EGU22-5764
https://doi.org/10.5194/egusphere-egu22-5764
EGU General Assembly 2022
© Author(s) 2022. This work is distributed under
the Creative Commons Attribution 4.0 License.

Estimates of technical wind energy potentials can be improved by incorporating information about the variation in mean boundary layer heights

Jonathan Minz[1], Nsilulu Mbungu[2], Axel Kleidon[1], and Lee Miller[3]
[1]Max Planck Institute of Biogeochemistry, Jena, Germany
[2]University of Pretoria, Pretoria, South Africa
[3]Pacific Northwest National Laboratory, Washington, USA

Policy and economic analyses use simple estimates of regional and global wind energy potential, or technical wind energy potential, to evaluate low carbon energy transition pathways. They neglect the reduction in mean wind speeds due to the extraction of kinetic energy (KE) from the lower atmosphere as a means to reduce the computational complexity. However, climatological analyses of proposed regional wind turbine deployments with capacity densities ranging from 2-10 MW km^{-2} show that this assumption leads to significant overestimation of wind energy potentials because the removal of KE does reduce wind speeds and turbine yields. This gap between policy focussed and climatology based estimates implies the need for the former to use a more climatologically descriptive, yet simple, approach to estimating technical potential. Framing regional wind energy potential within the context of a fixed lower atmosphere KE budget which uses variation in mean boundary layer height to define the KE budgets can improve estimates without increasing computational complexity. We evaluate this hypothesis by analysing a set of previously published Weather Research and Forecasting simulations of a hypothetical large scale wind turbine deployment in Kansas, US, which showed that nighttime yields were lower than daytime, despite wind speeds being 40% higher at night. We assess this seemingly counter-intuitive result by estimating day and nighttime yields while constraining them with separate day and night KE budgets. Daytime budgets are defined by higher mean boundary layer heights (2000m) while nighttime budgets by lower heights (900m). The combination of wind speeds boundary layer variations during day and night result in similar budgets. This means that turbines extract more KE from the atmosphere at night than daytime, leading to the nighttime budgets being depleted faster and thus lower deployment yields. Using the standard approach, which discounts the effect of KE removal by wind turbines, leads to a 180% and 600% overestimation in day and nighttime yields, respectively, relative to the weather model simulations. The KE budget approach , in contrast, leads to a significant improvement with day and nighttime bias being reduced to 20% and 60%, respectively. Using this approach, we revaluate existing technical wind energy potentials using the net area available for wind energy deployment in Kansas to show that yield expectations of 2000-3000 TWh yr^{-1} could be reduced by almost 50%. Despite this reduction, the technical potential remains almost 3-5 times higher than the state's 2018 primary energy

consumption. We show that framing the yield from regional wind turbine deployments within a fixed lower atmosphere KE budget framework that uses mean boundary layer variations to define the KE budget leads to more climatologically representative estimates of technical potential without increasing computational complexity. These estimates are likely to improve further with the inclusion of nighttime stability effects. Climatologically representative estimates of technical wind energy potential will enable the development of more robust renewable energy transition policy.