Estimating offshore wind power potentials that account for the kinetic energy removal by wind turbines: the Kinetic Energy Budget of the Atmosphere (KEBA) approach

Axel Kleidon¹ and Lee Miller²

¹Max-Planck-Institut für Biogeochemie, Jena, Germany (axel.kleidon@bgc-jena.mpg.de)
²Atmospheric and Environmental Research, Lexington, MA, USA (lmiller@aer.com)

Offshore wind power is seen as a large renewable energy resource due to the high and continuous wind speeds over the ocean. However, as wind farms expand in scale, wind turbines increasingly remove kinetic energy from the atmospheric flow, reducing wind speeds and expected electricity yields. Here we show that this removal effect of large wind farms and the drop in yields can be estimated in a relatively simple way by considering the kinetic energy budget of the lower atmosphere, which we refer to as the KEBA approach. We first show that KEBA can reproduce the estimated, climatological yields of wind farms of different sizes and locations using previously published numerical model simulations with an explicit wind farm representation. We then show the relevance of these reductions by evaluating the contribution of offshore wind energy in specific scenarios of Germany’s energy transition in the year 2050. Our estimates suggest that due to reduced wind speeds, mean capacity factors of wind farms are reduced to 33 - 39%, which is notably less than capacity factors above 50% that are commonly assumed in energy scenarios. This reduction is explained by KEBA by the depletion of the horizontal flow of kinetic energy by the wind farms and the low vertical renewal rate, which limits large-scale wind energy potentials to less than 1 W m⁻² of surface area. We conclude that wind speed reductions are likely to play a substantial role in the further expansion of offshore wind energy and need to be considered in the planning process. These reduced yields can be estimated by a comparatively simple approach based on budgeting the kinetic energy of the atmosphere surrounding the wind farms.