Improved Emission Functions for Generators, and How They Help Resolve a Controversy About the Emission Effects of Wind Power

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Overview

We demonstrate a method for estimating emission and fuel use functions for most of the fuel-burning electric generation units in the United States, and use it to address a controversy about the emission effects of wind power. Emission functions are necessary for estimating emissions and heat-input when measurements are not available such as in power system simulation scenarios, unit commitment and dispatch decisions, and when measurement equipment is absent, turned off, or malfunctioning. Commonly, the "functions" used assume that emissions of a generation unit are simply a constant multiple of its output. Our method estimates functions that are better in several ways: they include dynamic-through-time characteristics of generator emissions and include impacts of recent ramping and startup. Accounting for the effects of ramping and start-ups on emissions and heat rates, as we do, is particularly important for predicting the effects of scenarios that may significantly change the frequency of ramping or start-ups.

Simulations have shown that 20 to 30 percent renewables penetration in Western Electricity Coordinating Council (WECC) would result in a significant increase in ramping of generation units, including those fueled by coal (GE Energy, 2010). This increase in ramping may impact emissions and past studies arrive at vastly different results. Two studies have found that wind power increases the emissions of SO_2 and NO_x because of the emission effects of increased start-ups and ramping by fuel-burning generation units that adjust to varying windfarm output (Bentek Energy, LLC, 2010; Katzenstein & Apt, 2009). Other research has found that wind and solar power reduce emissions almost as much as they reduce generation by fuel-burning generation units (Fripp, 2011; Lew, Brinkman, Kumar, Besuner, Agan, & Lefton).

Methods

To estimate functions we use hourly data from the 2010 Environmental Protection Agency Continuous Emissions Monitoring System data set. We can estimate functions for each individual generator in the United States in that data set, which includes approximately 94% of fuel-burning generation capacity in the US. Emission functions are estimated using a modern statistical technique known as ARMAX. Our function takes into account explanatory effects of the level of generation output, the recent starting up of the generation unit, and if the unit has recently ramped up its output or if the unit has recently ramped down its output. The impacts of these events can last for several hours depending on the type of plant, and appropriate lags are used in the functions to include these persistent effects.

To find out the impact of a high wind penetration scenario, which will likely increase the ramping and instances of shut-down and start-up of fossil fuel based generators, we apply our estimated functions to hourly output results from high-wind-penetration and low-wind-penetration scenarios in part of the United States. The high-wind-penetration scenario will have more instances of starting up and ramping fuel-burning generation units than will the low-wind-penetration scenario. Our functions are specifically adapted to take ramping and start-ups into account, allowing for a careful emissions comparison between the two scenarios.

Results

Results indicate that emissions functions can be accurately generated for individual generators. Functions with R^2 values of up to 0.98 can be fit for SO_2 and NO_x emissions and around 0.7 to 0.8 for CO_2 emissions. Our functions illustrate the persistent effects on emissions from ramping and start-up for coal units, and less persistent effects on emissions from natural gas units undergoing similar ramping and startup. We also estimate the effects of using our more-accurate emission functions rather than the usual functional assumption of constant per-MW emission rates.

Conclusions

We show that emissions functions can be accurately estimated for individual electricity generators using our estimation method and appropriate explanatory variables. We demonstrate our ability to automate the process by which we can estimate accurate functions for each individual generator. This automation allows us to easily estimate functions for a large set of generators at once, while still allowing for individual generator functions. This is possible because all generators share the same explanatory variables for each emission type. We show the importance of using accurate emission functions and use them to carefully estimate the emission effects of a high-wind-penetration scenario.

References

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