ESTIMATING EMISSIONS OFFSETS OF INTERMITTENT RENEWABLE ENERGY

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Overview

In the US, the recent Clean Power Plan has a 30% reduction in carbon dioxide emissions by 2030, from the 2005 level, as one of its key goals (EPA, 2015). In order to achieve this, an electric grid powered by a significant share of renewable energy is a proposed alternative. However, the intermittent nature of variable renewable energy (VRE), particularly solar and wind, the lack of utility scale electricity storage and the complex congestion configurations in power transmission make it challenging to assess VRE carbon emissions offsets. Overcoming these methodological difficulties is necessary to estimate the economic value of renewable energy and to evaluate its policies.

Using historical data on the randomness of solar and wind generation, I estimate how much carbon is abated when adding variable renewable energy (VRE) to the electric grid in California, a worldwide leader in its adoption. This requires identifying the marginal emissions offsets related to the instantaneous displacement of the highest marginal cost generator (merit order effect) but also the indirect hydropower reallocation that occurs due to VRE effects on locational marginal prices. Controlling for this indirect effect via a dynamic model renders sensible estimates of wind and solar marginal emissions offsets in electric grids powered by a significant share of hydropower.

Methods

In this paper, using historical data on the randomness of solar and wind generation, I estimate how much carbon is abated when adding VRE to the electric grid in California, a worldwide leader in VRE adoption. The novel challenge lies in identifying the marginal generation and emissions offsets caused by adding two intermittent sources to an electric system that has a significant share of hydropower. Previous literature, centered on grids with small fractions of hydro generation, has identified marginal emissions offsets related to the instantaneous displacement of the highest marginal cost thermal generators, through the merit order effect (Kaffine et al., 2012, Cullen, 2013, Novan, 2015).

Nevertheless, adding significant amounts of VRE at low or zero value bids causes a reduction in the wholesale locational marginal price (LMP), which changes hydropower generators' price expectations and optimal allocation leading to another contemporaneous but indirect displacement of hydro generation away from periods with the largest price reductions.

Using a time series system of estimating equations, I model the usual merit order effect and the existence of the indirect price effect with a static framework that identifies the contemporaneous marginal generation offsets that solar and wind induce on thermal, hydro generation and imports.

Results

The results show that each additional MWh of solar generation instantaneously displaces between 0.130 to 0.132 MWh of hydropower and each additional MWh of wind relocates 0.047 to 0.057 MWh of water generation. However, the displaced hydro generation is switched to a higher LMP hour where it should displace a marginal natural gas plant. Hence, using a dynamic model, I estimate the appropriate average marginal carbon dioxide emissions offsets of solar (0.403 ± 0.02 tCO_2/MWh) to be larger than those of wind (0.369 ± 0.05 tCO_2/MWh). Also, the dynamic model calculates larger marginal natural gas generation offsets and smaller marginal hydropower offsets than its static counterpart.

Even with the dynamic correction for the indirect effect, I cannot reject the null hypothesis of having no net hydropower generation displacement caused by VRE. This could be the result of noise in the estimate, due to the nature of the data generating process, since it uses averages across all time hours. Or it could be showing that the change in hydropower producers' expectations, due to VRE changes on the LMP, has modified the optimal allocation and bidding in such a way that storing water for its future value is the expected profit maximizing decision. However, further inquiry and modelling are necessary to contrast this finding. The current research leaves an open question based on this counterintuitive result.

Conclusions

This research tackled the novel challenge of identifying the marginal generation and emissions offsets caused by adding two intermittent renewable energy sources to an electric grid that has a significant share of hydropower. Using a static model based on recent (2011-2015) historical data of random solar and wind generation, I estimated the instantaneous displacement of the highest marginal cost generator, through the merit order effect, but also the indirect hydropower reallocation that occurs due to VRE effects on locational marginal prices.

On the other hand, using a dynamic model, I identified how hydropower generation is reallocated due to changes in the LMP and the associated additional displacement of thermal generation and emissions. Hence, the dynamic model estimates larger marginal natural gas generation offsets and emissions offsets than its static counterpart. Even with the dynamic estimate I find no evidence of a full hydropower reallocation that would lead to zero displacement

From a broader perspective, several emerging economies with electric grids powered by a significant share of hydropower are increasingly adopting wind and solar plants. To the extent that these countries operate a wholesale electricity market with bidding hydropower producers, this research's methodology could be a good approach for estimating abatement benefits based on historical data.

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