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Wind speed reductions by large-scale wind turbine deployments lower turbine efficiencies and set low wind power potentials

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Wind turbines generate electricity by removing kinetic energy from the atmosphere. Large numbers of wind turbines are likely to reduce wind speeds, which lowers estimates of electricity generation from what would be presumed from unaffected conditions. Here, we test how well wind power potentials that account for this effect can be estimated without explicitly simulating atmospheric dynamics. We first use simulations with an atmospheric general circulation model (GCM) that explicitly simulates the effects of wind turbines to derive wind power limits (GCM estimate), and compare them to a simple approach derived from the climatological conditions without turbines [vertical kinetic energy (VKE) estimate]. On land, we find strong agreement between the VKE and GCM estimates with respect to electricity generation rates (0.32 and 0.37 W_e m^{-2}) and wind speed reductions by 42 and 44%. Over ocean, the GCM estimate is about twice the VKE estimate (0.59 and 0.29 W_e m^{-2}) and yet with comparable wind speed reductions (50 and 42%). We then show that this bias can be corrected by modifying the downward momentum flux to the surface. Thus, large-scale limits to wind power can be derived from climatological conditions without explicitly simulating atmospheric dynamics. Consistent with the GCM simulations, the approach estimates that only comparatively few land areas are suitable to generate more than 1 W_e m^{-2} of electricity and that larger deployment scales are likely to reduce the expected electricity generation rate of each turbine. We conclude that these atmospheric effects are relevant for planning the future expansion of wind power.