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Abstract

Humanity is facing unprecedented environmental, social and economic challenges. We ask what the role of the sustainability science community should be in tackling these challenges, focusing particularly on young scientists' perspectives on the issue. On the basis of a questionnaire and a workshop with young scientists, we identify four major challenges facing humanity and develop three guidelines for sustainability science that seeks to address them. Results show that to help address humanity's grand challenges, sustainability scientists need to move towards a trans-disciplinary system view of science and sustainability science problems. According to this view knowledge emerges from a collaborative and transdisciplinary environment and young scientists are trained to work across disciplinary boundaries and engage with policy communities.

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1. Introduction

Pondering on the crisis that faced humanity following the unleashing of the atom, Einstein remarked: "*a new type of thinking is essential if mankind is to survive and move towards higher levels*". Now well into the 21st century, humanity is faced with even more grand challenges, currently culminating in a multi-faceted global crisis involving the economic and financial system, the climatic system and other ecological dimensions, the energy system, and the distribution of wealth and capabilities. Due to the fact that over the last few decades the human population has increased substantially and the socio-environmental system has become so much more complex, this trans-dimensional crisis appears more difficult to tackle than the challenges of the last century. Wealth has increased, yet it is unequally distributed around the world and society.

The concept of the 'Anthropocene' is now widely applied to describe the current epoch and challenges linked to human activities (Steffen et al., 2007). The 'Anthropocene' is helpful in framing some of the issues raised in this paper because it focuses our attention on humanity's role in shaping the structure and functioning of the Earth System (Steffen et al., 2015a). Human modifications of the Earth System have led to changes in key indicators (e.g., tropical forest loss, surface temperature) which are well outside the envelope of environmental change observed in the geological record. The idea of human activities and development as operating within an envelope of 'safe' environmental change was first proposed by Rockstrom and colleagues (Rockstrom et al., 2009; Biermann, 2012), whose seminal work on planetary boundaries has helped framing some of the challenges of Earth System Governance discussed in this paper.

The scientific community has been urged to develop knowledge to identify and inform responses to these challenges (ICSU, 2015). Sustainability science is at the forefront in developing these responses, with young scientists carrying out much of the sustainability research and being responsible for important contributions to the field. Although the role of young scientists in leading the way on fresh ideas in science is generally recognized (Callaway, 2015), young scientists are rarely involved in identifying research priorities and shaping research approaches to tackle sustainability challenges.

To address this gap and explore young scientists' perspectives on sustainability science, we report the results of a survey of young scientists' perceptions about (i) humanity's grand challenges and (ii) research approaches required to respond to these challenges. Building on this survey and an ensuing workshop, this study identifies three guidelines from young scientists for sustainability science that seeks to matter. Sustainability science and research is here interpreted as the fields of science that aim to support "sustainable development within a safe and just operating space of a stable planet" (IIASA, 2015).

2. Methods

To assess young scientists' perceptions with regard to sustainability science and how this science needs to evolve to tackle the challenges of the Anthropocene, we conducted a survey and subsequently organized a workshop with the survey's participants. The survey was conducted anonymously and it consisted of a questionnaire where participants were asked two questions: (i) "What is one major challenge facing humanity in the years ahead?" and (ii) "How should sustainability science evolve to tackle this challenge?". These two simple questions were designed to allow participants to define issues in their own terms and to enable them to provide spontaneous, subjective and unfiltered responses (see Gelcich (2014) for a similar method).

Respondents were recruited amongst the participants of the 2014 Young Scientists Summer Program (YSSP) at the International Institute for Applied System Analysis (IIASA). This group of respondents consisted of 52 PhD students from a wide range of cultural and disciplinary backgrounds working on applied science problems, ranging from air pollution to overfishing and global trade.

Following the survey, we invited the participants to a workshop where the results of the survey were presented. The workshop was structured in a World Café format, whereby participants moved between a series of tables to discuss the major points that emerged from the questionnaire. Participants at each table were asked to cluster the answers to the two questions into broader categories of challenges and responses. The workshop was also attended by 6 senior researchers from IIASA who provided insight on selected topics and moderated the debate.

3. Results

3.1. Grand Challenges

Following the survey and the workshop, we were able to identify four categories of challenges facing humanity as described and discussed by the participants:

1) **Planetary boundaries and resource constraints:** (How) will we manage to live within planetary boundaries and resource constraints? Research on planetary boundaries (Steffen et al., 2015b) and environmental footprints (Hoekstra and Wiedmann, 2014) has shown that the rate at which we simultaneously consume resources and harm the environment is simply not sustainable. Underlying these concepts is the idea of 'humanity' as a whole, whose activities within the Earth system have become a planetary transformative force and therefore a common global concern. This raises the question: what kind of science is required for us to live within 'a safe and just operating space' (Richardson et al., 2009)?

2) **Adapting to changing environments:** Who will be affected and to what degree? The impacts of global environmental change will be distributed unevenly across societies and economies. The IPCC (IPCC, 2014) argues that poor communities in high-risk areas are those most likely to be negatively affected. However, given the nature of our inter-connected and globalized world, these global transformations and adaptations have the potential to produce unforeseen 'butterfly effects' across the world, for better or worse (Goldin and Mariathasan, 2014). Science is thus being called upon to devise mitigation and adaptation strategies which take into account both the ecological and human responses to environmental change, and to consider equity issues in (climate change) assessments (Adger et al., 2005) and other challenges such as energy, ecosystem services etc.
3) **Dealing with conflict:** What are likely to be the causes of future conflicts and how can they be overcome? Inequality is increasing globally with respect to the distribution of wealth, resources and capabilities and current and expected future impacts of climate change will only aggravate this. This is expected to lead to new, as well as intensify existing, conflicts in many different forms across the world. Working towards distributional justice globally by addressing the roots of the problems is key to avoid and mitigate future conflict within the context of continuing global change (Scheffran et al., 2012).
4) **Re-defining quality of life:** (How) can humanity prosper without economic growth? Conventional economic theory, which is used as a blueprint for today's economic praxis, is based on the paradigm of economic growth; this is no longer feasible if humanity wants to thrive on what is a finite planet (Farley et al., 2013). The concept of green growth, which demands and promises an absolute de-coupling of economic growth from natural throughput and emissions, needs to be questioned and re-assessed. The current challenges call for an economic system that promotes well-being, compatible with the planet's carrying capacity.

The questionnaire's responses to the first question indicate that most challenges identified by the participants are cross disciplinary and that they do not only involve an improved understanding of the Earth System and its response to human activities (Challenge number 1) but also an understanding of humanity's ability to respond to environmental changes. Furthermore, the list of challenges also calls for sustainability research capable of identifying institutional and economic structures capable of implementing and incentivizing sustainability solutions.

3.2. Three guidelines for research that seeks to matter

Building on the responses to the question on the challenges facing humanity, we invited the participants to a workshop. At the workshop, participants shared their views on how sustainability research and sustainability science need to change to address these challenges. The outcome of the workshop was not a list of answers or specific research priorities but three guidelines, which the participants suggested researchers should consider if they want to conduct sustainability research that matters for the future of humanity:

Guideline 1: Be aware that your research is part of the larger social, environmental and economic context - connect and relate to the bigger picture! Very often scientists, particularly those just starting their careers in research, are affected by

'cockpit-ism' (Hajer et al., 2015): when doing research, it is easy to get tangled up in details, fail to communicate the significance of your work to fellow researchers and the general public, and miss the bigger picture of why specific research matters. We identify three important strategies to avoid not seeing the wood for the trees when undertaking sustainability research. First, it is essential to reflect on the impact that the research has on society. Sometimes the consequences of new knowledge may be unknown and scientists should make it clear when this is the case. In other instances, scientists may be asked to provide advice on uncertain events and, in these instances, understanding co-production processes is essential for scientists to be able to delimit their responsibility. Second, and related to the first point, global change researchers need to engage not only with their research community but also with their broader audience in order to ensure that their findings are credible, salient, and legitimate. For instance, when dealing with abstract concepts in global change science, such as sustainable development, planetary boundaries and environmental footprints, a researcher needs to think about how to link these ideas to the broader issues at hand and how to make them relevant to the lives of the people concerned. Third, communicating research results means taking part in a broader societal discourse: every scientific question raises political and ethical challenges which cannot be separated from the individual researcher's activities.

Guideline 2: Accept that controversy is a given and that it is essential for reaching robust science-based solutions – engage with tensions within the societal system! The second key message to take away is that there is a lot of controversy around many of the issues dealt with in sustainability science (e.g. the feasibility of green growth or absolute de-coupling) and that this is sometimes a good thing. Controversy may occur at multiple levels (i.e., between individual researchers, or between researchers and other members of society or between disciplines). People's perceptions of a research topic may vary according to different (cultural) worldviews, politicized processes and how the issue itself is framed. Moreover, perceptions and knowledge may change over time, thus requiring researchers to constantly reassess their own views on a specific research topic. By accepting the existence of controversy in sustainability science, researchers will be more motivated to identify, defend, and potentially rethink implicit and explicit assumptions. This prevents polarization and ultimately leads to more robust scientific arguments, which drive research forward. As climate scientist Mike Hulme puts it, we also see disagreeing as a form of learning (Hulme, 2009).

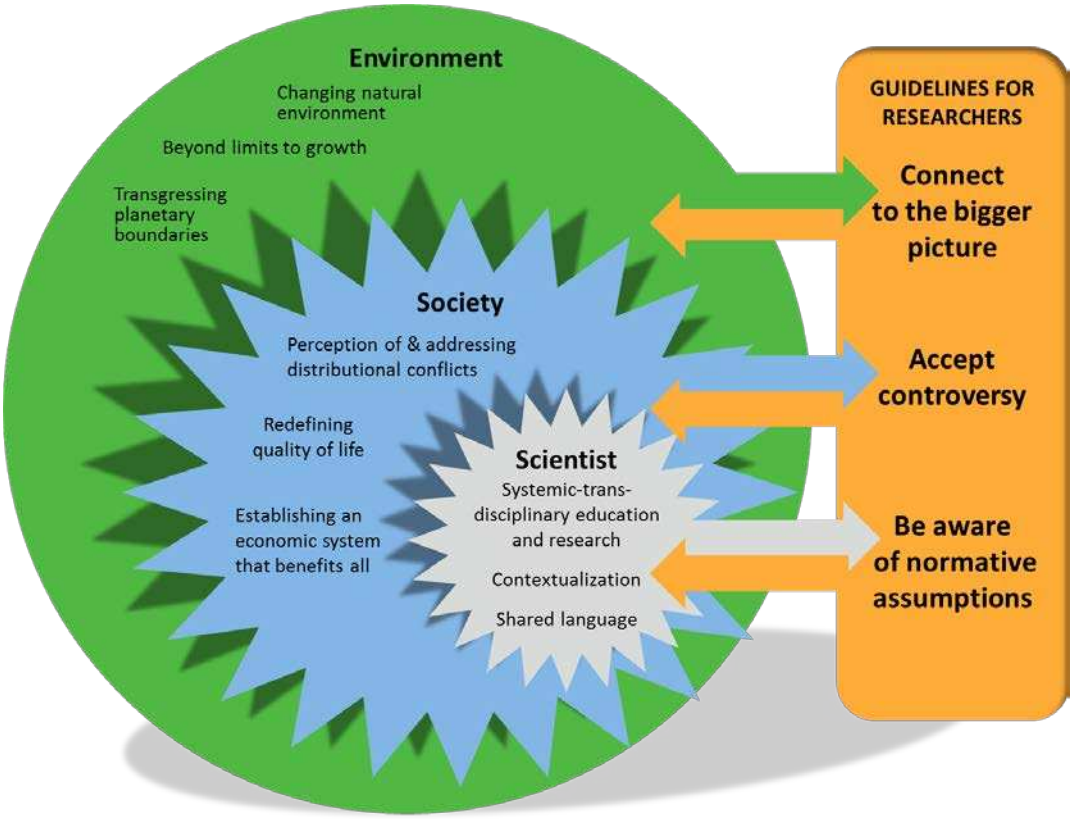
Guideline 3: Be more reflective about the normative assumptions underlying your research – you are part of a social context and have a specific view on it! The framing of a research question is driven by theories, hypotheses and assumptions made about it, either explicitly or implicitly. Formulation of hypotheses is central to the scientific method, as it is reference to a theory to explain observed phenomena. Assumptions are also necessary in research, as they are an inherent part of dealing with real world complexity, incomplete knowledge, and uncertainty. At the same time, however, it is important to be aware of these assumptions, and transparent about how they are made. We identify (at least) six important normative issues that a researcher should consider, which relate to the spatial, temporal and socio-political framings of research: Who are the stakeholders affected by the research, i.e. the potential winners and losers? Which geographical regions and socioeconomic groups are being looked at? Is the wellbeing of future generations being adequately accounted for? Which political agendas

are at stake? What are your own and your research colleagues' career goals? Who is funding the research and what are their implicit expectations?

4. Discussion: Moving towards systemic-transdisciplinarity and implementing the guidelines

We argue that in order to implement the guidelines listed above, there needs to be a radical shift in sustainability scientists' mindsets and practices towards a more transdisciplinary, holistic and systemic understanding of their research. We propose, in other words, a systems view of science and of sustainability science problems, whereby scientists' endeavors are considered within a broader social and environmental context. (see Figure 1). The scientist is part of society and his/her research and knowledge can provide solutions to social and environmental problems. At the same time, scientists' engagement with society and the environment means that they are also part of the systems they are studying.

Figure 1. Levels and processes of transformations re-shaping sustainability science in the 21st century.

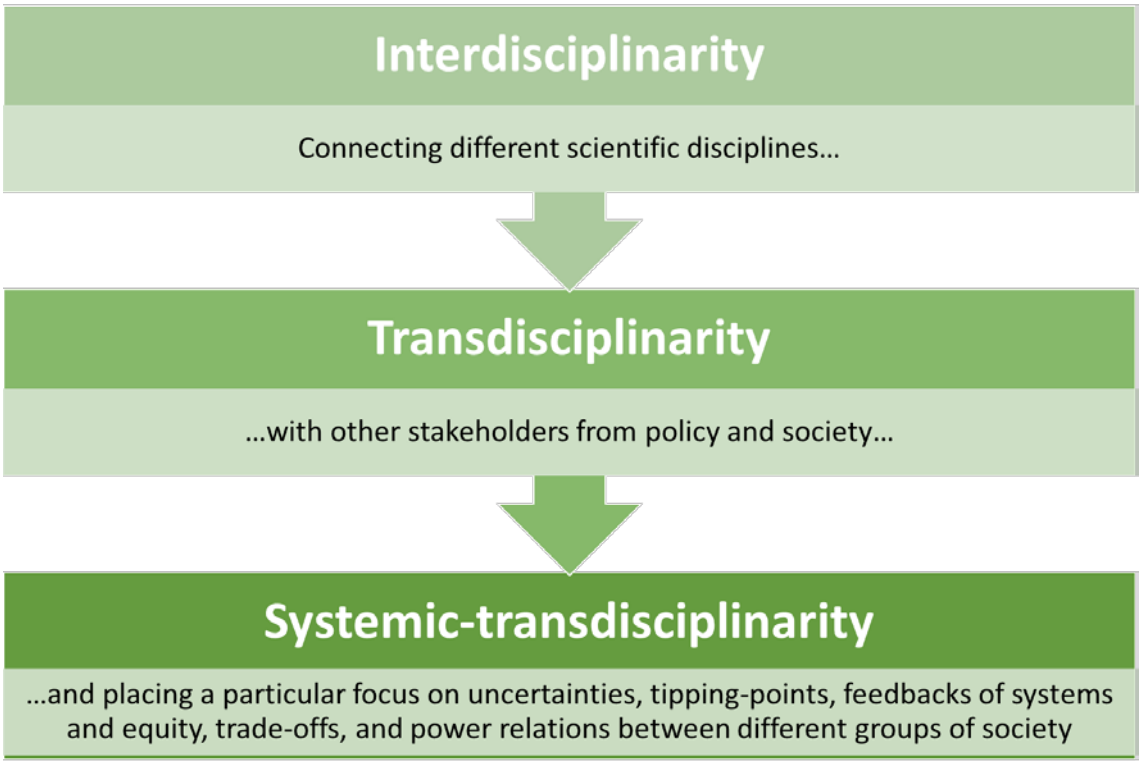


The limitations of sustainability science and the need to move beyond the analysis of coupled systems to examine the social, political and technological dimensions of sustainability knowledge have been discussed by scholars in the field (Miller et al., 2013). Scholars have highlighted the need to move towards solution-oriented sustainability

science (Kates et al., 2001; Wiek et al., 2014; Wiek and Kay, 2015). We argue that moving towards a system view of sustainability science can contribute towards positive impacts.

Implementing a systems view of sustainability science would require a big leap forward: moving from interdisciplinarity to transdisciplinarity to real-systemic-transdisciplinarity (see Figure 2). If interdisciplinary research was about bringing together different scientific world views, then transdisciplinary research is about embracing the broader societal controversies (Mauser et al., 2013).

Figure 2. From Inter- to Systemic-transdiciplinarity science and research.



Transdisciplinary research is here broadly interpreted as an approach (i) focused on problems relevant to society, (ii) capable of creating problem-oriented knowledge that can be implemented by society and, most importantly, (iii) devised to enable mutual learning among researchers from different disciplines and stakeholders (Lang, 2012). The systemic-transdisciplinary approach which we propose here shares these elements, yet, contrary to previous transdisciplinary approaches (e.g., Brandt et al., 2013; jahn et al., 2012; Popa et al., 2015; Blättel-Mink and Kastenholz, 2005), it places greater emphasis on understanding the role of uncertainty, trade-offs and feedbacks. Furthermore, the co-design and co-production of knowledge and the focus on scientific integration which characterize transdisciplinary research (Lang, 2012) are here expanded to consider power dynamics and diversity of values and views amongst participating scientists and stakeholders.

A systemic-transdisciplinary approach takes a system-view to develop solutions to sustainability challenges, which means that it not only integrates across disciplines but

also across problem areas (e.g., climate), their drivers (e.g., economic growth) and their impacts (e.g., sea level rise) focusing on the interactions and feedbacks between these three elements. A systems-based view needs to be at the core of transdisciplinary approaches to sustainability science that seek to assess sustainability challenges and develop responses to them. Systems-based responses to sustainability challenges are being increasingly recognized as crucial to achieve global sustainability (Liu et al., 2015). At the same time, systems-based approaches need to be accompanied by trust-based approaches which ensure that the knowledge and links of multiple stakeholders are included via dialogue.

Systemic-transdisciplinarity places particular focus on uncertainties. Recognizing that many decisions are subject to incomplete knowledge is a central tenet of the approach that emerged from the workshop. Acknowledging uncertainty matters, though we should not allow paralysis by analysis (Hall et al., 2012) nor let uncertainties be an excuse for inaction (Morton et al., 2011). Uncertainties can be transparently accounted for in many decisions, can be reduced in a co-designed stakeholder-science dialogue and are important in driving science forward. Our approach also emphasizes tipping points and trade-offs as being crucial elements of sustainability science. Achieving sustainability entails trading-offs outcomes for multiple stakeholders which often have conflicting preferences. Striking the balance between these conflicting preferences requires considerations of equity and power dynamics of human systems and also tipping points and threshold behavior of socio-ecological systems (Singh et al., 20015).

By broadening the horizons of (young) scientists, we are confident that truly systemic research can provide more robust policy advice than traditional, monodisciplinary or pseudo-interdisciplinary research, and inform the development of strategies to address the four big challenges detailed above. Moreover, the continuous and iterative integration of new (scientific) evidence, generated in a discursive (i.e., related to discourse and modes of organizing knowledge) research environment, prevents society from entering undesirable path dependencies, thus allowing for more robust decision-making. Within this context, global change and sustainability researchers have to both consider the transformations that are currently taking place, and, in order to safeguard our future, pro-actively engage with those big transitions that are yet to come..

5. Conclusions

The results of the survey and workshop provide an overview of concerns and ideas from young scientists with regard to humanity's challenges and sustainability science's role in addressing them. Although we have presented our views on systems thinking and transdisciplinary approaches for sustainability science, we are still left with the practical question of how we, as a sustainability research community, engage in transdisciplinary research so that the outcomes will have a positive impact on humanity's future. Furthermore, we are left with the question of how professional practices and habits need to be restructured to produce real change in the sustainability and global change science.

Following the guidelines above, we present three concluding recommendations for the sustainability research community. First, improved education of sustainability scientists, by which we are not simply referring to an increase in inter and transdisciplinary training and education, but much more: universities around the world would have to provide the kind of environments that, in addition to nurturing students'

cognitive and academic skills, also taught them interpersonal skills, empathy, and the ability to listen to and understand both each other and other stakeholder groups within the broader societal system. This is closely related to our second concluding remark (ii): research practice. Part of the challenge of doing inter- and transdisciplinary research is that, based on their individual scientific education, natural and social scientists often use very different language and have very different world views. Hence, before conducting any kind of systemic-transdisciplinary research, resources have to be made available for finding and developing a common language for the different stakeholders involved. Working with metaphors or narratives could be one way of opening the discussion and overcoming these differences through language. As a third point, we recommend that the current professional research environment, which today seems to be more set up for disciplinary careers (e.g. in order to establish yourself professionally you publish in prestigious specialist scientific journals), needs to be reshaped to allow young scientists – particularly in the sustainability research domain – to foster their systemic-transdisciplinary research without compromising their scientific careers.

Transforming current sustainability research into a truly systemic-transdisciplinary endeavor would also trigger transformations in the broader socio-environmental system, as well as the overarching global environmental landscape (as summarized in Figure 1). However, this chain of causation is by no means unidirectional; rather, the three (sub-) systems mutually affect each other in multiple ways. This strengthens our argument for employing a truly systemic-transdisciplinary approach in sustainability science and research, and by doing so making a substantial contribution towards re-shaping our future.

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