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Quantifying planetary limits of Earth system processes relevant to human activity using a thermodynamic view of the whole Earth system

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Food, water, and energy play, obviously, a central role in maintaining human activity. In this contribution, I derive estimates for the fundamental limits on the rates by which these resources are provided by Earth system processes and the levels at which these can be used sustainably. The key idea here is that these resources are, directly or indirectly, generated out of the energy associated with the absorption of sunlight, and that the energy conversions from sunlight to other forms ultimately limit the generation of these resources. In order to derive these conversion limits, we need to trace the links between the processes that generate food, water and energy to the absorption of sunlight. The resource "food" results from biomass production by photosynthesis, which requires light and a sufficient magnitude of gas exchange of carbon dioxide at the surface, which is maintained by atmospheric motion which in turn is generated out of differential radiative heating and cooling. The resource "water" is linked to hydrologic cycling, with its magnitude being linked to the latent heat flux of the surface energy balance and water vapor transport in the atmosphere which is also driven by differential radiative heating and cooling. The availability of (renewable) energy is directly related to the generation of different forms of energy of climate system processes, such as the kinetic energy of atmospheric motion, which, again, relates to radiative heating differences. I use thermodynamics and its limits as a basis to establish the planetary limits of these processes and use a simple model to derive first-order estimates. These estimates compare quite well with observations, suggesting that this thermodynamic view of the whole Earth system provides an objective, physical basis to define and quantify planetary boundaries as well as the factors that shape these boundaries.