First large-scale direct observation of wind energy's power density is consistent with physically-based models and inconsistent with wind resource estimates that ignore interactions between wind turbines and the atmosphere

Red studies indicate model-based estimates that consider turbine-atmosphere interactions; red range is 10-90th percentiles of US wind farms observed in Miller & Keith (2018) in ERL Miller & Keith, 2018 (Harvard) 0.7% Cont. US land Miller & Keith, 2018 (Harvard) 33% Cont. US land Jacobson et al., 2018 (Stanford) 53 North Am. cities Danish Tech. U for World Bank (2018)¹ 227 W_e m⁻² 10% global land Kammen & Sunter, 2016 (UC Berkeley) $30 W_{e} m^{-2}$ cities Miller & Kleidon, 2016 (Max Planck) 100% global land Miller et al., 2015 (Max Planck) 1% US land Fitch, 2015 (NCAR) 1% global land **US DOE. 2014** 2% US land MacKay, 2013 (U of Cambridge)² → 6.6 W_e m⁻² obs. of 66 UK wind plants Adams & Keith, 2013 (UNC Charlotte) 3% US land IPCC, 2012 from Rogner, 2000 ▶ 6.2 W_P m⁻² 23% global land Jacobson & Archer, 2012 (Stanford) 100% global land Lopez et al., 2012 (US DOE) 29% US land Dabiri, 2011 (Caltech)³ 🗲 21-47 Wբ m⁻² obs. over 49 m^2 Miller et al., 2011 (Max Planck) 100% global land Archer & Jacobson, 2005 (Stanford) 13% global land Keith et al., 2004 (U of Calgary)* 10% global land Gustavson, 1979 (Lawrence Livermore)* 100% global land 0 2 1 3 4 5 power density ($W_e m^{-2}$)

[*] for studies that compute power density limits (saturation), we report half the limit

- [1] "The mean power density is a measure of the wind resource," (https://globalwindatlas.info);
- used in McKinsey & Co. Exhibit 8 in Decarbonization of industrial sectors: the next frontier
- [2] relatively small wind power plants (range: 0.14-13.3km², avg=2.4 km²)
- [3] "Averaged over the 48.6 m² footprint of the six-turbine VAWT [vertical axis wind turbine array]..."

"in vacant desert...[with] topography [that] is flat for approximately 1.5 km in all directions" used in Kammen & Sunter (2016) for city-scale estimate; see our 2 eLetter responses at https://tinyurl.com/EstTooHigh