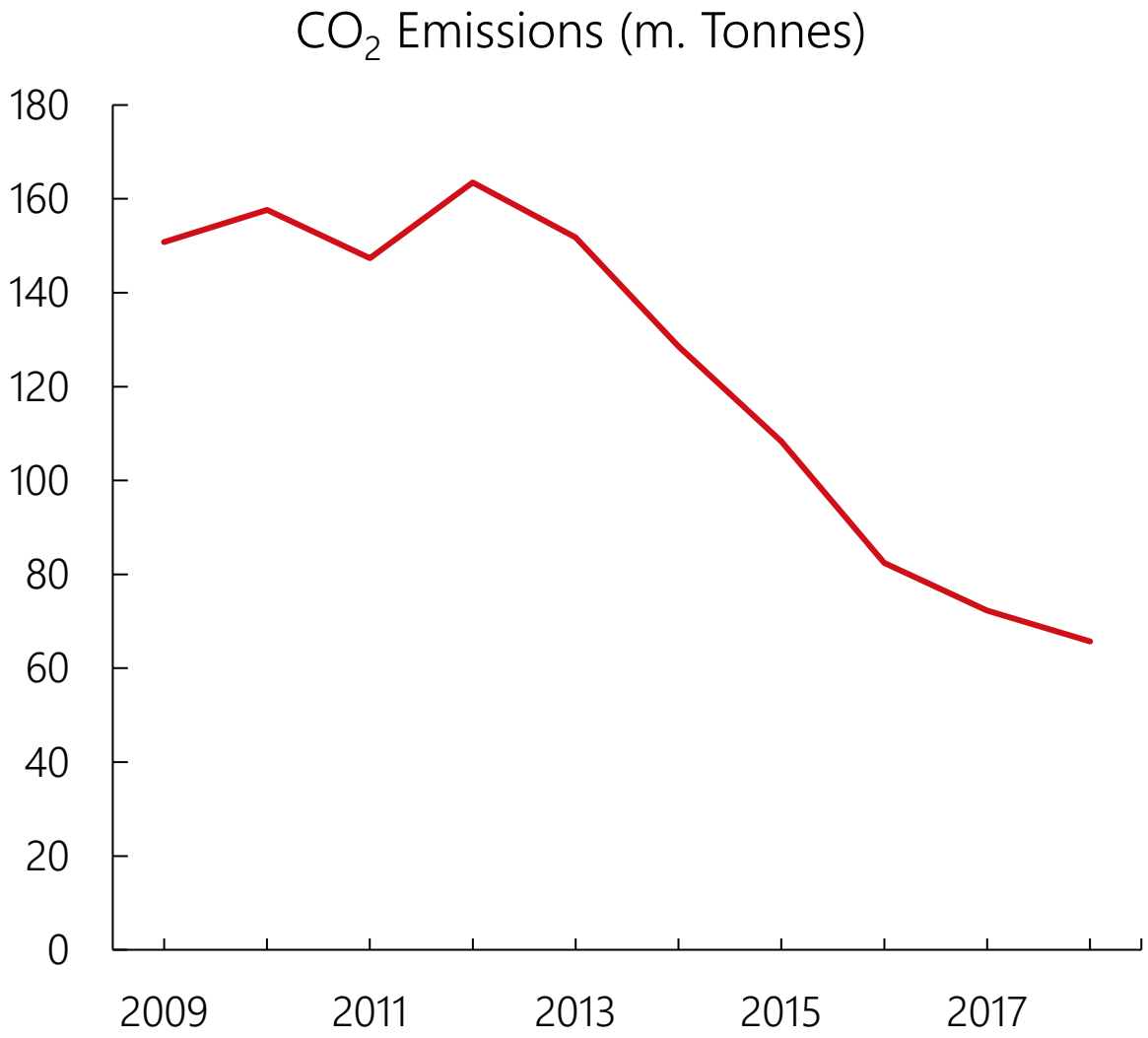
Power sector emissions

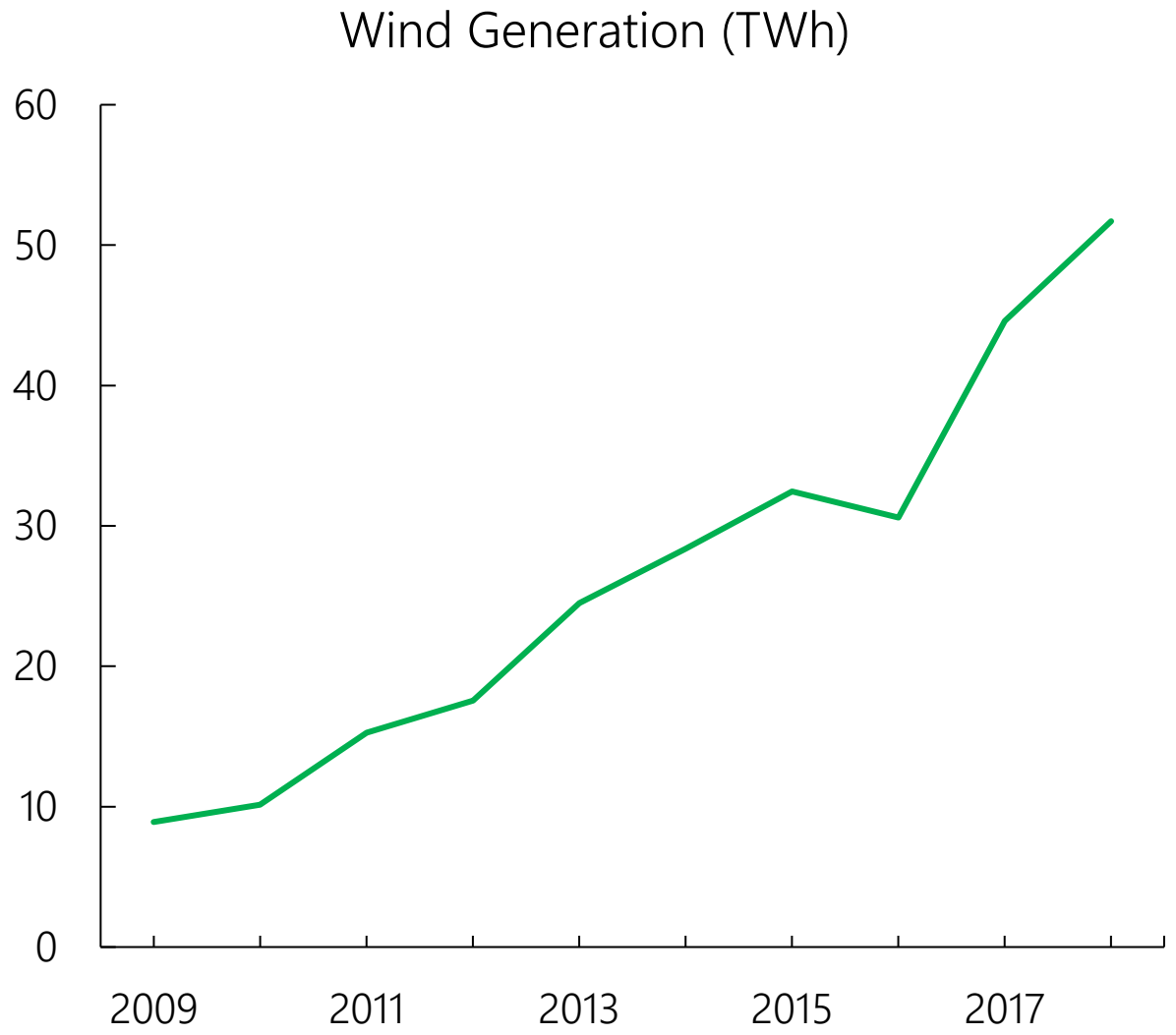
- The UK's power sector slowly decarbonised for 40 years
- But the law required 5x faster
- And somehow… it is working…



Source — Staffell, 2017, Energy Policy

What has changed?





Source — Electric Insights

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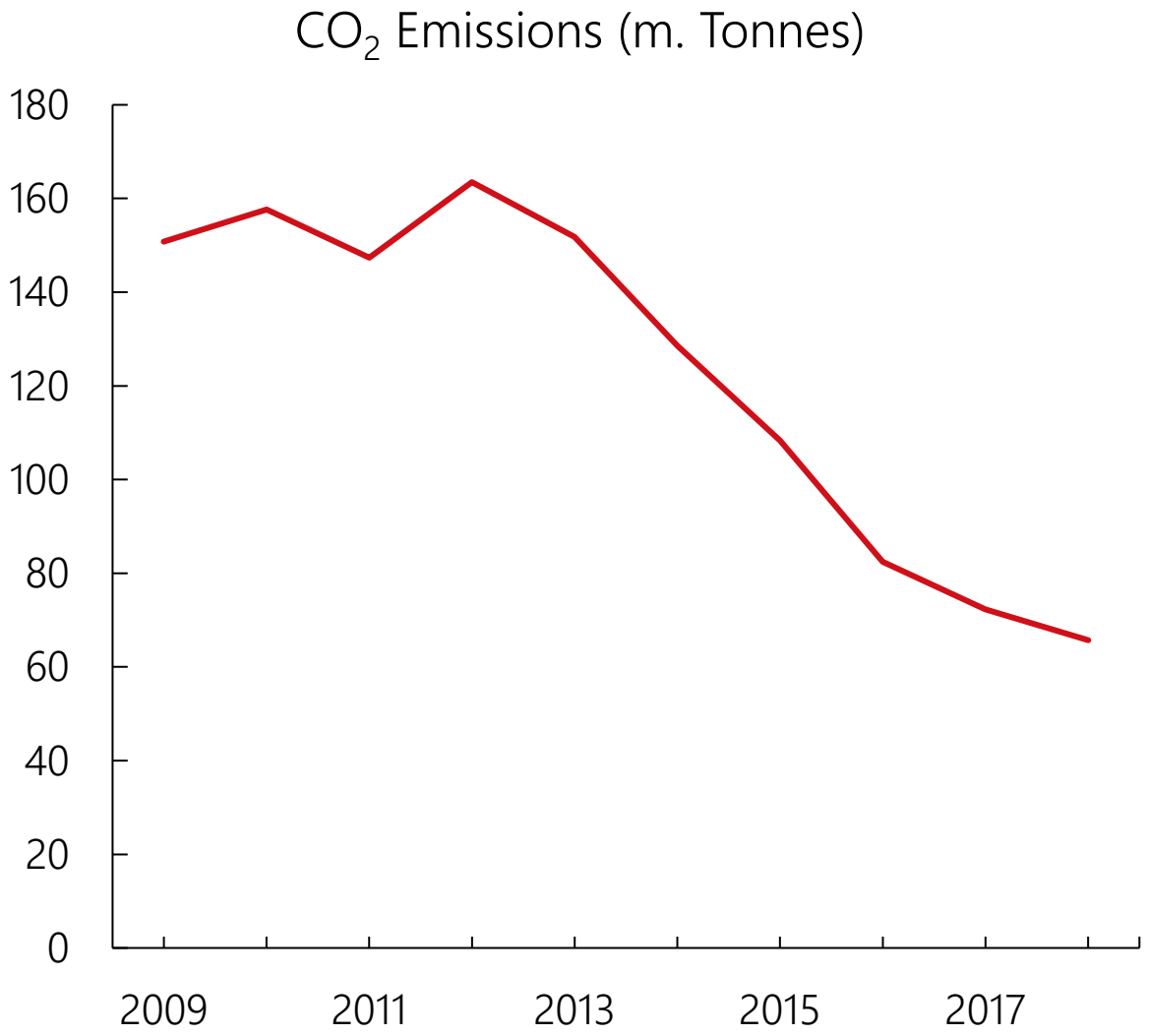

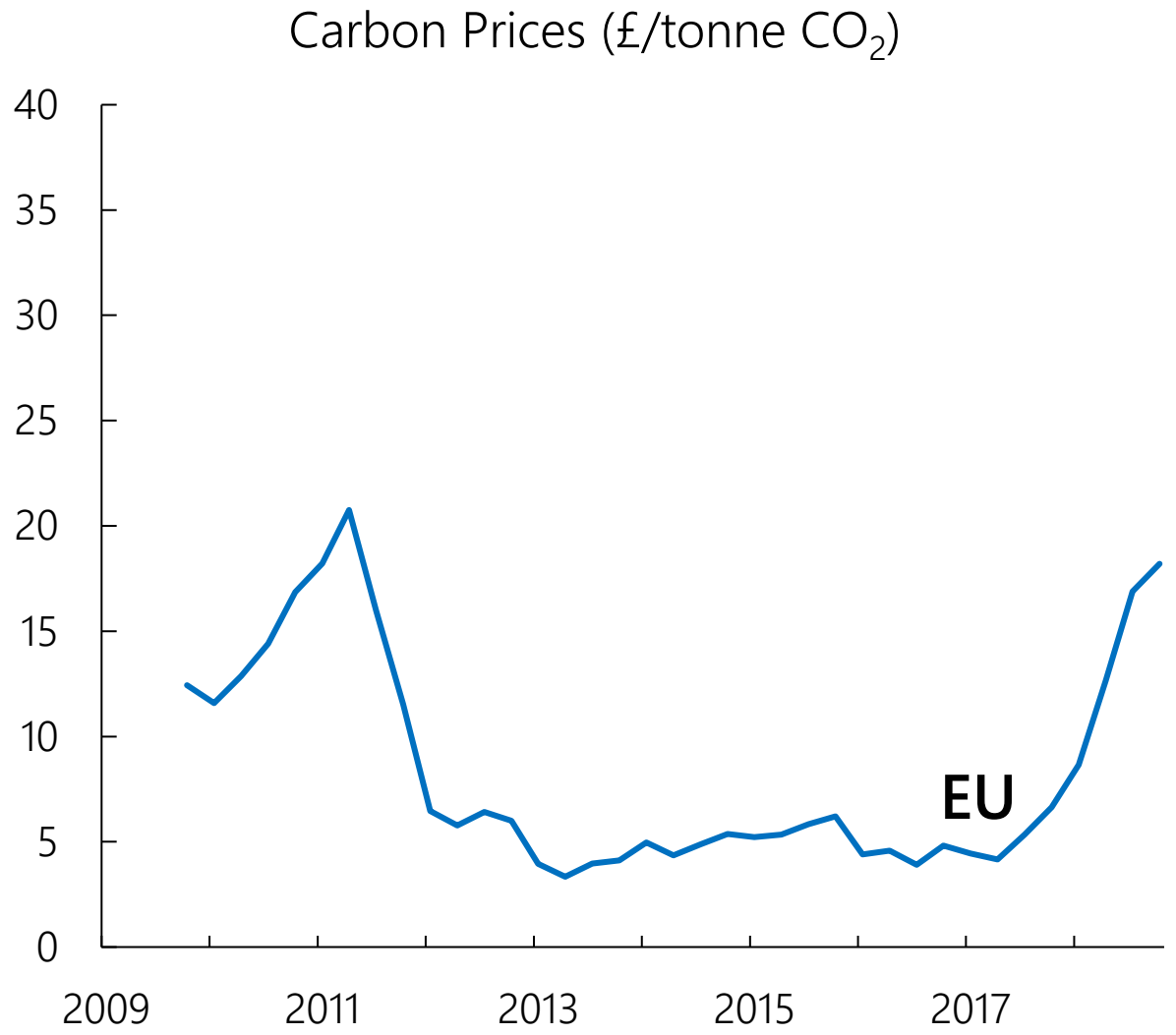

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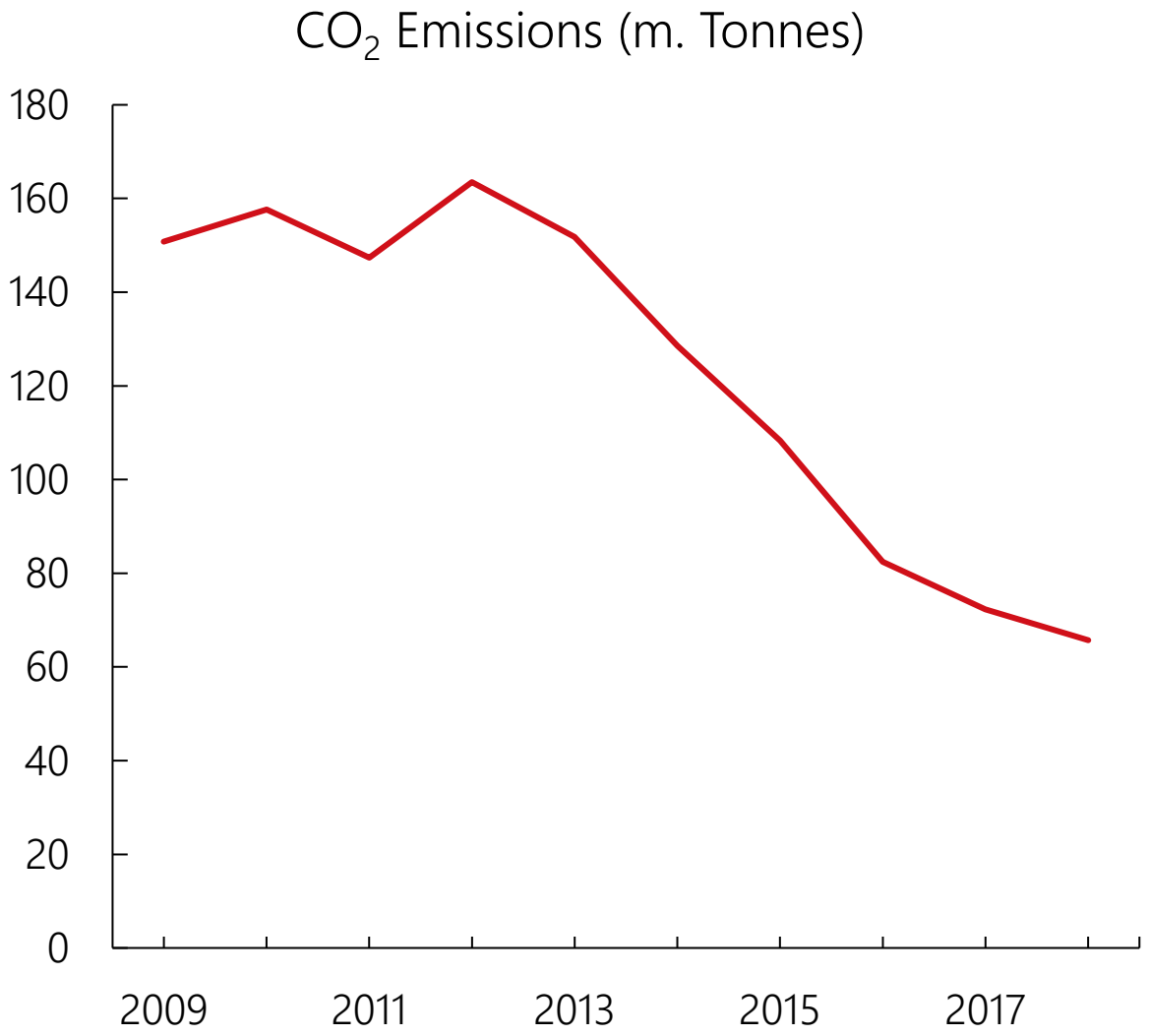

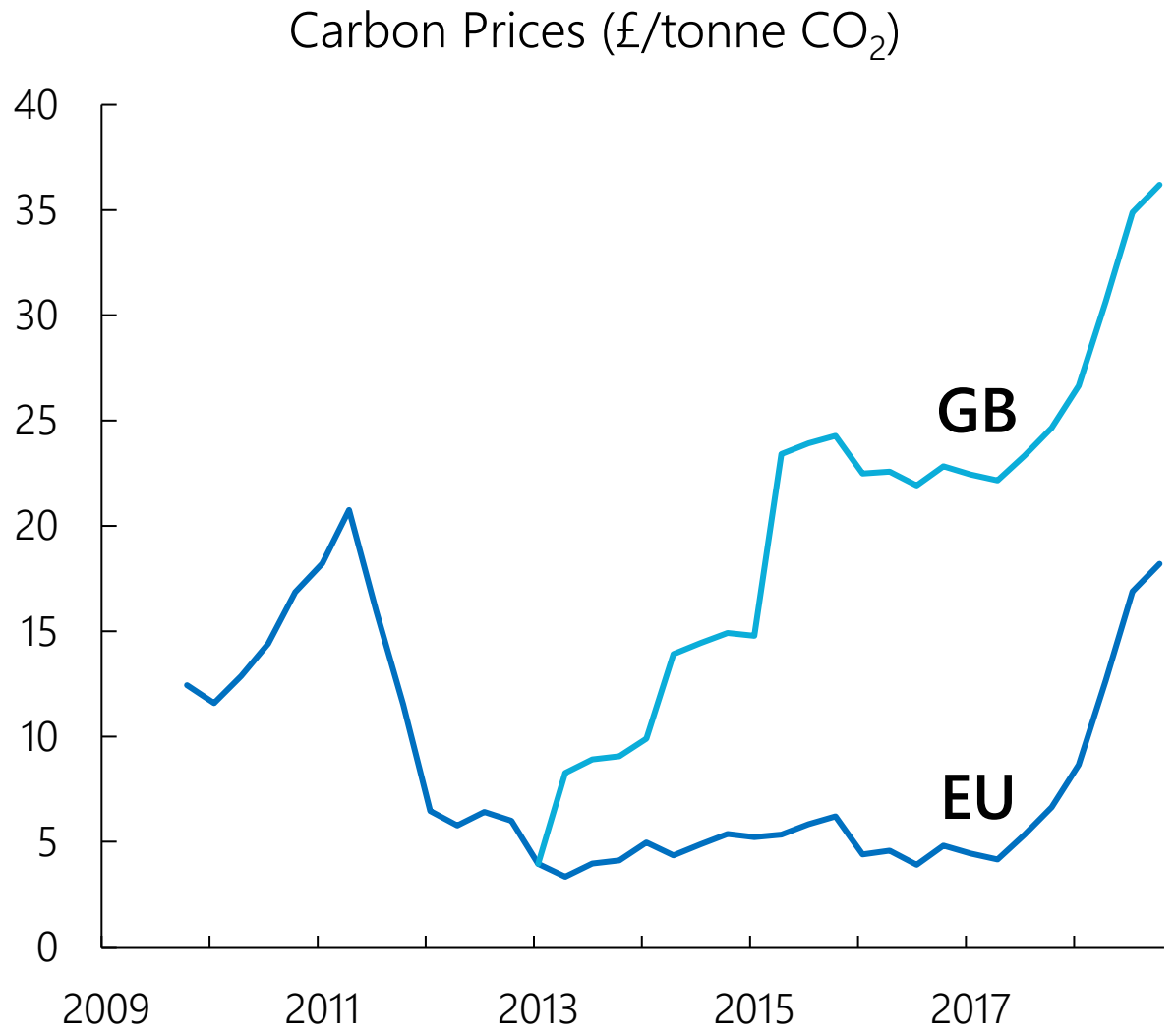

Source — Electric Insights, BEIS, ICE

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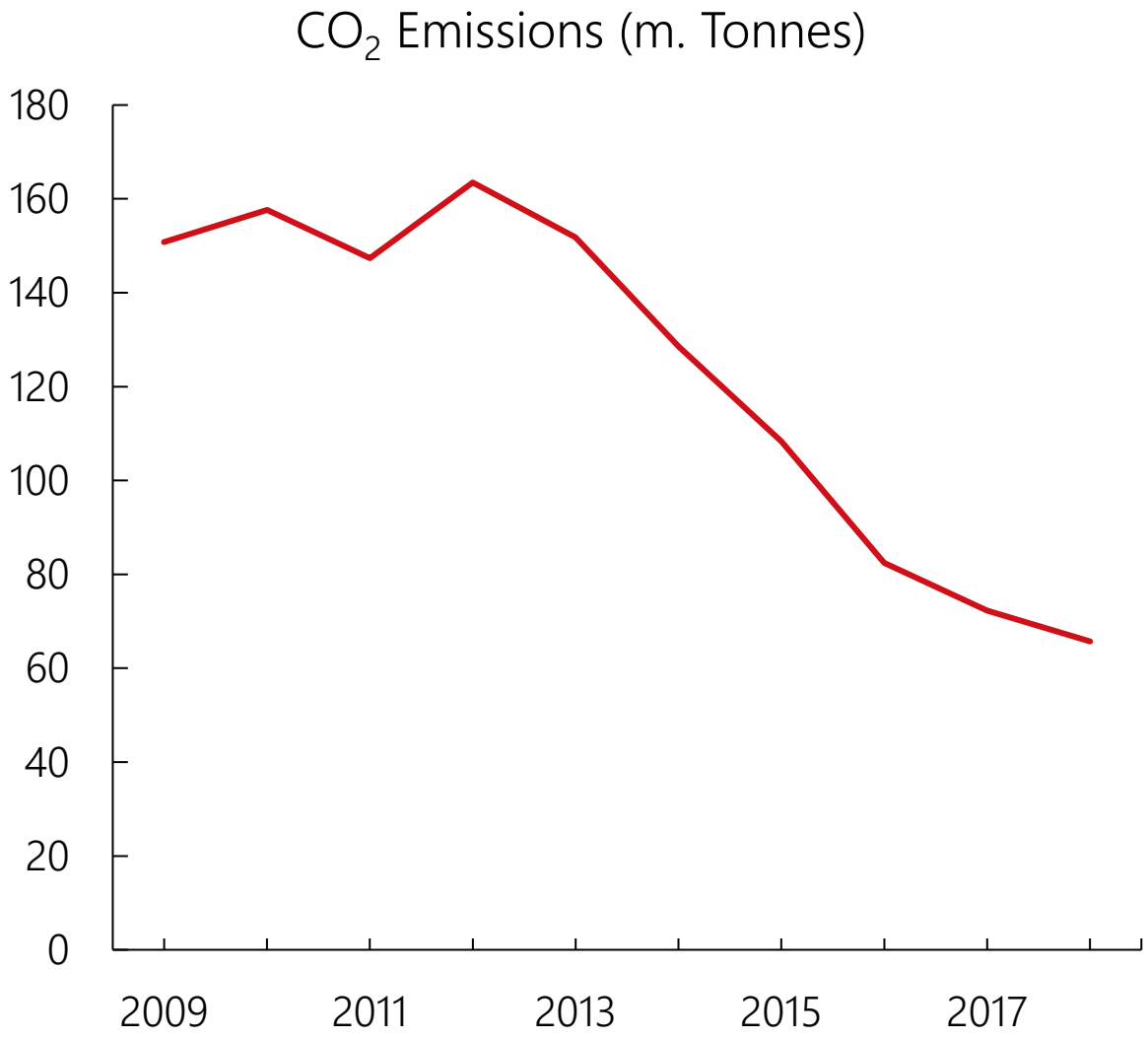

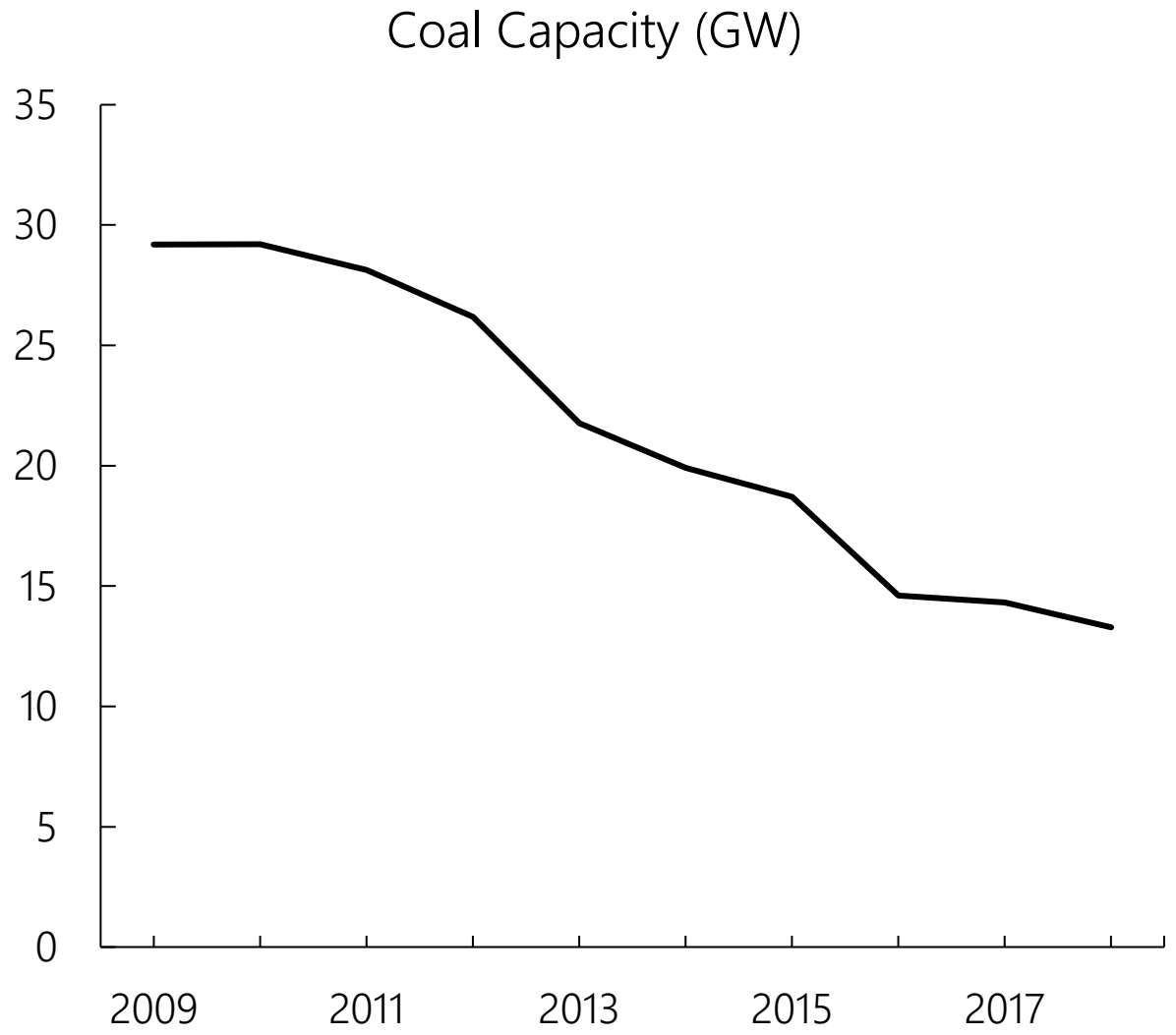

Source — Electric Insights

Britain’s generation mix

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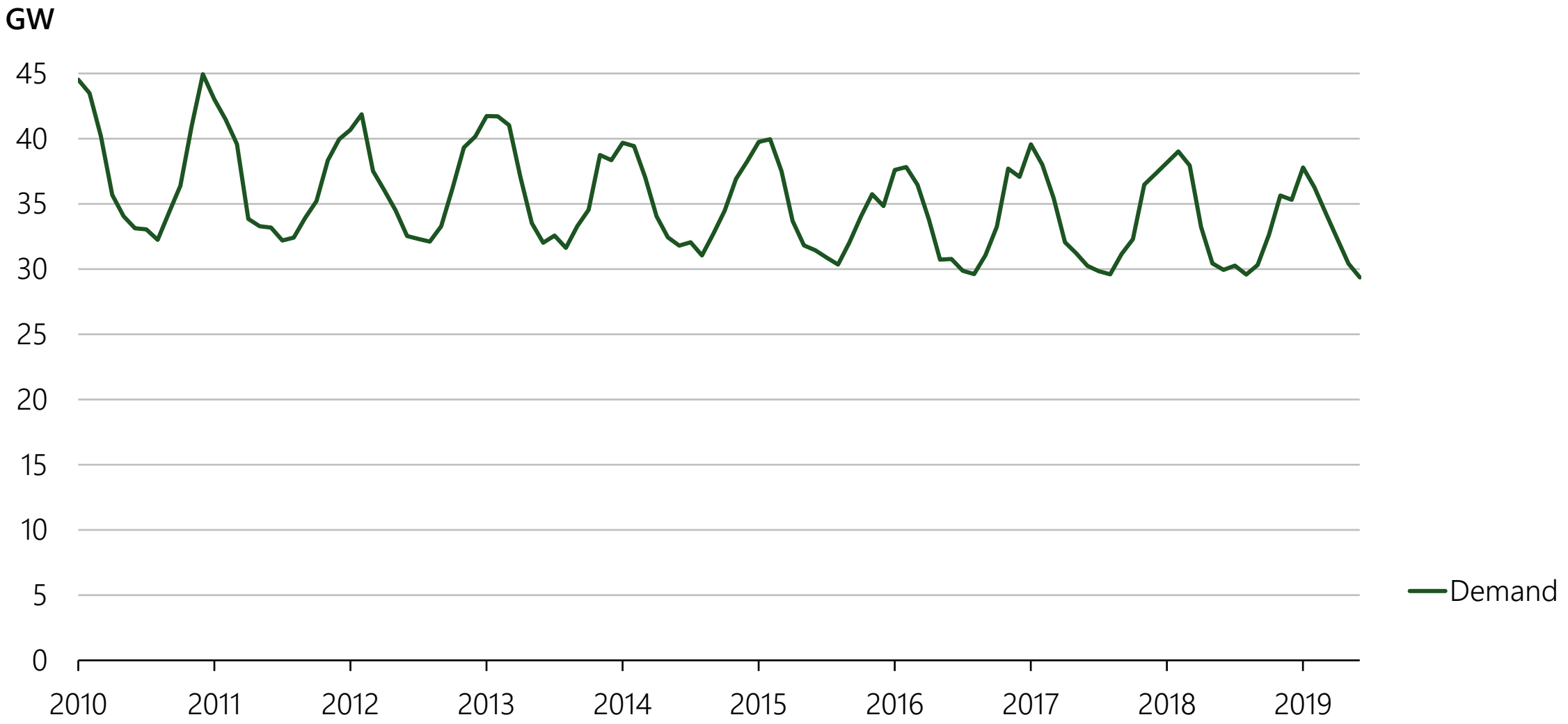

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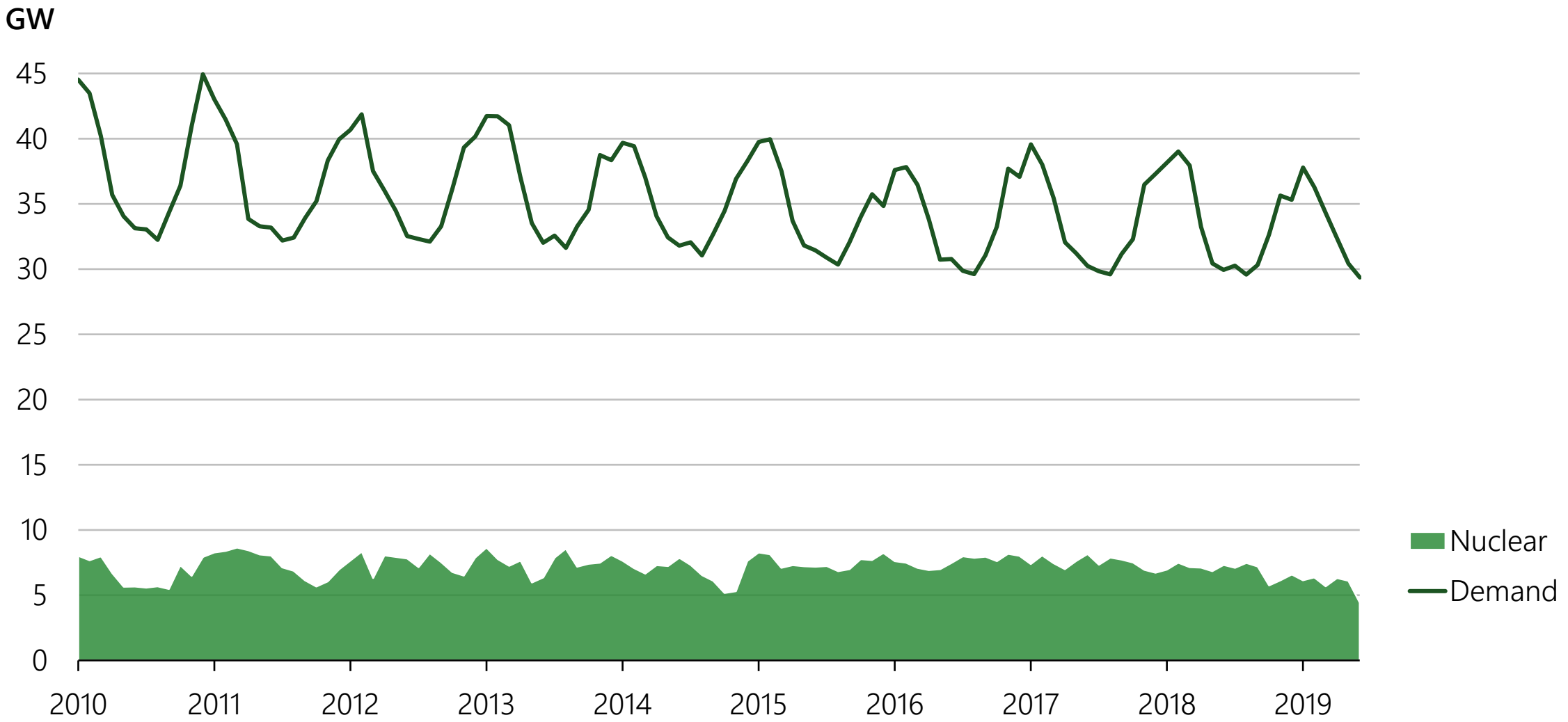

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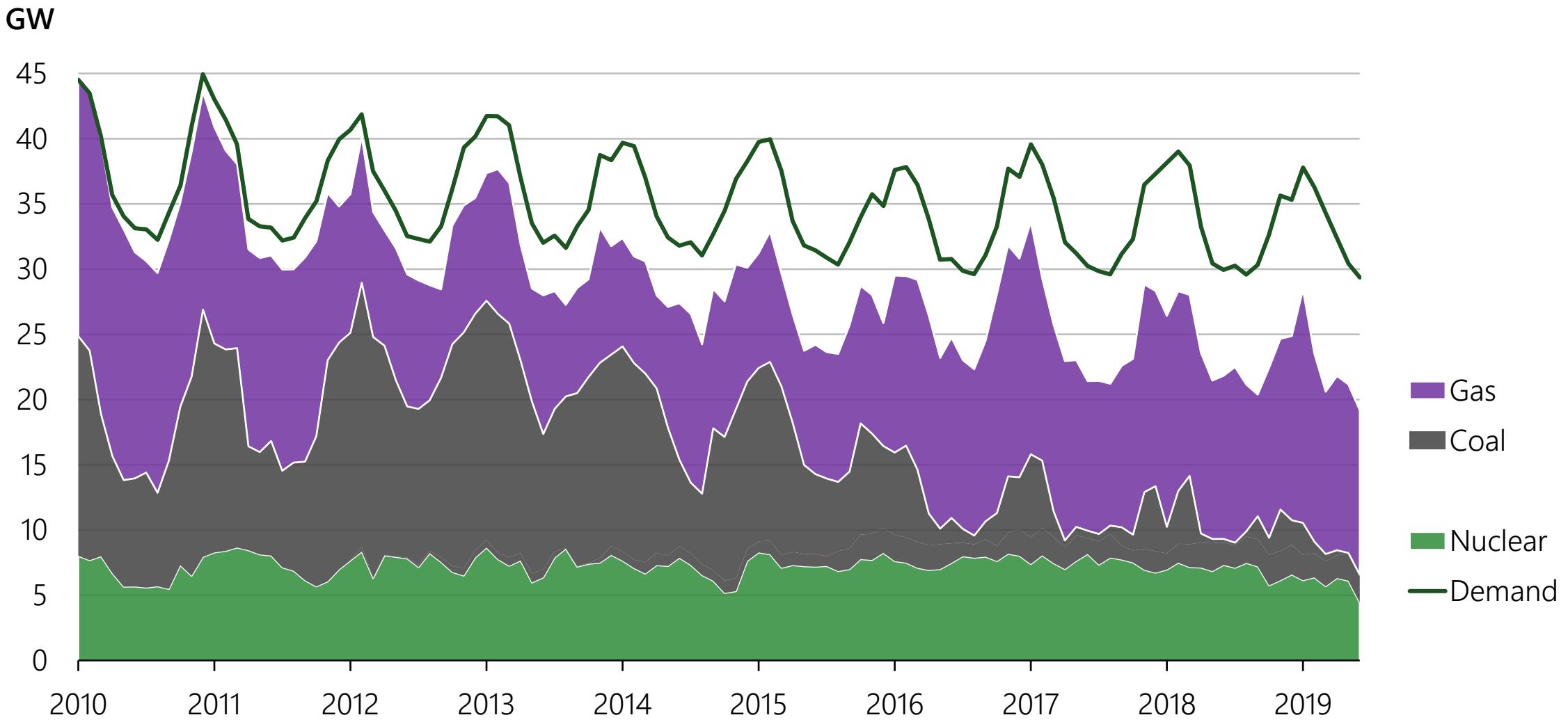

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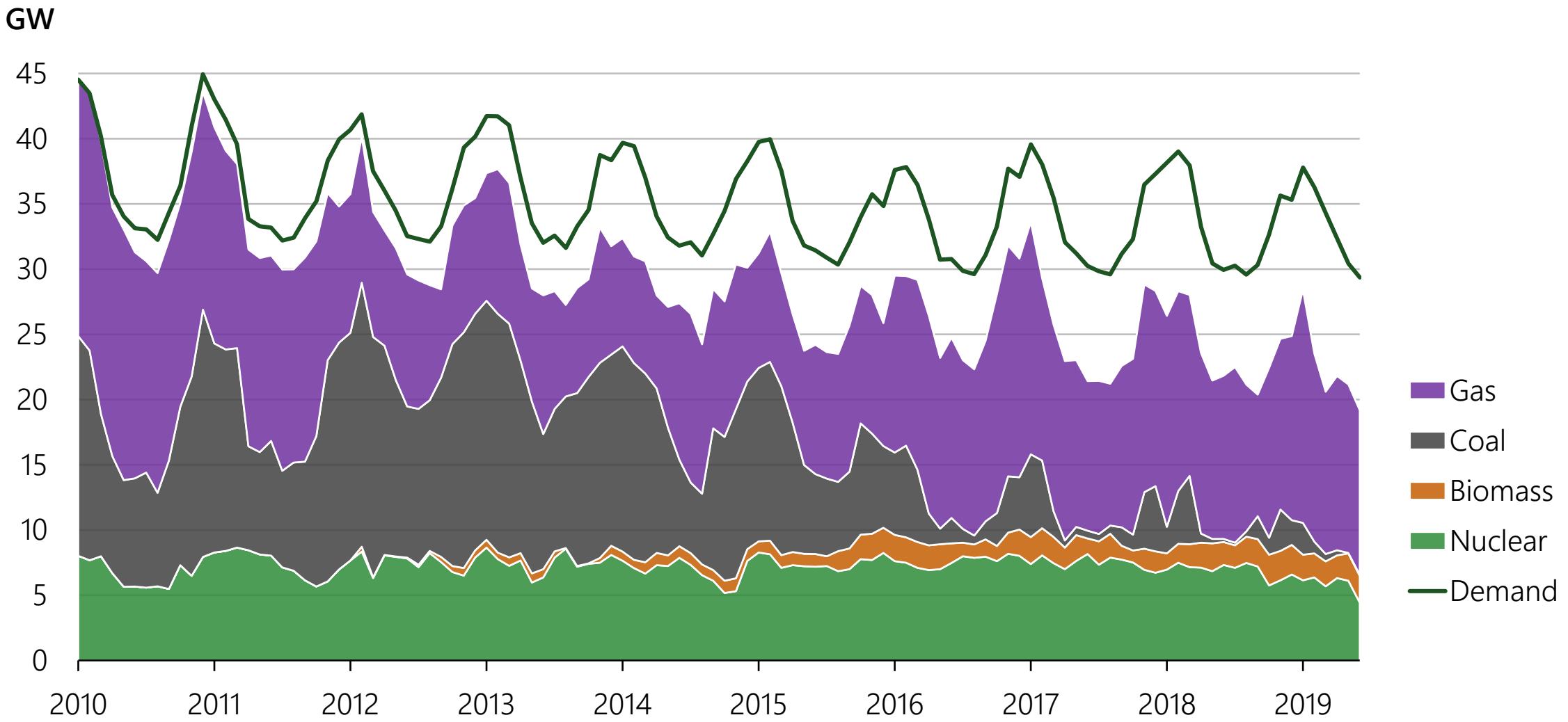

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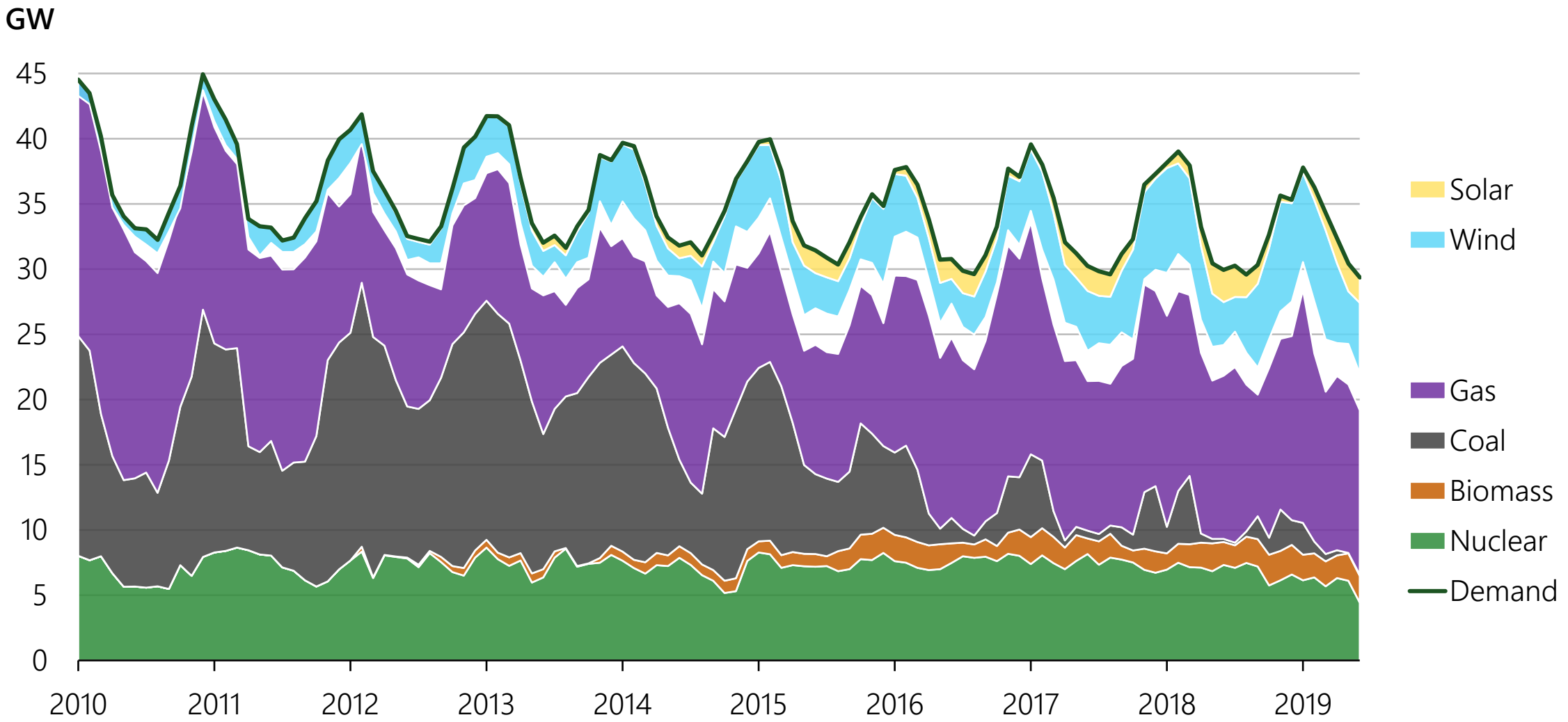

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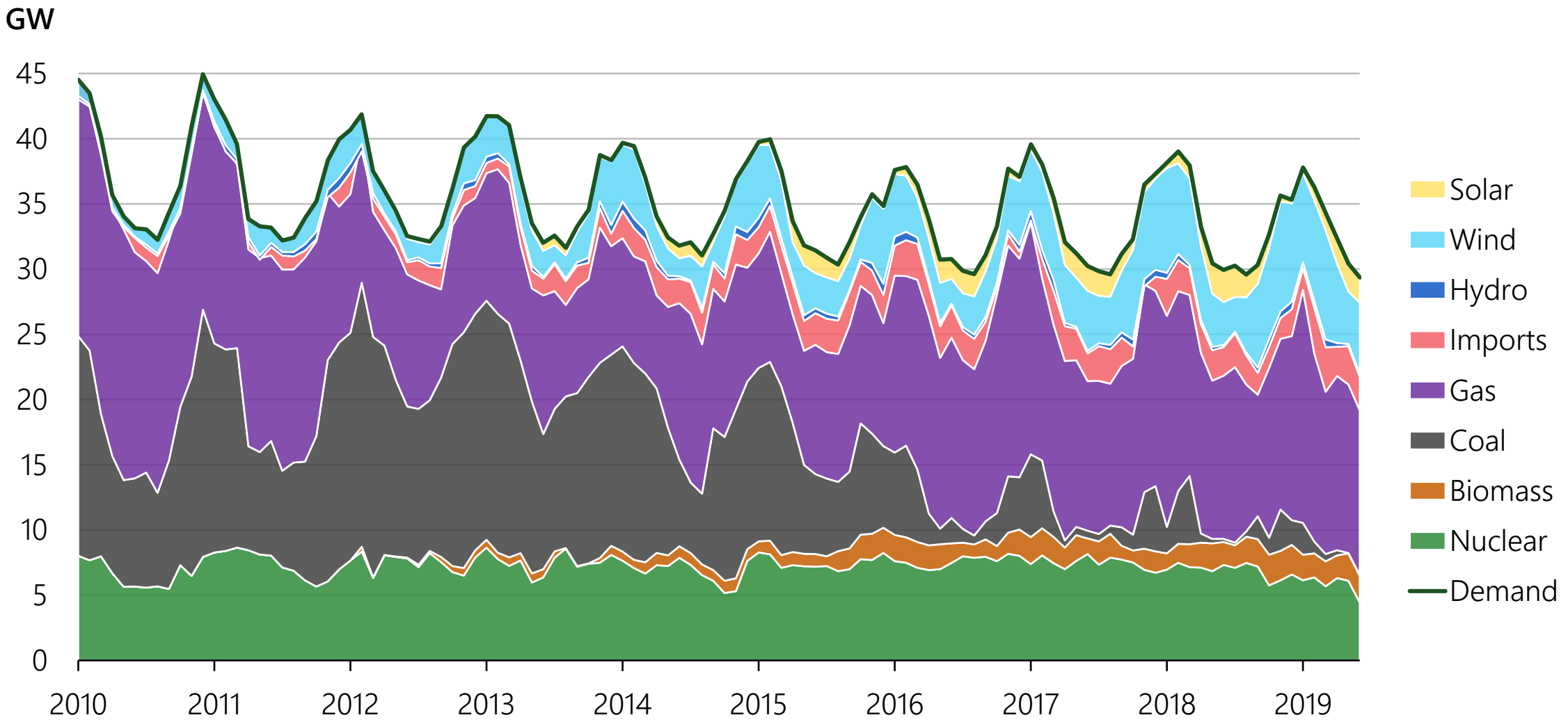

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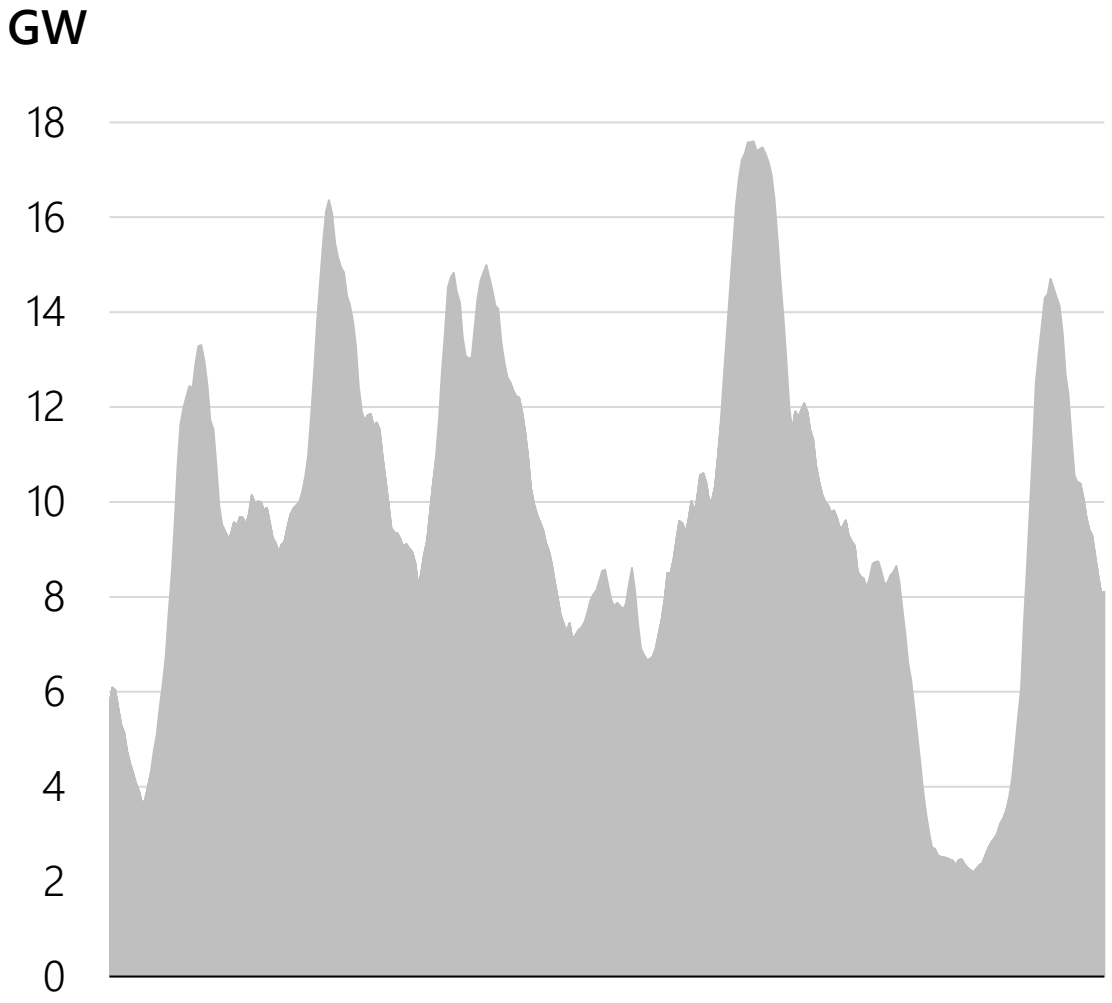
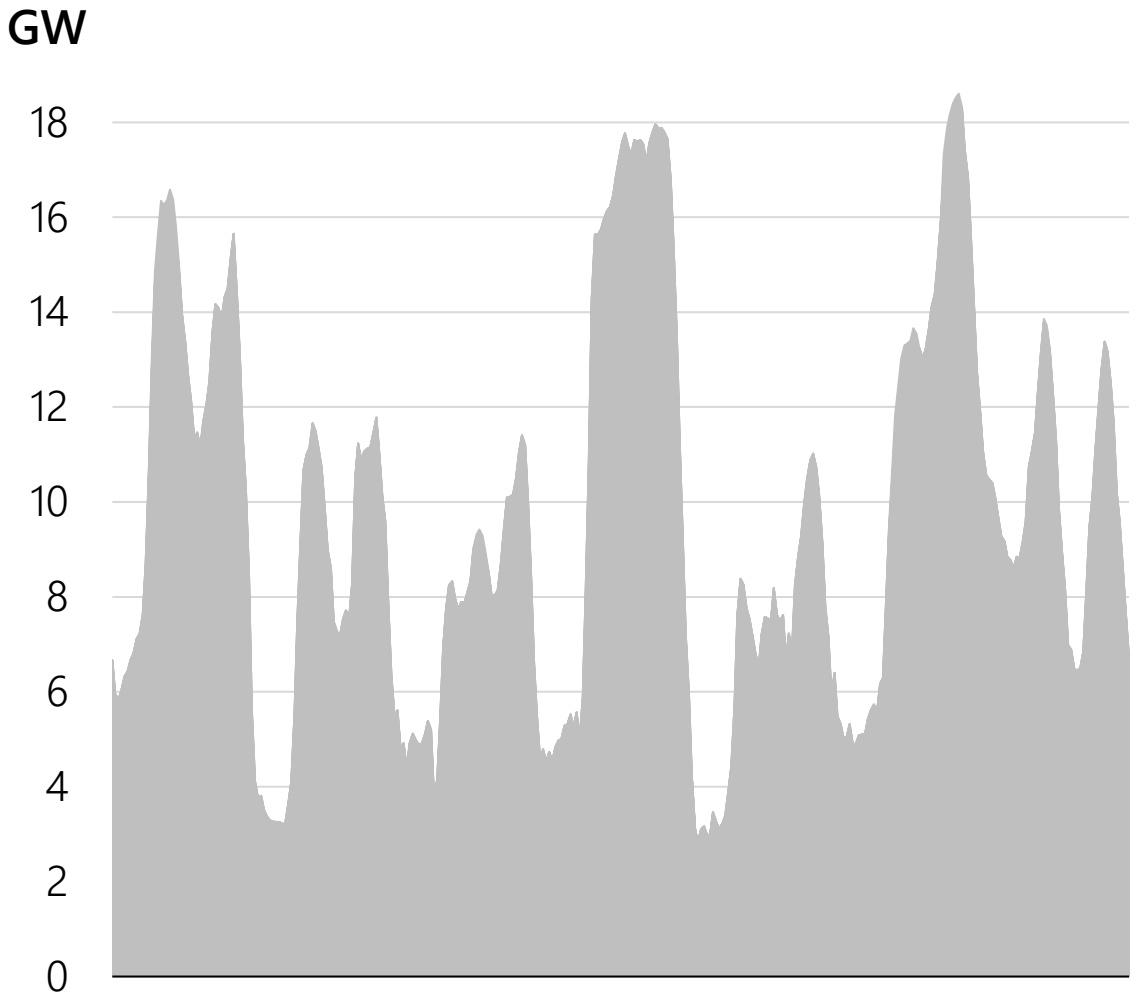
Coal, gas and oil vs. wind and solar





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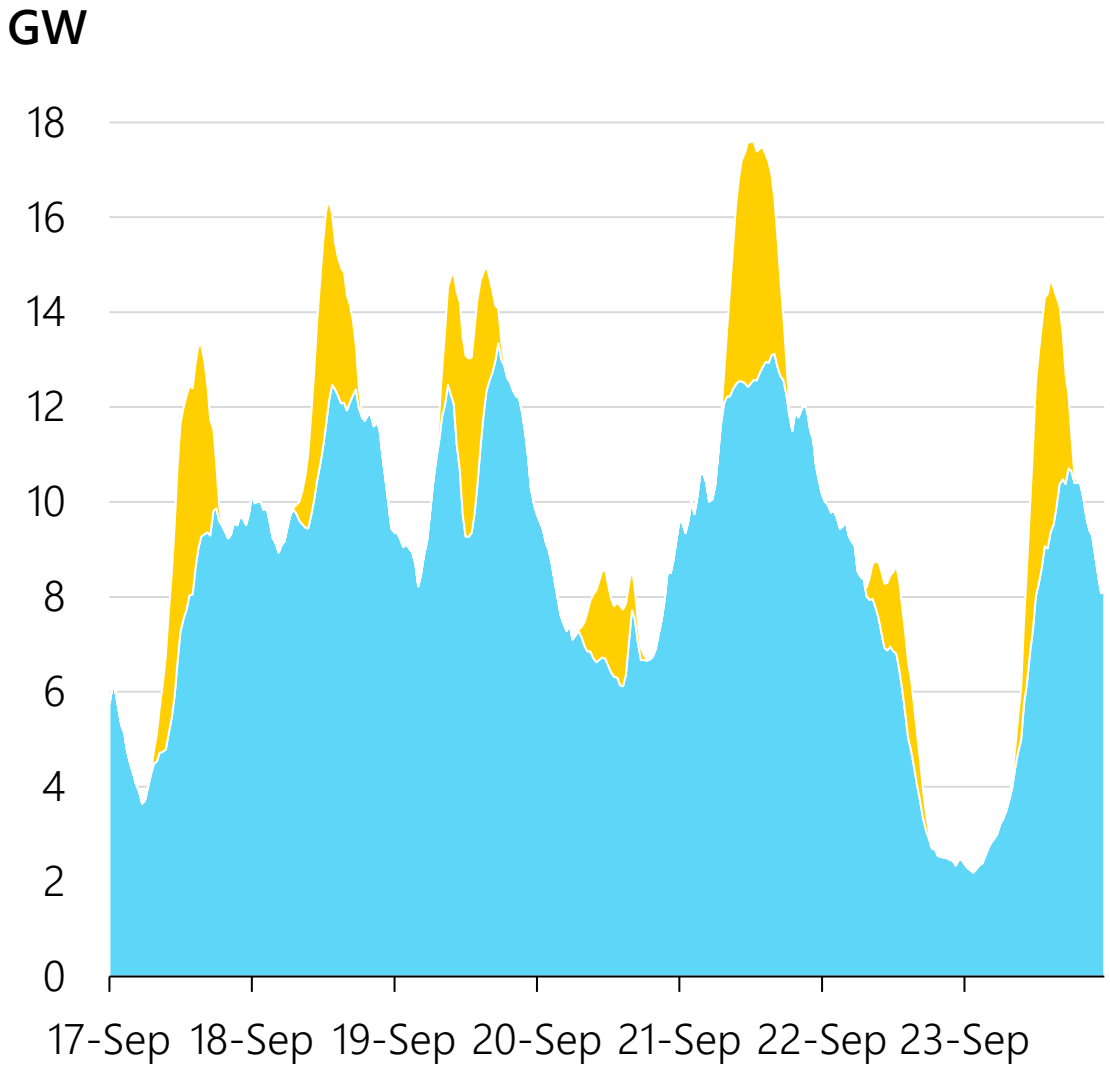
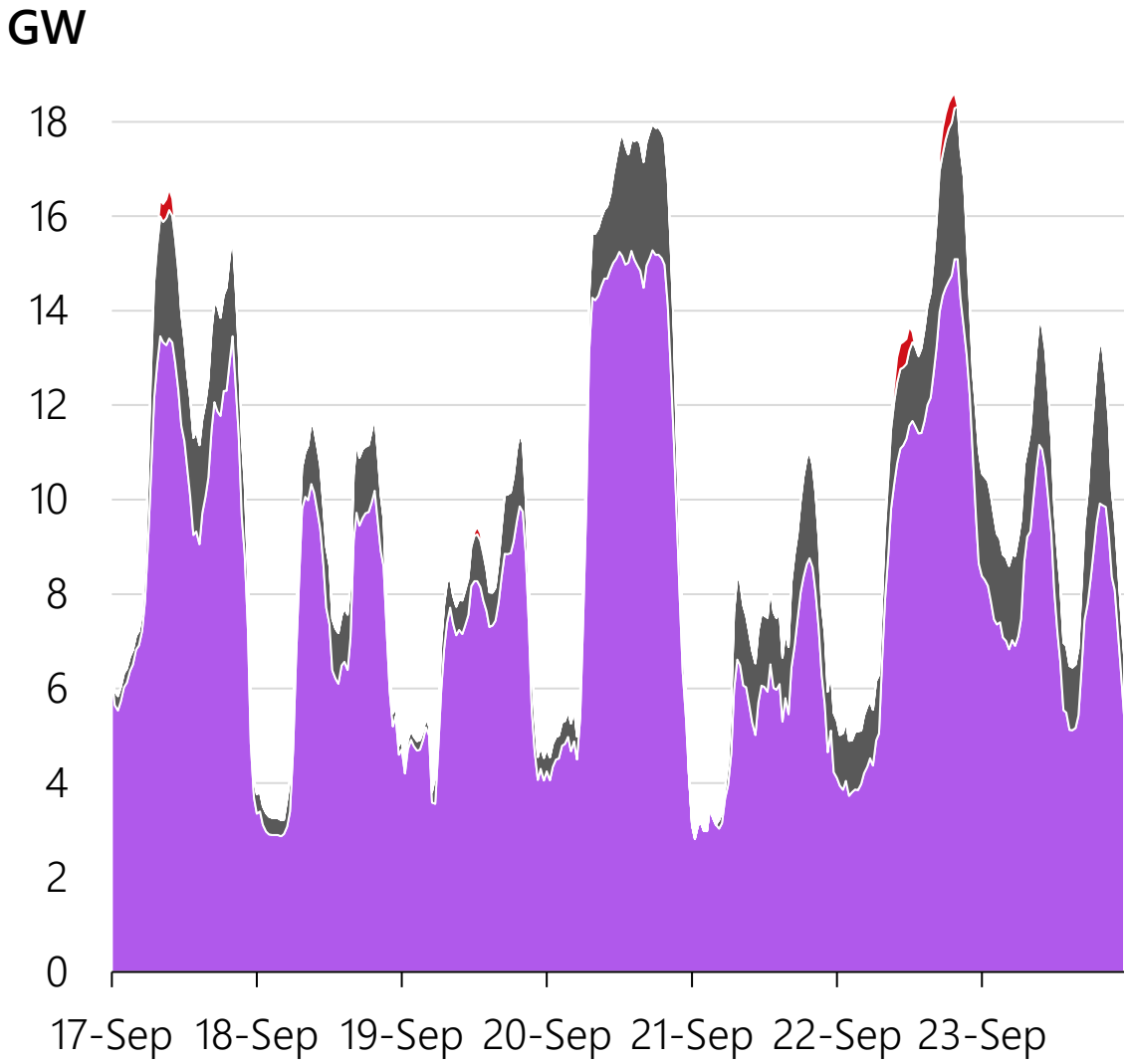




Source — Electric Insights

Previous studies

Marginal emissions savings

Who?	Where?	What?	How Much?	Reference
Hawkes	Great Britain	Demand	690 kg/MWh	Energy Policy, 2010
Siler-Adams *et al.*	United States	Demand	490-830 kg/MWh *(vary over place)*	Environ. Sci. Technol., 2012
Kaffine *et al.*	Texas	Wind	470 kg/MWh	Energy Journal, 2013
Cullen	Texas	Wind	429 kg/MWh 560 kg/MWh	AEJ: Econ. Pol., 2013
Thompson *et al.*	Great Britain	Demand Wind	490-660 kg/MWh 483-611 kg/MWh *(vary over time)*	Energy Policy, 2017
Chyong *et al.*	Great Britain	Wind	334-436 kg/MWh *(vary over time)*	EPRG working paper, 2019

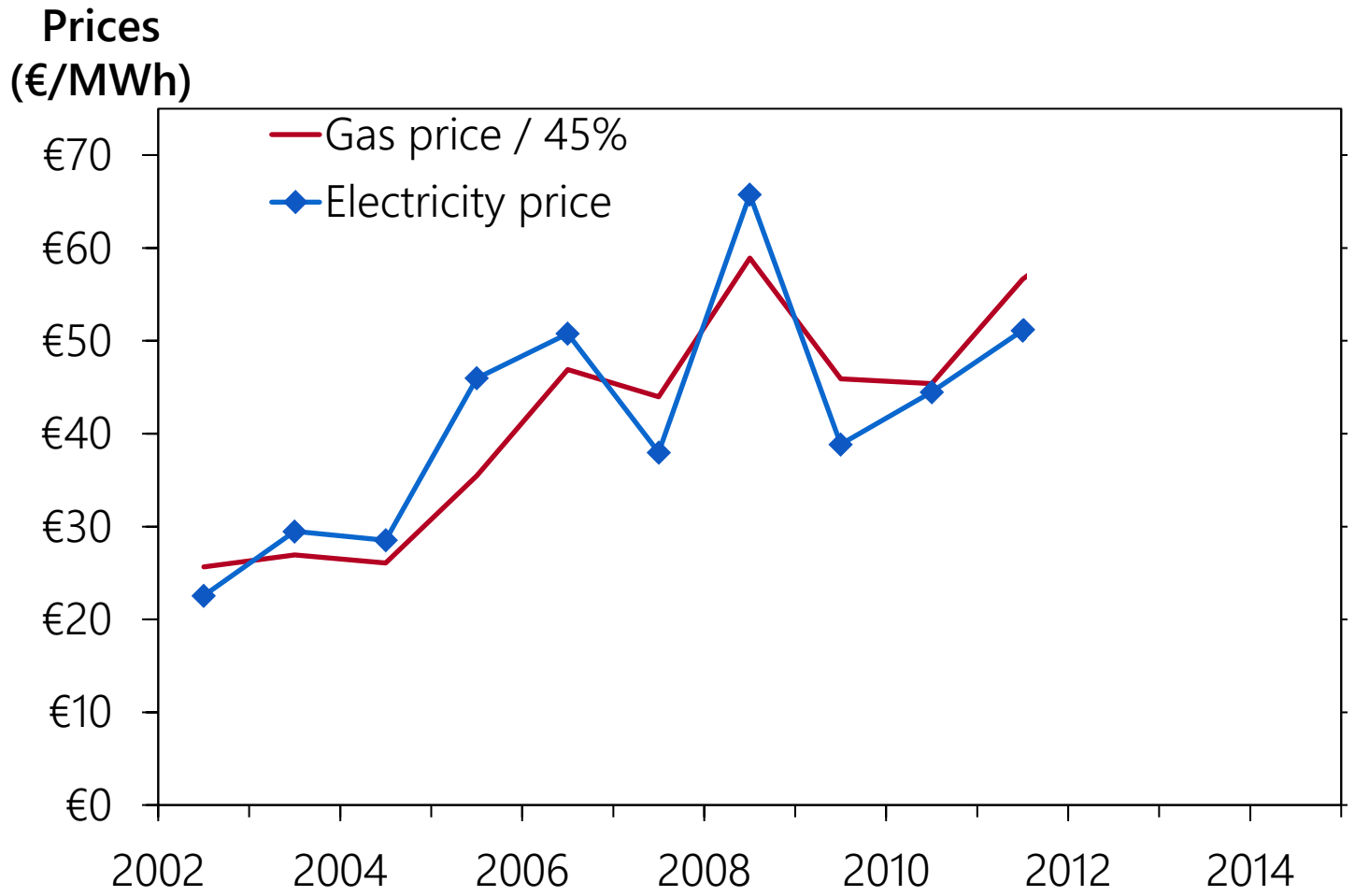
Renewables and prices

- The Merit Order Effect
  - Renewable output depresses prices until capacity adjusts
  - Sensfuß *et al.* (*Energy Policy*, 2008)
  - Sáenz de Miera *et al.* (*Energy Policy*, 2008)

- The Twomey-Neuhoff Effect
  - Renewable output depresses its own price
  - Twomey and Neuhoff (*Energy Policy*, 2010)

- The race between costs and revenues
  - Capacity gives learning, cutting costs; but revenues fall too!
  - Green and Léautier (*Toulouse WP*, 2015)

Germany's market



Source — Green, 2016, OxREP

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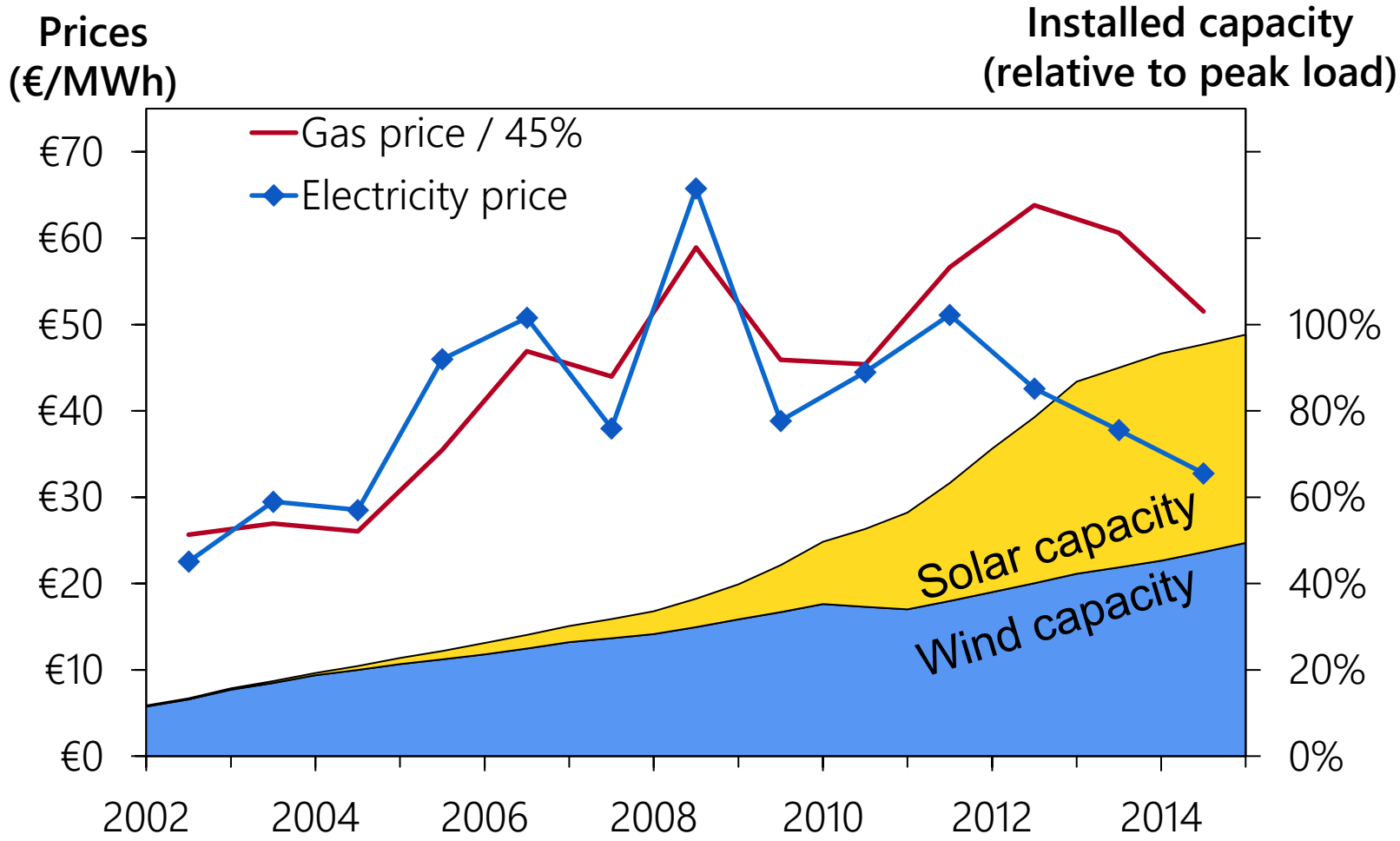

Source — Green, 2016, OxREP

German electricity prices

Source — Hirth, 2018, Energy Journal

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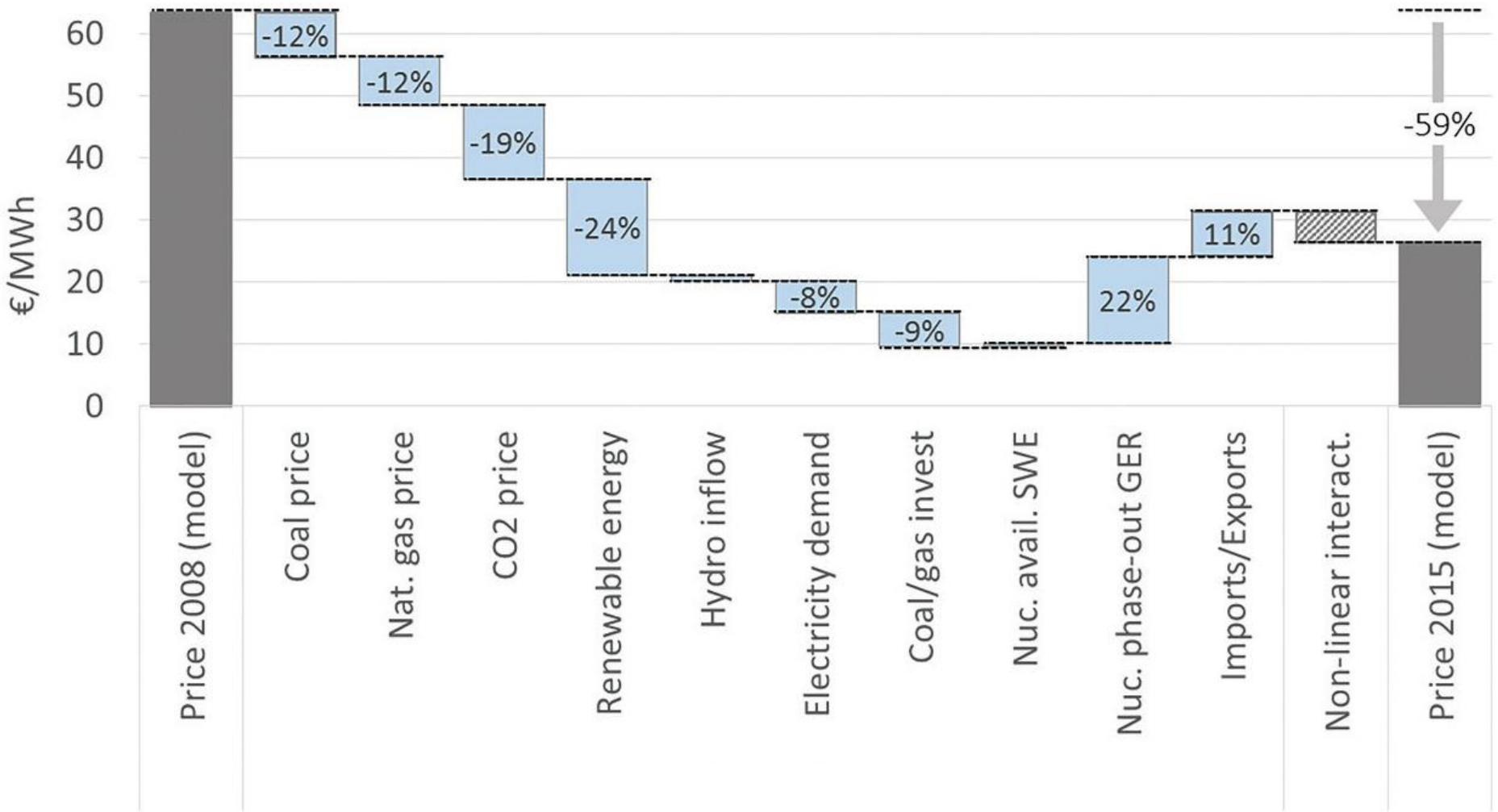

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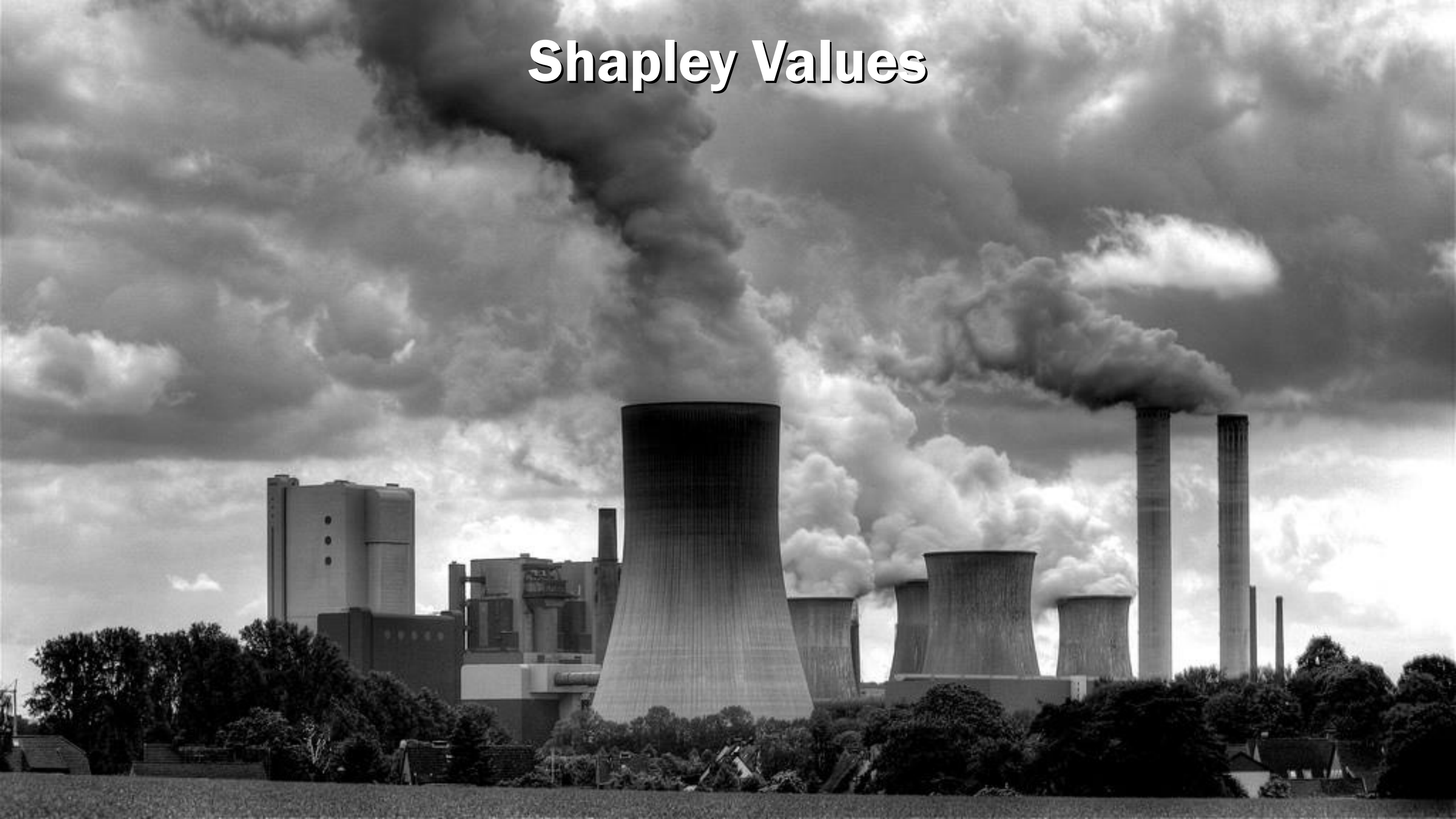
Shapley Values



Shapley Values

- How much do you bring to a coalition?
  - Add yourself to every possible sub-coalition and take the average impact

- N players in a game
- S is a potential coalition among them (there are 2^N possible coalitions)
- $v(S)$ is the worth of that coalition
- $\varphi_i(v)$ is the Shapley value for player i

$$\varphi_i(v) = \underbrace{\sum_{S \subseteq N \setminus \{i\}} \frac{|S|!\,(N - |S| - 1)!}{N!}}_{\text{weighting}} \underbrace{\big(v(S \cup \{i\}) - v(S)\big)}_{\text{marginal contribution of } i}$$

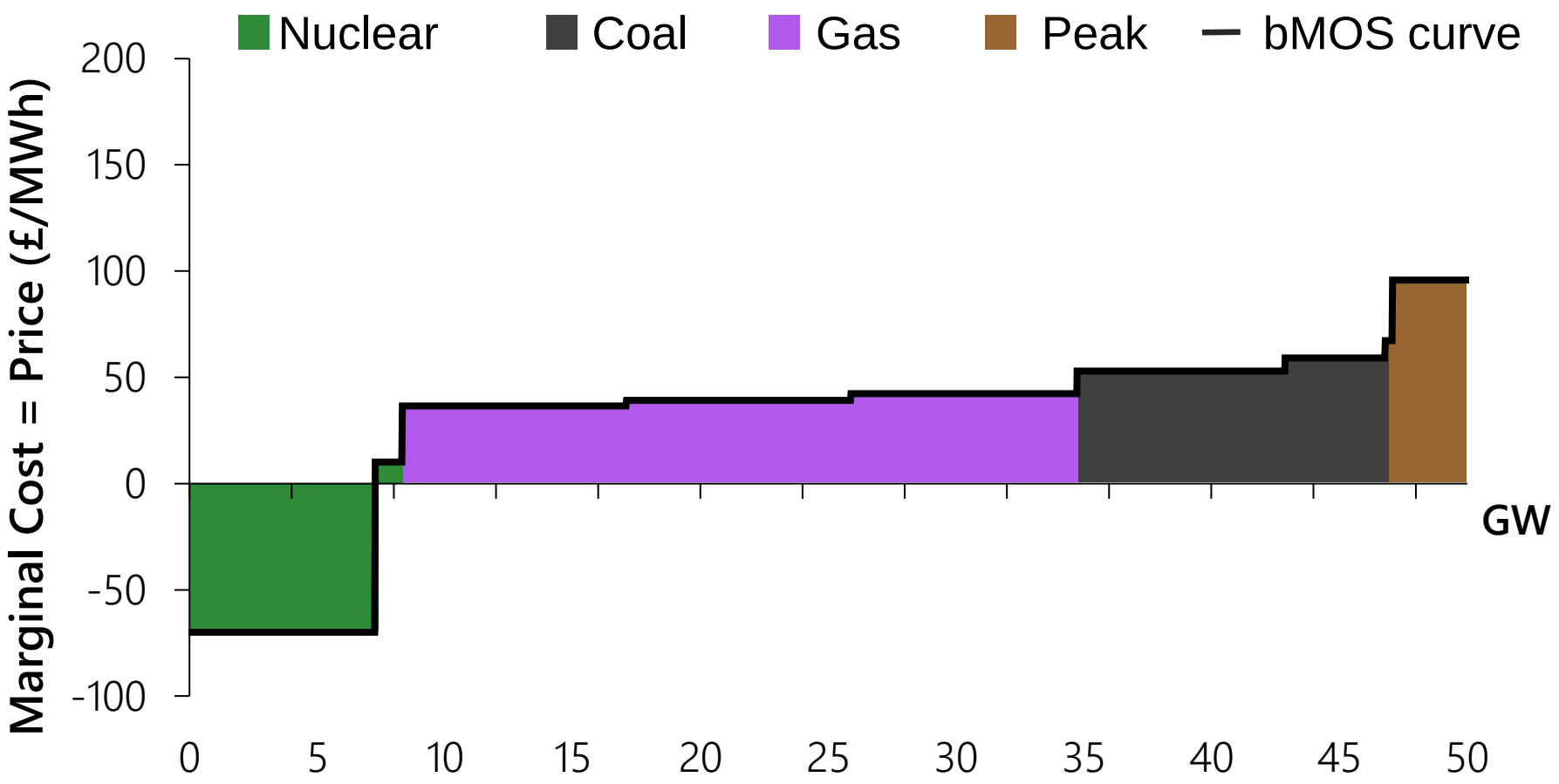
Shapley Values

- Applied to this ‘game’:
  - *Worth* is carbon emissions, which fell from 164 to 66 Mt.
  - *Worth* can also be electricity prices, which rose from £45 to £57 / MWh

- Coalitions are formed from:
  - Carbon price ⇗
  - Coal price ⇨ and gas price ⇨
  - Coal capacity ⇘ and gas capacity ⇨
  - Wind capacity ⇗ and solar capacity ⇗
  - Demand ⇘

Simulation: Enhanced Merit Order Stack

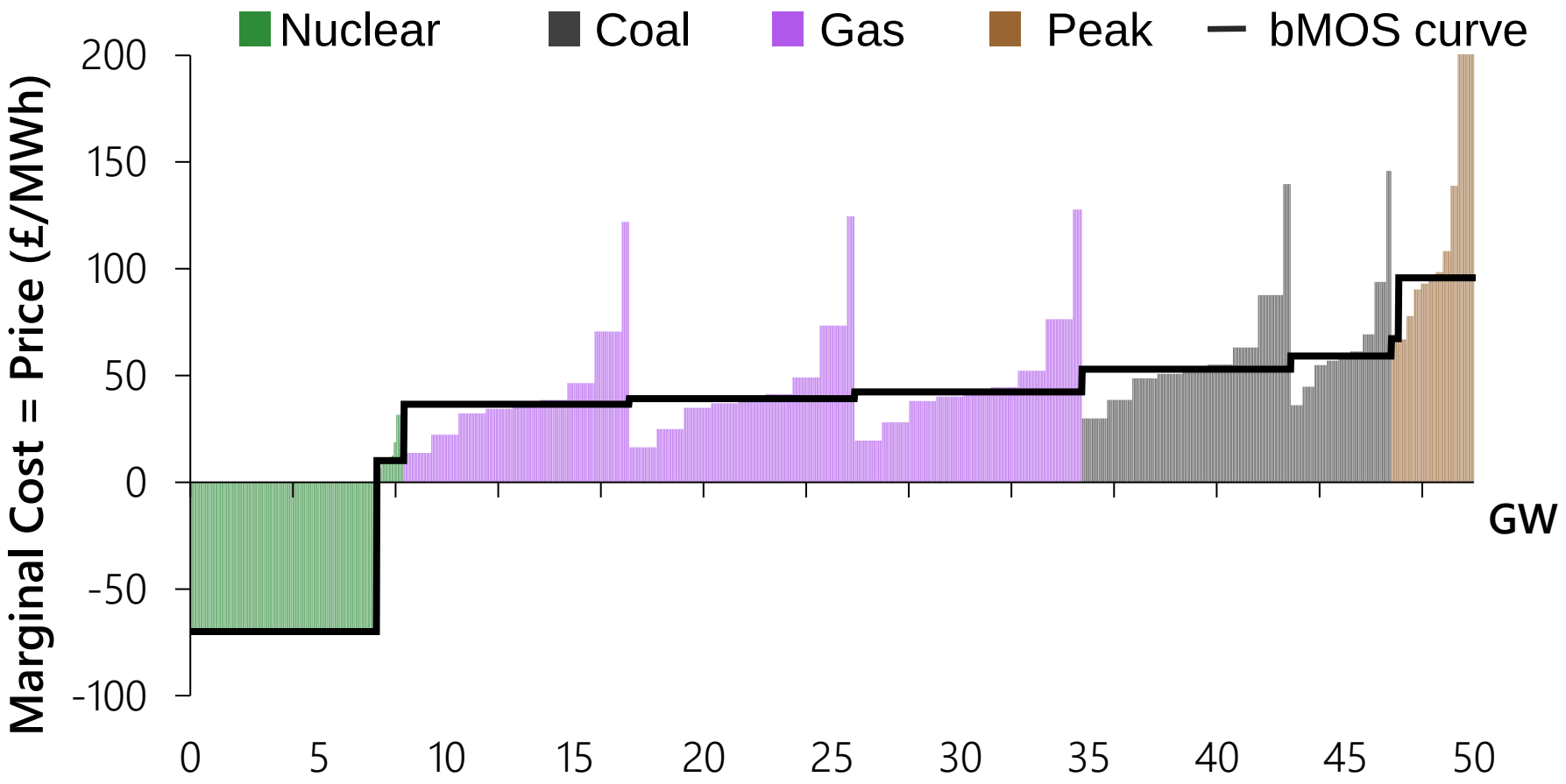
- A typical 'stack' model with blocks of plant:



Source — Ward, 2019, Energy Policy

Simulation: Enhanced Merit Order Stack

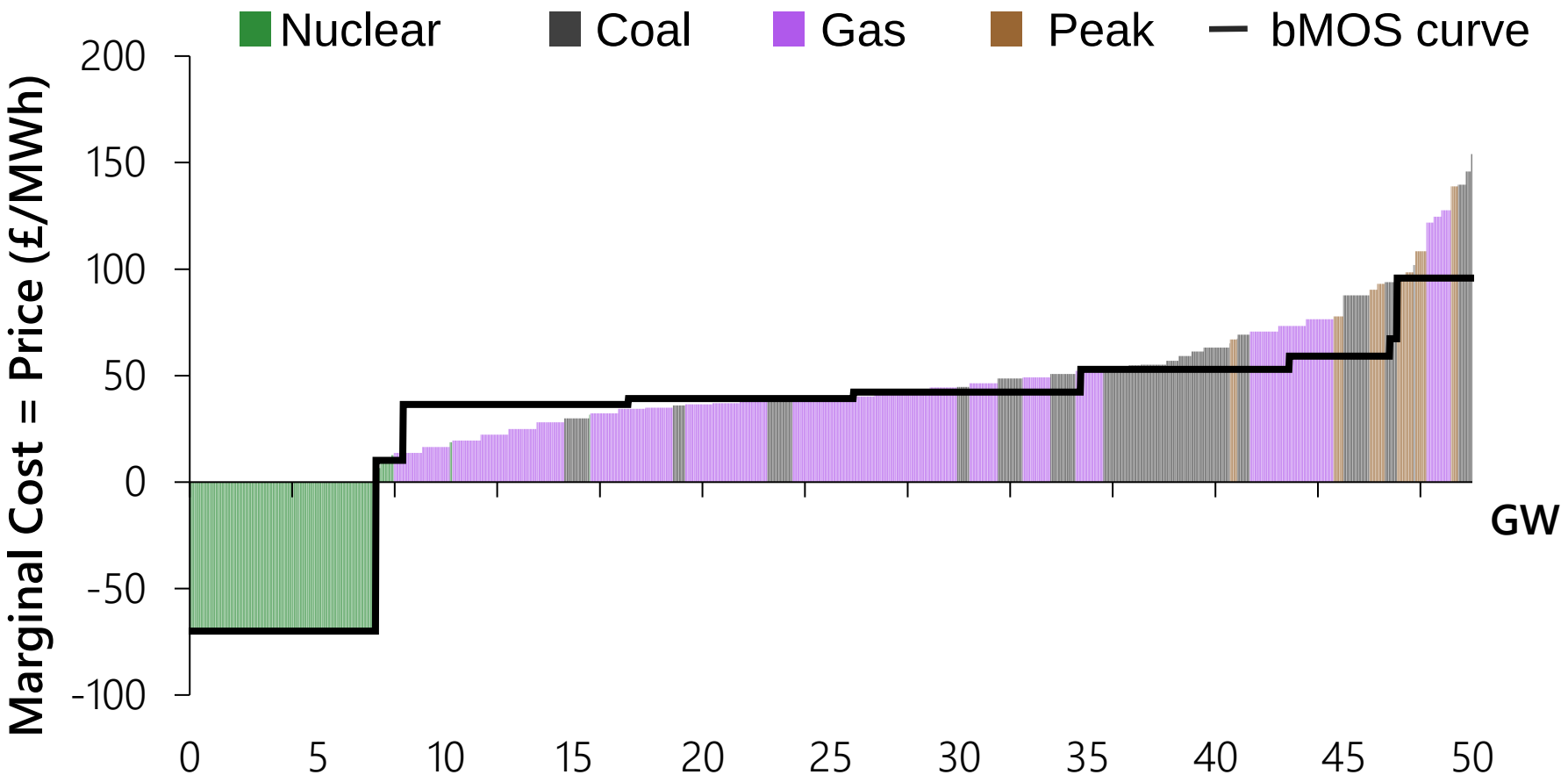
- Let each type of plant have tranches with different bids



Source — Ward, 2019, Energy Policy

Simulation: Enhanced Merit Order Stack

- Re-sort those tranches to get a more natural supply curve:



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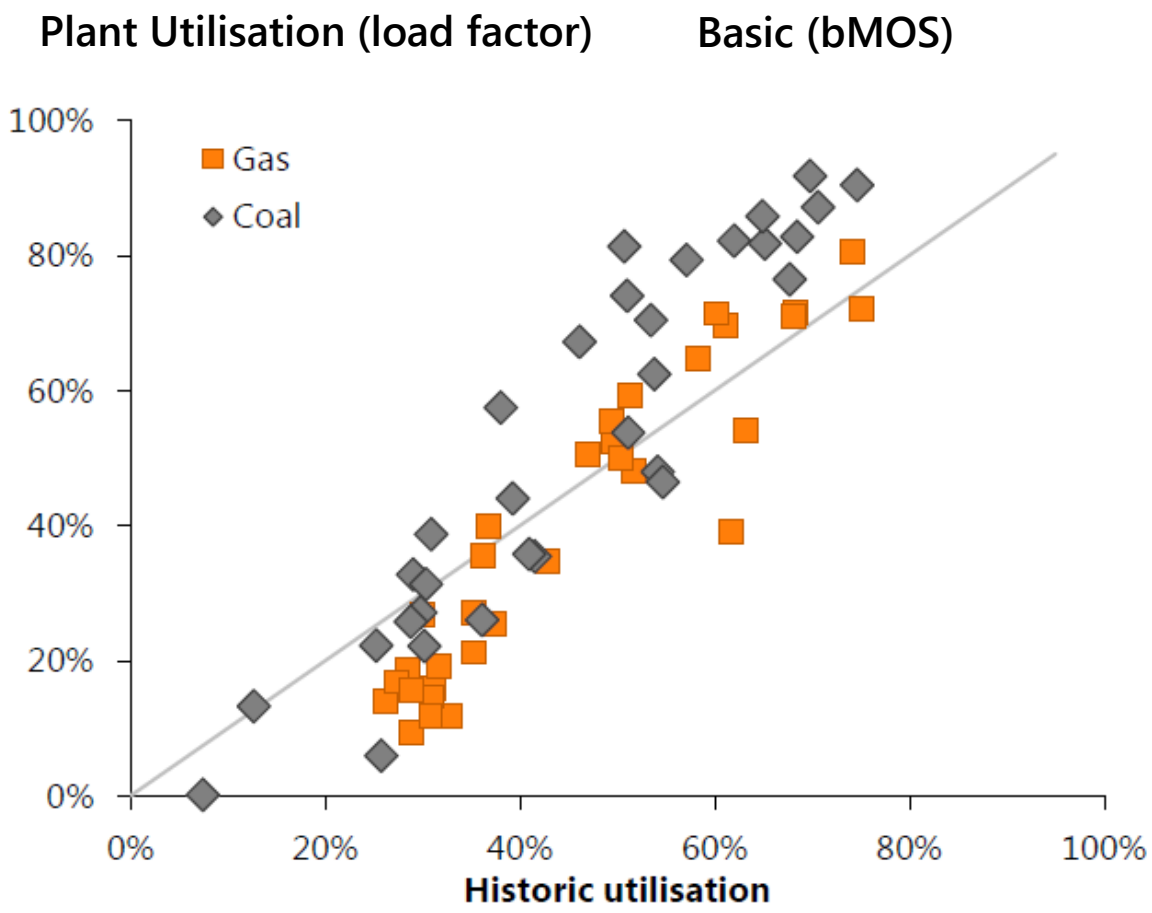

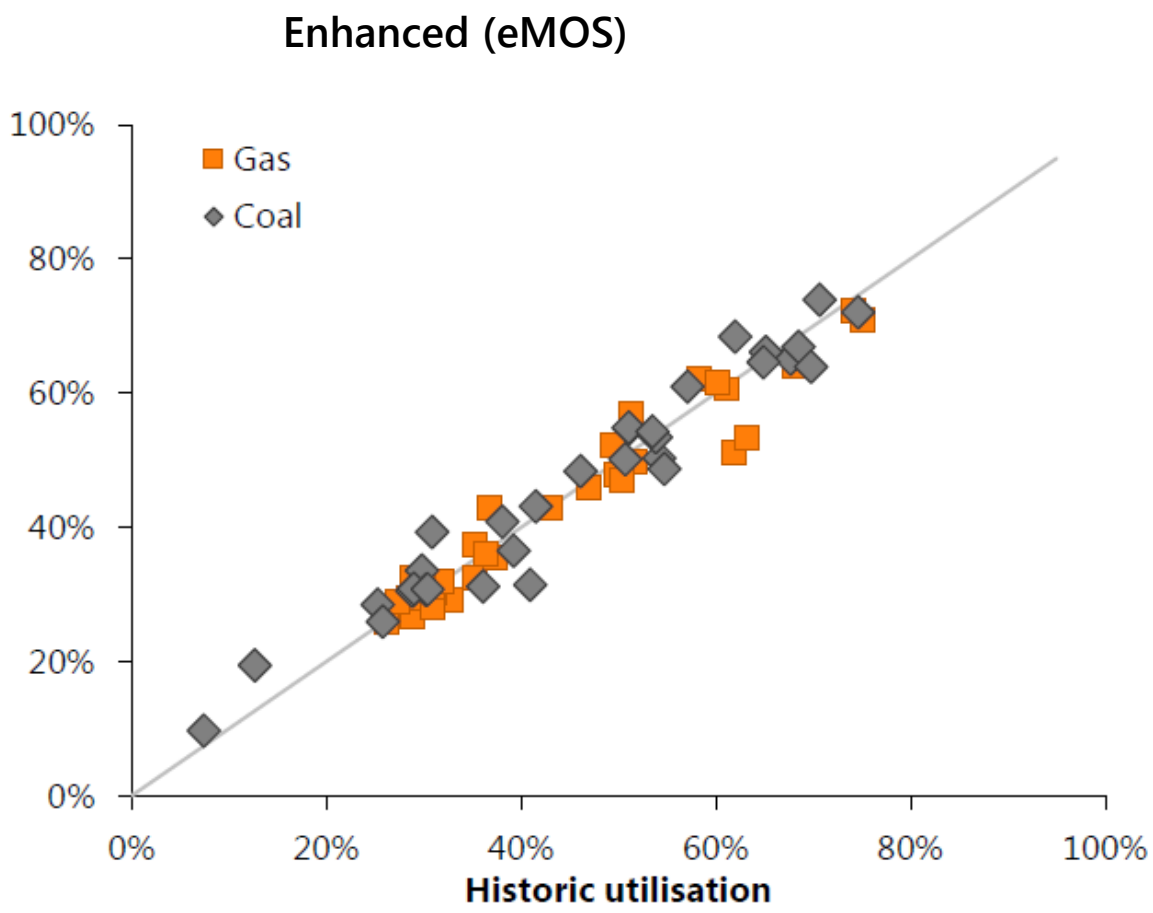

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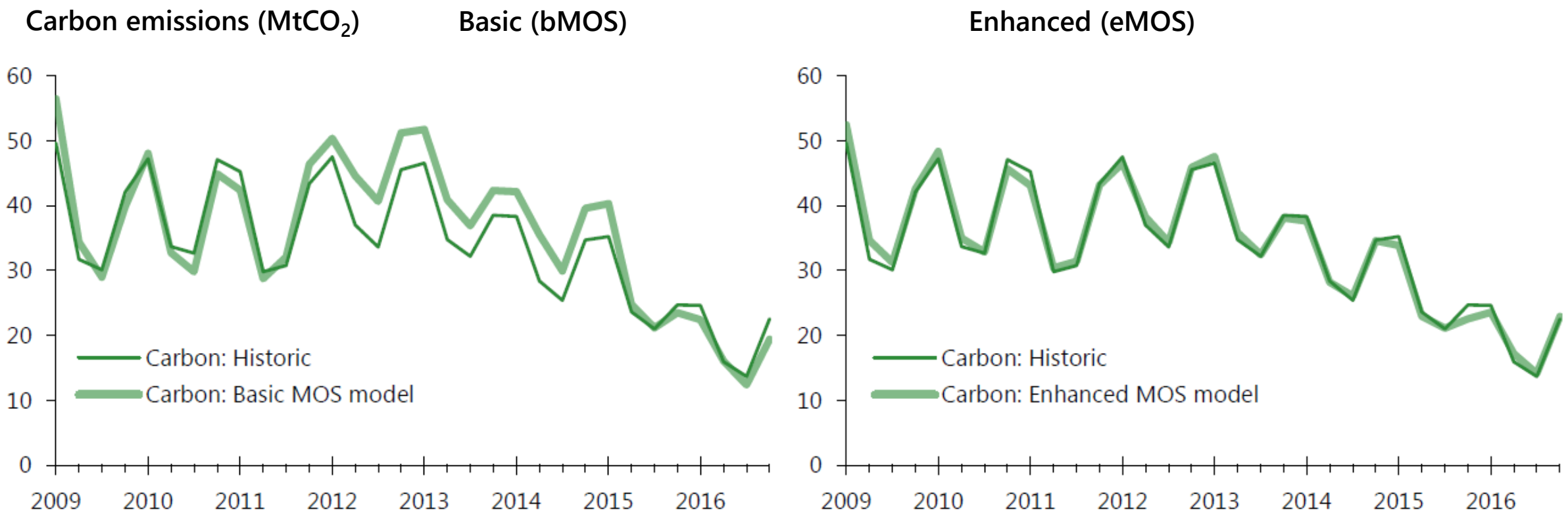
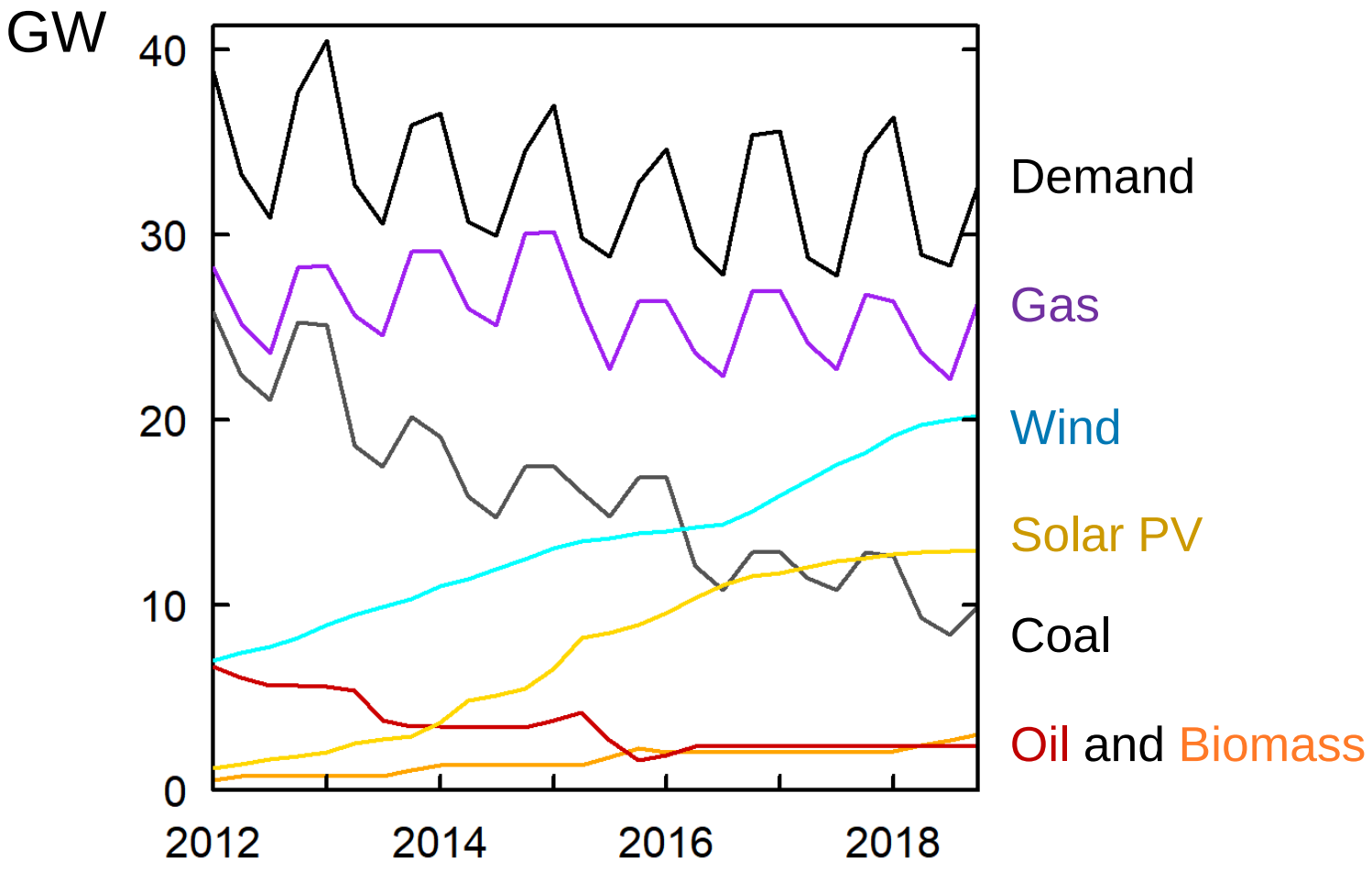
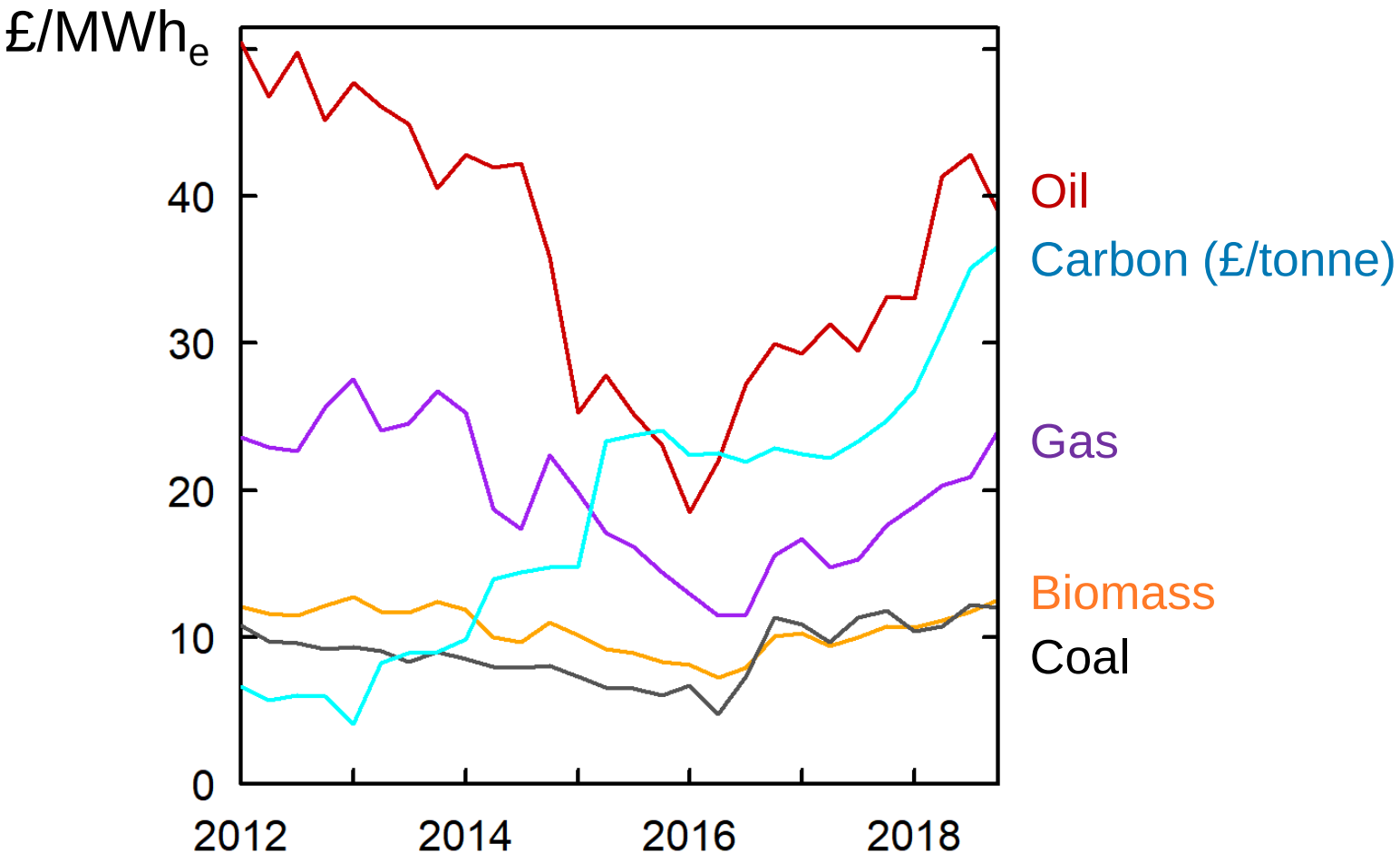


Source — Ward, 2019, Energy Policy

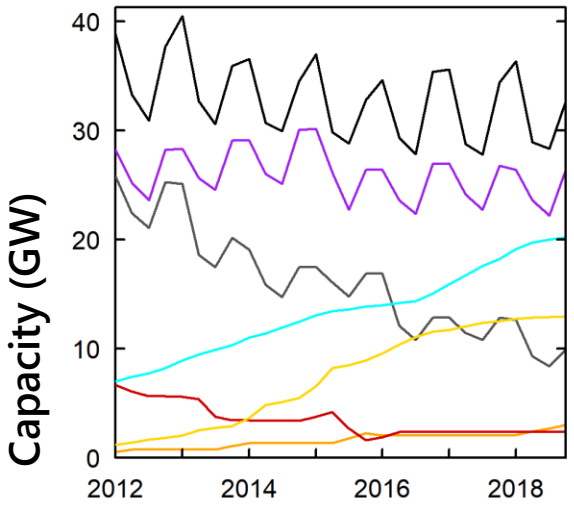
Model inputs: demand & capacity

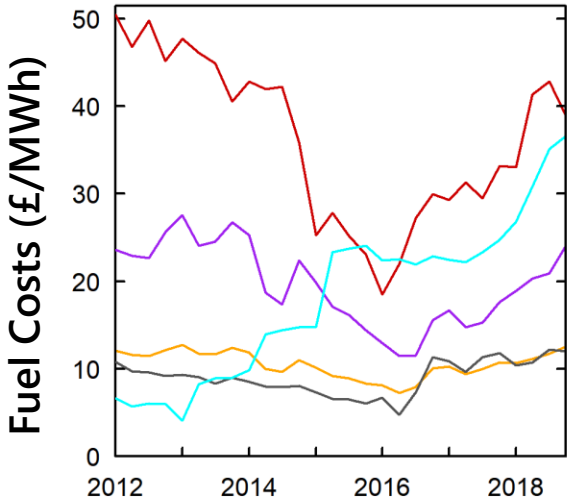


Model inputs: fuel & carbon prices

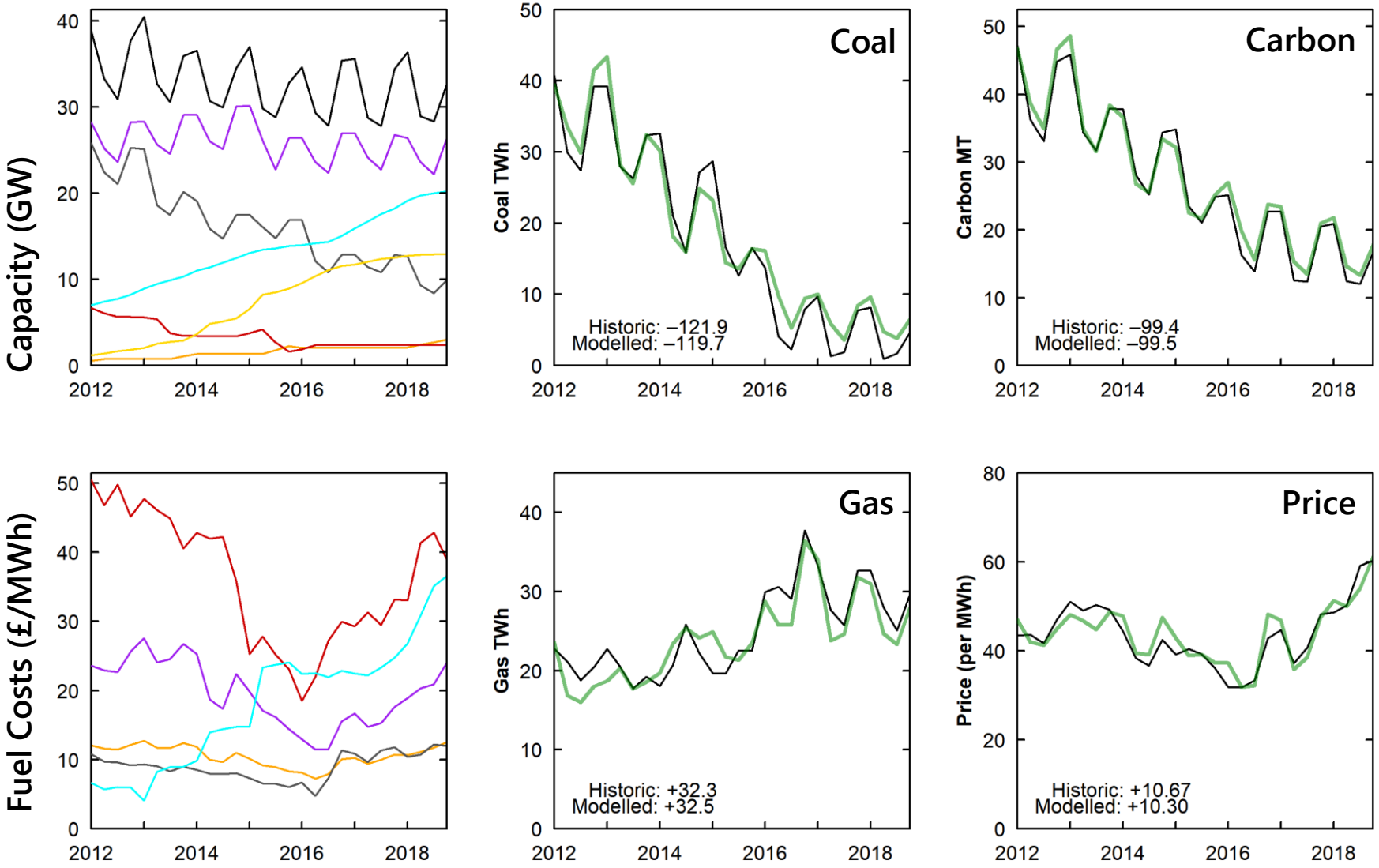


Model outputs





What if... nothing was fixed?



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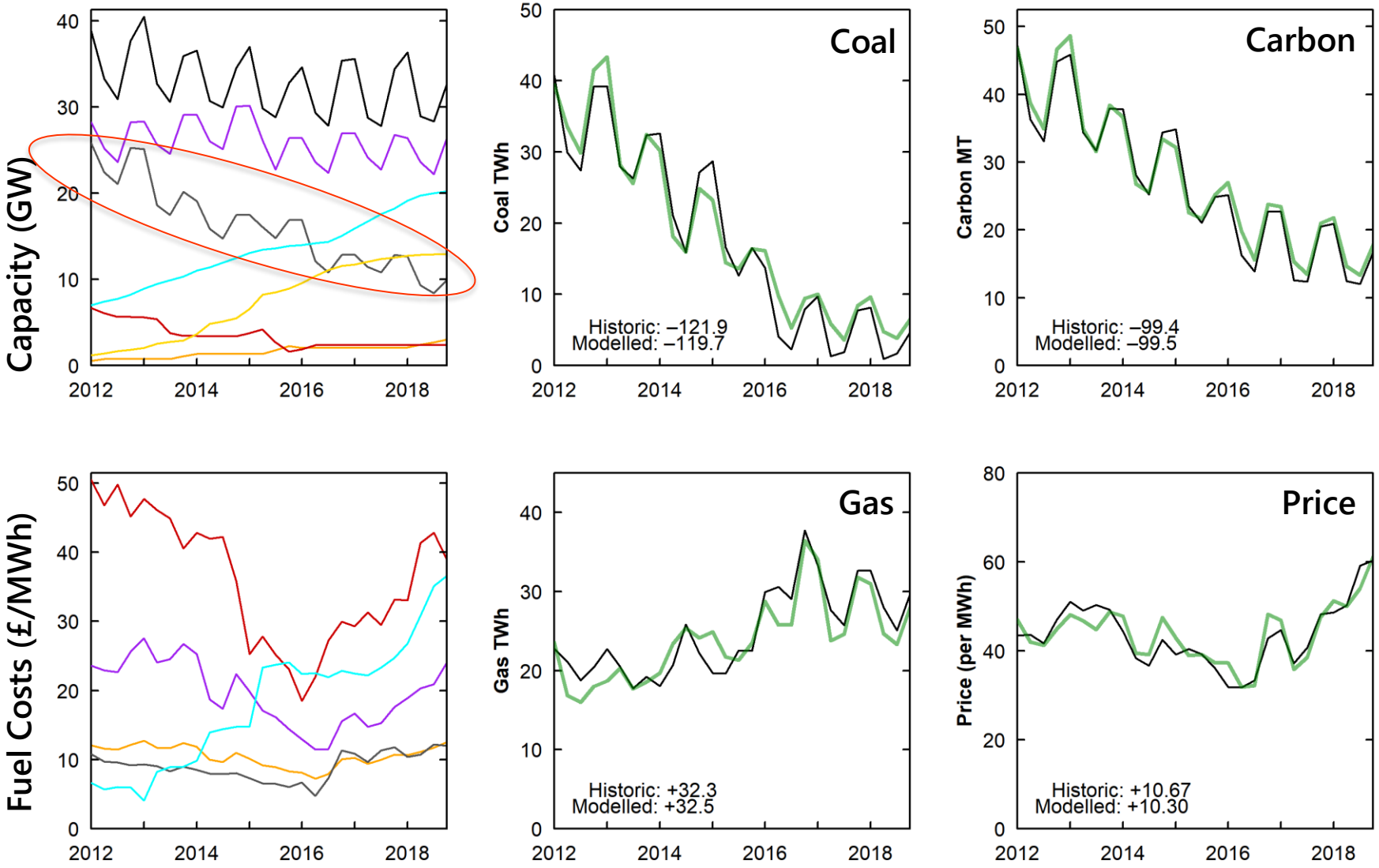
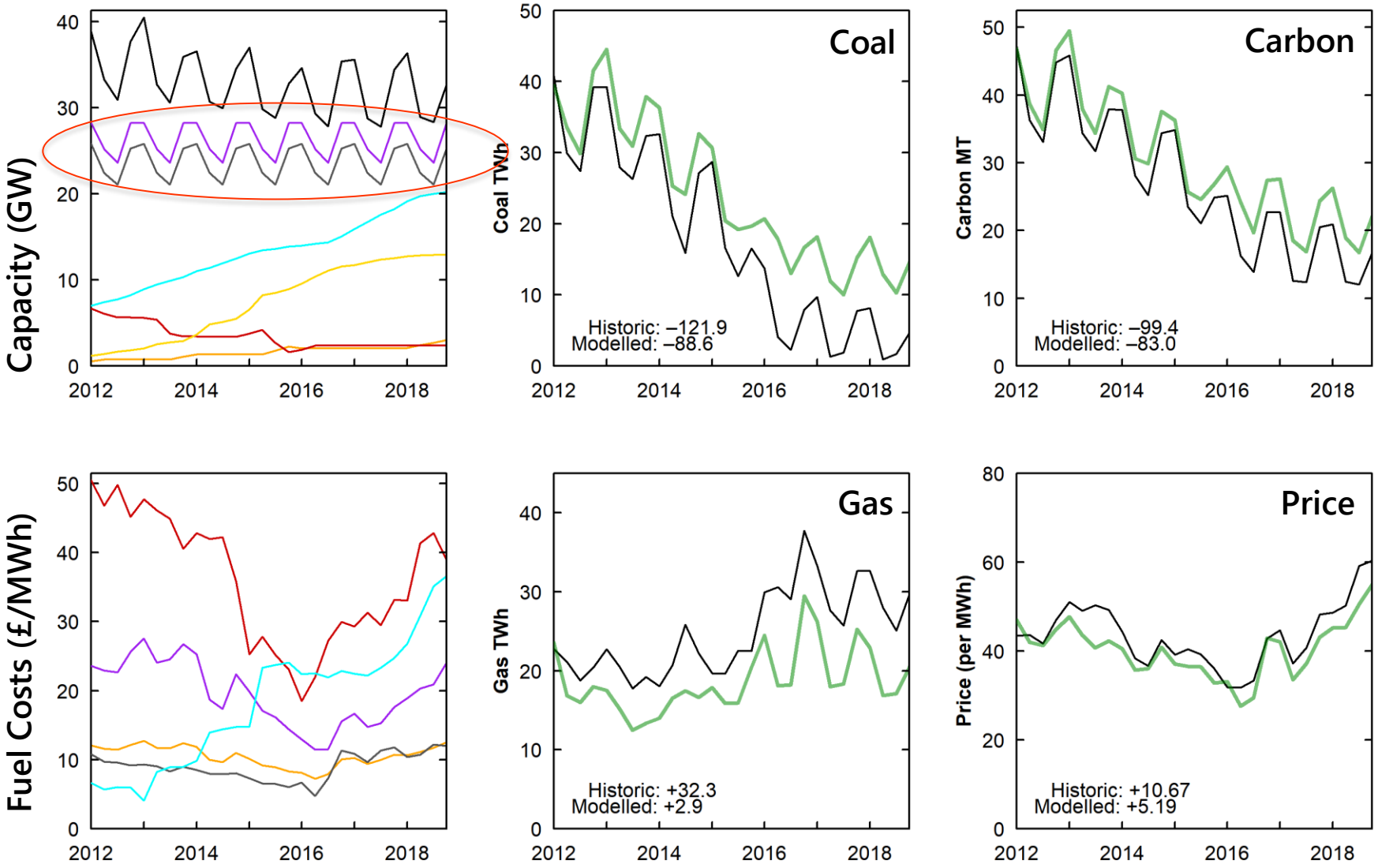
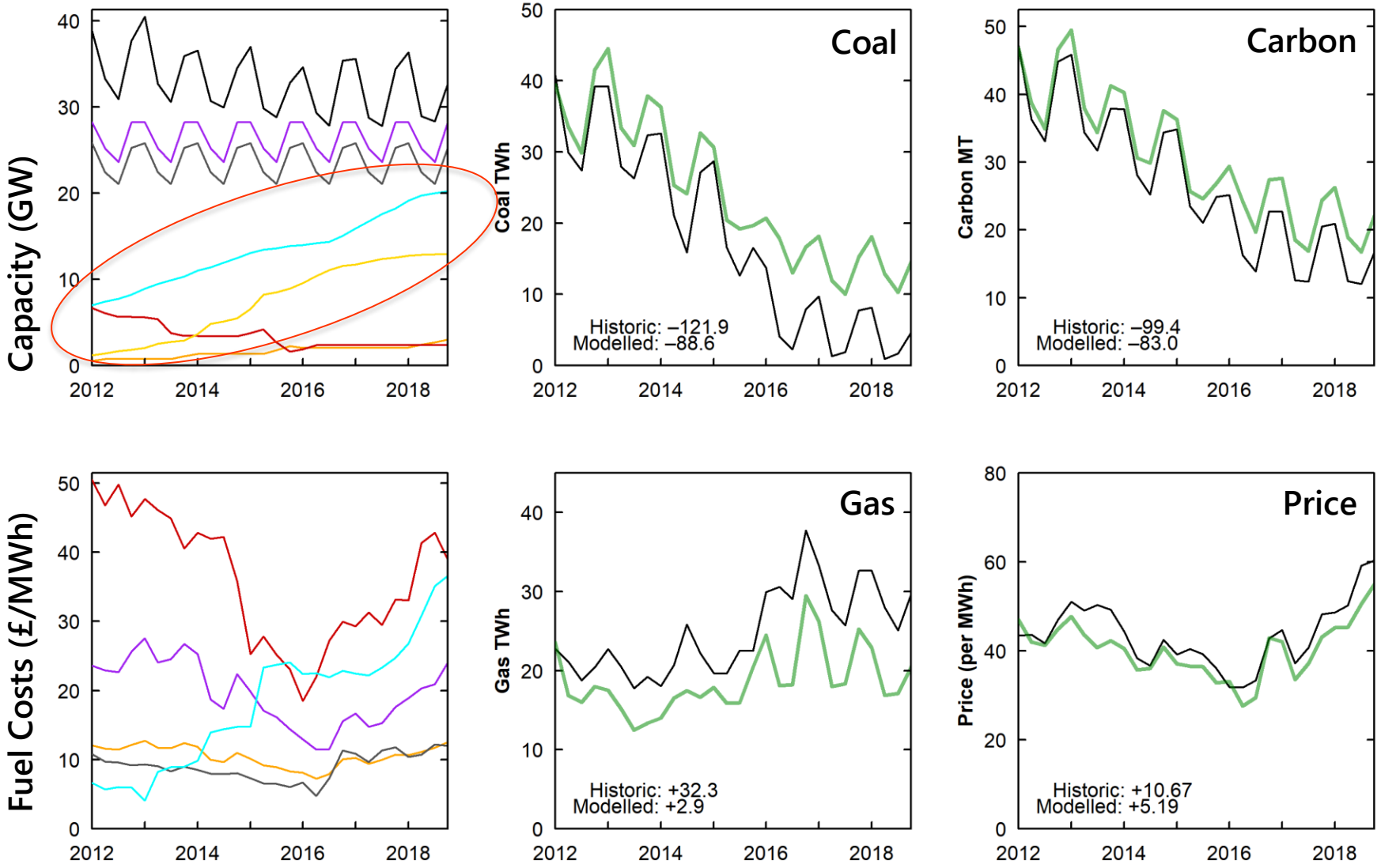


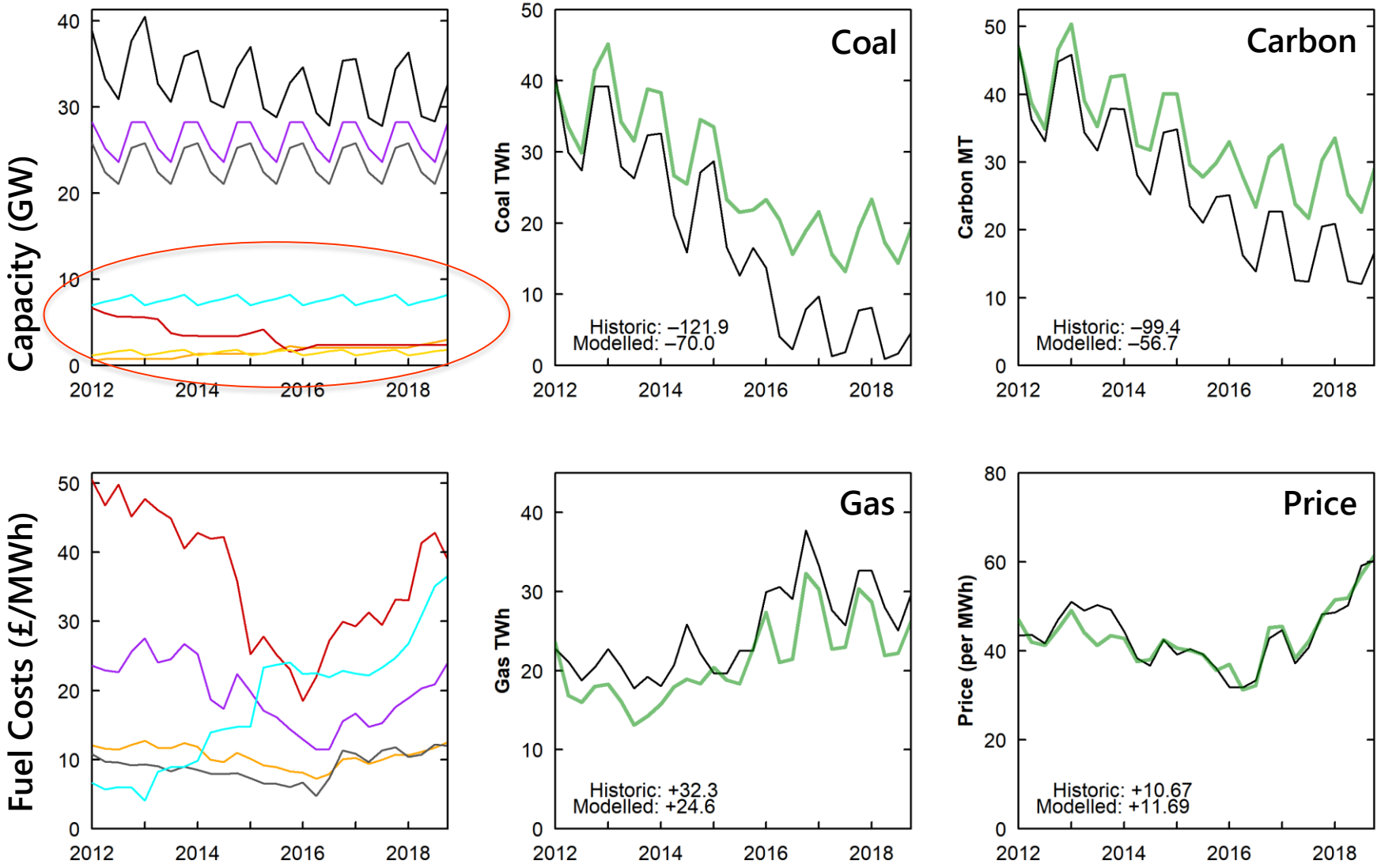
What if... fossil capacity was fixed?



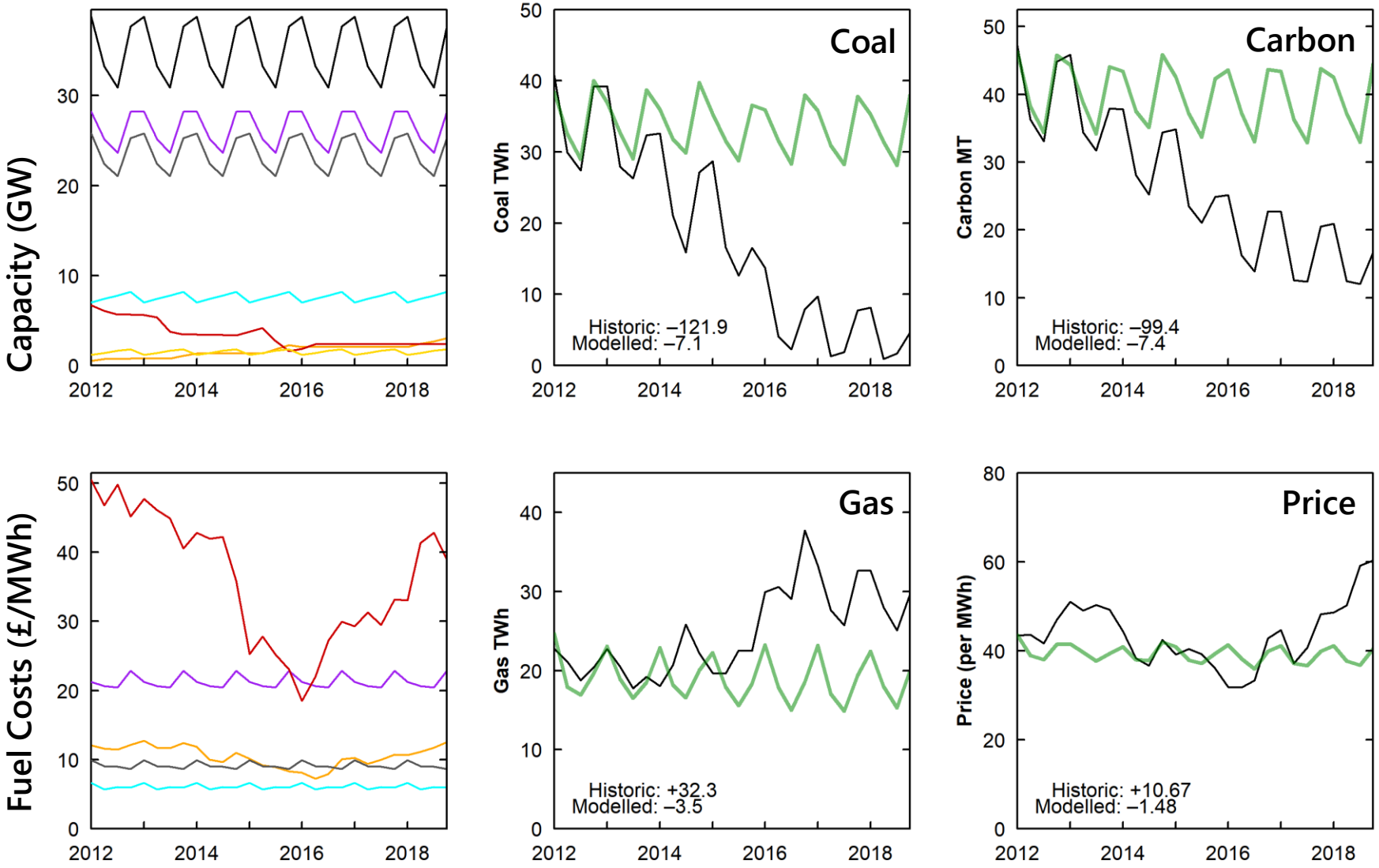
What if... fossil & renewable capacity was fixed?



What if... fossil & renewable capacity was fixed?



What if... everything was fixed?



What drove down emissions?

So… What drove down emissions?

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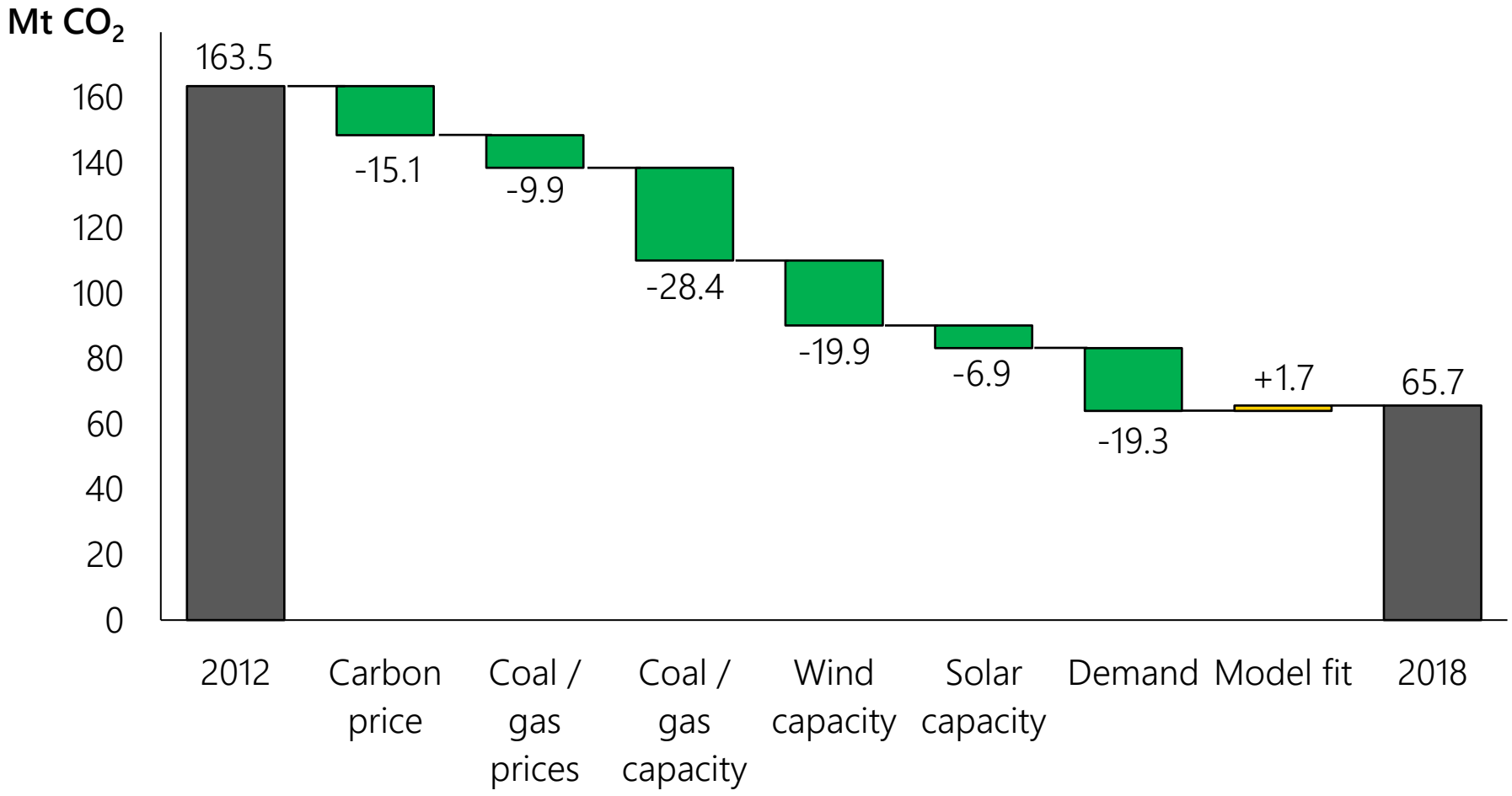
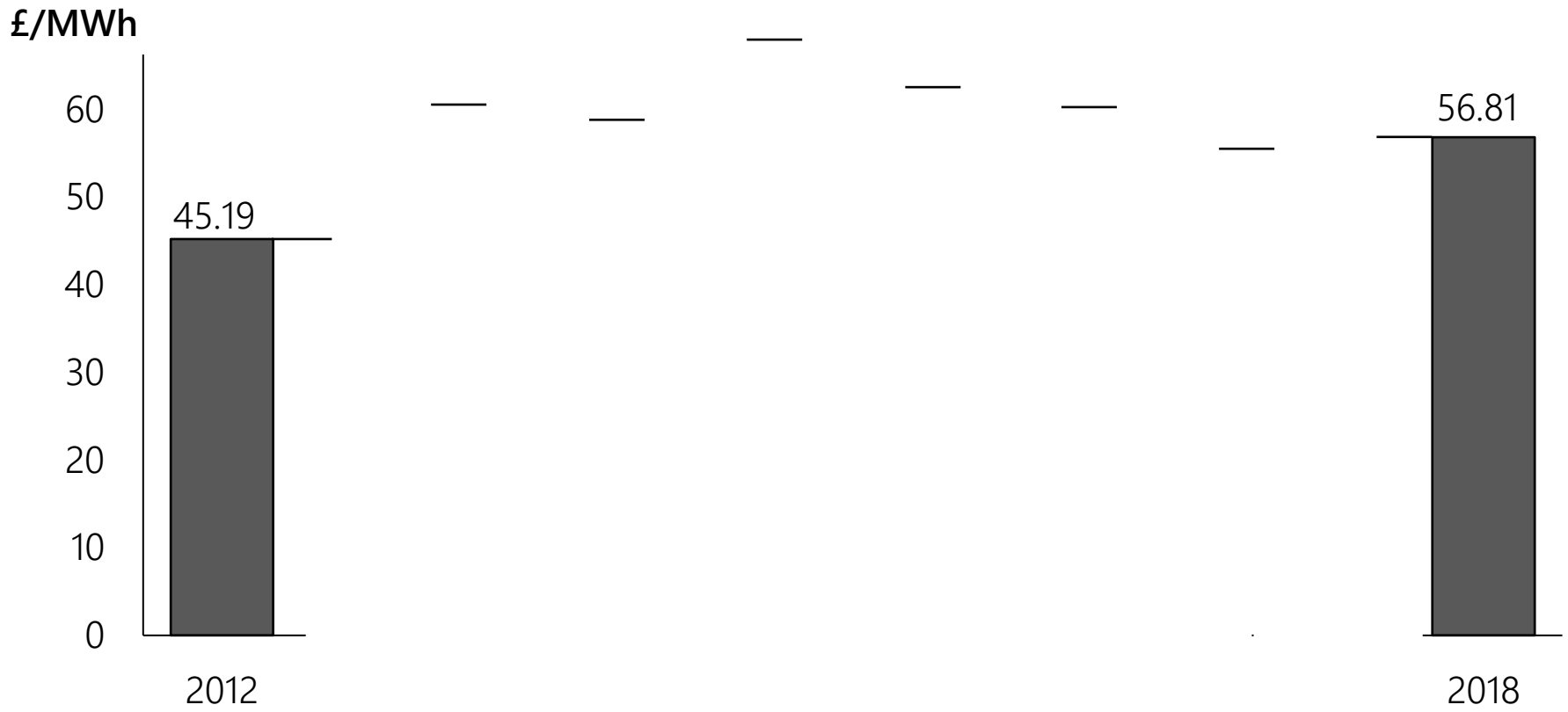
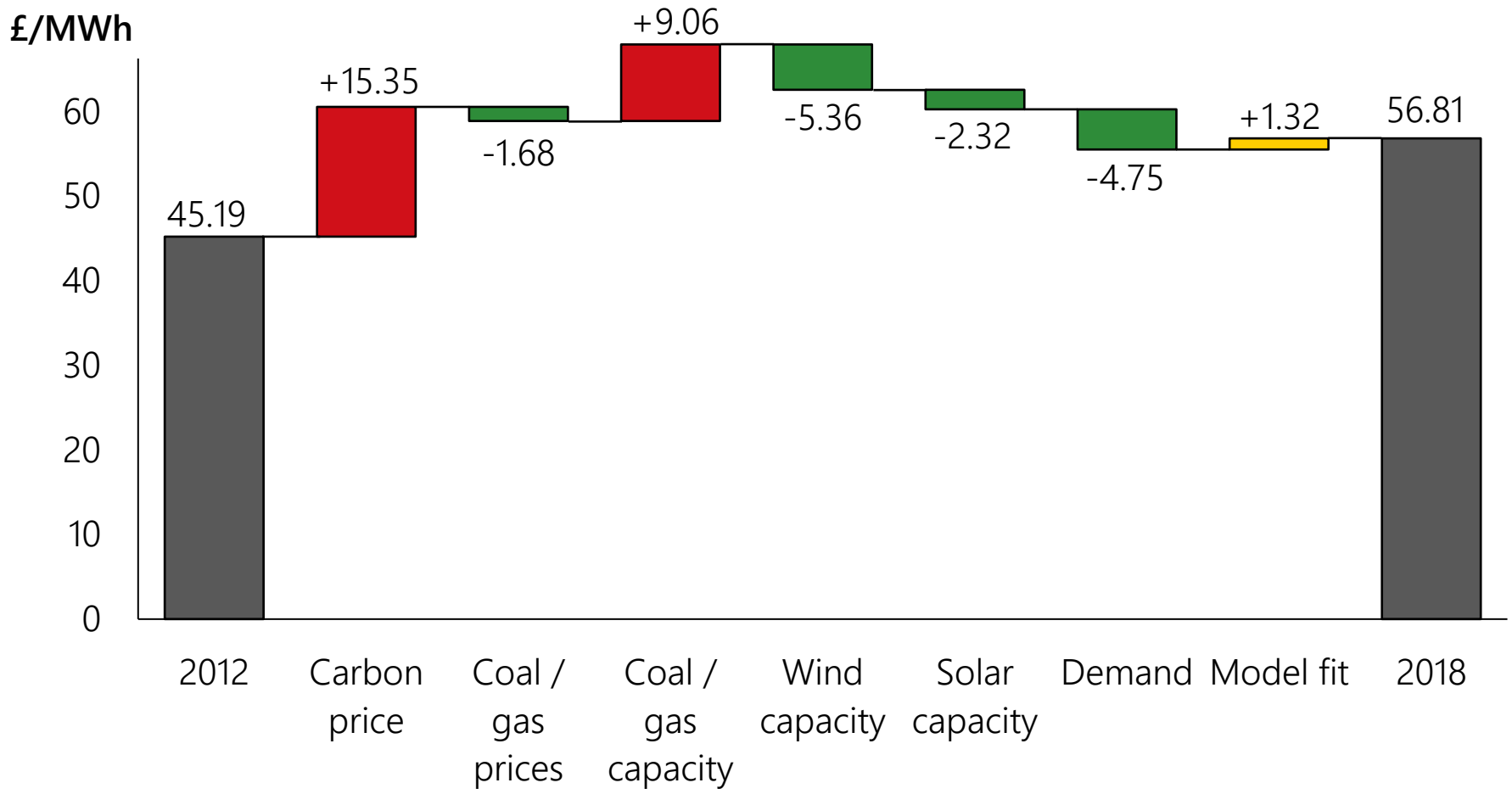


And… What drove up prices?

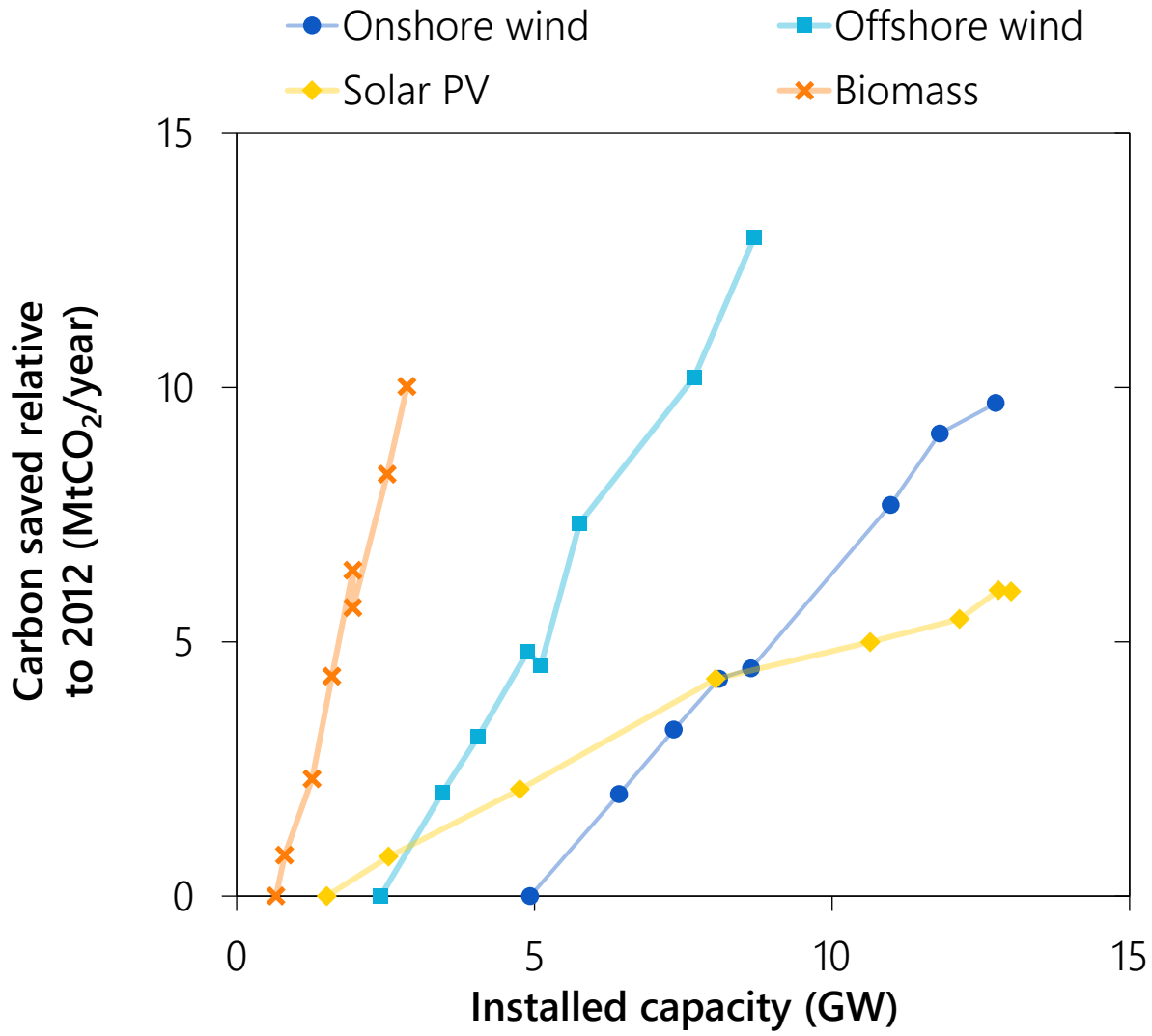


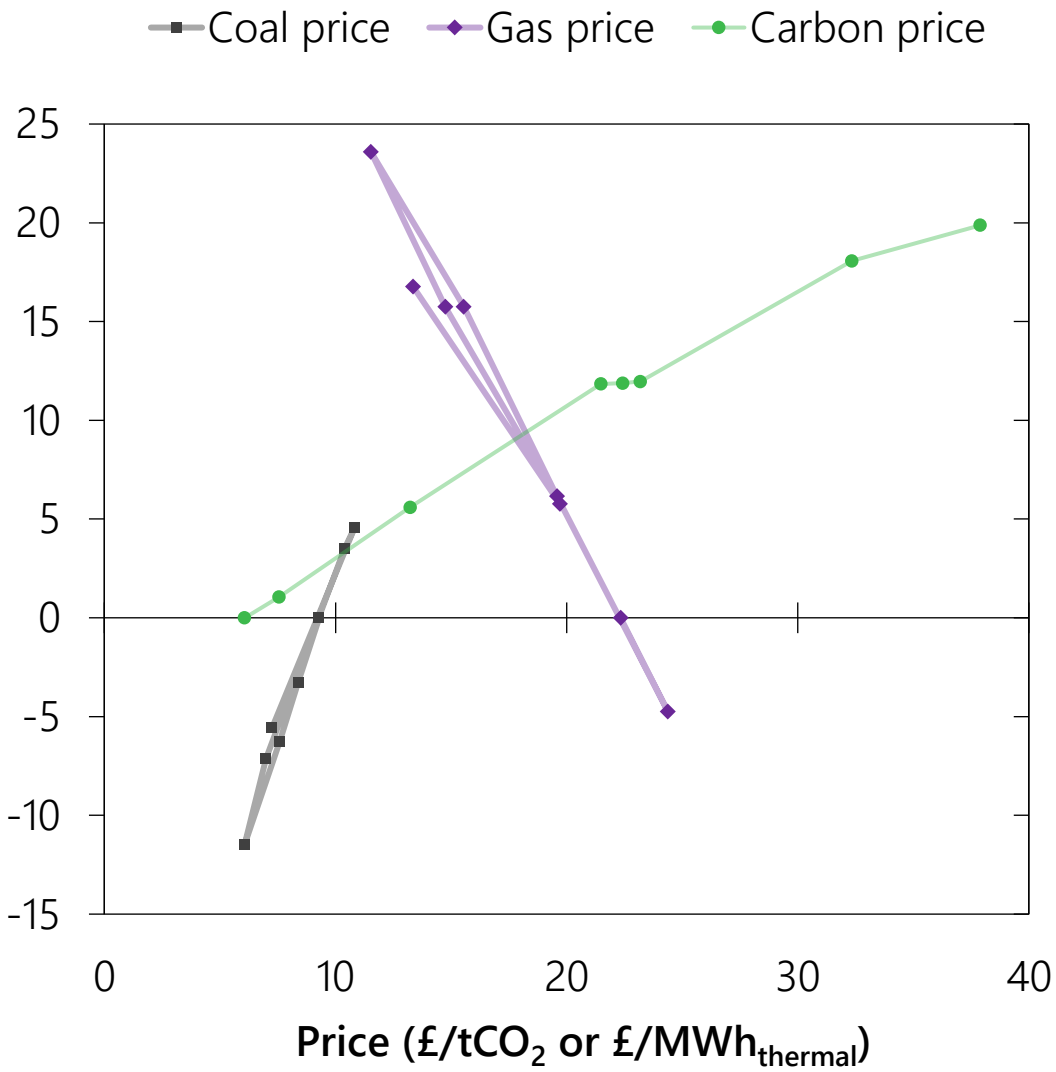
And… What drove up prices?



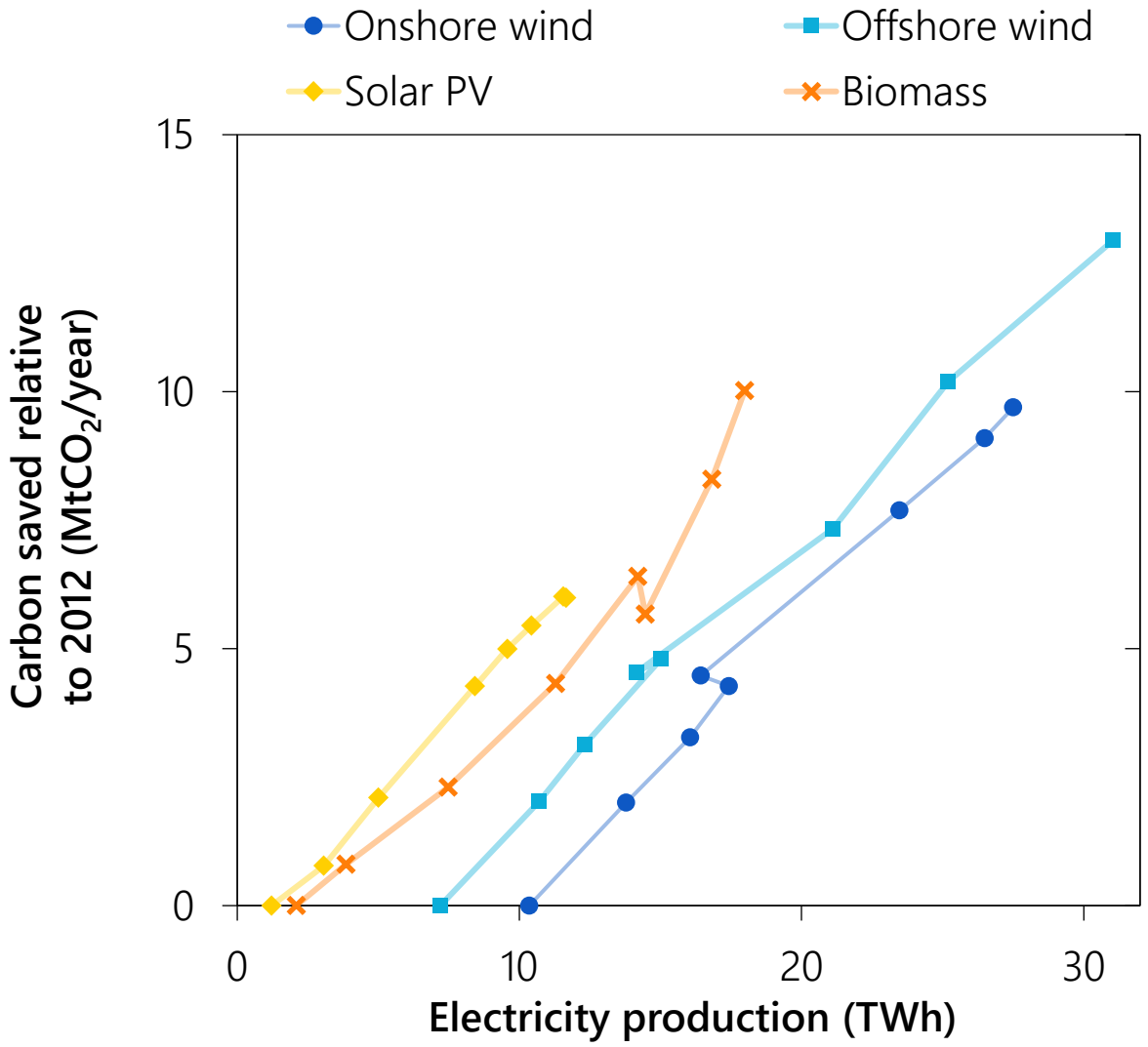
What can others learn from this?

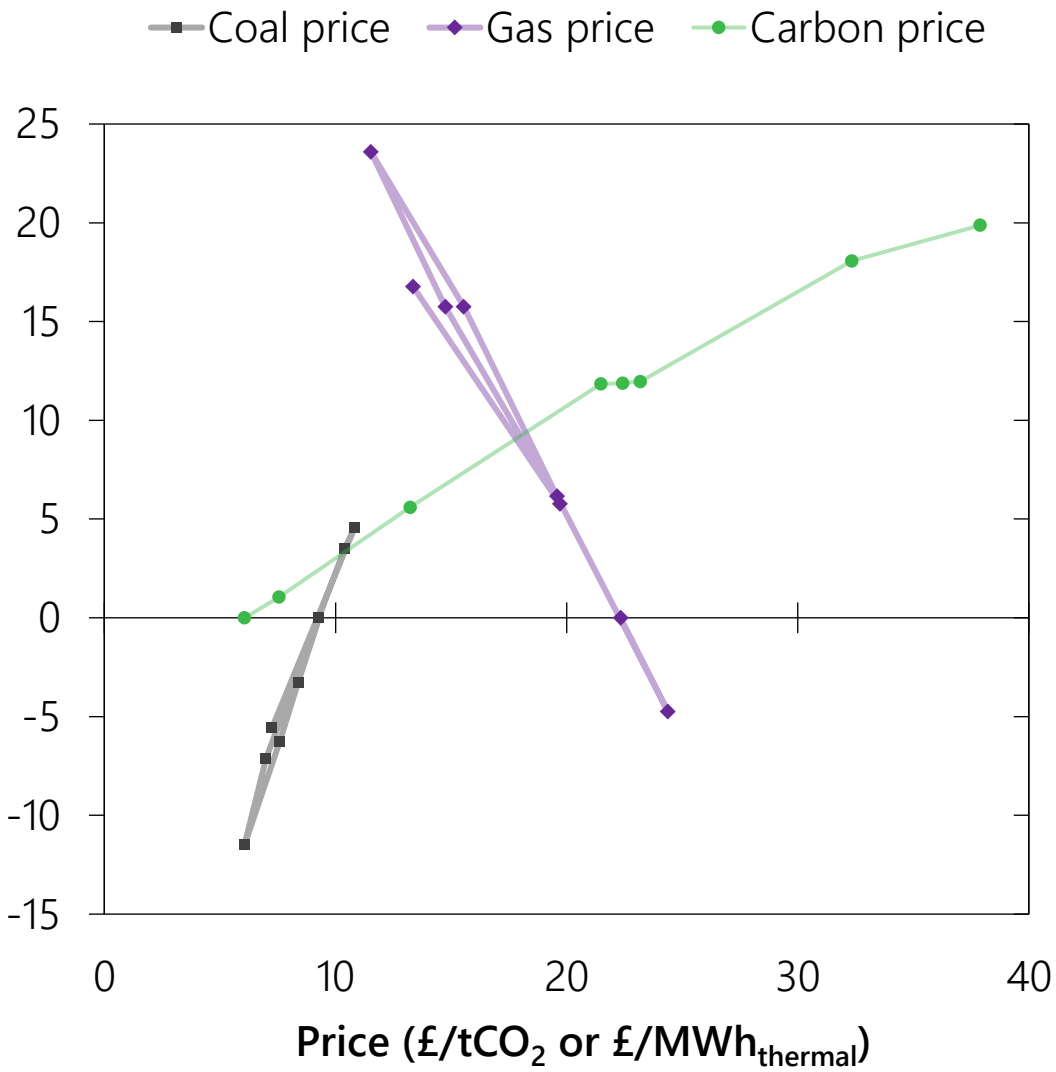
Specific impacts of actions



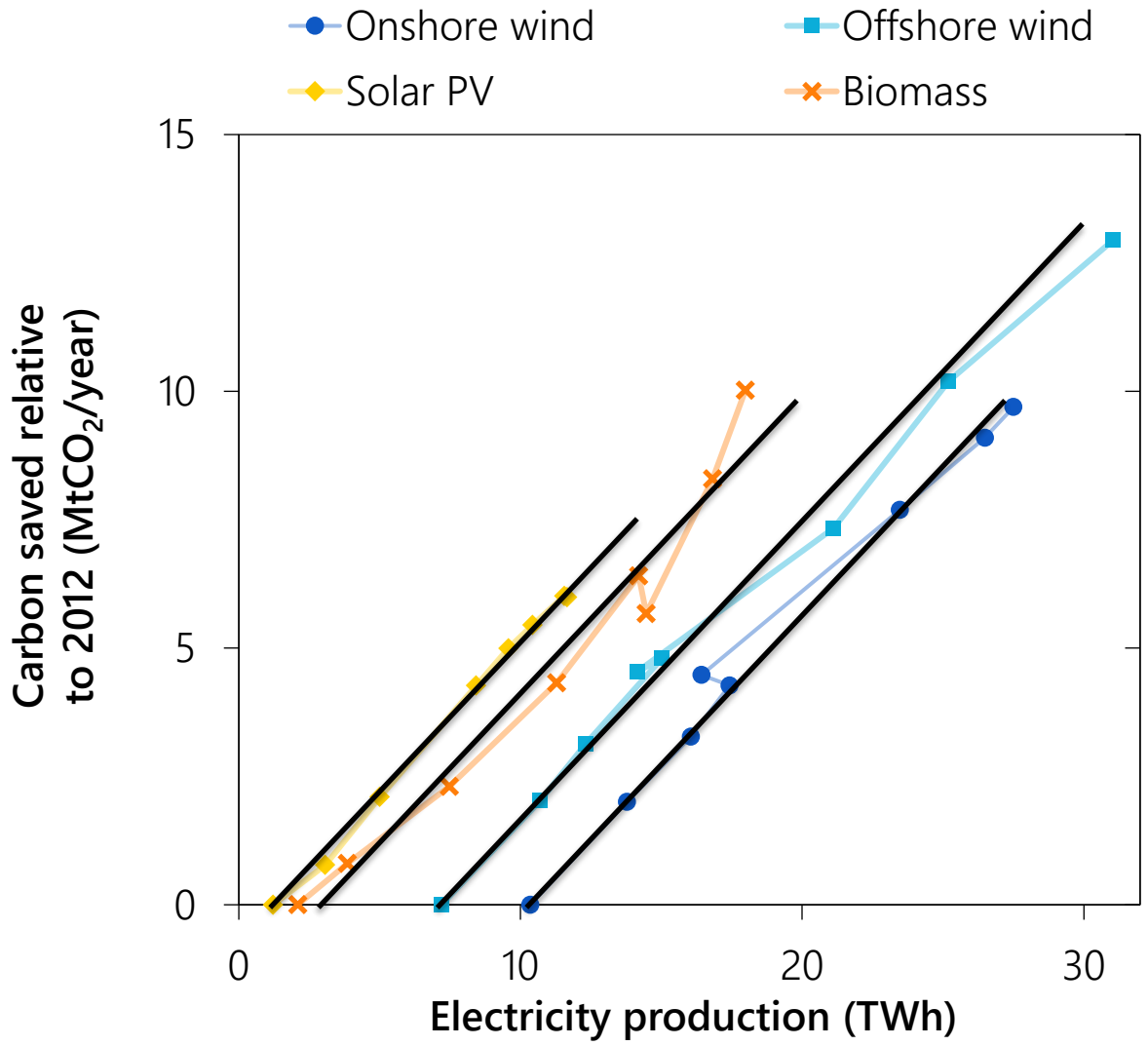


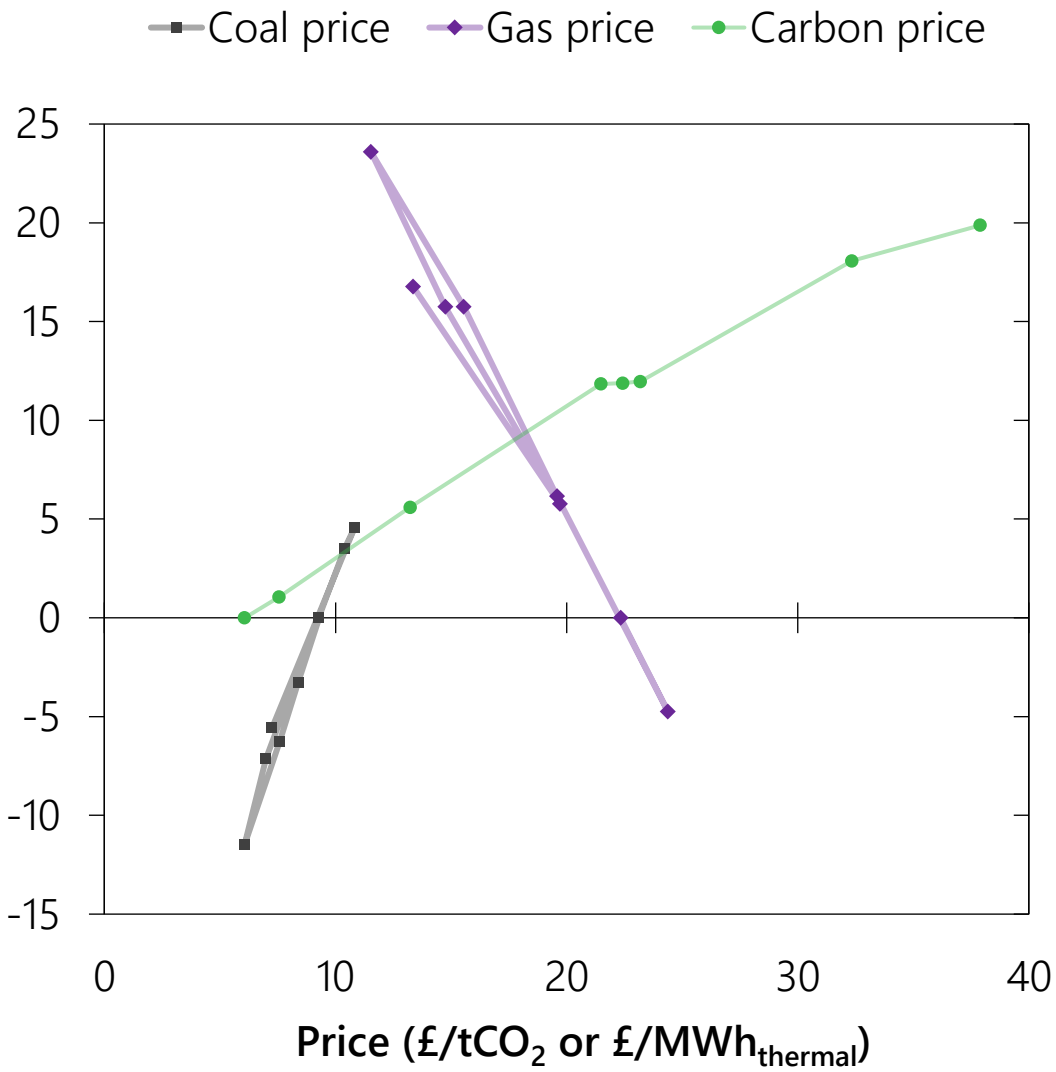
Specific impacts of actions





Specific impacts of actions





Some take-aways

- Emissions savings are consistent over time — even as the system changed radically
  - Every extra £/tCO_2 saves an extra 0.65 MtCO_2/year
  - Every GW of coal plant retired saves an extra 1.30 MtCO_2/year
  - Gas prices falling by £1/MWh saves an extra 2.11 MtCO_2/year

- This linearity may suggest In the long term — clean electricity is clean electricity…
  - Doesn't matter if you decarbonise with wind, solar, bio, nuclear, efficiency…
  - "Long-run marginal" savings range from 535–595 kgCO_2 per MWh

- It was a broad multi-faceted approach which reduced emissions by 66%
  - It is important to know how actions amplify or counteract one another
  - The simple linear relationships suggest the future, or other countries could be described in the same way

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Thank you!

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