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Transition to Sustainability: Science Support Through Characterizing and Quantifying Sustainability

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Humanity's sustainability crisis caused by a growing, resource-demanding population on a finite, rapidly changing planet challenges us with large uncertainties. While some see the planet on the edge, it is more likely that humanity as a global species is on the edge. However, science, Earth observations, and socio-economic data do not provide clear indications of where this edge is, and how close we are to this edge. The instruments in the cockpit of a modern airplane provide more relevant and actionable information to the pilots than the "cockpit" of planet Earth provides to those involved in the governance of our planet. There is no manual for those responsible to keep us on a track within the "safe operational space" of humanity.

What science and research is needed to make progress towards a future, where knowledge of sustainability and resilience allows for an evidence-based, adaptive policy and decision-making? Paradoxically, innovation over the recent decades have worsened the sustainablity crisis, but more innovation is imperative to bring us out of it. The comprehensive, conceptual framework for sustainability research that would provide an umbrella identifying the key challenges and a basis for this innovation seems to be missing. Defining sustainability as a characteristic of a process that can be maintained at a certain level indefinitely, we need to agree in a societal deliberation on a few aspects, including what processes we want to consider (the anthroposphere as embedded in the Earth system?), what time frames we want to aim at (not infinity, but very long time frames, e.g., 10,000 years?), and what spatial scales we need to look at (from local to global?). Most importantly, we need to acknowledge that humanity's sustainability is the result of intertwined social, economic, and environmental (s2e) processes that can not be separate. The research then has to clarify in the s2e context what are the attributes of sustainability, the relevant processes, impediments, and interconnections of conditions and processes (such as the food-water-energy nexus).

Who are the stakeholders that need sustainability knowledge for policy and decision making and how can we ensure (e.g., through co-design and co-creation of knowledge) that research is providing what these stakeholders need? What are the 'frontlines' of the sustainability crisis (e.g., the coastal zones; urban sprawl; global interdependency of the economic system; disasters)?

What metrics do we have to measure sustainability in s2e? We could agree on a minimal set of sustainability characteristics and aim to quantify these, including disaster risk, resilience, adaptive capabilities, and livelihood. We have many data sets but discoverability, accessibility, interoperability are often low and data sharing remains an issue. Consequently, we have very few s2e sustainability indicators, and unlike in the cockpit of an airplane, the knowledge of what the 'red lights' are is limited. Nevertheless, on a reengineered planet, for which the past is a poor analogue for the future and predictability of planetary trajectories is limited, we are rapidly transforming social and economic conditions and are creating interdependencies that reduce resilience and increase the probability of disasters, including those with the characteristics of "Black Swans."

How can science support planning for sustainability in the s2e context? We have to ask whether we know the s2e system well enough to decide on the nature of the support. We need to know the global and local boundaries of our "safe operational space," but this is not enough. If the s2e system is in "mediocristan" deterministic prediction-based planning makes sense and science can focus on predictions. However, if the s2e system is in "extremistan," adaptive, proactive, risk- and evidence-based governance is required. In this case, science support has to explore the range of possible system trajectories, provide hazard probabilities and sensitivities, facilitate realistic risk perception, comprehensively monitor the system's states and trends, and ensure efficient early warnings for any emerging critical trajectories. In this case, Earth system analysis considering the physiology of the anthroposphere, syndrome analyses identifying the red spots, and advanced model webs allowing answers to

“What if” questions are essential for the characterization and quantification of sustainability.