Overlapping Policies and British Electricity Decarbonisation

BY RICHARD GREEN AND IAN STAFFELL

Abstract

Richard Green and Iain Staffell (Imperial College London) show how Shapley values can disentangle the influence of various overlapping and interlapping policies on national reductions in CO_2 emissions.

Carbon dioxide emissions from electricity generation in Great Britain fell by 66% between 2012 and 2019 – a faster decline than in any other country. The UK government adopted all the standard policy responses to a negative externality: taxes on emissions, regulations to limit the use of high-carbon technologies, and subsidies for clean alternatives. How much each of these actions contributed towards reducing overall carbon emissions has been difficult to assess, as they happened simultaneously, interacted with one another, and were muddied by exogenous effects such as changing fuel prices and the weather. This mirrors a wider problem facing governments: without a precise estimate of how much emissions a technology or policy will save (including its knock-on impacts and interactions with the rest of the system), it is not possible to estimate the carbon cost, the marginal abatement cost, or the appropriate level of support to offer.

We have used Shapley values to attribute emissions reductions between 14 separate changes to the British power system, including fuel and carbon prices, the capacity of various types of power station, and electricity demand. The Shapley value, a concept from cooperative game theory, allocates the benefits created by individual players when they come together in a coalition. In our context, the "players" are the changes we study, and the "benefits" are emissions reductions. A player's Shapley value is effectively the average of all their possible marginal contributions, considering every (ordered) permutation in which they could have joined the coalition. The sum of the players' values always equals the available benefits.

An economist's first instinct might be to calculate each player's marginal contribution by asking what happens if they were to withdraw from the (final) coalition, but this will generally either over- or under-allocate the available benefits. In the context of carbon emissions from electricity, the effect of closing coal plants (for example) added to that of (separately) raising carbon prices will differ from the effect of doing both simultaneously; the impact of renewable generation will depend on whether coal or gas stations are typically at the margin, and so on. Previous studies based on marginal impacts therefore have to include a residual for interaction effects, which the Shapley value avoids.

We employed a (fast) simulation of the British electricity system that finds the cost-optimal half-hourly generation mix between 2012 and 2019. We ran this some 16,384 times, to represent every possible combination of our fourteen changes either following its historic evolution or staying fixed at 2012 levels (except for weather variation, where relevant). The modelled changes in emissions were used to calculate the Shapley values shown below.

The blue bars at either end of this diagram show that actual emissions fell from 161 $MtCO_2$ in 2012 to 53 $MtCO_2$ in 2019. The first grey bar shows that the

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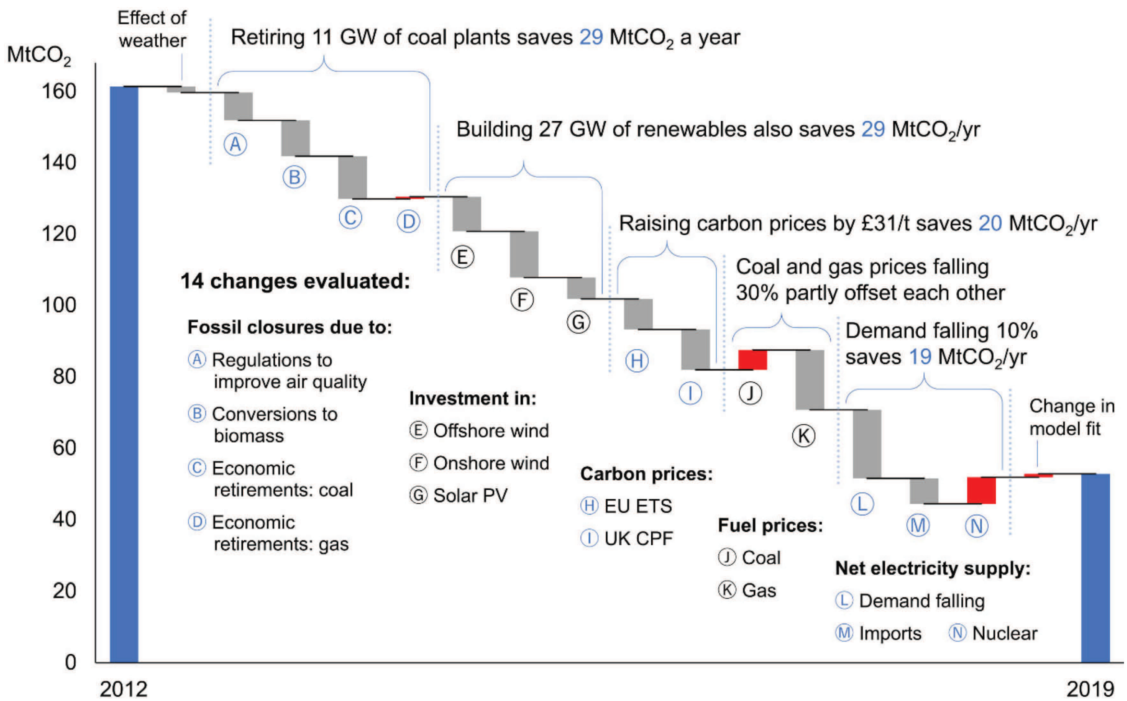

Emmissions were 161 $MtCO_2$ in 2012 and fell to just 53 $MtCO_2$ in 2019 weather was slightly better in 2019 than in 2012 (it was warmer by 0.8°C), reducing the emissions that a counterfactual system would have produced in 2019. The last red bar shows that our model's fit to the real system only changed slightly over the period (an over-prediction of 1.8 $MtCO_2$ fell to one of 0.7 $MtCO_2$).

In between these are the 14 changes we simulated. The reduction in coal capacity (some of it converted to burn biomass) and the growth of wind and solar output both saved 29 Mt of CO_2 emissions in 2019, compared to 2012. The British carbon tax and the (relatively recent) increase in the EU ETS price saved 20 Mt, while falling demand saved 19 Mt. Increasing imports (measured as a pure saving on a UK territorial basis, and still a net saving when comparing British and continental emissions rates) almost exactly offset falling nuclear output in 2019. The lower price of gas relative to coal saved 11 Mt.

Our analysis is not strictly causal. Changes in European carbon and fuel prices (labelled H, J and K in the diagram) were largely exogenous to developments in the UK electricity market. Investments in renewable capacity (B and E-G) depended on UK government policies, which also set our carbon tax (I). Nuclear closures (N) were age-related, and those under the EU's Large Combustion Plant Directive (A) were committed to at a time when (some) generating companies were still considering new build coal in the UK; the stations closed were old and flue gas desulphurisation retrofits uneconomic.

On the other hand, the post-2015 retirements of coal and gas plant (C and D) were affected by carbon prices and renewable capacity, and electricity demand (L) responded to prices (albeit inelastically) as well as to increasing energy efficiency. Imports (M) were also affected by electricity prices, though some of the factors affecting Britain were also relevant in neighbouring countries. We hope to reduce the importance of these caveats with further research, such as by making demand in the model price-sensitive.

We believe that this technique offers a robust way to estimate the 'value' of individual technologies or actions for decarbonisation, accounting for the complex interactions they have upon one another.

A full account of this research is available in Green, R.J. and I. Staffell (2021) "The Contribution of Taxes, Subsidies and Regulations to British Electricity Decarbonisation", *Joule*, vol. 5, no. 10, pp.2625-45, https://doi.org/10.1016/j.joule.2021.09.011