Executive Summary: Level versus Variability Trade-offs in Wind and Solar Generation Investments: The Case of California

Frank A. Wolak, Stanford University

Hourly plant-level wind and solar generation output and real-time price data for one year from the California Independent System Operator (ISO) control area is used to estimate the vector of means and the contemporaneous covariance matrix of hourly output and hourly revenues across all wind and solar locations in the state. This information is used to construct a model that can be used to compute an estimate of the distribution of total hourly wind and solar production and total hourly wind and solar revenue for any configuration of wind and solar generation capacity shares at existing renewable resource locations in the California ISO control area.

This model is used to compute aggregate hourly output and annual hourly revenue mean/standard deviation efficient frontiers for wind and solar generation capacity location decisions. These frontiers are computed by solving for the locational portfolio weights for wind and solar investments that yields the lowest aggregate variability in output (or revenues) for a given mean level of output (or revenues). For both efficient frontiers, economically meaningful differences between portfolios on the efficient frontier and the state's actual wind and solar generation capacity mix are found. The relative difference is significantly larger for aggregate hourly output relative to aggregate hourly revenues, consistent with expected profit-maximizing unilateral entry decisions by renewable resource owners.

Specifically, the output efficient frontier implies that for the same annual hourly renewable output risk it is possible to increase the mean hourly output from the state's renewable generation capacity by 48 percent by optimizing the locations of its wind and solar generation capacity. The revenue efficient frontier implies that for the same annual hourly renewable revenue risk it is possible to increase the mean hourly

revenues earned from the state's renewable generation capacity by 26 percent by optimizing the locations of its wind and solar generation capacity.

The portfolio weights from the output and revenue efficient frontiers reveal that most of the hourly output and hourly revenue risk-reducing benefits from the optimal location of the state's renewable generation capacity is captured by a small number of wind resource locations, with the addition of a small number of solar resource locations only slightly increasing the set of feasible portfolio mean and standard deviation combinations.

Location-specific measures of non-diversifiable wind and solar energy and revenue risk are derived. These measures quantify the extent to which movements in aggregate renewable energy output (or revenue) are correlated with movements in renewable energy output (or revenue) at each renewable energy location. These non-diversifiable location-specific risk measures help to explain why so few renewable resource locations have non-zero portfolio weights in the output and revenue efficient frontiers. They non-diversifiable risk measures demonstrate that for the same value of this risk measure, it is possible to achieve a higher level of expected output or revenue than the level at locations with zero portfolio weights on the efficient frontier by a combination of locations with non-zero weights on the efficient frontier.

Taken together, these empirical results are consistent with the view that for the same statewide capacity of wind and solar generation units, renewable generation unit owners could significantly increase their expected hourly output and to a lesser extent their expected hourly revenues by changing the installed generation capacity shares at wind and solar locations in the California ISO control area without increasing the standard deviation of hourly output or the standard deviation of hourly revenues.

A number of possible mechanisms are proposed to provide incentives for renewable generation investors to take into account the impact of their capacity location decisions on the variability in aggregate renewable energy output. Mechanisms for incorporating the impact of aggregate renewable energy output variability in the transmission planning process is also discussed.