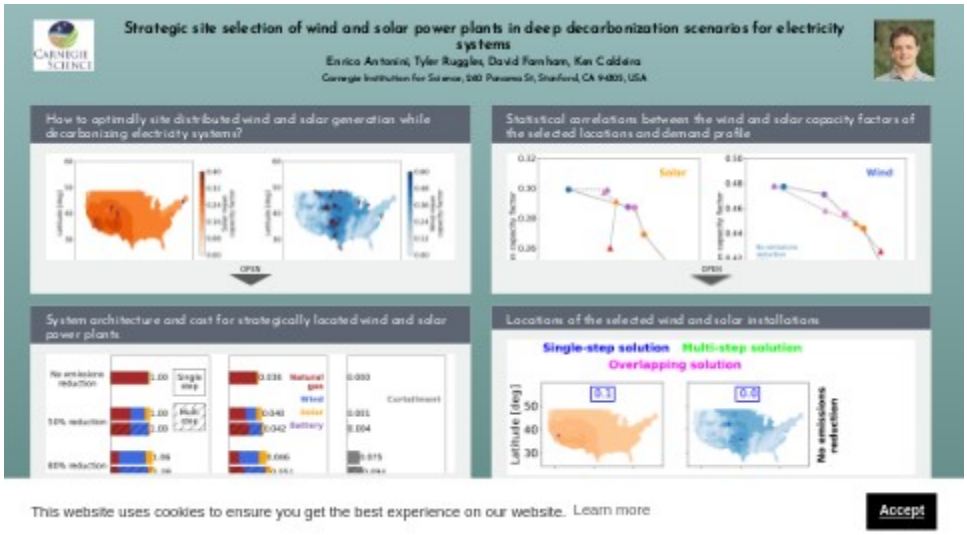
Strategic site selection of wind and solar power plants in deep decarbonization scenarios for electricity systems



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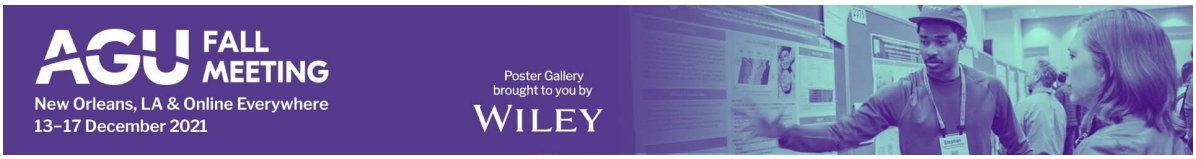
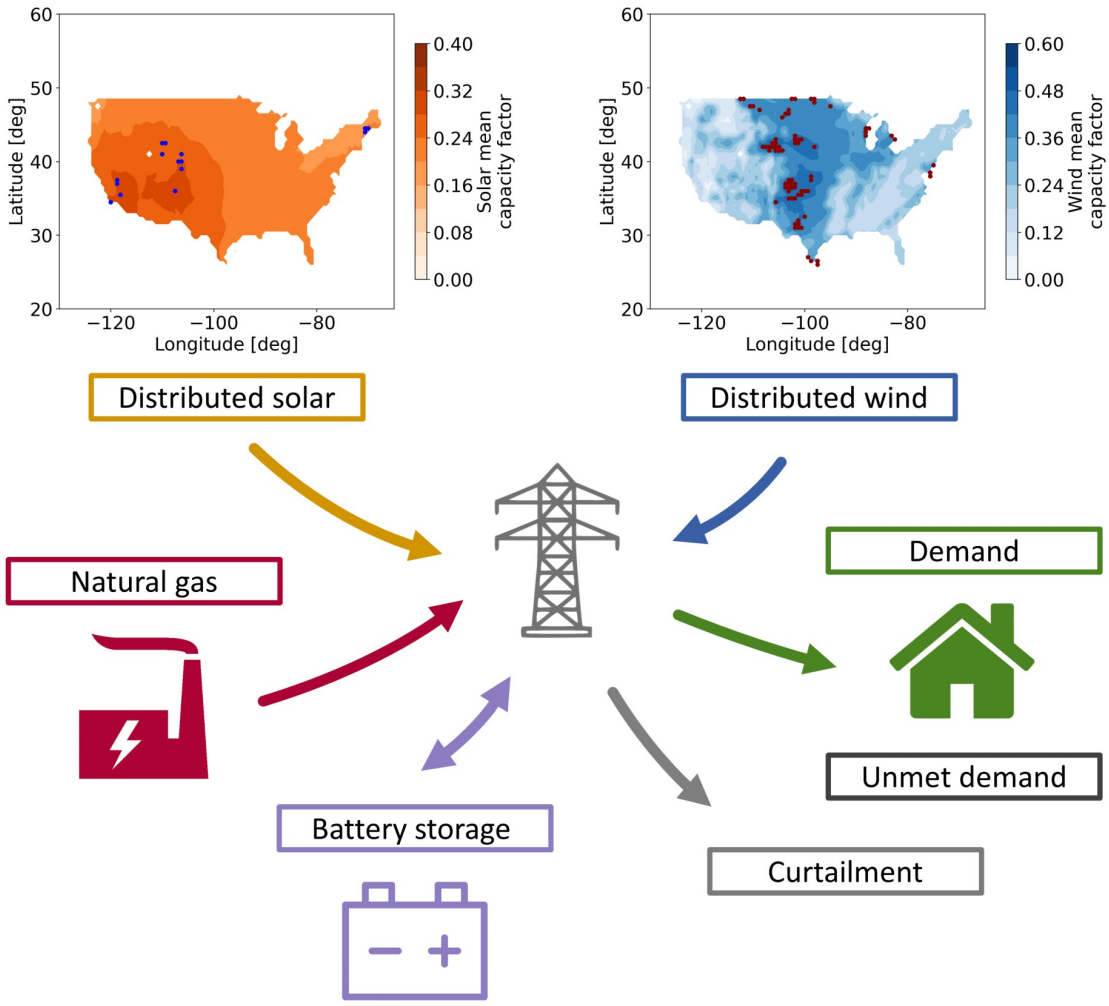
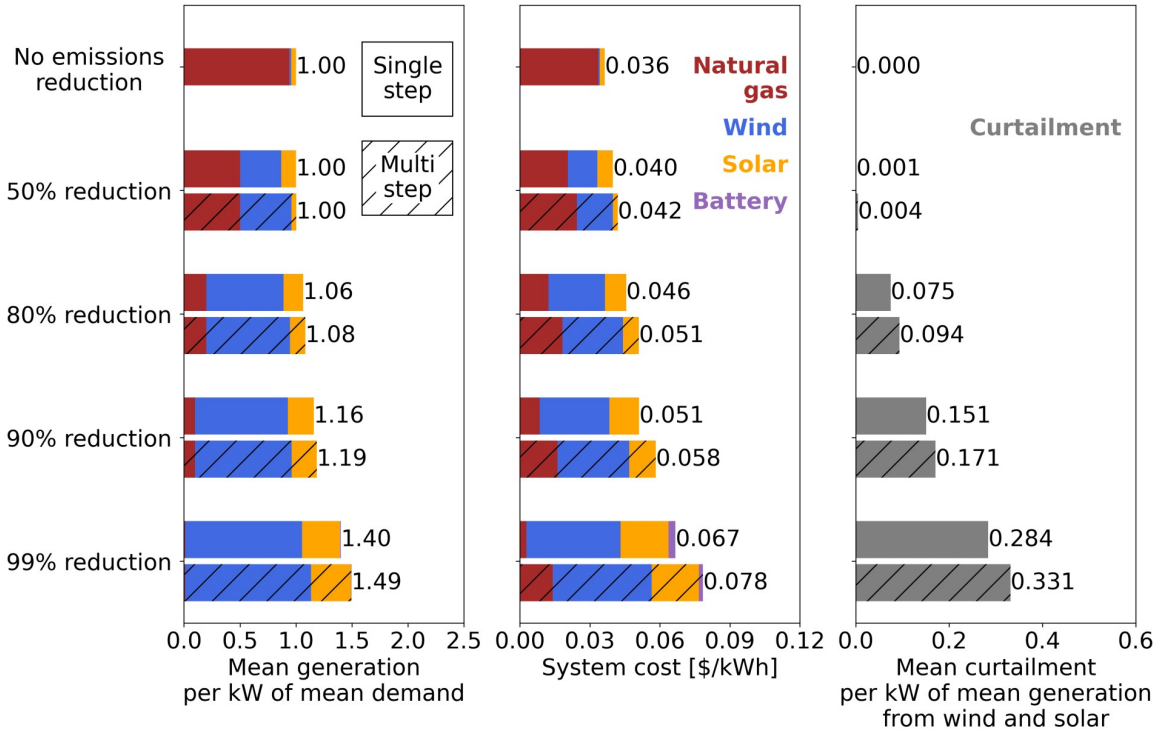


HOW TO OPTIMALLY SITE DISTRIBUTED WIND AND SOLAR GENERATION WHILE DECARBONIZING ELECTRICITY SYSTEMS?



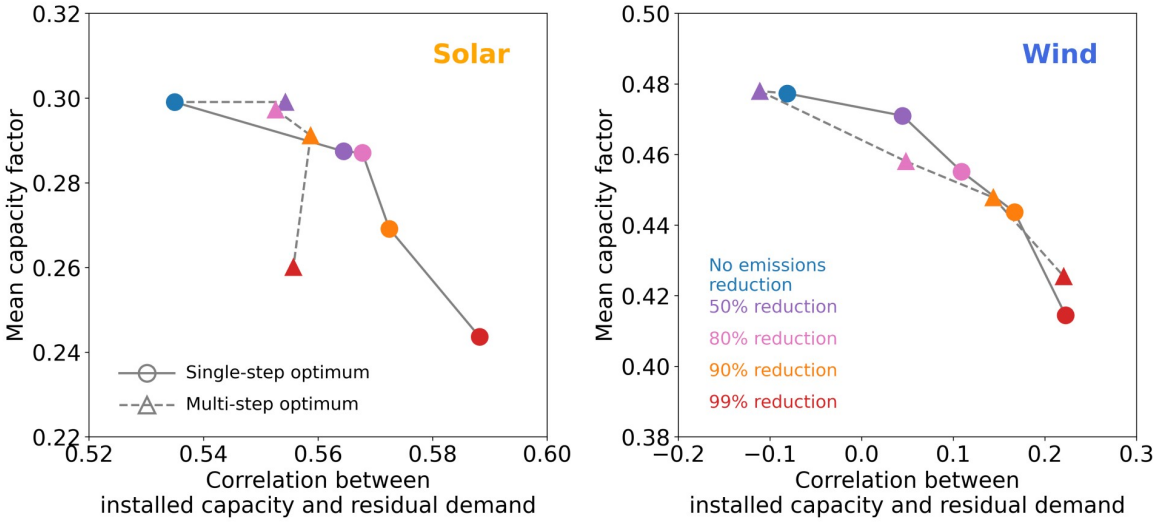
- Wind and solar power are likely to play important roles in any successful transition to a future net-zero emissions electricity system.
- Adding higher shares of wind and solar generation to a power system introduces the challenge of managing greater generation variability.
- When planning for new power generation facilities at the system level it is crucial to determine where to site new generation.
- Here, we show potential advantages of long-term planning when relying on distributed wind and solar power to decarbonize an electricity system using a macro-scale energy model.
- We evaluate optimal siting of distributed wind and solar generation in combination with energy storage and natural gas generation with increasingly strict carbon emissions limits.
- We illustrate in an idealized setting how siting decisions made with foresight can lead to more efficient asset allocation.

SYSTEM ARCHITECTURE AND COST FOR STRATEGICALLY LOCATED WIND AND SOLAR POWER PLANTS



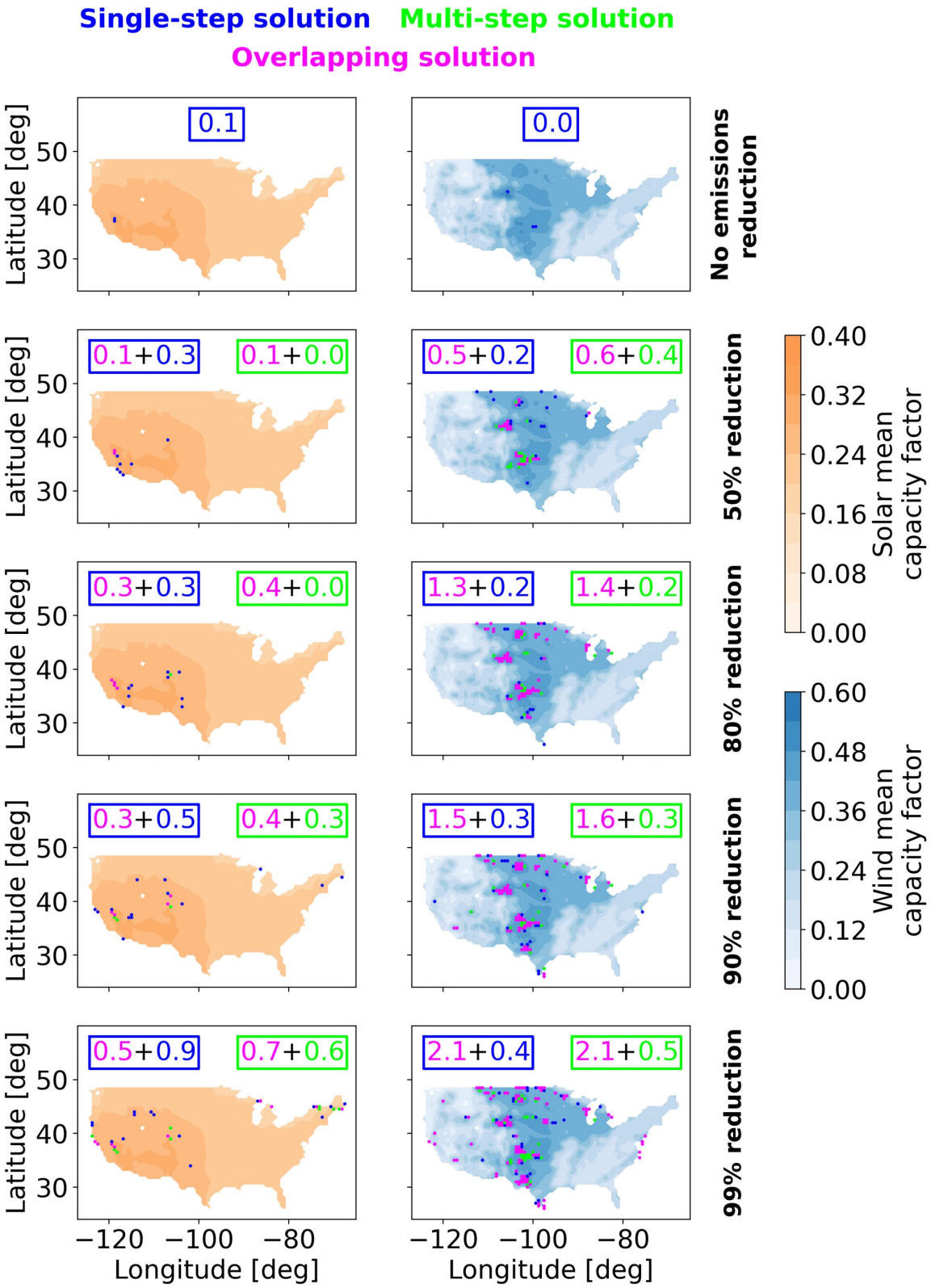
- Here, we show a high-level analysis of the system architectures and costs resulting from increasingly strict carbon emissions limits for both multi-step and single-step optimizations.
- Per kW of mean electricity demand, we show mean generation, system level cost, and mean curtailment of wind and solar generation for increasingly strict carbon emissions limits resulting from both multi-step and single-step optimizations. The mean electricity demand is approximately equal to 460 GW.

STATISTICAL CORRELATIONS BETWEEN THE WIND AND SOLAR CAPACITY FACTORS OF THE SELECTED LOCATIONS AND DEMAND PROFILE



- Here, we show changes in mean capacity factors of selected wind and solar installations versus the correlation between the capacity factor time series and the residual demand for different emissions reduction targets. The left panel shows results for the solar installations, while the right panel for wind.
- For increasingly strict carbon emissions limits, mean capacity factors generally decrease and correlations with residual demand increase.

LOCATIONS OF THE SELECTED WIND AND SOLAR INSTALLATIONS



- For each map, we show the spatial distribution of the wind or solar mean capacity factor along with dots

indicating the locations where generation capacity was installed in the multi-step and single-step least-cost solution. Overlapping optimal locations from these two approaches are plotted in fuchsia. The optimal, non-overlapping solutions of multi-step and single-step optimizations are plotted in green and blue, respectively. In each panel, we also indicate how much total normalized capacity is installed in the respective colored grid cells for both the multi-step and single-step optimizations.

- For the case without emissions limits, the installed capacity of both wind and solar is limited and concentrated in areas with high mean capacity factors.
- As emissions reductions are enforced and natural gas generation phases out, more locations are spread over regions with lower mean capacity factors.
- As the flexibility provided by natural gas diminishes, the correlation between generation and times when other generation is insufficient to meet demand becomes more important.

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ABSTRACT

Wind and solar photovoltaic are projected to play important roles in achieving a net-zero-carbon electricity system that meets current and future energy needs. Here, we show potential advantages of long-term site planning of wind and solar power plants in deep decarbonization scenarios for electricity systems. We use a macro-scale energy model to find the capacities and dispatches that minimize the cost of an electricity system comprised of distributed wind and solar generation, energy storage, and natural gas generation. We find the least-cost system for several scenarios with increasingly strict carbon emissions limits. If there are substantial amounts of sources of flexibility on the grid (e.g., dispatchable power, flexible demand), then capacity factor is a dominant siting consideration for wind and solar. With weak carbon emission constraints, relatively high value is placed on sites with high capacity factors because the added wind or solar capacity can efficiently substitute for natural gas. With strict carbon emission constraints, relatively high value is placed on sites with high correlation with residual demand because resource complementarity can efficiently compensate for a lower system flexibility. Our results suggest that decisions regarding long-term wind and solar farm siting may benefit from consideration of the spatial and temporal evolution of mismatches in electricity demand and generation capacity.