Are Australia's large energy storage assets supporting the transition to a low carbon grid?

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The Australian Energy Market Operator (AEMO) has forecast the need for 6 to 19 GW of new flexible, dispatchable energy storage, including pumped hydro, large-scale battery energy storage (BES), electric vehicles (EVs), and distributed batteries. These technologies will certainly support decarbonisation in the long-term by overcoming the intermittency associated with renewable energy and by providing network support like inertia and frequency control. The impact they have in the short-term during the transition from fossil fuel-powered to renewable generation, however, will vary depending on how they are operated. Previous works like Arciniegas et al. have highlighted that energy storage technologies can actually increase emissions by charging off higher emissions electricity like that from coal-powered plants and displacing renewable electricity and/or less emissions intensive electricity like that from gas-powered plants.

Marginal emissions are an estimate of the emissions intensity of the marginal generator/s in the grid, and an important metric for understanding the actual impact energy storage is having on decarbonisation. This is because, unlike average emissions that represent the total emissions intensity of generation in the energy grid, marginal emissions represent the impact energy storage charging or discharging will have on generators operating at the margin that will either be dispatched or displaced. As found by Nelson et al., marginal emissions are anti-correlated with the energy spot price, such that energy storage incentivised to minimise cost will likely operate in a way that increases marginal emissions. This was demonstrated in an industry report extending Nelson et al.'s findings, where it was shown that a battery operating to maximise profits with perfect foresight of prices had the net effect of increasing emissions. These works, however, only used 2019 marginal emissions data and didn't extend their analysis to determine the marginal emissions impact of actual energy storage operating in the NEM.

This work therefore sought to fill this gap, using marginal emissions, load, and generation data from 2019 to 2021 to perform a case study of three of Australia's large energy storages currently in operation: Shoalhaven power station (240 MW), Wivenhoe Dam power station (2x285 MW), and Gannawarra battery (30.875 MW). Using these case studies, the paper analyses the impact these energy storages are having on marginal emissions, and therefore how effectively they are contributing to getting us off fossil fuels.

Data

The AEMO marginal generator data for 2019 to 2021 was taken from the Australian National Electricity Market Dispatch Engine (NEMDE) database that contains publicly available historical data on the results of the NEMDE algorithm from 2009 to present in each five-minute time interval. The data shows the most expensive generator, referred to as the marginal generator, and provides the predicted increased amount for which generators will change their dispatch in response to a 1 MW change in demand in each region. To calculate the marginal emissions factor (MEF) for each time period, the emissions factor for the relevant marginal generator was used, varying from approximately 1 tCO_2e/MWh for coal-powered generation to 0.7 tCO_2e/MWh for gas-powered generation and 0 tCO_2e/MWh for renewable generation. In time periods where more than one generator was operating at the margin, the average of the generators' emissions factors was used.

The generation and load profiles for the selected energy storage power stations from 2019 to 2021 was taken from the AEMO Market Management System (MMS), which provides publicly available NEM data for each market participant.

Results and Discussion

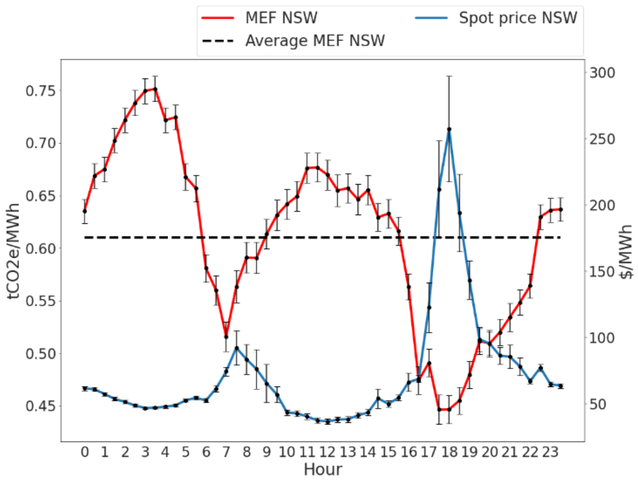

Figure 1. MEF vs. energy spot price (± standard error) averaged across the day for NSW in 2021

Figure 1 plots the MEF (shown in red) for NSW against the energy market spot price (shown in blue), averaged across 2021 for each 30-minute period in the day. Error bars showing the standard error of the mean have been added to both plots. The average MEF across 2021 for NSW has also been plotted. As can be seen, there is a significant anti-correlation between the average MEF in a 30-minute time period and the average energy spot price, as was found in Nelson et al.. The standard error of the mean for the MEF is small, suggesting low inter-day variability across the year and therefore high predictability. For energy storage operated only to reduce costs, it is therefore likely that the energy storage will charge overnight or during the day when the price is low and discharge during the morning and evening peaks when the price is high.

Figure 2 plots the 30-minute average MEF in 2019 to 2021 against the load and generation profiles for the three energy storages. As can be seen in all, operation is to maximise revenue from the energy spot price, generating when prices spike in the evening peak and also, to a lesser extent, during the morning peak. The Gannawarra battery and Shoalhaven power station are both charging significantly during the early hours of the day and midday, whilst Wivenhoe's load is mainly midday.

Using this load and demand data for 2019 to 2021, the marginal emissions impact of the energy storages was calculated. For all three storages, the total load demand was two to four times higher than the generation demand due to inefficiency (as low as 60-70% for pumped hydro and around 85% for BES), use of storage capacity for FCAS, and potential on-site energy demand. For the calculation, the emissions impact associated with storages operating in the FCAS market has not been included, meaning the calculated emissions may include a degree of over-estimation. As the Gannawarra battery is co-located with the Gannawarra solar farm, generation data for the solar farm was used to determine periods where the battery would be charging off solar, with a zero MEF, versus grid electricity.

Table 1. Emissions associated with energy storage operation (positive = increased emissions)

	Shoalhaven	Wivenhoe	Gannawarra
Emissions 2019-2021 (ktCO2e)	261.7	215.6	19.2

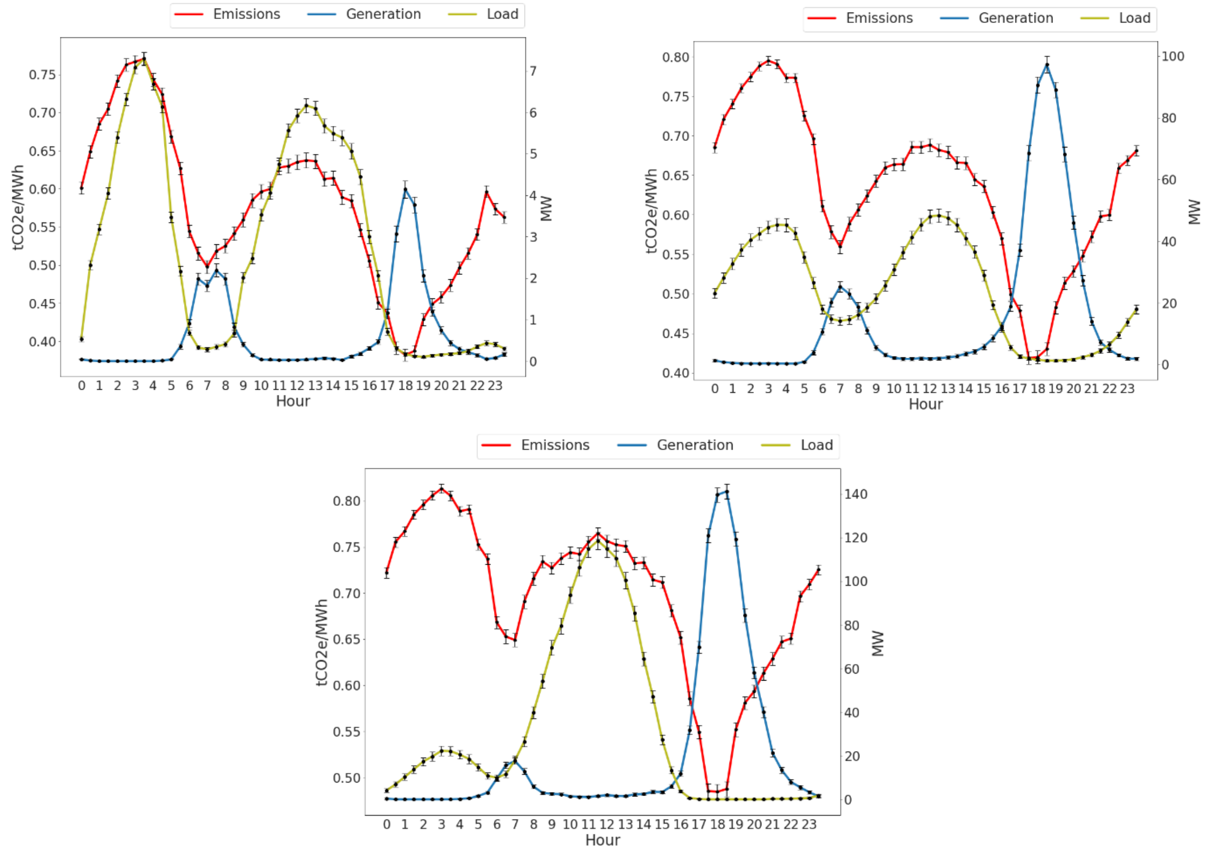

Figure 2. Load and generation profiles for Gannawarra battery (GB) (top left), Shoalhaven Power Station (SH) (top right), and Wivenhoe Dam (WHOE) Pump 1 and 2 (bottom) averaged across the day in 30-minute periods for 2019 to 2021. Plotted against the average 30-minute MEF in 2019 to 2021 for the relevant NEM region. In all plots, generation is represented by the blue plot and load for charging or pumping is in yellow.

Table 1 shows emission results for the storages‘ operation from 2019 to 2021, showing how Shoalhaven and Wivenhoe have contributed over 200 ktCO2e and Gannawarra Battery just under 20 ktCO_2e over the last three years. This is equivalent to approximately 80,000 and 8,000 extra cars on the road in a year, respectively. Whilst this may increasingly not be an issue in the future once there is greater renewable energy penetration, in the short-term this operation may act to extend the lifetime of fossil-fuel powered plants, specifically coal, operating at the margin by increasing demand during those time periods. For overnight load especially, where in states like NSW and QLD coal is the main generator, the operation of these energy storages might have adverse impacts on seeing the rapid phase-out of coal. The importance of both emissions and cost objectives in energy storage operation is therefore evident.

Conclusion

Using marginal emissions and case studies of three operating energy storage power stations in Australia, this paper has highlighted the importance of energy storage operated to minimise both costs and emissions to ensure marginal emissions are not increased. It concludes that energy policy and regulation need to be carefully considered to ensure they are having the desired decarbonisation impact, with the authors suggesting the possibility of dynamic carbon incentives or market tariffs to encourage energy storage to charge and discharge during particular time periods.

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