14. Advancing global environmental politics research through systems-oriented analysis

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INTRODUCTION

The Earth's biosphere where all life exists, dating back 3.5 billion years, has been shaped by tectonic shifts, at least one major asteroid hitting the Earth's surface, temperature changes and ice ages, and evolutionary processes. Modern humans—*Homo sapiens*—have lived in the biosphere for the last 250,000 years (Folke et al. 2021). The influence of *Homo sapiens* on the Earth's biosphere over time has increased to the point where humans are major drivers of global ecological change (Crutzen 2006). At the same time, human-induced turbulence in the Earth's biophysical systems increasingly shapes human societies. Turbulence, which is characterized by high degrees of complexity and dynamism, is also a hallmark of world politics (Rosenau 1990). Some present-day turbulence is the result of changes within the international political system, but it also increasingly stems from an unfolding environmental crisis. Thus, we have now reached a point in Spaceship Earth's history where human-caused turbulence related to biophysical systems interacts with world politics in complex and often little understood ways. This has deep implications for both scholars and practitioners of global environmental politics.

Growing turbulence from human-induced changes to the Earth's biophysical systems creates a challenge for the study and practice of global environmental politics. Meeting this challenge requires that researchers in global

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environmental politics look outside their own immediate field of study for data and interdisciplinary collaborations. One major area of global environmental politics scholarship focuses on institutional analysis, including the design of multilateral environmental agreements and other collective institutions for addressing environmental issues (Young 2002). In this chapter, I argue that there is a need to expand global environmental politics scholarship on institutions by simultaneously considering political and socio-economic dimensions and biophysical dynamics of different environmental issues. To this end, analysts can use the human–environmental–technical (HTE) framework first proposed by Selin and Selin (2020) as a means to integrate the study of global environmental politics with systems-oriented analysis of people, the environment, and technology, to advance both the theory and practice of environmental institution-building in support of advancing sustainability on a turbulent planet.

GLOBAL ENVIRONMENTAL GOVERNANCE AND INSTITUTIONAL DESIGN

Much sustainability-related research applies a human-centric perspective with a focus on enhancing human well-being for current and future generations. A central purpose of sustainability science research is to produce empirically grounded knowledge that informs and supports efforts to move societies toward greater sustainability (Clark and Harley 2020). Such research includes global environmental politics scholarship, including on issues of institutional design. Analysis shows, however, that many current legal, political, and economic institutions are largely ill-equipped and inadequate to manage a transition toward sustainability (Biermann et al. 2012). In an era of planetary turbulence in both biophysical systems and world politics, there is much need to further consider the future of international institution-building, including through the development of a new generation of international environmental law that is not merely reacting to different environmental problems, but assuming a more active role in steering societies toward greater sustainability (Kim 2021).

Effective environmental institutions are critical to guide collective action with the aim of advancing sustainability (Haas et al. 1993; Young 2002). Many scholars of global environmental politics argue that multilevel and polycentric governance structures across different governance scales are often better at ensuring a higher degree of institutional fit with environmental issues than more monocentric and traditional top-down governance structures (Selin 2010; Abbott 2012). Polycentric governance involves many actors and policy instruments that are not organized in a strict hierarchical way, and governance happens in a large number of forums at multiple geographical scales simultaneously. Such polycentricism facilitates policy experimentation, learning, and diffusion across forums and jurisdictions (Hoffmann 2011). This creates opportunities to address different aspects of complex environmental issues in separate forums, which can contribute to better overall environmental governance. It is also important that institution-building in one forum does not inhibit that in others, but rather creates synergistic benefits for governance (Selin 2010).

The design of an international institution supporting environmental management and sustainability, including multilateral treaties and transnational certification schemes, often involves trying to find a delicate balance between institutional robustness and flexibility (Young 2002). Robustness refers to the capacity of an institution to withstand external pressure without undergoing transformative change or collapsing. Such durability over time is important for setting consistent standards and expectations over time. Yet, any institution is the product of a particular set of actor-specific interests, capabilities, and knowledge about an environmental issue, and all of these factors are likely to evolve with time, not least during times of turbulence. This creates a need for an institution to have the flexibility to change over time, as both scholars and practitioners recognize the importance of designing adaptable institutions; and this has only become more important on an increasingly human-dominated planet. In addition, it may sometimes be necessary to actively break down an existing institution because it generates unsustainable outcomes.

Institutional design is shaped by how dominant actors understand and define an issue. Problem descriptions in the environmental politics literature often focus on political and societal aspects of an issue. Environmental problems have been classified on a spectrum from benign (relatively easy to address) to malign (much harder to solve) (Miles et al. 2002). Other types of issue categories found in the literature include wicked and super-wicked problems (Termeer et al. 2019). Super-wicked problems have been defined as comprising four key governance features: time is running out; those who cause the problem also seek to provide a solution; the central authority needed to address it is weak or non-existent; and policy responses discount the future irrationally (Levin et al. 2012). These kinds of problem characterizations, however, are too simplified to assist critical thinking about, and analyses of, the design of effective (international) environmental institutions during turbulence in world politics and biophysical systems. To this end, it is necessary to take both specific societal and biophysical aspects of an environmental issue into consideration during institution-building.

Many environmental issues are characterized by dynamic flows of materials through societies and the environment, generating both benefits and harm to human well-being. Analyzing societal and environmental flows of materials in an integrated way requires combining information from the social sciences, natural sciences, and engineering (Selin and Selin 2020). Societal flows can be studied by looking at production, trade, use, and waste handling of commercial substances and products. Gaining a better understanding of how materials flow through the environment is part of natural-science-oriented studies of biogeochemical cycling. Environmental flows may change as a result of alterations to natural processes, including through the exceedance of tipping points in the Earth system that are under growing pressure from human activities. Engineering studies of the operation and development of technology can also aid analysis of both societal and environmental flows of materials. Integrating information from the social sciences, natural sciences, and engineering is not easy, but systems analysis offers one way of doing this.

SYSTEMS-ORIENTED SUSTAINABILITY ANALYSIS AND THE HTE FRAMEWORK

Systems analysis for sustainability has become increasingly common over the past few decades (Biggs et al. 2021). Many sustainability-relevant relationships between human activities and biophysical processes involve nonlinearities, multiple feedback loops, and time delays in impacts. There are currently few analytical tools to empirically study the design of international environmental institutions that simultaneously capture integrated societal and biophysical aspects of environmental issues. However, combining global environmental politics research on institutional design with studies using the HTE framework can help advance institutional analysis as well as inform the design of the kind of environmental institutions that are needed to enhance sustainability. The four-step application of the HTE framework is briefly outlined below, with Selin and Selin (2020 and 2022a) providing more detailed descriptions.

The first step involves researchers identifying the central components of a particular system of relevance to sustainability. The HTE framework consists of five categories of system components (see Figure 14.1). Three of these are the material human, technical, and environmental components where two or more of such components interact in the context of two categories of non-material institutional and knowledge components. Determining both which individual components to include and the "right" number of total components is an empirical task—the total number of components needs to be large enough to capture important system dynamics, but the number of components also needs to be few enough to allow for applied analysis of system operations and effects on human well-being in practice. Each individual component has specific attributes, with Figure 14.1 listing specific examples. It is important to focus on those attributes that are particularly relevant for sustainability-oriented analysis.

Human components are individual people or groups of people such as laborers or a population in a particular geographical place who have attrib-

Human components	Technical components	Environmental components
Individual people or groups of people (genetic conditions, age, education, wealth)	Infrastructure or material artifacts of human society (mass, quantity, operational efficiency)	Earth's life-support system; biosphere; nonhuman living organisms (physical properties, biological characteristics)

Institutional components	Knowledge components
Social structures of rules, norms, and shared expectations (scope, stringency)	Information about other system components and their interactions (awareness, data availability)

Source: Selin and Selin 2022a.

Figure 14.1 The HTE framework's five sets of system components with sample attributes listed in parentheses

utes such as their genetic conditions and age. Technical components consist of infrastructure such as a manufacturing plant or material artifacts such as a fishing rod that have attributes related to their mass and operational efficiency. Environmental components are parts of the Earth's life-support system and nonhuman living organisms and can be a river or the fish in a lake that have attributes connected to their physical properties or biological characteristics. Institutional components are social structures of rules, norms, and shared expectation that may include national laws and international treaties with attributes of scope and stringency. Knowledge components consist of information about other individual system components and their interactions with attributes related to awareness and data availability.

In the second step of the HTE framework's application, researchers use a matrix-based approach to examine interactions among material system components in the context of existing institutions and knowledge. Analysts construct an interaction matrix to trace pathways of two or more linked interactions across human, technical, and environmental components. The matrix is read row first and column second, and a basic illustrative matrix is shown in Figure 14.2. The shaded square in the first row and second column indicates that human component H1 influences technical component T1, and this interaction is influenced by the existence of institutional component I1. Analysts can identify multiple interaction pathways of relevance to a single environmental issue that may vary in length. Importantly, the structure of the matrix and the tracing of pathways of linked interactions can be used as a diagnosis of levels of turbulence. The complexity of a system is higher the larger the numbers of components and linked interactions. If complexity and dynamism in the system is high, then the risk of turbulent behavior resulting in changes in system components' attributes is also high.

Analysts can trace pathways of linked interactions either forwards or backwards in the interaction matrix. When tracing forwards, the purpose is to look at how one material component affects the attributes of others. In Figure 14.2, one such pathway could be H1 (a factory owner making operational decisions) influencing T1 (a factory where operational changes result in more pollution), which in turn influences E2 (a nearby river into which much of the pollution is discharged). This pathway of linked interactions can be influenced by I2 (a national pollution law that specifies the use of pollution control technology) and K2 (knowledge about how to measure water pollution). Backwards tracing is used to look at causal connections for attribution of which chain of interactions resulted in a particular outcome, including those that lead to turbulence. In the same example of linked interaction above, the analysis starts with pollution being discharged into the river E2 and the reason for these discharges is then traced back through T1 and H1.

	H_1	T_1	T_2	E_1	E_2	E_3
H_1	I_1, K_1	I_1				I_3
T_1		I_3	K_3	I_4	I_2, K_2	
T_2					K_4	
E_1						
E_2						K_4
E_3	K_5					

Source: Selin and Selin 2022a.

Figure 14.2 Sample interaction matrix where shaded squares indicate an interaction in which the row influences the column. These interactions are influenced by institutional components and knowledge components

The third step in the application of the HTE framework involves evaluating prospects for change that promote sustainability. This involves the identification of interveners who possess agency to change how a system operates. Possible interveners include international treaty bodies, national and local governments, private sector actors, and nongovernmental organizations. Interventions can be studied through the construction of an intervention matrix; types of interventions are aggregated for illustrative purposes in an intervention matrix in Figure 14.3. Analysis can focus on both evaluating past interventions and considering the effects of new possible interventions. An intervener can target one or several human, technical, and environmental components or interactions among these. Interventions may include institutional change and/or the application of additional knowledge. Related to the pathway of linked interactions discussed above, national pollution law I2 can be strengthened or the K2 knowledge of how to measure water pollution can be advanced as a way to better protect human well-being.

The fourth and final step of applying the HTE framework involves researchers using the empirically grounded analysis in the previous steps to draw broader insights related to sustainability research and/or societal efforts to advance sustainability. Such insights can pertain to the design and operation of environmentally relevant institutions, including as part of broader multilevel or polycentric governance structures. This can help researchers in global environmental politics to draw lessons from past institutional interventions as well as examine political and practical opportunities for public, private, and civil society actors to strengthen or add to the total number of environmental institutions in ways that recognize the importance of turbulence in both biophysical systems and world politics.

INTERNATIONAL ENVIRONMENTAL INSTITUTION-BUILDING AND THE HTE FRAMEWORK

Global environmental politics scholarship—focusing on collective efforts to address environmental problems while considering the interests, strategies, and powers of a multitude of actors—plays an important role in both sustainability analysis and societal efforts to advance sustainability. As such scholarship is part of a broader study of international affairs, global environmental politics researchers have a history of engaging with the kinds of geopolitical competition over resources and turbulence in world politics described by Rosenau (1990). Much early scholarship in global environmental politics was state-centric, but research now also focuses on the roles of a wide range of non-state actors, including intergovernmental organizations, nongovernmental organizations, and private sector firms and groups. This expansion in actor

	Human	Technical	Environmental
Human	(H–H) Changes targeting people and interactions among people	(H–T) Efforts targeting the way people use technology	(H–E) Efforts to modify the impact of people on the environment
Technical	(T–H) Changes targeted at altering the impact of technology on people	(T–T) Alterations in the properties and operation of technical systems	(T–E) Changes in the ways technologies impact ecosystems
Environmental	(E–H) Actions that impact the way ecosystems affect people	(E–T) Changes to the limits that the environment poses to the operation of technical systems	(E–E) Modifications to ecosystems and related biological processes
Interveners			
International treaty bodies, National and local governments, Private sector actors, Nongovernmental organizations			

Source: Selin and Selin 2022a.

Figure 14.3 Generic intervention matrix where interventions by interveners can include changes to institutional components and knowledge components

focus is compatible with the HTE framework. Applying the HTE framework can help researchers analyze how different interveners can initiate institutional change on a multitude of environmental issues, explore trade-offs between possible interventions, and examine important power dynamics.

Both institutionally focused analysis and the design of environmental institutions are shaped by the fact that many societal transitions related to sustainability are characterized by strong path-dependencies and lock-ins. This is because established institutions and practices are intertwined with individual choices and lifestyles, cultural traditions, business models and economic systems, technology, regulations and other policies, and organizational and political structures can delay efforts to implement institutional change (Markard et al. 2012). In such instances, institutional robustness can be an obstacle to moving societies toward greater sustainability, as institutions that hinder sustainability transitions need to be dismantled and replaced. At the same time, a growing number of analysts are warning that crossing critical tipping points in the Earth's natural life-support system due to human activities increases the risk of more abrupt change (Steffen et al. 2015). This increased risk of more complex, unpredictable, and widespread change to biophysical systems and societies makes institutional analysis as well as the creation of flexible environmental institutions both more difficult and urgent.

It is challenging to predict and govern a turbulent future, but Kim (2021) calls for the development of a new kind of international environmental law that involves a shift away from a traditional focus on restoring the planetary past by, for example, reducing air and water pollution and protecting wetlands, to playing a more active role in the making of the future of the planet. Such international environmental law "should help imagine a safe and just future for all, put the 'derailed' spaceship back on a desirable trajectory, and monitor its course" (Kim 2021: 7). Systems-oriented analysis can help inform global environmental politics research on issues related to the design of new international environmental legal and political institutions as an important type of intervention in systems relevant to sustainability. The HTE framework's inclusion of non-material institutional and knowledge components together with the material human, technical, and environmental components, makes it particularly suitable to help advance institutional analysis that engages the ways in which both societal and environmental flows of materials impact human well-being and informs the design of appropriate institutions.

When analyzing roles of different interveners and possible interventions through modified or new institutions, the development of detailed interaction and intervention matrices is especially useful for exploring how different institutional options affect linked interactions. Specifically, researchers interested in institutional analysis can use an intervention matrix to empirically explore how specific institutional developments may change pathways of interactions among material components and the ways in which such changes may reduce environmental degradation and support human well-being. Such analysis can be informed by the study of past institutional interventions and draw lessons from how those interventions changed societies toward both lesser and greater sustainability. The use of an intervention matrix also allows for a structured comparative analysis of how different institutional developments change attributes of individual material components and associated interactions, which can be evaluated against a common sustainability criterion. Such institutional analysis can focus on functionally separate institutions as well as combinations of linked institutions that are part of a polycentric governance structure.

The HTE framework can inform research on interventions and institution-building on multiple environmental issues. Selin and Selin (2020) first applied this framework to the case of mercury use and pollution, but it can also be applied to many other material flows. For example, the design of institutions aimed at reducing environmental and human health harms from pesticide use requires considering how individual pesticides are produced, traded, and used to better protect local users as well as how these pesticides cycle long-distance through land, air, and water after their agricultural application with the ability to cause harm far away from their original use (Selin 2010). By first identifying the main human, environmental, technical, institutional, and knowledge components related to the pesticides case and then creating interaction and interventions matrixes, researchers in global environmental politics can examine the operation of existing chemical treaties and other relevant institutions. Such analysis also allows researchers the ability to explore how either modifications to existing institutions or the introduction of new institutions can help address governance gaps, by considering how institutional change influences system components and interactions.

The mercury and pesticide cases are examples of issues where there exist global environmental treaties (as well as other international and domestic institutions) designed to address related environmental and human health problems. Then, part of the institutionally focused analysis integrated with the HTE framework is to consider the degree to which existing treaties address both societal and environmental flows of substances. In contrast, the plastics case is an example of an environmental issue where there currently is no global treaty, but where treaty negotiations are beginning. In a case where there is no global multilateral agreement in place, the HTE framework can be helpful for thinking about what a future treaty could and should focus on. This involves constructing and using detailed interaction and intervention matrices to identify material and non-material system components and look at linked interactions related to the manufacturing and use of plastics, the flows of plastics through societies, and the environmental distribution and concentration of discarded plastics. Such analysis can then form the basis for considering what an effective life-cycle-focused plastics treaty may look like.

The HTE framework can also be useful to environmental politics scholars who study more place-based cases, including those related to natural resources management. The explicit incorporation of institutional components in the HTE framework as well as its combined focus on human, technical, and environmental components make the HTE framework particularly useful for integrating systems analysis and institutional analysis in more place-based studies of how people and governments set up structures for the governance of shared resources, including fish, water, and forests. Such analysis also allows analysts to explore how system interactions and outcomes that contribute to environmental degradation and threaten human well-being in a place-based case can be addressed by the introduction of new institutions and multilevel and polycentric governance structures that may range from local to global governance scales. Here, the HTE framework can be seen as a complement to other systems-focused approaches, including those labeled social-ecological systems (Ostrom 2009), social-environmental systems (Eakin and Luers 2006), or coupled human–natural systems (Liu et al. 2007).

Institutionally focused research building on the HTE framework can inform analysis on possible trade-offs from different institutional choices. Global environmental politics scholarship can contribute to such analysis by incorporating insights from the study of the politics of international environmental institution-building, where actors have different interests and levels of influence. Such analysis can be important as the "ideal" institutional response may not be politically feasible, and the pursuit of the most stringent institutional option could delay less ambitious but still important institutional developments. For example, one way to target emissions of mercury into the atmosphere would have been to ban all forms of coal-burning under the Minamata Convention on Mercury. But if the Minamata Convention had tried to introduce such a ban, it would almost certainly have been impossible to conclude the negotiations on a treaty that instead mandates the introduction of technology-based controls on mercury emissions from stationary sources (Selin 2014). Such a mandate pushed at least some countries to set such controls earlier than they would otherwise have done, reducing the amount of mercury that would otherwise be emitted to the atmosphere in the absence of the Minamata Convention (Selin and Selin 2020).

The HTE framework can assist scholars and practitioners of global environmental politics in thinking about institutional effectiveness for the purpose of identifying needs to strengthen treaty-related institutions and improving environmental governance. Evaluations of the effectiveness of global environmental treaties such as the Stockholm Convention on Persistent Organic Pollutants or the Minamata Convention can consider combinations of outcome indicators that reflect changes in impacts on human health and the environment by controlling particular substances, and process indicators that indicate levels of compliance by parties with treaty-based control measures and other mandates (Selin et al. 2018). Natural science research can provide some information related to outcome indicators, but causally linking one institution with an observed environmental change is often very difficult (and sometimes impossible). But when combined with global environmental politics research on treaty implementation and compliance, an effectiveness evaluation can rest on a more solid empirical basis. The HTE framework interaction and intervention matrices can then be used to consider the effects on system components and linked interactions of additional institutional interventions.

Institution-building may involve stakeholders with different interests and levels of resources where power issues are often central (Morrison et al. 2019). That we are now living on a human-dominated planet has led some researchers to conclude that humanity is at risk of crossing critical planetary boundaries in the Earth system (Rockström et al. 2009). Other researchers have criticized the notion of single, planetary-wide boundaries for individual environmental processes, stressing the importance of differences in local variations and vulnerabilities to environmental degradation (Selin and Selin 2020; 2022b). Biermann and Kim (2020) further argue that the planetary boundary concept obscures critical issues of justice and inequalities among countries regarding responsibilities and abilities to act. They point out that the planetary boundary approach was developed "by a group of university professors—largely male, with natural science backgrounds, and tenured in leading positions in OECD countries," which resulted in reduced credibility and legitimacy in developing countries (Biermann and Kim 2020: 511). Biermann and Kim (2020: 512) also criticize the planetary boundaries approach for embodying a "a belief in value-free global change science" where science is seen to have the ability to solve societal disagreements.

Using the HTE framework and the matrix-based approach to map out pathways of interactions and explore possible institutionally focused interventions to advance sustainability can help global environmental politics researchers to think about issues of power and equity, taking seriously the critique by Biermann and Kim (2020) about whose voices are heard and considered when designing new institutions. Stakeholders with varying levels of influence and power may have very different views on what should be a system's primary function, what institutional tools to use to shift a system toward greater sustainability, or even how to define sustainability. Many such changes are also highly localized and place dependent. Different interventions (or a lack of interventions) may affect separate groups of people in different ways. The way a specific institutional intervention that benefits a particular group of people, and possibly harms others, is valued depends on who matters and to whom. The HTE framework provides a way to trace both positive and negative effects of different institutional interventions on different societal groups (e.g., different human components) during sustainability transitions.

CONCLUDING REMARKS

Global environmental politics research is well positioned to continue to play an important role in both studying and advancing institutional development in support of sustainability. Human-induced biophysical turbulence poses significant governance challenges aimed at enhancing the stability and prosperity of contemporary and future societies. Instability in Earth system processes also contributes to greater uncertainty and turbulence in world politics. This highly complex situation, where biophysical and political turbulence are deeply intertwined, creates a need to further develop useful analytical frameworks and practical tools for analyzing and advancing human well-being both now and in the future. To this end, global environmental politics scholarship can be better integrated with interdisciplinary systems-oriented analysis, including for the purpose of advancing institutional analysis that addresses both societal and biophysical aspects of environmental issues. The HTE framework and the matrix-based approach for exploring interactions and interventions provide one option for such integrated analysis.

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