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Coupling fluid dynamic and economic wind farm models to determine optimal wind turbine spacing

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Now that wind-farms are becoming increasingly larger, the economics and physics of wind farms become intrinsically coupled and important when designing large wind farms. It is important to develop wind farm models in which economic considerations can be combined with physical considerations in a transparent and intuitive way. For smaller wind-farms the majority of the turbines can be placed such that physical wake effects are relatively limited and thus wake effects may be less important. However, for large wind farms (e.g. with many hundreds of turbines) it is important to consider the influence of wake effects on the optimal turbine spacing. In this work we combine economic and fluid dynamic models to determine the main parameters that are important for the design of very large wind-farms.

We expand the method used by Meyers and Meneveau [1] to determine the optimal turbine spacing in a very large wind-farm. The influence of several additional aspects, such as cable costs, maintenance costs, the wind-farm layout, and the effect of optimizing net revenue instead of normalized power per unit cost, are addressed. In agreement with prior results [1], we show that without cable costs the optimal turbine spacing strongly depends on the turbine to surface (land or sea surface) cost ratio (α), leading to spacings significantly larger than currently used for typical values of α. However, when realistic cable costs are included, the obtained optimal spacing can be smaller, approaching the commonly used spacings. Additional space reduction can be expected when including maintenance costs, specially in the case of off-shore wind farms.

To assess the influence of the wind-farm layout on the optimal spacing we evaluate the optimal spacing for aligned, staggered, and “best" array layout using the capabilities of the Coupled Wake Boundary Layer (CWBL) model [2] which couples the Jensen model [3] to the top-down model for very large wind farms. The differences in the optimal spacing for the staggered, aligned and “best" array layout are analyzed and discussed. The same considerations can be extended to maximizing profitability rather than power per unit cost.

We further present results that include costs associated with loading that are proportional to the turbulence intensity levels in the wakes. We examine the capabilities of the CWBL model to provide predictions for turbulence intensity as function of wind farm parameters and then use the results in the optimization approach. It is recalled that for the design of an actual wind-farm local effects and restrictions should always been taken into account. However, an analytical analysis such as presented here is useful to provide insights about the main trends and to develop intuition of the factors that are important for the design of wind-farms.

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