Inefficiency in Decentralized Renewable Energy Investment

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Overview

Electricity markets must balance at every point in space in time. Rather than relying on an unbounded spot energy market and a responsive demand system to achieve this goal, wholesale power markets in the United States impose price caps, and instead rely on a combination of ancillary service markets and out of market actions by the system operator to ensure reliability. In this environment, investment in new generation capacity will only be efficient if developers internalize the full system costs of their entry and decisions across all these balancing margins.

While essential for achieving decarbonization, variable renewable energy (VRE) poses a particular challenge to this system, for two reasons (Joskow, 2019). First, VRE sources are inherently intermittent. Moreover, this intermittency is highly spatially correlated, implying that considerable system variance will persist even as the number of plants grows large. Second, VRE plants have zero marginal cost, meaning that, when available, they will be dispatched first. In industries with undifferentiated products and large fixed costs, entry will generally be excessive (Mankiw and Whinston, 1986; Amir et al., 2014). Here the problem is exacerbated because renewable developers base entry on expected revenue alone, and do not bear the costs of entry on balancing actions taken outside of wholesale markets.[1]

In this paper we provide simple measurements of spatial inefficiency in the siting of wind plants in the United States. Wind capacity has expanded considerably over the past decade, and now represents 12% of generating capacity. At the same time, the grid has increasingly struggled to utilize this increased capacity. In 2022, 5.3% of wind production in the seven largest ISO was curtailed (U.S. Department of Energy, 2023), highlighting that the system value of wind capacity was considerably lower than the sum of its parts, due to the high correlation in wind speeds across locations. In this paper, we ask whether alternative, feasible, wind investment programs were available which would have produced more usable power, or lower system variability, for the same amount of aggregate investment.

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[1] Although capacity markets are supposed to provide a signal for the system value of entry, compensation schemes for VRE are based on coarse measures of average availability, and do not account for the spatial covariance with other intermittent resources.

Data

To conduct our analysis, we assemble a database of engineering based hourly wind production estimates. The National Renewable Energy Laboratory produced high frequency reanalysis measurements of wind speeds over four square kilometer grids covering the continental United States. We combine this with detailed information on the exact location of each turbine currently installed from the USGS. SNL energy provides information on the exact turbine model used at each plant. We then obtain the "power curves" – manufacturer provided production functions mapping wind speed to output – for each model from Bloomberg New Energy Finance. Running the wind speed each hour through the power curve produces an estimate of the potential production for each location-wind turbine combination.

Methods

To explore the potential gains from a centralized investment program, which would internalize the covariance in production across locations, we follow the portfolio choice approach of Wolak (2016). We first compute the covariance in output across all locations within a "market" (NERC Region or ISO). We then search for alternative allocations which would reallocate capacity away from plants whose output is highly correlated towards plants with less correlated output. These allocations trace out an expected output versus system variance frontier.

By restricting reallocations to the locations of existing wind farms, the previous exercise provides a lower bound on the excess variability in the current investment program. To relax this, we then consider extensive margin reallocations as well. NREL provides high frequency wind speed data for 4 square kilometer grids covering the entire continental United States, including locations which have not yet experienced entry. We first estimate the entry probability of existing locations as a function of wind quality, topography, surface demographics from the Census and distance to the transmission grid. We then compute the propensity score of entry for each grid. In our second reallocation exercise, we search for lower system variance reallocations across grids that have at least as a high propensity score as an existing location, again holding total capacity fixed.

Having computed these measures of entry inefficiency, we then explore potential mechanism which might cause excess variability to be larger or smaller. We first consider the impact of electricity restructuring. This paper is primarily concerned with the inefficiencies in decentralized investment in restructured markets. However, roughly half of the United States electric power system still operates under a regulated utility investment and dispatch model (Borenstein and Bushnell, 2015). For these markets, the investment incentives differ, but the task of balancing spatially correlated VRE is similar. We ask if wind farms entering under a regulated investment model have less covariance than merchant wind farms do.

Next we consider the impact of state level renewable policy. As of 2023, 28 states and DC have active renewable portfolio standards (RPS). These policies require that a certain share of consumption in each state come from qualifying renewable sources. RPS policies could lead to too much spatial concentration in states where renewable resource quality is high. However they could actually counteract the excess entry incentives in states where

quality is lower. We correlate plant-level measures of inefficiency from the previous exercise with state level RPS stringency.

References

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