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ARTICLE

Humanity's Future: Earth System Science Within and Beyond Planetary Boundaries

Paul Hart[1] and Catherine Hart[2]

[1]Faculty of Education, University of Regina, Canada and [2]Faculty of Kinesiology and Health Studies, University of Regina, Canada
Corresponding author: Paul Hart; Email: paul.hart@uregina.ca

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Abstract
The Planetary Boundaries framework aligns with Earth System Science to delineate the biophysical and biochemical systems known to regulate the state of the planet. Boundary ranges, as historically known, are scientifically likely to maintain Earth system stability and life support systems conducive to human welfare and social stability during the Holocene. The planetary boundaries literature brings a scientific understanding of Anthropocentric global environmental impacts into a framework for considering the state of the Earth system as a whole. Several boundaries have been transgressed while the others are close to boundary limits. As benchmarks for many scientific limits, boundaries may align to affect the Earth system boundaries as Anthropocentric activity related to the Earth's overall state. Recent research also provides strong evidence supporting the conclusion that climate change and biosphere integrity, as core boundaries, are in a zone of rapidly increasing risks. This paper explores recent developments relating to ongoing activities of Earth system governance in navigating transformations that underpin the global sustainability agenda.

Keywords: planetary boundaries; worldview; sustainability; eco-justice

Introduction

Since about the mid-twentieth century, there have been increasing signs that the Earth systems were approaching biogeochemical and physical limits to a degree that threatens Earth's capacities to maintain normal Earth system functioning. According to Rockström et al. (2024) tipping points were rapidly being approached within Earth System limits. The Planetary Boundaries framework emerged from this knowledge. Nine planetary boundaries were defined as key geosphere and biosphere functions that regulate the Earth system. Since the original framing, the new rhetoric has given rise to broad social discourse and adoption of the Planetary Boundaries framework in Earth System Science, governance and sustainable development. In this way, the Planetary Boundaries framework was recognized as a natural step in the integration of Earth System Science and sustainability science. This discourse was directly related to wider social discourse on the need to identify guardrails or limits to human pressures on critical Earth system processes.

Introduced in 2009, the Planetary Boundaries framework sets the environmental limits within which humanity can safely operate. It identifies nine key Earth system processes such as climate stability and water cycle dynamics and uses control/response variables to measure human impacts on the Earth system (Gopal & Pitts, 2024). The complexity of nature is crucial for ecosystem

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balance; thus, the urgent need to understand and address the impact of human activities. It falls upon the Planetary Boundaries framework to define a safe and sustainable operating space and to foreshadow how development can proceed while maintaining Earth system stability. While today's socioeconomics is increasingly under scrutiny, ecological economics offers a crucial lens for understanding the connection between our economic activities and the planet's health. Recognizing the essential role of ecosystem services, whilst respecting planetary boundaries, works toward a more sustainable economy.

Many proposals for compromise, such as Raworth's (2017) doughnut economics, serve to integrate planetary boundaries with societal foundations for work toward balance (i.e., sustainable development). While the concept of planetary boundaries has evolved (see Richardson et al., 2023) and only five original boundaries remain the same, Gobal and Pitts (2024) discuss such change that arguably provides a more comprehensive and accurate assessment of boundaries as new framing for assessing Earth's limits. Such framing serves as grounding for new policies and frameworks (Gopal & Pitts, 2024) and integrates updated information into strategies for future planning. Sörlin and Paglia (2025) recognize that science by itself is not capable of determining the structure and direction of global environmental governance and that political maneuvering is not convincing in realigning deeply held beliefs about human relationships with the biosphere. Thus, Earth systems consensus on an array of principles, priorities and practices governing the global environment is likely to remain somewhat elusive across highly contested social and political aspects of contemporary sustainability politics (recalling the 2012 Planet Under Pressure Conference in London).

Sörlin et al. (2025) admit that they do not know where future global environmental governance will go as they sketch some contours that may bring some cohesion to a century of dispersion by neoliberal soft governance. They argue that such contours offer beginnings of a new framework that may bring cohesion to Earth System Science by juxtaposing global targets with numerous local initiatives that should not adversely affect the present or future. Thus, the Planetary Boundaries framework (justice/equity) can now be extended to include new ideas of governance based on Earth System boundaries. This tendency toward global coordination, integration and multiple governance, as a new understanding of global environmental governance, foreshadows a new discourse beyond sustainability as a progressive path toward responsibility (Sörlin et al., 2025). Thus, it remains to actively engage the responsibilities of Earth System Science to extend the planetary boundaries concept as a shift towards the epistemic and temporal environment as mainstreamed in the UN Sustainable Development Goals. The upshot of this evolution is thinking that more actively engages "the planetary." The challenge of such profound change rests in the human-Earth relationship toward active formation of an Anthropocene.

Hard talk about education

A crucial dimension of planetary justice is education, given its association with the emergence and evolution of Earth System Science, is aimed at understanding the Earth as a complex adaptive system. This implicates the political nature of education within its role of advancing understanding human development on a changing planet. The context is to engage discourse concerning safe operating spaces within the politics of new concepts and frameworks of planetary environing (Sörlin, 2025). In view of scientific evidence that underpins Earth System boundaries on a changing planet, the task for environmental education is fast becoming its crucial role in learning within the relatively new science of wellbeing within Earth System justice.

Hard talk?

There are many current debates on "the planetary" within the humanities, social sciences and Earth System Science (e.g., cultural, social and economic geography) that explore the potential of

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new insights. Verne et al. (2025), for example, explore the potential of future habitability from a geographical viewpoint. They trace the planetary focus as a turning point from the global as resistance to the totalizing Anthropocentric concept of globalization. They do this in favor of the planetary as world ecology and as a foundation for the establishment of Earth System Science among continuing debates within both the social sciences/humanities and the natural sciences. Thus, despite a few essential differences that are being considered against the background of the Anthropocene thesis (i.e., humanity as the central geological factor), the focus becomes defining safe operating spaces for humanity, given that a number of boundaries have been exceeded. The challenge remains with human learning, now with the help of the concepts from Earth system governance/new planetary stewardship (Rockström et al., 2023; Steffen et al., 2011).

The planetary turn means moving beyond the techno-scientific framing of Earth system change and toward posthumanist possibilities for understanding ourselves as posthuman subjects, among a range of equally entitled parts of the planet "in view of an eventful Earth and cosmos" (Clark & Yusoff, 2017). Such a cultural/geographic turn, as planetary (as an environmentally savvy perspective), engages straight forwardly in interweaving an ecological/social focus. Such a focus tends toward specific "hot spots," such as the exploitation of the destructive transforming of Earth under capitalism along with new perspectives of Earth System Science. Following Verne et al., (2025), planetary futures, as it exists at the moment, as the Intergovernmental Panel on Climate Change (IPCC) warns, will, in the next few decades go beyond sustainability and towards habitability as collectively defined self-limitation.

Context

Over fifteen years ago Johan Rockström and colleagues published their findings on nine planetary boundaries (Rockström et al., 2009). The planetary boundaries concept has profoundly refocused the vocabulary and rhetoric of global environmental issues. More recently, the transgression of several of these boundaries, which had become a crucial reference in the literature on sustainability, has challenged capitalist societies to rethink such dynamics that impel highly unsustainable societal directions in terms of formulating societal boundaries, that is, as collectively defined self-limitation (Brand et al., 2023).

Given increasing signs that Earth's biogeochemical and physical capacities are reaching saturation, the Planetary Boundaries framework established nine global boundaries covering key geosphere and biosphere functions including stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, geochemical flows, freshwater change, land system change and change in biosphere. Human development within the Planetary Boundaries framework redefines sustainable development, has inspired Earth observation analytics for planetary health, and has informed new thinking in Earth system observation that defines a safe operating space for broad environmental as well as a societal discourse as a way of navigating sustainable justice pathways and policy.

In a recent update to "Earth Beyond Six of Nine Planetary Boundaries" Richardson et al., (2023) drew upon Earth System Science to delineate and quantify levels of Anthropogenic perturbation. Seven of the nine boundaries have been transgressed while the others edge closer to boundary limits. The Planetary Boundaries framework aligns with Earth System Science to delineate the biophysical and biochemical systems known to regulate the state of the planet. Boundary ranges are historically known and are scientifically likely to maintain Earth system stability and life support systems conducive to human welfare and social stability during the Holocene. The planetary boundaries literature brings a scientific understanding of Anthropocentric global environmental impacts into a framework for considering the state of the Earth system as a whole. For example, the boundaries framework formulates "limits" to the impacts of human changes on the Earth system by identifying scientific-based safe operating space

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for humanity. As benchmarks for many scientific limits, boundaries may combine to affect Earth Science that has been affected by Anthropocentric activity related to the Earth's overall state. Recent research also provides strong evidence supporting the conclusion that climate change and biosphere integrity, as core boundaries, are now in a zone of rapidly increasing risks. Thus, it seems an ideal time to explore recent developments relating to ongoing activities of Earth system governance in navigating transformations that underpin the global sustainability agenda.

Human pressures have also pushed socioeconomic and Earth system metrics into the Anthropocene or what Rockström et al. (2024) describe as a new trajectory, characterized by rising risks of pushing the limits of irreversible and unmanageable shifts in Earth system functioning. The Planetary Boundaries framework has emerged against these threats by setting safe limits for biosphere systems beyond the Holocene. This new global approach is meant to safeguard critical Earth system dynamics (i.e., regulating functions) by limiting human development within planetary boundaries with the precision to produce a high resolution and "real-time" state of the planet.

Power and temporality in pursuing transformative planetary justice

As Ryder et al. (2024) remind, environmental injustice stems from historical legacies of colonialism and capitalism where power arrangements structure conditions of regulations and legal systems that set the socio-ecological conditions of Earth system governance. Within educational contexts, where environmental justice concerns are embedded in historic, systemic and structural power arrangements, such contexts serve as control mechanisms that can stifle open learning within the meta power of rules and regulations. As such, circumstantial change demands examination that critically opens the underlying metapower that controls socio-environmental-educational conditions. This is where new dimensions of Earth system governance and other new theoretical amalgams can more consciously and directly engage crucial processes and practices, power concepts, and learnings of particular content. Insofar as planetary justice is concerned, the future becomes the focus, particularly on understandings of how systems of power can operate or be made to operate in relation to Earth System Science and governance, for example, concerning the planet in relation to human-dominated phenomena.

Earth system science

Although justice-centered approaches to environmental issues challenge the lack of political will for change, conceptual framings from new modeling within Earth system science actively engage planetary boundaries as required where global articulation must facilitate re-engagement with social and natural science to move toward planetary justice at the system level (Pedersen et al., 2024). Ryder et al. (2024) remind us that "forever chemicals," known as polyfluoroalkyl substances (PFAS), used in non-stick pans, waterproof fabrics and flame-retardant carpets, have been linked to increased risk of thyroid, kidney and liver disorders, infertility, certain cancers, and developmental abnormalities. This topic generates enough concern for a focus on its own, for example, risks that threaten the lifespan of present and future populations, hence the new focus on Earth System Science.

Lam and Rousselot (2024) use this new focus to engage interconnecting core Earth System Science concepts across planetary boundaries and values as tipping points to move discussions forward on environmental challenges. However, they also open new conceptual framings with intraacting physical, chemical, and biological processes which simultaneously engage atmosphere, cryosphere, land, ocean and lithosphere (Steffen et al., 2020). Such processes highlight human/cultural dimensions, that is, the dynamics of physical and social components of the Earth system.

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The upshot is to engage both physical components and social dynamics of planetary-scale impacts of human activities (Lam & Rousselot, 2024) within a conceptual framing (Lövbrand et al., 2015).

New science – new understanding

Earth System Science is deeply interdisciplinary and warrants serious discussion of Lam and Rousselot's (2024) conceptual framing. Although much more could be said, Lam and Rousselot indicate, there has been little philosophical discussion that implicates the conceptual framework of the global perspective of Earth System Science until the recent focus on the mixing of core concepts including Anthropocene, planetary boundaries and tipping points.

In the most recent decade, there has been a substantial literature within the social sciences concerning the global Earth System Science framework. Such an Earth-system centric cannot universally account for regional differences or techno-managerial debate and contestation. Such concepts as Anthropocene and planetary boundaries have enriched the scientific background and are now more commonly recognized as central to the narratives that highlight the threats posed by climate tipping points. These have direct implications for planetary boundaries as are officially acknowledged among increasing numbers and levels of governance who regard the future as worthy of continuing discussion and debate, with change in mind.

Such unification defines an interdisciplinary Earth System Science framework of natural and social systems, comprising the Earth System and conceptualizing Anthropocentrism as critical and as beyond ontological homogeneity. Recent developments in Earth System Science, as a critical science, are also intended to explore the dynamics of human society, as both relevant natural and social systems. Such a development can work to transfer global research strategies via critical social systems in their interactions with environments. This is a crucial difference in research as critical social science, where cause, rationalities and politics of environmental education research are approached by thinking creatively and critically within global and politics of environmental (educational) research and policymaking, that is, as political ecology. For example, Worth-Earth system modeling, within Earth System Science, includes social network dynamics (i.e., social norms and values, as value systems) as inspired by climate tipping points, as well as social tipping points, within a socio-ecological system.

The Earth System Science literature now acknowledges that issues with social processes, compared to physical ones whose models are mathematical, constitute a case of epistemic injustice, perhaps as credibility deficit considering "forms of knowledge" and "values" in Earth System Science. Such inquiry underlines the importance of transparency and diversity in the making of values judgments (Pulkkinen et al., 2022) and recognition of complexities of interdisciplinarity within the Earth System Science framework. This lack of value, diversity, and transparency works at different levels of possible trade-offs that need to be articulated across planetary boundaries (Biermann & Kim, 2020; Brand et al., 2021).

Earth system justice

Recent proposals expand the Planetary Boundaries framework to include societal boundaries and focus on an Earth system justice perspective in its approach to planetary boundaries. Gupta et al. (2023) and Rockström et al. (2024) also discuss an Earth system justice framework based on interspecies, intergenerational and intragenerational justice (Gupta et al., 2023) within a more complete discussion of Earth system justice within an Earth System Science context. The point of this activity is to address climate and environmental challenges democratically within a planetary boundaries frame and at different levels across several planetary boundaries (Biermann & Kim, 2020; Brand et al., 2021). More recently, Kortetmaki et al. (2025) created the theoretical notion of "just transition" boundaries (ecological and social) to help make sense of negotiations within

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non-negotiable limits concerning the two most critical planetary boundaries – climate change and biodiversity loss. Such boundaries leave room for plural values and for remaining within safe thresholds insofar as they do not contradict or risk the just transitions boundaries.

As we progress deeper into the Anthropocene with expanding pressures on the Earth system, there are increasing calls for a paradigm shift in governing social transition in ways that ensure planetary resilience and justice for present and future generations. Rockström et al. (2024), following serious exploration of a global commons solution, proposed the planetary commons as an alternative, new paradigm informed by Anthropocene dynamics. This is regarded as a global commons defined by functioning that provides Earth system stability and resilience which includes Earth-regulating biophysical systems. The purpose is to determine the stability of Earth system functions and governance responsibilities and obligations to collectively safeguard Earh systems. The goal is full planetary stewardship, via an overarching global institution responsible for the entire Earth system. The rationale provides grounding in response to the United Nations framework (Rockström et al., 2024). This is regarded as a new framework (paradigm shift) which recommends planetary commons governance to secure critical Earth system functions with obligations spelled out within a new planetary ethic.

As Gupta et al. (2023) write, living within planetary limits requires attention to "justice" as planetary and as within Earth system boundaries. The level of thought goes beyond planetary boundaries to include global justice perspectives and suggests transformations to achieve them, such as fair sharing, value and diversity, transparency, and management of remaining ecological space within boundaries, to ensure safe spaces for humans and other species and the planet, as dimensions of Earth system justice. The issue here within the Planetary Boundaries framework is the potential lack of value diversity and transparency within a relatively small number of experts. Within the context of Earth system justice, the challenge is to include the interests of relevant stakeholders whose values are embedded within the Earth System Science/Planetary Boundaries framework and the operation of Earth system justice (Gupta et al., 2023).

Science evolving

More recently, in work on planetary boundaries and Earth system justice (Brand et al., 2021; Gupta et al., 2023; Rockström et al., 2024), as overseen by the Earth Commission Network, the interest is in balanced interdisciplinary relations across the natural and social sciences. Such critical discussion can be of benefit to educators either eager to or obliged to structure their teaching within balanced views across social and science positions. However, in challenging the value dimension, engagement and implementation requires understandings across a range of different fields of (critical) social and natural science (e.g., within international science initiatives such as Future Earth).

At this stage of development there is no prescribed "correct" solution. Instead, there are serious considerations across categories such as recent works in science-technology-society studies. Here the emphasis is on interdisciplinary approaches that engage issues or topics as problems that transgress traditional disciplines. That is, following traditional groundings, explorations in knowledge production within the framework of Earth System Science. These have expanded to global considerations such as Earth system stewardship, steered along a safe planetary trajectory away from planetary tipping points (Steffen et al., 2018). The focus becomes "issues of values" or questions of justice/ (see Jasanoff, 2021) – ethical, political, and/or economic. Such thinking translates as responsibility, perhaps integrating/interrelating social/natural systems within Earth system studies in terms of planetary stewardship. This work constitutes engaging complexities beyond any one discipline, yet embraced, as we all are, within, as Brand et al. (2021) suggest, in ways that are political within these processes. We have moved beyond, as we once learned, just-the-facts solutions to problems that are naturally political.

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As scientists and lay people explore the changing dynamics of the modern world in terms of climate change, planetary boundaries, and sustainable development as key frameworks, we are guided in our understanding of ecological balance and to recognize the increasing impact of human activities on our planet. Gopal and Pitts (2024), for example, explore two key frameworks that guide our understanding of the risks and opportunities – planetary boundaries, and UN Sustainable Development Goals – within the new frame of nine key Earth system processes. These changes reflect evolving understandings of Earth system processes and indicate vulnerabilities where action is required to maintain the Earth system. The Earth system framework, also grounded in planetary boundaries, serves as a foundation for managing human impacts on the planet and maintaining safe operating space regarding Earth's future. This framework explores challenges and solutions and addresses planetary boundaries problems beyond nature-based solutions within previously silent markets of finance (environmental taxes and charges) as part of a broader strategy to integrate environmental considerations into normal financial decision-making.

It has become crucial that research explores the interfaces of Earth system processes where concepts of planetary boundaries assist in delineating the safe operating spaces beyond which critical Earth system processes would collapse. The need for information on long-term Holocene change can provide an interface for paleoecology and sustainability in constraining limits of acceptable change. And while it is true that sustainability supports continue to grow, they are not yet capable of bridging planetary-to-local scales. However, Broman and Robert (2025) prototype an approach for transitioning to sustainability that emerges from sustainable development goals and planetary boundaries (Richardson et al., 2023).

Gillson et al. (2025) extend these ideas in exploring the complexities of fundamental sustainability challenges by, for example, proposing the need is for systemic, systematic and strategic approaches capable of bridging disciplines, sectors and planetary-to-organizational scales to guide leadership, governance, innovation and problem-solving, according to the experts/leaders. Some well-known macrolevel supports, include the UN's Agenda 2030 sustainable development goals and the planetary boundaries described by Richardson et al. (2023). And while organizations are important for societal transition to push for change locally, nationally and internationally, the problem of strategically engaging in action requires many levels of support. For example, expanding support opens the problem of educating nonscience people at all levels of government and society. At the very least, we can refer to Gillson et al. (2025) who provide a prototype of sustainability supports, in order to work through a process of implementation.

Required: a precautionary principle

The concepts of planetary boundaries, planetary justice and Earth system justice are crucial to live within planetary boundaries as Earth system changes encroach on or threaten to go beyond these limits. If justice is not considered, the biophysical limits may not be adequate to protect current, let alone future, generations. It goes without saying, much work remains to be done. For example, ecological economics critiques traditional models that prioritize endless growth and overlook the real costs of environmental degradation. Many sustainability initiatives implicate new practices from farmers to business executive, from national governments to financial institutions, from current analyses to accurate data collection on environmental impacts such as nutrient use, greenhouse gas emissions, to ocean acidification monitoring. Significant resources will be required as well as overcoming resistance and long-term commitments and investments in advanced monitoring technologies, constructing international reporting standards, additional education and incentives to continue to strengthen regulatory frameworks (Gopal & Pitts, 2024). The goal is to understand longer term risks if we ignore the frameworks, that is planetary boundaries, planetary justice (Kurki, 2024) and sustainable development.

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Re-engaging planetary boundaries in the anthropocene: perspectives and practices

Anthropogenic impacts on the Earth System must be considered within a systematic context (Richardson et al., 2023). If a core challenge of the 21st century is achieving good living conditions for all, then current political and economic trends, hidden behind capitalist market logic, remain at the expense of humanity. For example, Steinberger et al. (2024) argue that capitalist market logic must be confronted by economic democratic deliberation, the challenge and rethinking of social, political and economic relations, population growth, and provisioning systems that seriously engage capitalist economics (Steinberger et al., 2024).

The Planetary Boundaries framework formulates limits of the impact of the Anthroposphere on Earth systems by identifying a scientifically based safe operating space for humanity. Boundary positions research provides strong evidence that implicates levels where further perturbation could potentially lead to systemic planetary changes, as zones of increasing risk implicated in boundaries of climate change and in biosphere integrity. Recent Earth system modeling suggests that the Earth system could retain stability if each of the boundaries were actually respected, despite current cases slipping temporarily outside designed safe ranges.

At present Richardson et al. (2023) provide accumulating evidence that the current level of boundary transgression has already taken the Earth systems beyond safe zones. Yet we lack a comprehensive, integrated theory that can identify evolution from a Holocene-like Earth system For example, complexity increases where new evidence suggests that transgressing one boundary can lead to more steeply increasing another, in the absence of a more comprehensive Earth system model/heuristic. Thus, there remains speculation concerning various scenarios of transgression (as complexities) that must be considered within a systematic context.

In these terms, the Planetary Boundaries framework formulates limits to the Anthropocentric dimension of the Earth system by identifying a scientifically based safe operating space for humanity. It would appear that we can actually safeguard Earth's resilience. For example, biomes across Earth have largely remained stable within the Holocene, as the planetary boundaries references state, for a stable and resilient planet. This focus is directed to an Earth system framed by a Planetary Boundaries framework that evolves in light of updates from various fields of science, in terms of functional biosphere integrity. Components of the Planetary Boundaries framework suggest more deeply integrated modeling of the Earth system as impacted/affected by evolving (human) Anthropocentric activities relevant to the Earth's overall state (i.e., system dynamics and Anthropocentric activities). That is, the nine dimensions (i.e., boundaries), as Earth system components, could always be critically affected by Anthropocentric activities, as relevant to the Earth's overall state. For example, global reduction of forest areas is the strongest functional coupling to the climate system and a control variable representing land system change and thus a possible harbinger of systemic planetary change and/or Earth system stability, if boundaries are respected.

According to Richardson et al. (2023), there is increasing concern that the current level of six of nine boundary transgressions has already compromised the Earth system beyond a safe zone. As a result, the International Panel on Climate Change (IPCC) has introduced the "burning embers" approach to represent gradual transitions from moderate to high risks, initially to focus on core boundaries (climate change and biosphere integrity) as an opening proxy for the geosphere. However, quantifying interactions among boundaries remains a major challenge. Transgressions of one boundary immediately implicate others in ways yet to be determined. The challenge: for research on more extensive transgressions, as multiple within an Earth system model, that can capture a more complex model that fully engages interactions as increasingly serious.

Such discussion implicates a renewal of the politics of planetary boundaries (Biermann, 2016) that opens a political ecology of boundary work as well as a new development paradigm (Rockström & Klum, 2015). The challenge, for social and educational inquiry, is to critically engage the political complexities of the Anthropocene created by global aspects of natural science within relevant dimensions of social science (Castree, 2015).

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Perspectives and outlook

Rockstöm et al. (2024) argue for a new global approach to safeguard critical Earth systems. They propose that a global commons framework must now evolve in order to secure critical Earth system functions with stewardship obligations, for planetary resilience and justice. Such a planetary commons should articulate stewardship obligations through Earth system governance to secure large elements of Earth's system limits, including boreal permafrost, tropical rain forests, and coral reefs. The main challenge is global commons governance for safe operating spaces for protection which include, for example, climate tipping points that have the potential to disrupt/transgress socio-economic and political systems. Thus, Rockström et al. (2024) propose transforming the global commons as a "planetary commons" defined within Earth system regulation of biophysical systems. Implied is the ability to ensure responsibilities for continuation of the planetary commons within a recognizable governance framework. Such action can ensure Earth system governance that acts on a planetary scale with primary responsibility shared amongst nations via the United Nations (Chapin et al., 2022).

Internationally shared responsibility must expand with research and speculation focused on planetary justice as a challenge for Earth system governance – whether it is, in fact, possible to govern in such a way as to achieve a safe and just corridor for people and the planet? Rockström et al. (2009) and Steffen et al. (2015) have identified essential critical boundaries as required to maintain the planetary biosphere. As Raworth (2012) writes and Hickel (2018) speculates, any vision for development within a safe and just space will require the abandonment of growth as well as a shift to post-capitalist economic models. This will also require more detailed conceptualizations of planetary justice, placed within the broader debate on planetary stewardship, Earth system transformation and Earth system governance (Biermann & Kalfagianni, 2020). Critical perspectives also must attend seriously to the role of political agency (e.g., Fraser, 2009). Biermann and Kalfagianni (2020) provide a research frame to assess planetary justice in detail including principles, mechanisms and application for the 2030 Agenda for Sustainable Development, as well as founding documents of the Future Earth platform that provide support at planetary scale. As indicated in the periodical *Earth System Justice*, we are in the middle of a planetary crisis that requires strong modes of Earth system governance, hence the call for planetary justice in search of alternative approaches (Kashwan et al., 2020).

Biermann and Kalfagianni (2020) insist that critical debate on justice at the global level is urgently needed. They reconceptualize the idea and practice of justice within the new frame – planetary justice, which encompasses environmental justice – within the broader debate on planetary stewardship, Earth system transformation, and Earth system governance. With only one percent of the world's population responsible for half of the global greenhouse gas emissions, serious debate on (in)justice, now planetary justice, is required to ground forms of environmental injustice beyond ecological justice with more focus on international relations and the global order (i.e., planetary stewardship, Earth system transformation and Earth system governance). Authors Dirth et al. (2020) develop a conceptual framework on the matter of justice which becomes more obvious among work concerned with areas of planetary justice that implicate the social metanorms of Earth system governance.

Hickey and Robeyns (2020) contribute to understanding the concept, planetary justice, by illuminating theoretical landscapes in discussion of a range of reasons and values that matter for planetary justice, including those relating to humans, animals and nature, and why this matters, that is, the need for a planetary just transition (Kashwan et al., 2020). They extend this idea with an explicit concern for alternatives such as the needs of the poor. Lawless et al. (2020), also focus on metanorms for Earth system governance. These include equity and justice among these concerns as they proffer their research synthesis of drivers of norm diffusion. Biermann and Kalfagianni (2020) build on this planetary justice framework to examine the critical, newly needed relation between political philosophy and empirical social science research. Global environmental

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governance originated for such environmental agreements internationally, beginning in 1972 with the Stockholm UN Conference and lately with the planetary and Earth System Science discourse that implicates conceptual shifts in human-Earth relations. A core tenet (Rockström et al., 2009; Steffen et al., 2015) is that planetary stability increasingly focuses on planetary boundary dimensions as well as performative qualities that act to maintain planetary boundaries towards a more temporal environment. These ideas were mainstreamed as 17 UN Sustainable Development Goals and the 2030 Agenda with Earth System Science as foundation, focused on social transformation of the planetary guide.

The evolution in thinking about global environmental governance for more than 20 years has evolved into a much richer socio-environmental model for more progressive Earth System governance. An expanded socio-environmental narrative of the human-Earth relationship is now directly linked to the Earth System as guidance for continuing societal transformation within Earth system boundaries within the deeper planetary history of the Anthropocene. This places Earth System Science within a rapidly expanding community, further exposing the depth of human-Earth entanglement inspired by new modes of thought with deep relevance for global thinking/programs. For example, the human dimensions of the human-Earth relationship and new inquiry into Earth system indicators delimit safe operating space for humanity as related to Earth system stability. Such a connection was not obvious until concepts such as planetary boundaries were explained scientifically. The planetary boundaries models were made more comprehensible as they were made public by focused working communities such as those related to planetary boundaries, as well as *Anthropocene Reviews* and global acceleration rates. It was argued that economic, social and cultural forces were not the only factors contributing to understating physical and biological systems that underpinned Earth System thinking. Co-evolving narratives have recently emerged within planetary boundaries effecting profound changes with Earth System Science revelations concerning Anthropocene pressures, as political, on global systems.

Complexities of co-evolving narratives: towards rethinking politics

Scheffran (2025) refers to the politics of the Anthropocene, building on conceptions of human relationships, the discourse of the limits to growth, and the great acceleration in human development on planetary boundaries. Future trends that challenge existing world order include transformation of capitalism, power shifts in global politics, and societal influences on democracy. To address such challenges requires societal justice innovations in order to stabilize human development within available environmental space (Earth system boundaries). These challenges aim at transformations in sustainable development arenas such as merging solution concepts and synergies that question use and distribution of natural resources and technical innovation. Such fundamental system change toward new socio-economic and political world order is shaped by challenges of conflict and cooperation, coexistence within diversity, and adaptive governance that integrates socio-ecological and environmental cooperation within conflict-sensitive and resilient political cooperation. Engaging issues of such complexity is crucial for long-term existence across a broad spectrum of possible futures. Although questions remain about any such transition the potential exists within a liberal socio-economic political world order.

Challenges and responsibilities for strategic sustainable development

These scenarios demand serious engagement to address the challenges of political and economic system change towards new socio-economics as part of a new order. There remain questions of readiness within the complexities of nations, if humanity has already reached or passed critical thresholds beyond which destabilizing tendencies will undermine or disrupt reasonable

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transitions/new pathways/resilience for sustainable development and peace (Brauch, 2025). A key question, always in the background, is whether transition beyond existing capitalist economic systems also requires fundamental system change as different ways of facing normative challenges for policies and politics (Scheffran, 2025), for example, implementation of Sustainable Development Goals.

Going further will undoubtedly require serious debate as conditions continue to decline, and limits continue to be breached. Addressing ambivalence and political complexities of multiple crises and going further is crucial. It remains essential that there must be limits to human expansion in the Anthropocene (Scheffran, 2025). We have known this since the Club of Rome report and subsequent arguments for transition to degrowth (Hickel, 2022; Kallis et al., 2025; Rockström et al., 2024).

Growing complexity challenges humanity to engage opposing trends of oversimplification and assesses multiple pathways relating to changes and impacts connecting societal stability within an Earth System. Implications include ways of engaging ecological systems stability of social and natural responsibilities for geopolitical spaces, including local, national and global boundaries. Implicated is the process of adjustment to human activities such as addressing tipping points or cascading effects that can destabilize, for example, Earth systems vulnerable to climate change. Combined effects of environmental change and social conflict can exceed adaptive and coping capacities with diverse consequences, affecting societal stability.

The challenge, according to Scheffran (2025) is to purposefully dwell on conceptions of human nature relations and the discourse of limits to growth, building on the great acceleration in human development on planetary boundaries and polycrisis in the Anthropocene. There is also the need to address multiple limits and pathways in the complex interaction among global expansion, multiple crises and geopolitical conflicts challenging the existing world order. Such challenges relay a need to highlight major areas of risk and conflict, for example: Environment and resource; climate and migration; biodiversity and the transformation of fossil capitalism. The goal is to move step-by-step- inside the issues mentioned and toward solutions that stabilize expansive development on all fronts, to balance human needs within a stable population and within available resources.

Challenges such as these also suggest a kind of governance that pits capitalism against social fundamentals of system change toward socio-political transformation and resilient climate policies. This includes thinking politically within the Anthropocene but towards future-oriented sustainable interactions within the Earth system, including Earth's natural systems. This could provide a basis for developing detailed models that correspond with a more universal sense of sustainable development, proposed some time ago in *Our Common Future* (the Brundtland Report).

Perspectives and outlook: governance and politics within education

In 2026 there remain increasing concerns with expanding economic growth leading to explorations of environmentally sustainable, socially beneficial possibilities such as post-growth inquiries for improving human wellbeing within planetary boundaries. Such inquiries explore development of ecological macroeconomic models for reducing growth dependencies as well as resource use. As one might expect, questions also remain concerning the politics of transition across diverse national politics. For example, post-growth research as part of sustainability science is increasingly influenced by the politics of new ecologically based economics aimed across post-growth to steady-state economics and eventually to degrowth. The emphasis to reduce ecological impact implicates lowering resource use within economic limits to growth. As related to Earth System Science, this kind of change implicates a politics of transition and election of savvy, new politicians with a broad view of livable futures (i.e., the economic limits to growth).

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As a result of these issues, political leadership must now address important questions concerning the possibilities of transition and the satisfaction of basic human needs/wellbeing within planetary carrying capacities, steady state economics and degrowth. The implication is a planned transition of the economic system or at least qualitative improvement without relying on quantitative growth (post-growth ideology) within Earth System Science (Steffan et al., 2020). At the same time and for the same reasons, contemporary education needs to re-engage with critical theory in order to develop a more situated critique of education as a more reflexive and situated approach to critical theory, somewhat more critical of contemporary capitalism, and in particular, their return to engage humanistic concepts. The idea could be, as Robertson and Beech (2024) indicate, the generation of a set of propositions that might guide education into the future, as a matter of social justice. Examples might include Nancy Fraser's ideas concerning putting critical theory to work with education, for instance engaging students in more focused participant and observer stances to better understand the engaging workings of power and for the suffering and alienation of others, rather than the shortfalls of others, as neoliberal societies would have us believe.

In "'The unbearable lightness of being' a post-industrial learner: Contemporary capitalism, education and critique," Robertson and Beech (2024) re-engage critical theory to develop a situated critique of education within contemporary capitalism. They propose a set of propositions that might guide education into the future as a matter of social justice, foregrounding the questioning of our assumptions about our concepts, beliefs and commitments as contingently made up of complex relations of power, domination and violence (Fraser, 2022). In educational settings, this involves engaging students in participant and observer stances to better understand the ongoing workings of power, as well as fully understanding the suffering or alienation of others that are contingently made up of complex relations of power, beliefs and commitments (Robertson & Beech, 2024).

It follows that we need education that is strongly immersed within matters of social justice within open conversation in ways that implicate learning to reason across divides, exploring how these divides were constructed. The nature of power relations begs examination as critical pedagogical engagements and encounters that aim to make visible power domination as well as the conditions for overcoming, as part of a reflective engagement of global and local governance. The more general idea is to educate how to critically reflect on taken-for-granted conceptual ideas as a base for critical governing of educational futures within, and possibly beyond, the context of contemporary capitalism. The aim is to create focus on promoting conceptions of agency and well being in the face of big challenges of ecological responsibility amidst problematic futures of political–economic system. The challenge is in looking towards education student development of their own capacities for collective action towards a better world (Robertson & Beech, 2024) beyond the expansion of global capitalism. The idea is to consider how to generate interest within and beyond formal education to actively engage democratic practices of equitable inclusion with values, ethics and pedagogies, that is to say, the rise of environment as a challenging, longer-term political project with moral implications, on a planetary scale!

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Author Biographies

Paul Hart is Professor Emeritus and Adjunct Professor of Science and Environmental Education at the University of Regina, Canada. He has authored and edited many book chapters and journal articles, served on Canadian research awards selection committees and received local, regional, national and international awards for his publications including the *Journal of Research in Science* Teaching Research Award, the North American Association for Environmental Education (NAAEE) Research Award as well as the NAAEE Jeske Award for leadership and service to the field of environmental education. He has served as Executive Editor of the *Journal of Environmental Education* and on editorial boards for EE journals including the *Australian Journal of Environmental Education* and *Environmental Education Research*.

Catherine Hart (PhD) is an Instructor in the Faculty of Kinesiology and Health Studies at the University of Regina, Canada. Her research interests include environmental subjectivity and discourses, intersections between environment and human health, and gender issues in environmental education. She is also interested in postqualitative approaches to research at ontoepistemic, theoretical and (non)methodological levels. She is a Consulting Editor for the *Journal of Environmental Education* and regular reviewer for *Environmental Education Research, Environmental Studies and Sciences*, the *Canadian Journal of Environmental Education,* and the *Australian Journal of Environmental Education*.

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