EFFECTS OF GRID-SCALE ELECTRICITY STORAGE ON SYSTEM CARBON DIOXIDE EMISSIONS AS A POWER SYSTEM DECARBONIZES

Michael Craig, Carnegie Mellon University, 717-979-1463, mtcraig@andrew.cmu.edu
Dr. Paulina Jaramillo, Carnegie Mellon University, 412-268-6655, pjaramil@andrew.cmu.edu
Dr. Bri-Mathias Hodge, U.S. National Renewable Energy Laboratory, 303-384-6981, bri.mathias.hodge@nrel.gov

Overview

Grid-scale electricity storage (hereafter "storage") could be a key technology for deeply decarbonizing the electric power system. However, the net effect of storage on system carbon dioxide (CO_2) emissions largely depends on which power plants charge and are displaced while discharging the storage unit. Consequently, storage could actually increase system CO_2 emissions, as demonstrated by several studies using historic CO_2 emission and electricity price data across the U.S. Since studies have focused on historic or decarbonized power systems, how storage will affect system CO_2 emissions as power systems shift from historic to decarbonized systems remains unclear. To better understand how storage transitions from increasing to decreasing system CO_2 emissions, we quantify the effect of storage on CO_2 emissions as a power system decarbonizes under a moderate and strong CO_2 emission reduction target through 2045. Under each target, we compare the effect of storage on CO_2 emissions when storage participates in only energy, only reserve, and energy and reserve markets.

Methods

Taking the Electric Reliability Council of Texas (ERCOT) system as our study system, we use two power system optimization models in sequence while reducing CO_2 emissions by 50% and 70% from 2015 levels by 2050. To forecast how the generator fleet evolves over time, we use a capacity expansion (CE) model and several heuristics. The CE model adds generators to an existing fleet in order to meet hourly demand and reserve requirements while minimizing fixed and variable costs under an annual CO_2 emission limit. To quantify the effect of storage on system CO_2 emissions, we run fleets output by the CE model in a unit commitment and economic dispatch (UCED) model with and without storage. The UCED model meets hourly electricity demand and reserve requirements while minimizing total energy and reserve costs and enforcing unit-level constraints. To quantify the effect of storage on system CO_2 emissions while participating in different markets, we limit storage to participating in energy and/or reserve markets. We also test the sensitivity of our results via scenario analysis to early coal-fired generator retirements, low natural gas prices, and high storage capacity and storage efficiency.

Results

We find that storage increases CO_2 emissions in the 2015 ERCOT system (Figure 1), as in prior studies. Under both decarbonization targets, though, storage reduces CO_2 emissions in 2025, well before deep decarbonization of the generator fleet. Storage achieves these emission reductions in the mid-term by enabling a shift from coal-fired to gas-fired generation and, to a lesser extent, by reducing wind curtailment. Storage further reduces CO_2 emissions through 2045 under both decarbonization targets. Through 2045 under the moderate target and through 2035 under the strong target, these emission reductions arise from storage enabling a shift away from coal-fired generation towards gas-fired generation and, increasingly over time, wind and solar generation. In 2045 under the strong decarbonization target, though, storage reduces emissions significantly less than in 2035. This decrease is driven by storage switching from enabling a shift from coal-fired to gas-fired generation to enabling a shift from gas-fired to renewable generation.

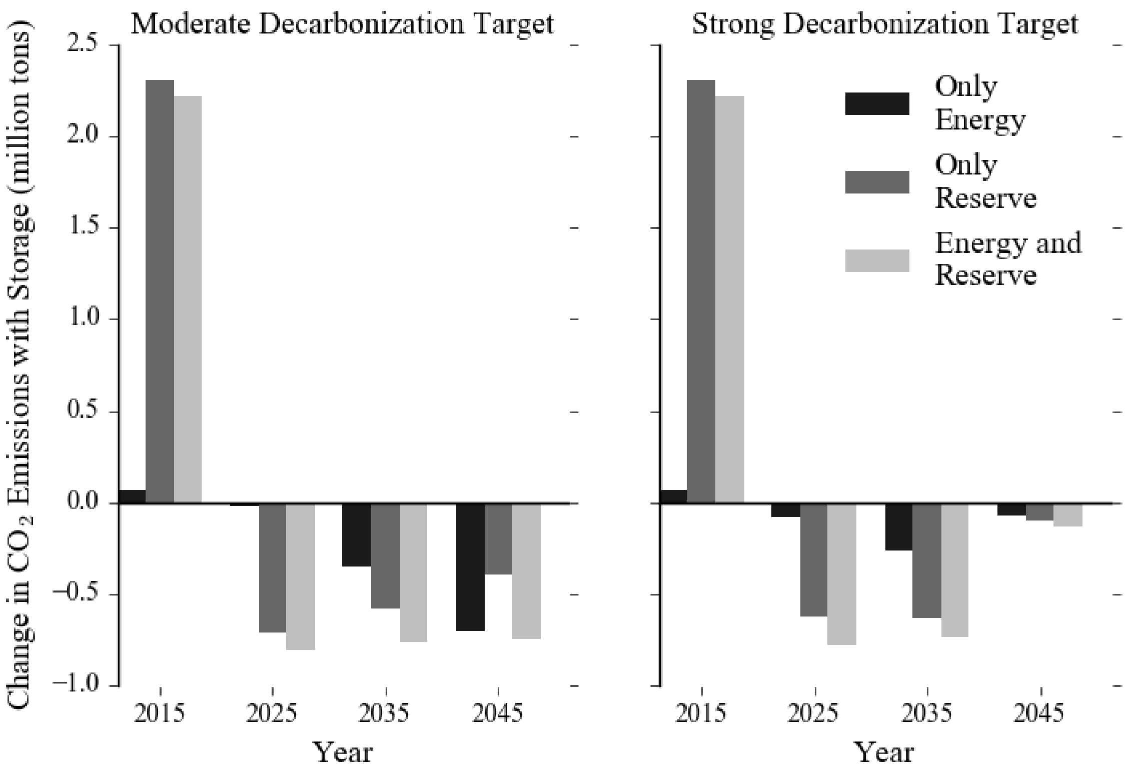

Figure 1: Change in system CO_2 emissions with storage versus without storage under the moderate (left) and strong (right) decarbonization targets when storage participates in only energy, only reserve, or energy and reserve markets. Positive values indicate storage increases CO_2 emissions.

Storage reduces CO_2 emissions through 2045 under both decarbonization targets when participating in only energy, only reserve, and in both energy and reserve markets (Figure 1). However, the magnitude by which storage reduces CO_2 emissions varies significantly with which market storage participates in. Notably, across years and decarbonization targets, storage achieves the greatest CO_2 emission reductions when participating in both energy and reserve markets rather than in just energy or just reserve markets.

Via sensitivity analysis, we find our results are robust to higher storage capacity and efficiency and lower natural gas prices. Early coal-fired generator retirements reduce or negate emission reductions with storage, as reduced coal-fired capacity reduces the implicit cost of CO_2 emissions under a decarbonization target. Similarly, decarbonizing only through fleet composition changes, rather than through fleet composition and operational changes, negates nearly all emission reductions due to storage through 2045. In the absence of fleet operational changes to meet decarbonization targets, i.e. when not enforcing a shadow CO_2 price in our UCED model, storage only reduces CO_2 emissions in 2045 under the strong decarbonization target, when coal-fired capacity is nearly eliminated.

Conclusions

We find that storage can reduce system CO_2 emissions in the mid- and long-term, including well before deep decarbonization of the generator fleet. Storage achieves these emission reductions by enabling a shift from coal-fired to gas-fired and, to a lesser extent, renewable generation. This finding is largely robust to low natural gas prices and high storage capacity and efficiency. However, early coal-fired generator retirements and, in particular, decarbonizing only through fleet composition (and not operational) changes reduce or negate emission reductions with storage. Thus, our results indicate that storage can contribute to decarbonization efforts in the mid-term, but only if decarbonization policies that affect fleet composition and operation exist. We also find that which market storage participates in can significantly affect the magnitude of emission reductions due to storage. Thus, by incentivizing storage to participate in energy versus reserve markets, policies can drive to what degree storage affects CO_2 emissions.