Using Storage to Decarbonise Electricity Consumption

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Summary

Energy storage is a key enabler of low carbon electricity generation, however its use can result in non-trivial increases in greenhouse gas emissions, even if the storage has 100% round-trip efficiency. Therefore, it is crucial to understand the impact of different storage operation modes on emissions levels. Marginal emissions factors (MEFs) at different time periods allow for this analysis, however previous work has predominantly considered MEFs aggregated for whole energy systems, i.e. national power systems. Hence, there is a lack of understanding regarding emissions at local scales.

We have addressed this research gap by developing statistical approaches to determining regional MEFs using data on regional electricity demand and generation by fuel type, coupled with a validated power flow model to account for the Great Britain transmission network. It has been found that the impact of storage varies widely by location and operating mode, with large emissions reductions achieved when storage is used to reduce wind curtailment in areas which consume high levels of fossil fuel generation, and significant emissions increases occurring where storage is used for wind balancing in areas where wind is not curtailed. The difference between the highest emissions reduction and highest emissions increase is very significant, at 828 gCO_2 per kWh passing through. We conclude that power system regulators should pay increased attention to the impact of storage operation on system CO_2 emissions.

Methods and Data

To determine the impact of storage operation on carbon emissions while accounting for the regional distributions of demand and generation, we have calculated regional MEFs using a power system model and a statistical linear regression approach inspired by the work of Hawkes [1]. These regional MEFs have been calculated for different levels of demand and wind output to evaluate the emissions associated with a number of storage operating scenarios.

National Grid ESO provides regional carbon intensity data through the Carbon Intensity API (www.carbonintensity.org.uk). This uses a model of the power system in Great Britain to calculate the historical carbon intensity of electricity consumption, in gCO_2/kWh, for each of the 14 distribution zones on a half-hourly basis.

These half-hourly regional carbon intensities have been multiplied by the corresponding regional electricity demands in order to determine regional consumption-based emissions. The regional demands were calculated by summing transmission-level demand, obtained from Elexon's P114/CDCA-I029 dataset, and embedded solar PV generation, as provided through the PV Live API (https://www.solar.sheffield.ac.uk/pvlive/). We then created a linear fit of the form

$$\Delta C_i = \left(a_{0,i} + a_{1,i}D_{r,i} + a_{2,i}D_n + a_{3,i}G_{PV} + a_{4,i}G_w\right)\Delta D_{r,i}$$

where ΔC_i is the change in regional consumption-based emissions in region i, $D_{r,i}$ is the regional demand, D_n is the national demand, G_{PV} is the national solar generation, G_w is the national wind generation, and $\Delta D_{r,i}$ is the change in regional demand. Once the coefficients a have been determined for a given region using least-squares fitting, the bracketed term gives a time series of MEFs.

Because of limited data availability, this analysis has been performed over the period 14th May 2018 to 13th January 2019. The goodness of fit is poor in regions consuming high levels of power from non-dispatchable sources such as nuclear, wind, and solar. Results are only presented for regions where the R^2 value exceeds 0.4.

We have used a simple approach to simulate storage operation, assuming 100% round-trip

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efficiency and disregarding storage capacities. Three storage operating scenarios have been studied, with their impact on emissions calculated according to mean MEFs in lower and upper quartiles of system net demand (i.e. demand net of wind and solar output) or national wind output, as shown in Table 1. The reducing wind curtailment scenario assumes the storage is charged using energy that would otherwise have been curtailed.

Scenario	Charging Times	Discharging Times
Load Levelling	Low net demand	High net demand
Wind Balancing	High wind	Low wind
Reducing Wind Curtailment	Curtailed wind	High net demand

Table 1 Storage operating scenarios.

Results

GB-level marginal and average emissions factors are shown against system demand net of wind and solar power in Fig. 1, and can be compared with similar profiles for GB in 2002-2009 developed by Hawkes [1]. The highest MEF is now lower than the minimum in each of the years 2002-2009, as a result of the large-scale replacement of coal, open cycle gas and oil generation with low carbon power. The drop in MEF at high levels of net demand is a result of hydro and pumped storage being used for load following at high demands.

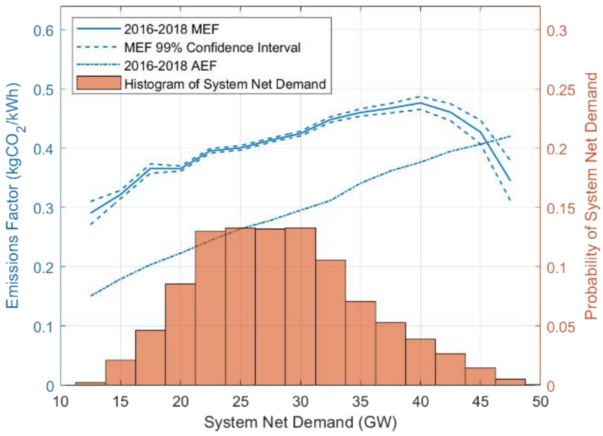

Fig. 1 Emissions factors in Great Britain over 2016-2018.

Marginal and average emissions factors for regions with R^2>0.4 are presented in Fig. 2. A breakdown of electricity consumption by source is presented for all regions in Fig. 3, calculated by multiplying the half-hourly regional consumption mix data from the Carbon Intensity API by the regional electricity demands. MEFs span a significant range, from 155 gCO_2/kWh in North Scotland up to 501 gCO_2/kWh in the East Midlands, over double the national average emissions factor. In some regions, particularly South England, there is considerable difference between the average and marginal emissions factors.

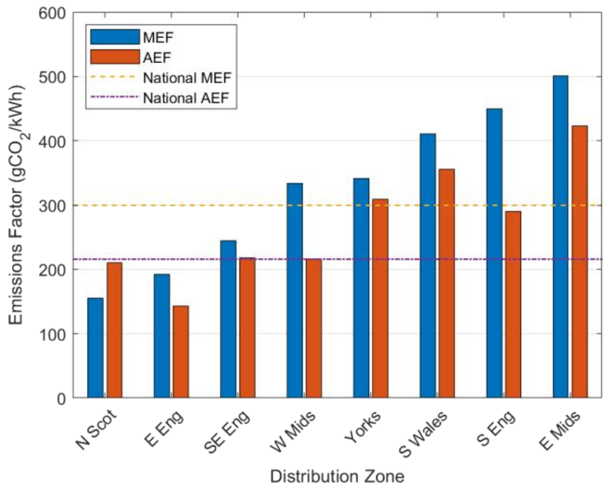

Fig. 2 Marginal and average emissions factors in selected GB distribution zones.

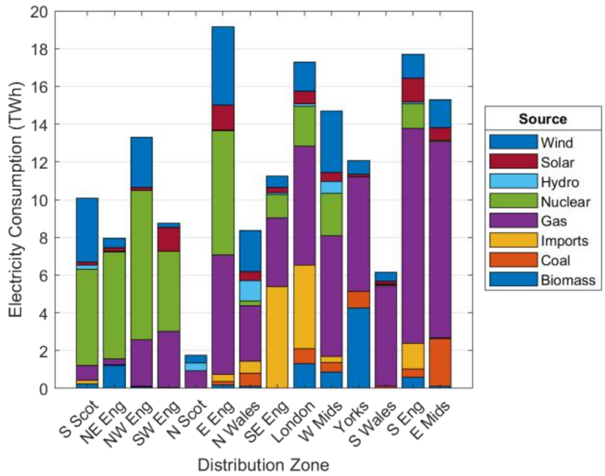

Fig. 3 Breakdown of electricity consumption by source.

The potential emissions reductions from storage operation are shown in Fig. 4. There are considerable differences between the impact of storage operation on emissions depending upon location and operating strategy. The difference between the greatest reduction (reducing wind curtailment in the East Midlands) and increase (wind balancing in North Scotland or the West Midlands) is significant, at 828 gCO_2 per kWh passing through storage.

The reducing wind curtailment strategy provides the greatest emissions reductions, with reductions generally highest in areas with high levels of fossil fuel generation. Using storage for wind balancing can cause increases in emissions unless the charging energy would otherwise have been curtailed. Load levelling provides emissions reductions in all regions, contrasting with earlier findings in the Irish power system [2].

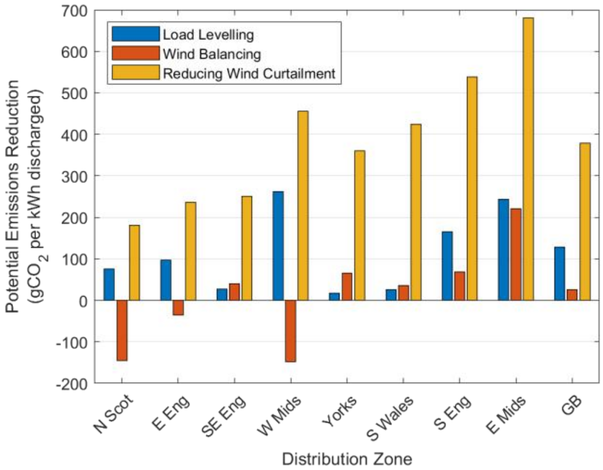

Fig. 4 Emissions reduction potentials from storage operation in selected GB distribution zones.

Discussion and Conclusions

It has been found that the emissions associated with electricity storage operation vary widely between regions and storage operating modes, with the highest emissions reductions being achieved when storage is used to reduce wind curtailment in areas which consume high levels of fossil fuel generation. Emissions increases can occur when storage is used for wind balancing when no energy would otherwise have been curtailed, as there is little coupling between wind speeds and electricity demand.

Across the regions and storage operating strategies, the difference between the highest emissions reduction and highest emissions increase is 828 gCO_2 per kWh that passes through storage. This is significant and, per kWh of electricity delivered, is higher than the carbon savings achieved through the replacement of coal power with gas or biomass (though emissions factors for biomass remain disputed).

The results are limited by a small number of factors, including the limited dataset size and assumed storage and generator efficiencies. However, it is not expected that these factors will have a large impact on the results.

We conclude therefore that operating electricity storage with the objective of reducing grid CO_2 emissions has potential to offer significant environmental benefits to the GB electricity system. If these benefits are to be fully realised in the current liberalised market system, we encourage the UK government and regulators to establish policies that ensure the price paid for each unit of electricity consumed fully reflects the carbon dioxide emitted in producing it.

It is likely that other national electricity systems with a mix of variable low carbon and fossil generators may show similar characteristics. While we have not been able to analyse systems other than that of Great Britain, we have presented a general methodology that can be readily applied in future studies. Our approaches have been used to study the impacts of electric vehicle smart charging (presented in a separate briefing note), and could also be adapted to explore the carbon intensity impacts of other technologies such as electrolytic hydrogen production and heat pump operation.

Acknowledgments

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The methods and results are presented in more detail in an accompanying open access paper:

Pimm AJ, Palczewski J, Barbour ER, Cockerill TT. Evaluating the potential for emissions reduction using electricity storage. Submitted.

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