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Planetary Boundaries – Exploring the Challenges for Global Environmental Governance

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ABSTRACT

A range of studies from Earth system scientists argue that human activities drives multiple, interacting effects that cascade through the Earth system. Recent contributions state and quantify nine, interacting «planetary boundaries» with possible threshold effects. This article provides an overview of the Earth system governance challenges that follow from this notion of multiple, interacting and possibly non-linear «planetary boundaries». Here we discuss four interrelated global governance challenges, as well as some possible ways to address them in future research. The four identified challenges are related to 1) the interplay between Earth system science and global policies; 2) the capacity of international institutions to deal with individual planetary boundaries, as well as interactions between them; 3) the role of international organizations in dealing with planetary boundaries interactions; and 4) the role of Earth system governance in framing social-ecological innovations.

1. Introduction

The possible implications of abrupt climate change have induced considerable scientific and political attention. Recently, scientists engaged with global sustainability have put the climate issue in a broader Earth system context by exploring additional so-called "planetary boundaries" [1-2]. These are nine, possibly non-linear Earth system processes that manifest themselves at the planetary level and include in addition to climate impacts, ozone depletion, atmospheric aerosol loading, ocean acidification, global freshwater use, chemical pollution, land system change, biodiversity, and biogeochemistry. Planetary boundaries are however not fixed. They represent estimates of how close to an uncertainty zone that the global human community can act, without seriously challenging the continuation of the current state of the planet.

Drawing a "safe operating space for humanity" as suggested by Rockström and colleagues [1-2] is bound to be a highly controversial project. Until now the consequences for policy-making and institutional analysis are unexplored. While some responses from international policy-makers such as several UN-bodies have been positive, others have questioned the political usefulness of the approach [3-4]. Given these highly conflicting perspectives, it is remarkable that the scholarly study of the implications of multiple, interacting and possibly non-linear global environmental changes have been a rather peripheral research object.

Here, we explore the notion of "planetary boundaries" from the perspective of Earth system governance [defined in 5]. Hence this is an attempt to provide a synthesis overview of the Earth system governance challenges that follow from the recognition that human activities drive multiple, interacting effects that cascade through the Earth system in complex, non-linear ways [6-8]. We explore the issue by asking:

What are the implications of multiple, interacting and quantified "planetary boundaries" for critical elements of Earth System Governance (ESG)?

Our analysis is by no means an exhaustive list or analysis of Earth system governance challenges. Rather, we focus on what we believe are a few key ESG challenges posed by the Planetary Boundaries framework. In the following, we elaborate the issue further by discussing four interrelated ESG challenges, as well as some possible ways to address them analytically.[1] The next part deals with the role of Earth system science, and it's relationship with global policies. The third part elaborates the role of international institutions and their capacities to deal with individual, as well as interacting planetary boundaries. This discussion is followed by a brief elaboration of the role of international organizations. And lastly, we discuss the links between innovation, governance and planetary boundaries.

2. Planetary Boundaries, Science and Policy

The first challenge we explore is the one that arises as Earth system science meets the field of global policies. It should be noted that the analysis presented in [1,2] synthesizes decades of research from a number of academic fields concerned with the Earth system. The quantified boundaries could therefore, despite considerable uncertainties, be viewed as a rough operationalization of the biogeophysical component of "sustainable development" [9], or as a target for emerging notions of Earth system governance [10]. This way of thinking seems resonates well with key international agencies such as UNEP [11]. However, the translation between PB science and policy is far from unproblematic as it is often portrayed.

First, the concept of «boundaries», can be viewed as strongly normative. While «boundaries» can hold a positive connotation as a motivation for collective action [12], they also imply contested scientifically defined frames to human activity. One example is the likely North-South dimension in defining what constitutes a "safe" operating space. Rockström and colleagues explicitly chose a conservative boundary in the identified

[1] The word "interrelated" is important here, as global governance always implies considerable overlap and interplay between knowledge systems, institutions and actors such as organizations. The division in different themes has been done to simplify the analysis within the limited space available.

"zone of uncertainty" [1:473, 2:fig 2]. While this might seem reasonable based on the precautionary principle, it is also likely to induce considerable debate between nations with different risk perceptions, and needs for development.

For example, international attempts to address deforestation [21], protect coral reef ecosystems [22], govern fisheries [23], and transboundary river basins [24] have all had limited success due to differences in interests and risk perceptions between international, national, and local interests. Planetary boundaries pose additional challenges due to their uncertainties, and dynamic features. The argument non-linear effects are possible [1,2], does not guarantee political action, but could on the contrary induce actors to focus on, and invest in post-threshold adaptation, rather than on drastic pre-threshold mitigation efforts [31].

The fact that estimated quantified PB are likely to change over time seriously complicates attempts to reach political agreements through scientific consensus [68]. The changing nature of PB is not only due to possible scientific advances which can result in revised estimates of individual PB, but also as the result of bio-geophysical interactions among the boundaries [1-2, 7].

Planetary Boundaries, Information Processing and Earth System Governance

The uncertainties created by the interconnectedness of boundaries brings to fore issues related to the information processing capacities of ESG. Governance failure is imminent when the information needed to monitor planetary boundaries and their interactions, is dispersed among a wide set of agencies and scientific communities [14,15]. The interaction between the boundaries climate change, ocean acidification and marine biodiversity provides an example of this. Ranges of international as well as non-governmental organizations address different aspects of the marine-climate-ocean acidification complex, ranging from the UN Food and Agriculture Organization (FAO), to the International Council for the Exploration of the Sea (ICES), the World Bank and UNEP and its science centers. Differences in organizational goals, approach, culture, and structure are however known to account for the reluctance of agencies to share information with each other, and with external non-state actors [16].

Such fragmentation poses severe ESG challenges if planetary boundary interactions result in rapid and unexpected environmental change. Previous analyses show that institutional capacities tend to be severely outstripped when amplifying feedbacks in social-ecological systems [definition in 60], a) either do not match previous experiences; b) embed scientifically and socially contested cause and effect relations; c) lead to secondary effects that cascade rapidly in time and space; and d) when information integration and analysis are challenged by organizational silos and geographical and temporal gaps in ecological monitoring [18]. This creates severe Earth system governance challenges.

A final issue is related to the speed of iteration of Earth system scientific assessments and reporting. This has been an emerging controversial issue for the Intergovernmental Panel on Climate Change (IPCC) [19] as an increasing number of actors call for more rapid assessments to keep up with the rapid developments of climate science. This debate has additional implications for global coordination and institution building around planetary boundaries. As Earth system science makes advancements in the understanding of planetary boundaries and their interactions, how often to iterate syntheses and outreach activities, remains a crucial ESG issue.

Moving Ahead

Despite serious governance challenges related to information processing and monitoring in institutionally fragmented settings, it should be noted that a number of arenas for cross-system scientific synthesis indeed have emerged the last decades. The Millennium Ecosystem Assessment [15] provided an important, and collaborative scientific process that holds great potential due to its cross-disciplinary approach and combination of global outlook and regional depth [27]. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) currently being developed, could potentially play a fundamental role in the science-policy landscape for biodiversity and ecosystem services [20] not only by setting international knowledge standards, but also by constructing spaces for deliberation between science and societal actors [26].

However, IPBES' impact on global and national policy cannot be taken for granted, as indicated by decades of insights about the use, and uptake of scientific knowledge in policy-making and governance [25,65]. As observed by [25,69], increased salience of an issue is not enough to trigger international action, but needs to be combined with institutional mechanisms that enhance the credibility and legitimacy of the information produced. Next steps in research in ESG should hence explore the institutional architecture [*def.* 5] needed to support repeated and integrated assessments of planetary boundaries, with a special emphasis on possible PB interactions where institutional fragmentation is severe; as well as explore institutional mechanisms that enhance the salience, credibility and legitimacy [69] of planetary boundaries science.

3. Government, Governance and Planetary Boundaries

A second challenge is the degree to which current institutional arrangements have the capacity to deal with individual planetary boundaries, and their poorly understood interactions. In elaborating on this issue we focus first on institutional reform to address individual boundaries, and second on how to address interactions between them.

Individual Planetary Boundaries

Despite the scientific usefulness of defining a «safe operating space for humanity», any discussion about possible institutional solutions at the international level, has to acknowledge that these always are the result of negotiation between sovereign states [29, 68]. At least two main options seem to exist to address this: either to create *new* institutions at the international level, *or* to adjust existing ones to adequately address individual planetary boundaries and their interactions.

Each of these options has different benefits and drawbacks, a contested discussion with clear parallels to ongoing debates about a possible World Environmental Organization (see below), or the regulation of large-scale interventions in the climate system, known

as geo-engineering [68,70]. While a “new” overarching institutional framework based on the notion of PB could bring some coherence into a highly fragmented institutional landscape, the development of such a framework is likely to be very slow, or end up in intentionally vaguely defined and ineffective agreements due to the biogeophysical and political complexity of the issue [c.f. 68].

A number of international institutions that match specific boundaries are indeed already in existence. Examples include the Montreal Protocol on Substances that Deplete the Ozone Layer, and the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity (CBD). Some, such as the Montreal Protocol [37], have been effective while others, like the CBD, have suffered from weak implementation capacity [63]. Other boundaries such as global water cycles [30], global nutrient cycles, ocean acidification, and land-use change including deforestation and conversion to agriculture [22], are considerably less well captured by existing international institutions, and would require considerable international political momentum to induce global reform. In addition, even though all PB are not governed through a coherent institutional architecture, they are still affected by a range of non-environmental international clusters, such as those related to world trade [36-38].

This is not a trivial observation. The impacts of the rapid expansion biofuels on a range of planetary boundaries, is illustrative in this sense. While the major drivers play out at the global level - e.g. through decline in global stocks of grain, increasing energy costs, increased global food demand, speculation in financial markets [41], the ability of the international system to mitigate the social-ecological impacts in a coordinated way, seems severely constrained. More precisely, the biophysical impacts of the rapid expansion of biofuels on PB such as land-use change (no current regime existing); hydrological cycles (no current regime existing); biodiversity (weak regime); and increased global uses of phosphorous and nitrogen (no current regime existing); are difficult to tackle due to the complex institutional setting, and absence of international environmental institutions as well as overarching principles to guide their conduct [41].

Planetary Boundaries Interactions

Provided ESG could be arranged in such a way as to match each planetary boundary, the question remains how the *interactions* between these would be governed. Again, the question is whether to attempt to create an overarching institutional framework, or focusing on creating interlinkages and synergies among existing institutions.

Drawing on the analysis presented by Oran Young [32], the problem complexes implied by the notion of interacting planetary boundaries, incorporate many of the characteristics that make the emergence of robust inter-institutional coordination very difficult. That is, planetary boundaries interactions are at present not well-understood scientifically; they are difficult to match or "fit" institutionally due to their multilevel (local-global) interactions; and interventions are likely to interact with a range of environmental and non-environmental institutions. This poses a critical collective action dilemma: sovereign states are they key locus of action in the international system, yet the complex dynamics of the Earth system seriously dilutes the incentives for collective action [cf. 33].

Moving Ahead

A further elaboration of overarching principles in international law could potentially be an approach to tackle these difficult challenges. Overarching principles are crucial as they allow for the governing of interactions between different institutions, and the regulation of norm-conflicts between these institutions. Examples here include the principle of common but differentiated responsibility, integrated funding mechanisms, and joint mechanisms of custom control [37]. Many of the different issue areas of world trade law are for example regulated under the overarching principles enshrined in the Agreement on Establishing the World Trade Organisation [68].

Similar overarching agreements could hence theoretically also be conceived for the governance of planetary boundary interactions. In terms of international law, the concept of planetary boundaries even invites further exploration of the concepts of peremptory norms of international law (*ius cogens*), i.e. norms that no state may derogate from [8]. The practical consequences would obviously be debatable, however it opens up for

important general discussions amongst ESG scholars about the role of international law in supporting not only legal certainty and openness, but also flexibility and multilevel linkages across planetary boundaries [46].

The issue of institutional interactions has been elaborated in detail the last years [36-40]. One interesting development in the field is the argument that these interactions could be managed strategically by international organizations, to promote environmental policy integration at the international level [39]. Some suggested strategies include the endorsement of inter-institutional learning through joint management among international bureaucracies; expert assessments aiming to promote inter-institutional learning and diffusion; and giving environmental objectives «principled priority» in cases where environmental and non-environmental institutions are in conflict [39, 40]. Overarching principles and agreements, as well as the strategic management of institutional interactions hence all provide interesting future pathways for more detailed analyses of ESG and planetary boundaries and their interactions.

4. International Organizations and Planetary Boundary Interactions

A third and related ESG challenge focuses on the role of international organizations (IOs) such as the United Nations Environment Programme (UNEP) and the United Nations Development Programme (UNDP). International organizations play a key role in global environmental governance as coordinators, knowledge brokers, bridging organizations, and by setting international agendas [42]. Although IOs have been studied extensively the last years [35,37,42] the emphasis has largely been on their ability to deal with incremental environmental change, rather than non-linear processes and planetary boundary interactions. The difference between trying to govern individual incremental environmental changes, versus rapid interacting change, is fundamental.

For example, while some implications of climate change and ocean acidification on marine ecosystems can be projected with some certainty, others are likely to unfold as non-linear social-ecological surprises at multiple levels – such as regional collapses of coral reef ecosystems, and rapid irreversible loss of fish stocks with severe food security

implications. This poses a difficult coordination challenge for IOs. On the one hand, dealing with incremental changes in PB (say, coordinating policies to deal with the food security impacts of ocean acidification) require coordinated action evolving around repeated interactions, predictability, and execution by nations, regional organizations and IOs (section 3). At the same time, dealing with ecological surprise and cascading effects of environmental change, requires multilevel and *adhoc* responses, where a high degree of flexibility and experimentation is allowed [17]. Intriguingly enough, these two capacities seem to be difficult to maintain within the same institutional architecture [43].

Another challenge relates to the *mandates* of IOs. The mandate of IOs has, and will continue to, change over time as their respective member states identify emerging global needs [37]. Against the backdrop of planetary boundaries and their interactions, identifying negative and harmful interactions between international institutions, and proposing, negotiating and implementing counter-measures could therefore be an emerging future mandate of IOs.

Although the United Nations Environment Programme might seem like the obvious actor to be entrusted with such tasks, existing shortcomings in the influence of this IO makes its transformation into a stronger specialized agency of the United Nations – a World Environment Organisation [44] – controversial. In particular, a centralized organization runs the risk of creating negative side effects and increase complexity to international environmental decision-making processes [45].

Focusing less on the idea of one centralized organization, there is also an important aspect of the role of IOs as coordinating a range of international, cross-sectoral and multi-organizational initiatives, such as those elaborated in the literature on polycentric systems in climate policy [71], and international partnerships and networks [67]. These initiatives could be viewed as self-organized complements to formal international agreements, by providing the sort of "bridging" functions previously identified for the governance of large-scale ecological systems [47,48].

Currently, this remains a potential, however. We know little empirically about how and if these partnerships and interconnected networks enhance the "fit" [50] between global environmental governance and social-ecological dynamics at planetary scales, simply because non-linear social-ecological dynamics has not been a phenomena of interest for scholars of public private partnerships or transnational networks [e.g. 35, 49, 67].

While actor networks of this sort can be seen as a strength by supporting flexible forms of polycentric coordination [29, 51, 71], they may also cause malign diffusion of responsibility, induce accountability problems, and lead multi-actor networks to externalize the costs of their actions onto others [52]. This is a particular problem in cases where the effective global of governing of planetary system interactions, where international mandates are vague, international monitoring is weak or non-existing, and scientific uncertainties about cause and effect are considerable.

Moving ahead

The role of IOs as coordinators and key actors in globally spanning polycentric initiatives hence remains a key research issue for scholars of Earth system governance. While the field has made substantial progress in identifying the strengths and weaknesses of IOs in Earth system governance [44,45,63], much remains to be done in the context of PB. The key in this context is to explore 1) to what extent existing transnational polycentric initiatives address the diverse set of planetary boundaries identified by Rockström and colleagues [1,2]; 2) analyze their capacities to "enhance the fit" [50,51] with complex Earth system interactions through e.g. new forms of cross-system monitoring systems (elaborated in section 2); and 3) elaborate the role IOs could play a role in initiating, coordinating and evaluating polycentric and/or transnational initiatives and their effectiveness from a PB perspective.

5. Innovation and Governance of Planetary Boundaries

A fourth challenge is related to the role of Earth system governance in supporting, coordinating and regulating "innovations" – that is, the introduction of novel technologies, management practices, organizational structures, or institutional solutions that profoundly changes the system in which they arise [c.f. 55]. The need for integrated technological, institutional, social and ecological innovations to deal with the problems of global environmental change is well known in the literature [53]. Providing food security for a future human population of 9 billion, without transgressing several of the identified planetary boundaries is only one critical example of the need for water, agricultural and institutional innovations [54].

Supporting and regulating innovation through global policies is however far from a simple task. Despite an increasing interest in innovation by international actors - such as the World Bank's 2009 World Development Marketplace, and the 2007 ECOSOC Innovation Fair - current academic understandings of innovation dynamics is limited, and tends to have a bias towards technical systems [56,57], rather than on innovations that address social-ecological feedbacks, and support the stewardship of ecosystem services [e.g. 57-62].

Innovations of this latter kind are not necessarily only local phenomena, but can have large-scale effects through diffusion or up-scaling, like the suggested re-greening of the Sahel [61], or controversial schemes for iron fertilization of oceans for carbon-dioxide removal [70]. The diffusion dynamics and externalities of innovations highlight the need for not only supporting innovation, but also establish overarching governance principles that help resolve potential conflicts, and facilitate scientific and societal debate in institutionally fragmented settings [37]. These issues have however attracted little systematic attention from the Earth system governance community. For example, the intricate linkage between innovation dynamics, and global governance plays a marginal role in the ESG Science plan [5].

Innovation is a complex and socially contested process driven by the interplay between micro (such as the individual inventor) and macro (such as policies and economic context) dynamics. This implies that any governance approach designed to support or

regulate innovation, needs to consider its multilevel nature [64]. While this might seem like an almost impossible task, some interesting national governance experiments have nonetheless emerged the last few years. These will prove useful in trying to link Earth system governance to innovation as they relate to planetary boundaries.

Moving Ahead

A suite of strategies is worthy of further analysis in the context of planetary boundaries. One example is the creation of “space for innovation” and “transition arenas” – that is attempts to bring together networks of diverse actors that develop a shared understanding of how they collectively can influence dysfunctional and path-dependent systems, such as water and waste management and energy supply [55]. These sorts of spaces for informal interactions have not only proven to be important for social learning, but also allow for novelty to emerge [66].

The strategic support of experiments that seem to hold the potential for innovation that challenge existing ways of steering or managing social, technical or ecological systems. Lastly, decision-makers must be able to continuously monitor, evaluate and diffuse emerging insights from ongoing experimentation. These strategies are currently being explored through national policies in the Netherlands [55], and regions in Austria, and Australia [34].

Whether, and how these “spaces” or “arenas” can be created and framed at the international level in the context of planetary boundaries, is an interesting question worth further exploration by the Earth system governance community. Particular emphasis should be placed at a) analyzing the sort of conflicts that emerge at the international level when trying to actively support, or regulate innovation [e.g. 68, 70]; b) the diffusion dynamics of innovations that address not only technical systems, but also social-ecological interactions, and their institutional setting; and c) whether it is at all possible to upscale insights from national innovation governance experiments to the transnational and international level.

6. Conclusions

Can the international system cope with the challenges posed by complex, multi-level and possibly non-linear global environmental change? *What are the implications of multiple, interacting and quantified "planetary boundaries" for critical elements of Earth System Governance (ESG)?*

Calls for international institutional and UN reform are common [8,28,37,56], yet should not only build on a thorough understanding of the features of the international system, but also the complex dynamics of the Earth system. As we have explored, the notion of planetary boundaries embeds a range of challenges for Earth system governance. These include the need to elaborate the institutional architecture of repeated, legitimate and inclusive PB assessments; the role of IOs and their ability to oversee regional and globally spanning polycentric initiatives; and the need to take the support and regulation of social-ecological innovation seriously. Table 1 summarizes the main insights from this synthesis overview. In essence, each cell indicates a possible way ahead for both research, and attempts to reform Earth system governance.

[Table 1 here]

The notion of planetary boundaries hence brings a number of important Earth system governance issues to the fore. At best, PB can provide a new target for emerging attempts to support an international environmental governance structure that is more integrated, binding, and synergistic [37], and help steer self-organized multi-organizational networks, and social-ecological innovations in a way that helps us avoid transgressing critical planetary boundaries. However, a range of issues related to the interplay between Earth system science and policy; a suite of monitoring and information processing challenges; as well as possible differences in risk perceptions in defining what is a "safe" boundary condition, remain critical and poorly explored subjects by the Earth system governance community. Hopefully this article has been able to highlight some constructive ways ahead.

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