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Assessing the theoretical potentials of global solar and wind energy from climate reanalysis data

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The physics of energy conversions limit the rate and efficiency of solar and wind energy conversion for human energy use. These limits are reflected in the present-day climate system, where only about 1% of solar energy reaching the Earth's surface results in the generation of wind, defining wind energy as a converted form of solar energy. Here, we use physical thermodynamic limits to energy conversion, combine them with 2001-2011 ECMWF climate reanalysis data to estimate theoretical potentials for solar and wind energy. For solar energy, our estimates of direct and direct+diffuse solar radiation conversion are derived by applying the Carnot limit to the direct and diffuse components of the radiative entropy fluxes. For wind energy, our estimate is derived by quantifying the maximum rate of kinetic energy transport from the free atmosphere to 80-meters above the Earth surface, where wind turbines could convert this kinetic energy to electricity. Both estimates are similar to and consistent with more advanced modeling techniques, while also being easily applied to other climate datasets. These near-surface estimates also show that more than 100-times more solar energy than wind energy could be converted in the present-day climate, while providing both a spatial and temporal context to the renewable energy quantities. In this way, while the present-day limitations of solar or wind energy technologies may suggest that their global potentials are nearly equivalent, we conclude that solar energy has a substantially greater theoretical potential to meet future human energy demands.