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Global ecosystem water limitation under warming driven by energy constraints and physiological CO_2 effects

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Energy and water availability are essential controls on terrestrial ecosystem functions. Recent studies suggest widespread shifts from energy- to water-limited conditions under global warming. We demonstrate that incorporating a thermodynamically appropriate energy indicator fundamentally changes this projection. Surface energy availability for evapotranspiration is primarily determined by net radiation rather than downwelling shortwave radiation or air temperature, as supported by both theory and observations. Using this improved framework, we find no projected net increase in terrestrial ecosystem water limitation under greenhouse warming. Instead, projected bidirectional transitions between water- and energy-limited conditions exhibit comparable magnitudes, with a slight net reduction in the water-limited regime in 1.4% to 2.9% of global warm land areas. These findings are consistent with patterns reported in other ecohydrologically based studies and are supported by empirical evidence of reduced vegetation sensitivity to dry conditions under elevated CO2. Our study bridges ecological and physical theories to improve ecosystem water-energy limitation analysis and provide a clear mechanistic understanding of future ecosystem dynamics.