A Multidisciplinary Assessment of Earth and Planetary Sustainability

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Abstract

The study of Earth and Planetary Sustainability applies sustainability principles to our planet and its space environment, including the need to protect those environments for future generations. Sustainability fosters a well-functioning balance between societies, economies, and regenerative capacities of the planet's life-support systems. In the planetary context, sustainability is the "long game;" it will depend upon how well we safeguard versus consume resources to not exceed the physical, chemical, and biological planetary boundaries of the Earth and its space environments.

Keywords: Earth, planetary, sustainability, human, space

Una evaluación multidisciplinaria de la sostenibilidad de la Tierra y el planeta

Resumen

El estudio de la Sostenibilidad Terrestre y Planetaria aplica los principios de sostenibilidad a nuestro planeta y su entorno espacial, incluyendo la necesidad de proteger dichos entornos para las generaciones futuras. La sostenibilidad fomenta un equilibrio adecuado entre las sociedades, las economías y la capacidad regenerativa de los sistemas vitales del planeta. En el contexto planetario, la sostenibilidad es un objetivo a largo plazo; dependerá de la eficacia con la que protejamos o consumamos los recursos para no sobrepasar los límites físicos, químicos y biológicos de la Tierra y sus entornos espaciales.

Palabras clave: Tierra, planeta, sostenibilidad, humano, espacio

地球和行星可持续性的多学科评估

摘要

地球与行星可持续性研究将可持续性原则应用于地球及其空

 doi: 10.18278/sesa.5.4.31

间环境，包括“保护这些环境以造福子孙后代”的必要性。可持续性旨在促进社会、经济与地球生命支持系统再生能力之间的良好平衡。从行星层面来看，可持续性是一项“长远之计”；它取决于我们如何有效保护资源而非过度消耗资源，从而避免超出地球及其空间环境的物理、化学和生物承载力极限。

关键词：地球，行星，可持续性，人类，太空

Introduction to Planetary Sustainability: Our Place in the Stars

The study of Earth and Planetary Sustainability applies sustainability principles to our planet and its space environment, including the need to protect those environments for future generations. Sustainability fosters a well-functioning balance between societies, economies, and regenerative capacities of the planet's life-support systems (Sharma, 2024; Ben-Eli, 2015). In the planetary context, sustainability is the "long game"; it will depend upon how well we safeguard versus consume resources to not exceed the physical, chemical, and biological planetary boundaries of the Earth and its space environments (Galli, et al., 2024).

Carl Sagan referred to Earth as our "pale blue dot"—the only planet we know, so far, that harbor's life. Sagan envisioned that our human future in space and on Earth necessitates human compassion and environmental stewardship (Sagan & McCurdy, 1995).

The study of Earth and Planetary sustainability is deeply rooted in human society; it balances human well-being with the long-term health of Earth's ecosystems and life-support systems which are the natural processes and cycles that continue to shape our living planet. A balance of how human societies address and respond to planetary (global) change is critical as it involves people's access to water, food, and energy, protection from climate change impacts, healthy and equitable economic growth from renewable sources, sustainable use and sharing of off-planet resources, and so on (Galli, & Losch, 2019).

Planetary Boundaries. Planetary sustainability necessitates respecting the planetary boundaries of the Earth system (i.e., biodiversity, atmosphere, fresh water), within which "a safe operating space for humanity" can exist (Rockström et al., 2024 & 2009).

Planetary boundaries are thresholds—how we measure our safe operating space of a resilient and stable planet. This concept, developed by Dr. Johan Rockström of the Stockholm Resilience Centre, measures nine boundaries, including: climate change, biosphere integrity, stratospheric ozone depletion, ocean acidification, biogeochemical flows (both N and P), land-system change, freshwater use, atmospheric

aerosol loading, and the introduction of novel entities (Rockström et al., 2024 & 2009). The planetary boundaries framework explores anthropogenic (human-caused) disturbances to critical Earth-system processes; also, it examines risks of these disturbances propelling Earth toward a less hospitable state for humans and other living beings on planet (Kopittke et al., 2021).

A Multidisciplinary Systems Approach. The study of Earth and Planetary Sustainability is complex and multi-disciplinary. Examining global-scale hot topics (i.e., climate change, food security) requires us to use a multidisciplinary systems lens. For sustainable solution-finding, it is important to examine Earth and planetary sustainability using a systems approach and resilience framework.

Our impacts on Earth are not singular nor just contained in the biosphere. We impact every sphere (i.e., hydrosphere, geosphere, cryosphere, atmosphere). Our impact shows how interconnected we are to many systems and cycles on the planet and to our ability to survive and thrive in its safe operating space. Our disruptions to the complex self-regulating Earth systems occur from the ocean (acidification) all the way to the stratosphere (ozone depletion)—and everywhere in between. Also, we impact major Earth cycles; for example, nitrogen and phosphorous cycles, carbon cycle, water cycle, in addition to land use, biodiversity, water and resource consumption, air and chemical pollution, and other functions which regulate biomass and carbon sequestration on the planet.

A systems-approach includes many considerations for Earth and Planetary Sustainability: Recognizing we are in the Anthropocene, our current Epoch where human activities are now the main driver of global system change; 2) Understanding our human connections within and among Earth systems, spheres and cycles; and 3) Acknowledging that humans are *part of* the Earth's system and not *apart from* them (Bohnet et al., 2025; Berkes & Folke, 1998); and, as such, we have a direct role to play in developing and implementing solutions for planetary systems sustainability.

Sustainability for Space Exploration. Humanity's responsibility for sustainability goes beyond Earth. In addition to sustainability considerations on Earth, there are also sustainability considerations for space exploration. By understanding the Earth systems, spheres, and cycles, and our role in them, we can be more informed for our exploration of other terrestrial worlds such as the Moon, Mars, and beyond. More specifically, understanding Earth systems dynamics—and sustainability issues on a planetary scale—can inform how we pioneer, understand, and explore other space bodies too.

Sustainability should be a core principle of space and planetary exploration. Atri, Umansky, and Sreenivasan (2024) explain:

> Existing planetary protection policies must be expanded to include requirements for protecting the Lunar and Martian

environments beyond biological contamination, and guidelines founded on space sustainability should be expanded to include issues beyond orbital debris, crowding, and security.

Integration of sustainability in space exploration is a global necessity. The United Nations Office for Outer Space Affairs (UNOOSA) has proposed an additional 18th goal "Space for All" for the global Sustainable Development Goals (SDGs), which includes mitigating space debris, equitable access to space, and using space technologies (i.e., satellite remote sensing) to accomplish other SDGs (UNOOSA, 2025). In the context of Earth Planetary Boundary (EPB) framework, recognizing the accelerating environmental implications of human activities beyond Earth's atmosphere, the integration of orbital spaces (and outer space) to the EPB framework is needed (Cirkovic & Wood, 2025).

Earth and Planetary Sustainability: Overview of SESA Conference Session

Each of the speakers in the Space Education and Strategic Applications (SESA) Conference session "Earth and Planetary Sustainability" demonstrated how as humans, we are interwoven with our planet's systems, cycles, and spheres. Our actions have system and space implications.

The Earth and Planetary Sustainability session started with three short presentations and concluded with a panel discussion. Below are the descriptions of each presenter and her/his presentation.

1. **Dr. Andreea Mosila.** Dr. Andreea Mosila is a Fulbright scholar and APUS alum. She has been conducting important research in Romania on climate change, specifically the intersection of climate impacts with gender roles, cultural knowledge, and local adaptation strategies which influence community-based resilience (Mosila, 2025).

The title of the presentation was: "What the Danube Delta Taught Me About Planetary Sustainability: A Visual Ethnography of Climate and Human Insecurity in the Danube Delta." The presentation's description was:

> Planetary sustainability is frequently framed through quantifiable indicators such as carbon emissions, sea-level rise, and biodiversity indices. However, in regions like Romania's Danube Delta, sustainability emerges as an embodied and lived experience shaped by the rhythms of nature, intergenerational memory, and the evolving relationship between people and place. Drawing from Fulbright-funded ethnographic fieldwork in the Danube Delta's remote communities, this presentation explores the human dimension of environmental fragility through a visual ethnographic lens. Utilizing photographs and translated ex-

cerpts from oral interviews, primarily with women who have navigated decades of ecological change, I examine the intersection of climate impacts with gender roles, cultural knowledge, and local adaptation strategies. These voices offer vital insight into forms of community-based resilience grounded in observation, memory, and traditional ecological knowledge, underscoring the importance of including peripheral and often marginalized perspectives in the discourse on planetary protection. This study challenges conventional sustainability paradigms and emphasizes the value of integrative approaches that connect scientific analysis with the lived realities of affected communities. The research contributes to a broader understanding of Earth sciences and defense as concerned with preserving natural systems and safeguarding the human communities embedded within them. Ultimately, this presentation advocates for reframing planetary sustainability as a profoundly human endeavor that requires listening to those on the frontlines of environmental change and acknowledging their crucial role in shaping more inclusive and resilient planetary futures.

2. **Terry Trevino.** Terry Trevino is a faculty member of the Space Studies and Earth Sciences Department at American Public University System (APUS). He has been conducting important research on microplastics and nanoplastics in our oceans, specifically, disruptions measured from space to photosynthesis and oceanic carbon cycles which have clear implications for crop yields and global food security.

The title of the presentation was "Remote Sensing of Ocean Health and Nanoplastics via Hyperspectral Detection." The presentation's description was:

> Our planet is resilient, but the challenges ahead demand urgent action. Microplastics and nanoplastics are not just pollutants, they are an evolving planetary crisis, infiltrating ecosystems at every level, from the deepest oceans to the highest atmospheric layers. These microscopic invaders disrupt photosynthesis, alter oceanic carbon cycles, and threaten global food security. Our latest research, along with work from hundreds of scientists worldwide, quantifies the staggering impact: annual losses of up to 360 million metric tons in crops and over twenty-four million metric tons in seafood due to microplastic-induced photosynthetic decline. This is a challenge we can measure from orbit. Satellites equipped with hyperspectral imaging and advanced AI models are now tracking the net effects of microplastics on primary productivity, ocean health, and atmospheric feedback

loops. We are at the forefront of integrating this data into actionable mitigation strategies.

3. **Jane Ielmini.** Jane Ielmini leads a business at the center of space sustainability, including work on space debris. Jane has been investigating how our planet's orbit has become more congested with debris, traffic, and aging infrastructure and how sustainability of the space environment is paramount.

The title of the presentation was: "Orbit on the Edge: Redesigning Space for a Sustainable Future." The description of the presentation was:

> The message is clear: space is not just exploration, it is infrastructure. And just like on Earth, sustainability begins with smart design, global collaboration, and accountability. In this talk, Jane Ielmini, Co-Founder & COO of Orbotic Systems explores how innovation and stewardship intersect to enable a safer space environment. Our planet's orbit is more crowded—and more critical—than ever before. From GPS and internet access to weather monitoring and national defense, modern life depends on a safe and sustainable space environment. Yet orbital space is becoming increasingly risky due to accelerating debris, growing satellite traffic, and aging infrastructure. This presentation examines the scope of the space sustainability challenge and explores the international frameworks, technological breakthroughs, and cooperative efforts underway to address it. From passive tools like Orbotic Systems' D3 deorbit device, to the capabilities fostered by COSMIC, NASA's national consortium for In-Space Servicing, Assembly & Manufacturing (ISAM) launched in April 2023, and the transformative role of ISAM, we'll dive into how the industry is evolving from one-time-use missions to reusable, sustainable orbital ecosystems. Space is evolving into vital infrastructure, one that demands ingenuity, collaboration, and care. Join us on this journey as redesign orbital space for future generations.

4. **Dr. Daniela Messina and Dr. Kelly Reiss.** Dr. Daniela Messina is a Professor in Natural Sciences. Dr. Kelly Reiss is a Professor in Environmental Sciences (Reiss, 2025). They are part of a new faculty initiative: The Center for Earth and Environmental Sciences, Sustainability and Technology (CREST). Their 40-minute panel discussion invited several faculties, including Dr. Lauri Byerley (Health Sciences), Dr. Kristen Miller (Space Studies), and Dr. Kristin Drexler (Earth Sciences) as well as graduate students Bridget Kimsey and Anthony Caole to talk about their roles in field research collaboration at APUS. The research has planetary system implications, with topics including climate

change, pollution, food security, a global pandemic, and others.

The title of the panel was: "The Center for Research in Earth & Environmental Sustainability and Technology (CREST): A Proposal for Promoting Student-Faculty Research in Sustainability." The description of the panel was:

> The proposed Center for Research in Earth & Environmental Sustainability and Technology (CREST) will engage students in science research to explore Earth and Environmental Sciences, Sustainability, Climate Resilience, and related topics. These efforts will foster innovation, environmental stewardship, and sustainable solutions for the future and can contribute to the American Public University Systems (APUS) Global Digital Journey. In this panel discussion, faculty and students will discuss who, what, where, when, why, and how of student-faculty research collaboration through existing projects, new opportunities, and future ideas.

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