Challenges in Sustainability

Special Issue
Earth System Governance - Task Force
Initiative on Sustainability Science

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Cover image
indigenous children going to school in Zanzibar (Photo by Johanna Nalau).

Special Issue:

Earth System Governance - Task Force Initiative on Sustainability Science

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Scope:

As the Earth System Governance Task Force Initiative on Sustainability Science, we are soliciting submissions for a special issue on Sustainability Science in the journal Challenges in Sustainability (CiS). The aim is to offer succinct, quality submissions for peer reviewed articles covering four broad themes:

- Mission and mandate of sustainability science;
- Achievements in sustainability science research and outreach;
- Theoretical and methodological conflicts in sustainability science; and
- Future developmental challenges of the field.

About *Challenges in Sustainability*

Focus & Scope

Challenges in Sustainability (CiS) is an international, open access, academic, interdisciplinary journal dedicated to the publication of high-quality research articles and review papers on all aspects of global environmental and transformational change toward sustainability. Research articles, reviews, communications or short notes and films are welcomed. Manuscripts must be prepared in English; they will undergo a rigorous peer review process, and they will appear online immediately after final acceptance. We especially encourage submissions from early stage researchers.

Objectives & Aims

The objective of the journal is to be a front-runner for original science that stimulates the development of sustainability solutions in an era of global environmental change. CiS defines its place at the interface between natural, socio-economic, and the humanistic sciences, creating a unique platform to disseminate analyses on challenges related to global environmental change, associated solutions, and trade-offs. The journal helps to further the field of sustainability science by bridging gaps between disciplines, science and societal stakeholders while not neglecting scientific rigor and excellence. The journal promotes science-based insights of societal dynamics, and is open for innovative and critical approaches that stimulate scientific and societal debates.

Examples of topics to be covered by this journal include, but are not limited to:

- Environmental and resource science
- Governance for sustainability
- Transition experiments and pathway studies
- Education for sustainability
- Future and anticipatory studies
- Transdisciplinarity
- Sustainable urban systems
- Sustainable energy
- Place-based sustainability studies
- Resource exploitation
- Impact assessment and integrated modeling
- Carbon accounting and compensation

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Challenges in Sustainability

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Table of Contents

Challenges in Sustainability | 2017 | Volume 5 | Issue 1 | Page 1
DOI: 10.12924/cis2017.05010001
ISSN: 2297–6477

Challenges in Sustainability

Editorial

The Taskforce on Conceptual Foundations of Earth System Governance: Sustainability Science

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We are pleased to introduce the second special issue from Challenges in Sustainability, this time as a part of the Taskforce on Conceptual Foundations of Earth System Governance, an initiative by the Earth System Governance Project (ESG; http://www.earthsystemgovernance.net/conceptual-foundations/).

The ESG Project is a global research alliance. It is the largest social science research network in the field of governance and global environmental change. ESG is primarily a scientific effort but is also designed to assist policy responses to pressing problems of earth system transformation.

The Taskforce on Conceptual Foundations is one of four current task forces operating under the auspices of the project, each open to and involving other research communities. It is a research initiative established to explore central ideas that frame the discourses and discussions around the challenges of governance in times of global environmental change and earth system transformation. The taskforce is an international research effort involving scholars from different regions, disciplines and career stages clustered in working groups focused on specific concepts. The key concepts that unite task force researchers include, amongst others, the *Anthropocene, Anticipatory Governance, Environmental Policy Integration, Resilience, and Transformations and Transitions toward Sustainability*. Activities around each of the concepts are diverse and include workshops and seminars, conference sessions and plenaries, webinars and blog posts.

This special issue of Challenges in Sustainability captures some of the output from the taskforce working on the concept of Sustainability Science. In a set of articles and a short film, the special issue showcases the state-of-the-art in sustainability science research and education. Each submission provides a specific contribution to key developmental areas that have emerged in sustainability science over the past fifteen years.

In addition, the special issue is an important milestone for deliberations within the taskforce on sustainability science, and is the first comprehensive and explicit effort to bring together the related concepts and epistemic communities on earth system governance and sustainability science.

We would like to thank Anne Jerneck, from Lund University Centre for Sustainability Studies, for her commitment to this taskforce and bringing this special issue to fruition. In addition, we would like to thank Ellinor Isgren and David O'Byrne, also from LUCSUS, for their commitment, often during non-office hours, to assemble the submissions for the special issue. Lastly, we would like to thank James Meadowcroft at Carleton University for his work to establish the Taskforce on Conceptual Foundations of Earth System Governance, and for his enthusiasm and leadership that have fostered so many interesting and productive discussions and activities across communities, disciplines, and concepts.

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Challenges in Sustainability | 2017 | Volume 5 | Issue 1 | Pages 2–6
DOI: 10.12924/cis2017.05010002
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Challenges in Sustainability

Editorial

Pluralism in Search of Sustainability: Ethics, Knowledge and Methdology in Sustainability Science

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Sustainability Science is an emerging, transdisciplinary academic field that aims to help build a sustainable global society by drawing on and integrating research from the humanities and the social, natural, medical and engineering sciences. Academic knowledge is combined with that from relevant actors from outside academia, such as policy-makers, businesses, social organizations and citizens. The field is focused on examining the interactions between human, environmental, and engineered systems to understand and contribute to solutions for complex challenges that threaten the future of humanity and the integrity of the life support systems of the planet, such as climate change, biodiversity loss, pollution, and land and water degradation. Since its inception in around the year 2000, and as expressed by a range of proponents in the field, sustainability science has become an established international platform for interdisciplinary research on complex social problems [1]. This has been done by exploring ways to promote 'greater integration and cooperation in fulfilling the sustainability science mandate' [2]. Sustainability science has thereby become an extremely diverse academic field, yet one with an explicit normative mission. After nearly two decades of sustainability research, it is important to reflect on a major question: what critical knowledge can we gain from sustainability science research on persistent socio-ecological problems and new sustainability challenges?

As a step in that direction, we solicited submissions to a special issue on Sustainability Science in the open access journal *Challenges in Sustainability* (CiS). Whilst the question above will not be sufficiently answered in this special issue, what is provided are some examples of what sustainability science can offer and how parallels can be drawn with other study areas dealing with issues of sustainability. As direction for the issue and as inspiration for authors, we asked them to reflect on the field's mission, achievements and conflicts. To complement more systematic assessments such as literature reviews, we hope that this type of exercise can be a recurrent one, as a way to continually spur active reflection among scholars in the field.

1. Reflecting on the Evolving Characteristics of Sustainability Science

Sustainability science seeks knowledge integration across disciplines, domains and scales including the natural and social sciences, nature-society, science-society and knowledge-to-action. The quest to produce knowledge and expertise on global sustainability challenges while working actively to reduce the distances between disciplines, theory and practice is what most distinguishes it from other fields [3]. These ambitions have led to specific criteria being proposed, for example that sustainability science should be salient in focus and findings, credible in data and methods, and legitimate in outreach and solution options, as stated early on by Cash et al. [4]. In a further step to describe the mission of the field, proponents have emphasized that sustainability science is defined more by the problems it studies and the type of solutions it seeks—rather than by its disciplinary content [5]. In that respect the field is often defined by its research purpose, its applicability, and our roles as reflexive researchers [6]. This explains why proponents stress the constructive, normative and transformational attributes of the field along with the core values of integrity, justice, and viability [7,8]. Furthermore there is agreement that to match the ambition of being problem-based and solution-oriented, the process of knowledge production within sustainability science is to be characterized by collaborative approaches in the form of interdisciplinary or even transdisciplinary research [9]. To that end, it builds on several foundational disciplines and employs methodological pluralism. Variety in perspectives is crucial for understanding how multiple persistent social problems interact with new sustainability challenges [9,10]. Concepts like socio-ecological system and transition management are used as theoretical frames and foundations to bridge and better understand different but interrelated problem areas [11]. Sustainability science also goes beyond these frames to engage with critical theory and other perspectives necessary for bridging the boundaries between disciplines, social and natural systems, science and society, and knowledge and action [4,11].

All of these characteristics contribute to clarify the mission and mandate of sustainability science, but also increase the demands on the field thus making it difficult to grasp in its entirety [12]. By continuously integrating previously separate research problems and methodologies, the landscape of sustainability science is rapidly changing and expanding [11,13]. Reflecting on this process, some scholars are partly critical of the extent to which the field's aspired characteristics have materialized; Wiek et al. [7] for example, claim that sustainability science fails to make sufficient and significant contributions to potential options for transformational change, and [9] point to a discrepancy between promises to provide solutions and the actual delivery. These must be taken seriously. Others argue that both interdisciplinarity and transdisciplinarity in sustainability science are making progress, albeit the latter at a slower pace [11]. Why is this type of reflexive debate important? Some argue that sustainability science emerged as a revolutionary concept in the Kuhnian sense [14,15], referring to how the field responded to the scientific crisis in the normal sciences which could neither deal appropriately with the complexity of the new sustainability challenges nor bridge the science-society divide. Although this may be contested, it is widely acknowledged that sustainability science aspires to a new mode of knowledge production [6,16,17]. Given this ambitious agenda, including core questions, announced at the field's inception and followed by a rapid expansion that has also added new dimensions to this agenda, scholars need to engage in continuous assessment of sustainability science as a field—both challenges that remain, and achievements that point to promising ways forward.

2. Introducing the Contributions to This Special Issue

2.1. How Can Transformative Processes of Knowledge Co-Production and Partnership Be Designed

How do we need to proceed as researchers if we think that sustainability science should progress in ways that matter to people? Many scholars advocate pluralism in pursuing this task [18,19]. It implies that we should use approaches in sustainability science that take various forms of knowledge into consideration even if this can give rise to new challenges. As an example, efforts to integrate western science with indigenous knowledge may run into difficulties if they clash either in worldviews or in forms of knowledge production—or in both. To overcome this, and to support a wider sustainability agenda that takes both time and scale seriously, we may follow Meg Parsons et al. in their call for environmental ethics that help recognize the influence that colonialism and environmental determinism have in shaping views on and for sustainability. In doing so we must consider the underlying aims of research, how it is designed, how the dynamics between past and present is studied, and how communities that we do research *with* and *for* (rather than *on*) are defined, framed and represented. To illustrate this, Parsons et al. discuss insights from a case study on *Waipā River* in New Zealand where an indigenous community successfully renegotiated and enacted new approaches to tackle several socio-ecological crises. In that process, knowledge sharing and mutual learning were appreciated, practiced and found useful.

In another case study, Cordula Ott persuasively illustrates how North-South collaboration across the science-society divide can promote and provide transformative knowledge, and how the notion of sustainable development in itself has integrative potential when used as a shared frame of reference by the different actors involved. Over a fifteen year period, this partnership program, based on meaningful participation, interaction and agency, generated context-based knowledge and innovations for sustainability while also taking into account local needs. Ott emphasizes that transdisciplinary practice in the context of North-South research partnerships is a complex process that requires long-term commitment, adaptiveness, and particular attention to Southern partners' capacity and ownership.

2.2. How Can Film as a Medium Serve The Purpose of Knowledge Integration and Distribution?

It is an oft-spoken ambition in sustainability science to combine critical analysis with problem solving activities [20]. For that purpose researchers may take a critical theory approach to inform the substance and process of dialogue with citizens and communities who have a stake in certain socio-ecological matters. Multiple strategies, methods and techniques can be used in such a dialogue, sometimes taking the form of a real co-production of knowledge, including social learning. The film that Elina Andersson and Ann

Åkerman produced in collaboration with small-scale farmers in Uganda, is a perfect illustration of how academic and local knowledge can be fused and also aligned with a suitable outreach strategy. In the film we learn about causes and consequences of land degradation and soil nutrient depletion and how problems of low agricultural productivity can be tackled and partially overcome in a setting of food insecurity.

2.3. Sustainability Science and Urban Planning—How Can We Foster Mutual Learning?

Also in line with the ambition to foster interdisciplinarity and knowledge integration, sustainability scientists can point to opportunities for scholars and practitioners in neighbouring fields to benefit from work done within sustainability science, and vice versa. Concerned with both continuity and change in the search of sustainability, François Mancebo argues that as part of its mission, sustainability science can help change the way urban planners think about and engage with urban problems. Given that effective standard planning may not be either possible or relevant for sustainability, urban planners should be flexible and continuously consider contextual and long-term consequences of decisions, policies and technology change. In order to understand how change is received by and responded to, planners should build effective action on the basis of collaborative planning together with interests in society—both organizations and civil society.

2.4. What Kinds of Methodology Are Appropriate for Solutions-Oriented Research In a Complex World?

Henrik von Wehrden et al., like Mancebo, conceptualize the problems that Sustainability Science seeks to treat as wicked problems. They do so in order to tease out some of the methodological and knowledge integration challenges that complexity and solutions-orientation generate. Suitable methodologies, they show, ought to be at once flexible and precise: they must consider a variety of different approaches while at the same time employing firm procedural and ethical guidelines. The authors close with a call for longer-term research projects and longitudinal designs to track the development and shifting of sustainability problems over time.

2.5. Are There Ways to Address the Challenges of Contradicting Norms and Value Based Dilemmas?

Sustainability problems are often described as deeply normative [1,21] both in the sense that sustainable development itself is a normative goal and that competing norms in society need to be understood and considered as part of research in sustainability science [22]. In a paper on competing norms and contradictory principles, Tim O'Higgins takes environmental legislation in the EU as a case to illustrate how directives and legislation are embedded in both past and present norms, and how a more proactive and transformative approach is required to halt biodiversity loss. O'Higgins examines how biodiversity norms are translated into three types of environmental policies—Practical, Popular and Pure—which vary in the approach to biodiversity and environmental protection. Importantly, they display a particular tension between giving priority to the practical provision of food versus ensuring pure protection of nature. Here the use of the concept ecosystem services may help resolve some of the tensions.

2.6. Education for Sustainability—What Are the Best Criteria and Methods to Continually Assess Field Based Courses?

There is a call for educational programs at all levels to foster the next generation of sustainability professionals both within and outside of academia [23]. To make the most of such programmes, course designers and teachers must consider both content and instruction format, and establish quality criteria and procedures to continually assess how well education meets the requirements of sustainability and the need for social change. In their study, Ricardo San Carlos et al. focus on procedures to assess problem-driven approaches in educational programmes in sustainability science. They do so—specifically in field based courses and by using the criteria of the 'five key competencies' [24] serving to increase students' awareness of their future roles in science and society. Although this set of criteria may function well as a basis, they recommend that we go beyond them in further assessments to include other aspects that are pertinent to sustainability science education.

3. Applying Plurality in Perspectives, Procedures and Values as a Way Forward

What are the principal achievements, persistent challenges and pathways forward in sustainability science, as reflected by the snapshot of the field presented in this special issue's articles? Some clear themes emerge; some we recognize from the mission for sustainability science, which were set out in the founding work of the field. Other themes represent familiar challenges to those who do research in and teach sustainability science; these have become more apparent as the field has developed. The themes notably connect to different kinds of plurality, and describe domains where considerable progress has been made, sites of ongoing struggles, and indications of promising avenues for future research in this burgeoning field.

3.1. Knowledge Integration

There is agreement that sustainability science is supposed to take an integrated, comprehensive and participatory approach [15]. As such, sustainability science seeks knowledge integration across disciplines, domains and scales [9,20]. A number of articles in this issue deal with different aspects of this broad question of knowledge integration.

Mancebo discusses the mutual learning and benefits that can occur between fields or disciplines concerned with solving complex problems, while both Ott and Parsons et al. deal with the incorporation of different forms of knowledge, with the latter highlighting the ethical dilemmas involved. Andersson and Åkerman cross both the science-society and the knowledge-to-action gap, using film as medium for both dissemination and transformation. Looking to the future, we are reminded to remain vigilant about how we achieve integration between disparate forms of knowledge. At the same time, we are challenged to make more conscious efforts to engage systematically with what may seem to be unexpected disciplines, and to use creative methods like non-traditional media, which can not only facilitate more useful dissemination but also contribute to transformative processes.

3.2. Ongoing Methodological Challenges

The challenge of knowledge integration across many conventional 'gaps', though recognized early on, was perhaps underestimated in terms of understanding what approaches and methodologies would be effective, both for research and learning. In this issue, von Wehrden et al., speaking of sustainability science research in general, deal with the tension between the need for pluralism and flexibility on the one hand and the requirement for precision in methodological approaches on the other. In relation to teaching and learning sustainability, San Carlos et al. investigate the best methods and criteria for evaluating non-traditional problem-based field courses, proposing a continued and broadened focus on such evaluation in the future. That the methodological challenge was initially underestimated should spur us forward, to continue critical discussions but more importantly to dare to innovate, to investigate the variety of forms that pluralism can take, both in research and in the classroom, and to discover what knowledge and understandings such pluralism can produce.

3.3. Dealing with a Plurality of Values

Lafferty pointed out 20 years ago that sustainability transitions are normative actions [25]. Social and political theory has struggled for centuries with conceptualizing the causes and effects of a plurality of values in society, as seen by, Hobbes, Rousseau and many more, and so it is a subject not likely to be settled anytime soon. Nevertheless, two of the articles herein suggest how we might address this plurality more directly when it comes to the specific challenges of sustainability science. As mentioned earlier, Parsons et al. employ an ethical approach as a means to mediate between discrete forms of knowledge. O'Higgins, on the other hand, in a piece on European biodiversity policy, makes the norms entailed in policies the subject of theoretical investigation, with the intention of solving value-centred dilemmas. While the question of normativity has been central to sustainability science since its inception, the articles here provide a glimpse of the wealth of approaches within the social sciences and humanities, which has not yet been fully exploited. This is an inspiring challenge for up and coming interdisciplinary and transdisciplinary researchers.

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Challenges in Sustainability | 2017 | Volume 5 | Issue 1 | Pages 7–14
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Research Article

Alternative Perspectives on Sustainability: Indigenous Knowledge and Methodologies

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Abstract: Indigenous knowledge (IK) is now recognized as being critical to the development of effective, equitable and meaningful strategies to address socio-ecological crises. However efforts to integrate IK and Western science frequently encounter difficulties due to different systems of knowledge production and underlying worldviews. New approaches are needed so that sustainability can progress on the terms that matter the most for the people involved. In this paper we discuss a case study from Aotearoa New Zealand where an indigenous community is in the process of renegotiating and enacting new indigenous-led approaches to address coupled socio-ecological crises. We reflect on novel methodological approaches that highlight the ways in which projects/knowledge are co-produced by a multiplicity of human and non-human actors. To this end we draw on conceptualizations of environmental ethics offered by indigenous scholars and propose alternative bodies of thought, methods, and practices that can support the wider sustainability agenda.

Keywords: Aotearoa New Zealand; climate adaptation; colonialism; culture; Indigenous Knowledge; sustainability science

1. Introduction

Globally, researchers and policy makers are increasingly recognizing the importance of Indigenous Knowledge (IK) in the development and implementation of policies and management approaches [1] . The recent Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report signals this importance of IK as a building block of human security in stating that there is a high likelihood and robust evidence to demonstrate that "indigenous, local and traditional forms of knowledge are a major resource for adapting to climate change" ([2], p. 758). The integration of such bottom-up place-based knowledge with science is hoped to promote more robust approaches in increasing community resilience, adaptation, sustainability, and disaster preparedness [3]. This is based on the premise that the integration of scientific and other knowledge systems can "lead to a more effective interface between science, policy and society" ([4], p. 4). We argue that the transdisciplinary nature of sustainability science has the potential to examine the world through a more holistic approach, something that is often associated with indigenous groups' way of viewing the world. In this paper, our main aim is to discuss the range of challenges

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regarding integration, the ways IK is currently understood and researched, and the need for recognition of historical ideologies and processes, particularly in relation to matters of equity, accountability and fairness in indigenous-related research.

The interest in IK has partly emerged through decades of 'failed' development and the recognition that participatory, locally-led and locally-informed processes are more attuned to indigenous groups' priorities and aspirations [1]. Attempts to integrate IK with Western scientific knowledge often struggle, however, due to the problematic treatment of IK by scholars. The dominant framing of IK is as a complementary source of knowledge to (Western) science, which can be used to augment empirical data on local environmental conditions including the status of biodiversity [5], impacts of climate variability and change [6,7], and frequency of hazards [8–10]. This is problematic because it positions scientific knowledge as objective, rational, and universal and IK as highly situated, specific, embedded, and subjective. Thus scholars criticize Indigenous Knowledge-holders for having "inaccurate and poor conception. . . of past ecosystems and the changes undergone in their surrounding environment" ([5], p. 279), without acknowledging, for instance, the impacts of colonization and globalization on IK traditions. There is also little appreciation or questioning of the knowledge base/roots where Western science and colonialism originated from, with their conceptual roots in European local histories that have became globally applied [11].

Instead of direct comparisons with Western scientific knowledge, IK systems should be viewed as different but nevertheless equally valid ways of understanding the world [12]. IK systems can be defined as "the combination of knowledge systems encompassing technology, social, economic, and philosophical learning, or education, legal and governance systems" ([13], p. 8). Indigenous approaches therefore use, for example, reciprocity as part of the process in responding to social problems and perceive themselves as "respectful partners in genealogical relationships of interconnected humans, non-human beings, entities and collectives who have reciprocal responsibilities to one another" ([14], p. 25; Figure 1). Greater appreciation and consideration of IK is crucial if sustainability science is to encapsulate and build upon people's values and worldviews in a meaningful manner [2,15,16].

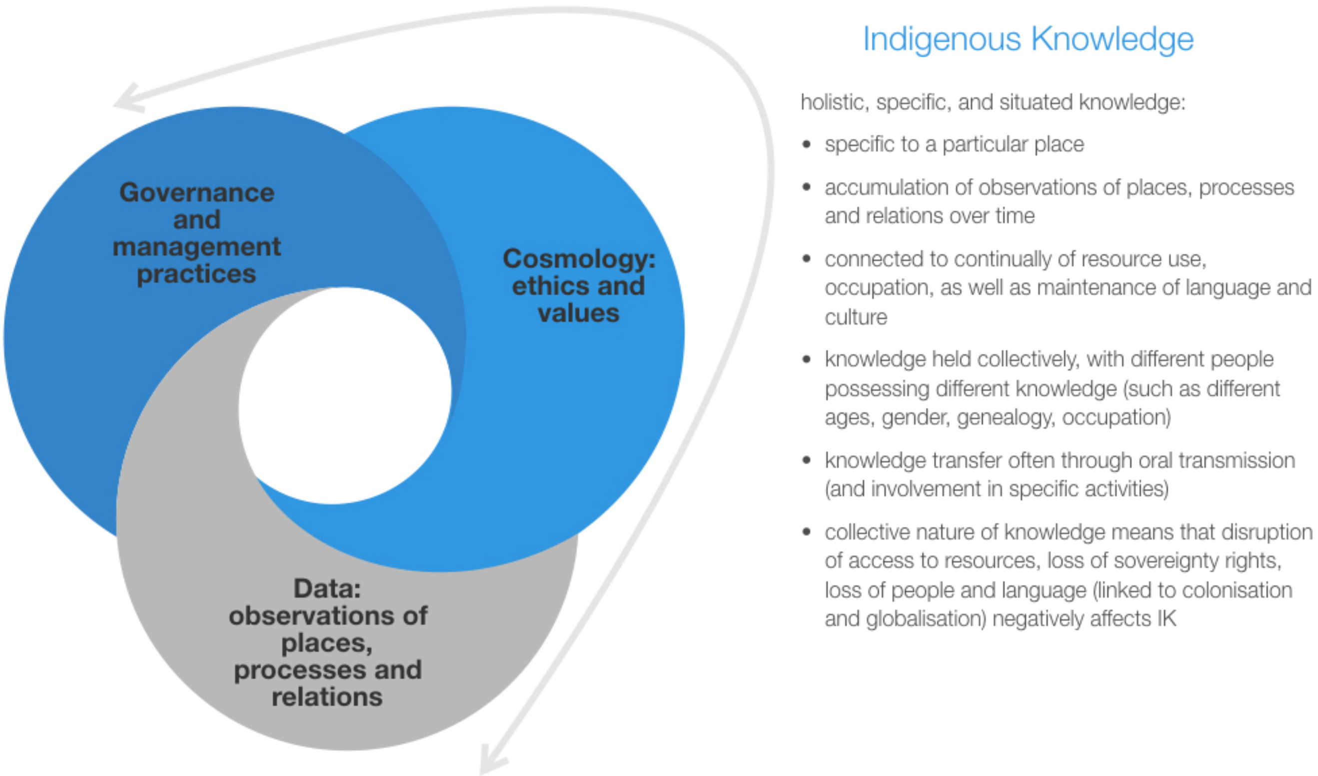

Figure 1. The different dimensions of Indigenous Knowledge and its basis.

While it is outside the scope of this paper to provide a review of the definitional differences, sustainability is broadly defined by scholars in terms of the themes of interconnection of the social, economic, and environmental domains and intergenerational resource usage and requirements. Cutter ([17], p. 73) defines sustainability as "the potential to maintain the long term well-being of communities based on social, economic, and environmental requirements of present and future generations" ([17], p. 73). One of the challenges for sustainability science is to diversify the meaning of sustainability and well-being, which so far have been reliant on measures such as GDP. The incorporation of indigenous conceptualizations of well-being and sustainability, and their inclusion as driving values in policy and research, potentially offer a more inclusive platform for an enriched conversation as to what the goals and outcomes should be and why. This is crucial given that issues of equity and fairness are at the core of any discussion on sustainability [18]. Moreover, an increase in 'reflexive science' [19,20] is helpful for enhancing the validity of, and accountability in, sustainability science. Reflexive approaches which call for a greater recognition of both of our personal norms and values and those at work in processes where knowledge is generated and assessed could offer an avenue for a broader acknowledgement of indigenous perspectives and ways of being.

The paper is organized in the following manner: the next section examines the role of IK in sustainability science and the range of issues that arise in conducting indigenous-related research. The third section presents the case study of indigenous sustainability research from Aotearoa New Zealand where a new innovative knowledge integration methodology is used to provide a more inclusive and holistic approach to the notion of sustainability. This example is used to demonstrate the underlying different worldviews that IK holders and scientists often have and to highlight the necessity of considering the differences and similarities of different types of knowledges in knowledge production processes. This, we argue, does not mean only considering IK but finding innovative ways to understand and consider the multiplicity of meanings that exist in each context and influence what 'sustainability' can and should look like. The last section summarizes the main points of the paper and also provides some suggestions how to move forward in this area of research.

2. Synthesis of IK Methodologies and Sustainability

Sustainability science has been critiqued for not giving indigenous issues and knowledge a prominent place in its investigations [21]. For example, the proposed Sustainability Science research agenda [22] that sought to define the domain of sustainability science makes no mention of indigenous groups or differential vulnerabilities across particular groups in society. While many of the proposed research themes can certainly be applied to indigenous sustainability research, the agenda treats 'society', to some extent, as a somewhat uniform collective, with agreed processes of knowledge production. Yet, recently some sustainability scientists are starting to recognize IK as an integral part of sustainability science and draw attention to the ways IK can contribute to the research agenda [14,21].

It is important to recognize the colonial histories and origins of many of the social sciences, and the ways in which research was used to justify colonial rule over indigenous and non-white (non- indigenous) populations [23]. In particular geographical knowledge about environment, race, and health were intricately bound up with the emergent systems of governance in colonial societies [23]. Theories of environmental determinism sought to explain indigenous populations' 'primitivism' as a consequence of environmental constraints and racial deficits, which in turn informed colonial policies that sought to exclude or marginalize indigenous and other non-white (non-indigenous) populations [24,25].

Coombes et al. ([26], p. 846) argue that place-based ethnographies, a popular approach in global environmental research, all too frequently . . . frame Indigenous peoples as eco-friendly denizens of particular localities. . . which seek to lock Indigenous peoples into pre-modern development, perpetuate gender bias, or invalidate national-scale activism". Cameron [27], Watson and Huntington [28], and Parsons [25] critique in turn how indigenous experiences in a diversity of contexts (the North America Arctic, Australia) are narrated in the climate change scholarship as either passive victims or heroic resistance to external forces, which subtly works towards reinforcing a disabling social pathology [29].

One of the most frequent objections to research pertains to intellectual property rights, and the appropriation of IK by researchers and the use of this knowledge for economic purposes (such as the commercialization and copyrighting of IK about biological agents).Akom [30] and Coombes et al. [26] draw on Freie's ideas of liberatory praxis as a way to address indigenous peoples' objections to research through a deliberate shift away from neocolonial representations of the indigenous Other towards indigenous social science research centered on advocacy, activism and collective problem-solving. In an indigenous context, how knowledge is created and transferred, and the kinds of social relationships that are built, are an important part of the 'engagement' that determines the extent to which knowledge is considered useful for communities. Participation and dialogue should therefore be at the heart of this engagement to ensure the research and policy initiatives address and fit within the communities' priorities [31].

Understanding power relations and rights to knowledge dissemination is equally important. A research project examining indigenous weather forecasts in Vanuatu considered these dimensions and enabled the indigenous participants to first agree on the kind of information that could be reported for the general public and was not considered sacred or owned by particular bloodline or role in the community [32]. Indeed this shift, we suggest, should be at the heart of emergent Indigenous co-design research projects that aim to understand the indigenous socio- political transformations to more sustainable futures. Next, we present a case study that looks at how Indigenous values and perceptions can provide the basis for a more inclusive multi-value management approach and one of the bases for sustainability research and policy formulation.

3. Case Study: Rethinking the Future of Freshwater Systems in Aotearoa New Zealand

InAotearoa New Zealand, freshwater systems are affected by persistent degradation due to human activities. Some of the most immediate problems include nutrient contamination, heavy metals, flooding, biodiversity loss, invasive species, and over extraction. These problems present ongoing threats to the health and well-being of both ecological and human communities. Researchers at the University of Auckland are undertaking a transdisciplinary research project that investigates attempts to accommodate mātauranga Māori (Māori IK) and scientific knowledge in river co- governance and co-management. The three-year project (2016–2018) investigates the ways in which Ngāti Maniapoto (a Māori iwi or tribe in the central North Island) are asserting mātauranga and kaitiakitanga (Māori stewardship according to iwi aspirations and practices) in relation to the co-governance and co-management of the Waipā River.

The Waipā River is the major tributary of the Waikato River, New Zealand's longest river, and has been identified as one of the most degraded freshwater systems in Aotearoa New Zealand [33,34]. The Waipā River and its tributaries flow through environments that have been radically changed by human activities over the last 180 years. The consequences of radical environmental changes within the river catchment now present challenges for local communities and institutions (including local iwi). Co-governance and co-management of the Waipā River are formalized through legislation passed in 2012 (Nga wai o Maniapoto (Waipā River) Act 2012) following the settlement of a Treaty of Waitangi claim. The Treaty settlement was enabled by right to redress for grievances under the Treaty of Waitangi, which was signed by representatives of the British Crown and Māori Chiefs on 6 February 1840. The starting point for the Maniapoto co-governance and co-management arrangements was the settlement between the Crown and Waikato-Tainui in 2008 in respect of the Waikato River. The current research examines the histories of the Waipā River and the close links between Māori dispossession and environmental change from the 1860s to the 1900s; contemporary governance arrangements and institutional changes that emphasize collaboration between Ngāti Maniapoto and the Crown; and, the ways in which expectations about uses of rivers and aspirations for river futures are evolving and being translated into restoration actions.

The formal project was preceded by a six-year engagement between one of the researchers and Ngāti Maniapoto. As well as enabling a personal relationship (connecting with the researcher's own iwi) and professional relationship (participating in various projects and taking roles on various iwi environmental boards) the enactive and performative nature of these entanglements provided the foundation for research premised on co-production [35,36]. Enactive research and performative methods provide a means by which to address the criticisms leveled at ethnographic research and the tendency to essentialize indigenous peoples and communities, and extractive research approaches that perpetuate colonizing technologies and subjugate IK and practices. Moreover, the intersubjective nature of this research entanglement [36,37] and the time spent interacting with various iwi members in a range of forums enabled trust to be built. This period of interaction was accompanied by ongoing critical reflection to make sense of the researcher's changing subjectivities and positionality as iwi member (insider), academic researcher (outsider), professional 'expert' (outsider), and expert for *iwi* (insider) [38,39].

First-hand experiences and reflections were complemented by secondary data sources; specifically, plans designed to manage the Waipā River and to inform restoration efforts. These data provided a platform for the "Rethinking the future of freshwater systems in Aotearoa New Zealand" project. The project was designed as an intrinsic case study [40] and adopts a mixed method approach that utilizes both quantitative and qualitative data [41]. Explicit to the research is the need to adopt an approach that is sensitive to the cultural requirements of Ngāti Maniapoto. This means respecting cultural traditions and customs with regard to engagement, interaction, and knowledge sharing and conducting research in a culturally appropriate manner. Qualitative research techniques include: semi-structured interviews with key stakeholders, including local *iwi*, local governments, industry and civil society groups; workshops with diverse stakeholders to explore people's lived experiences of the Waipā River; observations of changing environmental conditions in specific locations; and the use of Photovoice to document people's experiences in particular places [42]. These techniques are supported by quantitative data obtained from surveys, census data and other statistical datasets, and maps.

The research findings to date indicate that progress in freshwater restoration and management of the Waipā River, as with other rivers in Aotearoa New Zealand, depends on building a better understanding of the multiple ways through which the biophysical, socio-cultural and economic dimensions of freshwater have been experienced, understood and narrated over time. For Waikato Regional Council (WRC), the regional government body responsible for the planning and management of the Waipā River, river management and, thus, water quality concerns focus on sedimentation, nutrient levels as a consequence of agricultural intensification, and microbial contamination (Waikato Regional Council 2014). In response, the WRC developed the Waipā Catchment Plan in collaboration with the Waipā Zone Liaison Subcommittee, Maniaipoto Māori Trust Board and representatives of other *iwi* groups with an interest in the Waikato River (Waikato- Tainui Te Kauhanganui Incorporated, Raukawa Charitable Trust, Ngāti Mahanga and Ngāti Koroki Kahukura). The Catchment Plan adopts a catchment approach and the WRC seeks to address water quality problems through the use of models to identify highly erodible land, pressure points and sediment yields. In addition, monitoring stations are located along the Waipā and its tributary to measure changes in water quality. While this conventional scientific approach to estimating sediment losses and levels of nitrogen and phosphorous in waterways is useful for addressing the physical dimensions and characteristics of H_2O [43], the social, cultural, spiritual and metaphysical characteristics of the *awa* (river) are absent from such calculative practices.

For Ngāti Maniapoto the Waipā River is identified as being at the heart of Maniapoto spiritual and physical well-being and tribal identity and culture. The Waipā is considered a *taonga* (treasure) and the *mauri* (life force) of the *iwi*. As such, decisions on how to manage the Waipā necessarily include attending to Waiwaia, a taniwha and kaitiaki (guardian) of the Waipā River and the Ngāti Maniapoto people. *Taniwha* are supernatural creatures that inhabit rivers, lakes, or caves, and may be seen as symbols of the mythical and metaphorical embodiment of the relations between Māori and their rivers. To Maniapoto, Waiwaia is held to be the essence and well-being of the Waipā. This relationship is explicitly acknowledged in Nga wai o Maniapoto (Waipā River) Act 2012. Following the passing of this legislation, Ngāti Maniapoto have engaged in a number of projects that focus on managing and restoring the Waipā. The *Maniapoto Upper Waipā Fisheries Plan 2015* provides for the protection, restoration and enhancement of the fisheries resources of the Waipā River catchment (Watene-Rawiri, Kukutai and Maniapoto Māori Trust Board, 2015). In developing the *Fisheries Plan*, the Fisheries Reference Group adopted a *mātauranga* framework to convey the ontological and epistemological commitment by the group to acknowledging the multiple dimensions constituting the Waipā River (Kukutai, Watene-Rawiri and Maniapoto Māori Trust Board, 2015. Not only is Waiwaia explicitly identified and acknowledged within the *Fisheries Plan*; he was ever present at the meetings undertaken to develop the *Fisheries Plan* through recollections and stories shared by members of the *iwi* (Watene-Rawiri, Kukutai and Maniapoto Māori Trust Board, 2015). Ensuring the continuation of the reciprocal relationship between Waiwaia and Ngāti Maniapoto is at the forefront of the *Fisheries Plan*.

These plans speak to the challenges of reconciling different knowledge traditions and ways of knowing rivers that characterize western science and Indigenous knowledge. In acknowledging that transforming freshwater management requires a broader appreciation of the diversity of communities, knowledges, and future planning needs, there is currently no consensus about how best to accommodate these different dimensions or how they can be used to build a freshwater management system able to halt environmental decline and enhance river health for future generations. For WRC, while the *Waipā Catchment Plan* acknowledges the special relationship between Ngāti Maniapoto, Waiwaia and the Waipā, an explicit *mātauranga* approach is absent. Rather than a lack of care or disregard for Waiwaia and *mātauranga* Māori, the care and protection of a supernatural creature and the spiritual dimensions of the river are not the traditional purview of a management organization utilizing western science. The *Maniapoto Upper Waipā Fisheries Plan 2015* can be seen as an attempt to incorporate scientific information into a *mātauranga* framework. While there is potential for this plan to precipitate changes in how fisheries (and river) management is imagined and practiced, the possibility also exists that a dual system is perpetuated in which Ngāti Maniapoto concerns are essentialized as simply ‘cultural’ and Western science retains its privileged position in determining river futures. New, innovative, transdisciplinary approaches that move beyond the reliance on conventional scientific knowledge as the sole basis for thinking about freshwater management and restoration are needed (Figure 2).

The overall goal of the “Rethinking Freshwater” project is to co-produce knowledge about freshwater with Māori, particularly Ngāti Maniapoto, and stakeholders in the Waipā River catchment. Stakeholders include local and regional governments, scientists, individual farmers, recreational users of the Waipā River, as well as a range of private sector and industry organisations. Understanding how IK can be accommodated in river restoration to enable the expression of cultural and spiritual values provides an opportunity to enhance ecological restoration scholarship and practice and to rethink how water resource management practices are done. By considering different knowledges and values (social, cultural and spiritual, in addition to economic and ecological) that are attached to the Waipā River, this project seeks to shift conceptual thinking away from narrowly delineated scientific measures of river value to a more inclusive approach.

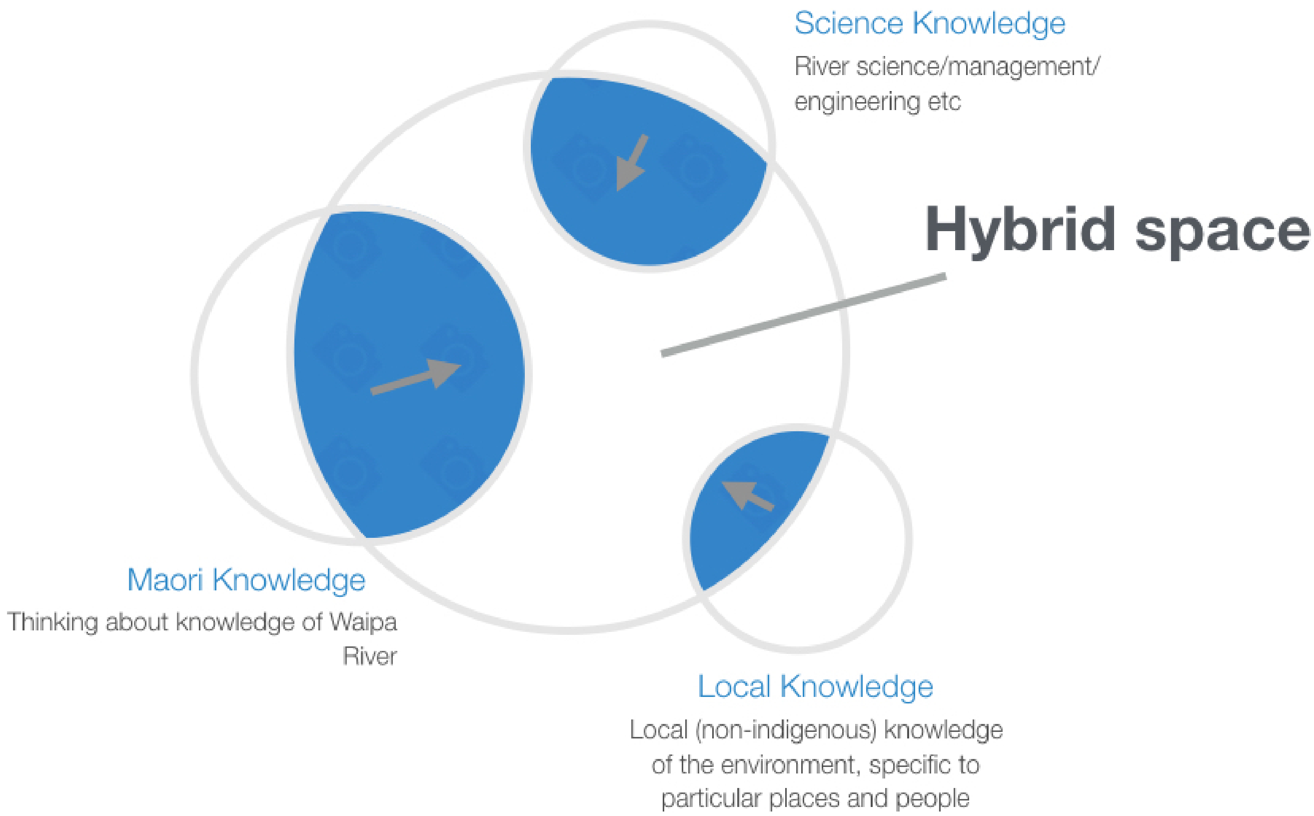

Figure 2. The different kinds of knowledge creating a hybrid knowledge space in the context of the Waipā River catchment and its management.

4. Way Forward

In this paper we have discussed the role of IK in sustainability science and the challenges associated with the inclusion and consideration of IK in scientific discourse in general. We discussed the rationale for considering scientific knowledge and IK as mutually inclusive and useful sources of knowledge in reaching a fuller understanding of sustainability. Our Waipā River case study demonstrates attempts by conventional resource managers and indigenous peoples to utilize different knowledges to inform river management practices. In both cases, we found that the existence of different interpretations of river degradation and identifying possible solutions in a more holistic manner was recognized; however, the extent to which these different knowledges were translated into management plans (and practices) varied.

We argue that there is a need to recognize the influence that environmental determinism and colonialism have in shaping the sustainability research agenda as is the need to pay closer attention to how research is designed, to what ends, and how communities are framed in research. All too often who is included in 'society' and the assessment of desired outcomes is exclusive of indigenous groups and represents mainstream ideologies that have become manifested overtime through visions which in turn have guided modifications of landscapes [44]. We suggest that scholars need to adopt innovative methodologies that take into account both the historical legacies and present day concerns of indigenous communities about research, which includes confronting the "lingering imperialism... embedded in self-proclaimed critical methodologies" [26]. In our research, we examined the historical records on governance decisions on New Zealand's landscape modifications [44]. For the Waipā, we are constructing narratives of river knowledges and practices through historical analyses, interviews with diverse stakeholders, workshops run according to Māori tradition and cultural practices, and other ethnographic techniques that facilitate the sharing of stories to gain deeper insights into the diverse ideologies and sources of knowledge embedded across time and space.

We further propose four key principles that should be applied especially in indigenous-related sustainability research:

1. *Acceptance and advocacy of Indigenous Knowledge systems:* Accepting and adequately representing knowledge systems that do not conform to Western scientific standards. For Indigenous communities, their narratives, oral histories, and cultural practices are essential avenues for knowledge transmission. Hence, approaches that view knowledge systems as contextually-based and located in specific places and times is necessary while also recognizing the broader insights that place-specific IK has.
2. *Positionality in research:* Critical awareness of how re-

search is shaped by power, relationships, and ethics. This approach views people as collaborators and partners in co- design of research and production of knowledge, rather than merely as informants.

3. *Co-designing research agenda:* Research agenda needs to be co-designed by Indigenous communities and fit with their priorities.
4. *Two-way knowledge sharing:* Since academic research is about searching for 'new' knowledge or 'new' ways of thinking, researchers rarely consider sharing their research. Sharing knowledge needs to be an ongoing and two-way process. Giving indigenous communities access to all copies of research documents and engaging them in the analysis process will ensure that the results are participatory and representative.

We encourage approaches that are explicit about the kind of knowledge each stakeholder group holds as most 'valid' to guide the development of solutions to achieving sustainability. In our opinion, such an approach enables a deeper understanding of the diversity of perceptions needed for more holistic approaches to sustainability. This is, however, not always straight forward particularly when ideas embedded in IK and/or policy discourse conflict with researchers' own ideas and values. IK is not a homogeneous body of knowledge and claims of the need to promote a particular traditional practice and way of being can be contested within a cultural group. To respect the diversity found within IK, we as researchers must work with different segments of the communities (e.g. women, younger people, people with disabilities), to ensure appropriate protocols concerning the sharing and representation of IK are accepted across the group.

In such cases a normative and ethical challenge emerges that requires unpacking how researchers and the groups we work with conceptualize 'sustainability', what expectations we share and do not share in terms of how sustainability could be achieved, and what goals and values are ultimately driving these aspirations. While this necessitates the integration of different knowledge systems [45] and finding ways to accommodate spiritual, material and technical views embedded in natural resource management, it also calls for closer introspection of our own biases, values, and preferences. Creating such diverse yet shared visions of sustainability [46] can lead to richer and more inclusive ways to tackle solutions.

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Research Article

Enabling Transformative Research: Lessons from the Eastern and Southern Africa Partnership Programme (1999–2015)

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Abstract: World leaders at the 2015 United Nations Sustainable Development Summit in New York have reconfirmed the relevance of sustainability as the guiding paradigm in countering the development and climate crisis of the Anthropocene. Recent decades however, have been characterized by confusion, contestations, and arbitrariness in defining the nature and pathways of sustainable development. Humanity must urgently find ways to unlock the potential of the sustainability paradigm and organize a sustainability transformation. An emerging sustainability science community has already established considerable consensus on essential features of transformative science and research. Sustainability scholars are providing growing evidence that an emancipatory and democratic construction of sustainable development and more equitable, deliberative, and democratized knowledge generation are pivotal in tackling sustainability challenges. These findings are further underpinned by experiences gained in the *Eastern and Southern Africa Partnership Programme* (1999–2015)—a rare case of a long-term, transnational, and transdisciplinary research endeavour already completed. The programme fulfilled the dual role which is compulsory in transformative research: It generated contextualized knowledge and innovation at the science–society interface while simultaneously securing meaningful participation and Southern agency in a co-evolutionary process. This paper offers insight into the programme's adaptive structure and implementation processes, which fostered deliberation, capacity development, and joint programme navigation benchmarked against local needs and broader sustainability demands. The ESAPP experience confirms that, if taken as the overarching frame of reference for all actors involved, the sustainability paradigm unfolds its integrative and transformative power. It enables sustainability-oriented actors from all scientific and practical fields to seek consilience between differing development and innovation paradigms and synchronize their development agendas and research frameworks on behalf of societal co-production of knowledge and innovation. Accordingly, the sustainability paradigm has the power to guide development and innovation policy, and practice out of the current confusion and ineffectiveness.

Keywords: capacity development; deliberation; equity; innovation; knowledge; partnerships; research; sustainability science; sustainable development; transformation

1. Introduction

1.1. Confusion and Arbitrariness in the Understanding of Sustainable Development

At the 2015 United Nations Sustainable Development Summit in New York, world leaders responded to alarming scientific evidence showing that we humans are interfering with the Earth system at a scale and magnitude that threatens our own survival. With the adoption of the *2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals* (SDGs), they reconfirmed the primacy of sustainability as the guiding development paradigm (UN, 2015). Framed in the so-called "Brundtland Report" [1] and endorsed at the 1992 Earth Summit in Rio, the sustainability paradigm is not novel; and looking back, it has fallen short of expectations in various ways. Nevertheless it continues to be the official global response to the development and climate crisis of the Anthropocene. But—and this is confirmed by the renewed global commitment—science and society must urgently find ways to unlock its potential and organize a sustainability transformation [2].

The Post-Brundtland world is characterized by confusion, contestations, and arbitrariness in identifying the nature and pathways of sustainable development [3–5]. The implications of the sustainability paradigm as an antithesis to the paradigm of growth and transfer are not easy to capture. Although our understanding of development intervention and global governance has fundamentally changed [6–8], the normativity and the transformative power of sustainability have reached buzzword status [9]. At the same time, unorthodox scholars across diverse fields in science, technology, and development, have observed narrow, exploitative, and often destructive use of promising post-Rio development concepts such as innovation [10,11], gender mainstreaming [12], livelihoods [13,14], justice [15], or transformation [16], to mention just a few. Scholars argue that systemic thinking, equity-based science-society interaction, and reflexive learning – which are all indispensable in generating knowledge and innovation for sustainable development—continue to be marginalized, confined to single sectors, and used to serve vested interests [17–19]. Despite progress on the integration of civil society in global environmental assessments and negotiations, power disparities and self-interest are hampering action and creating new tensions, disparities, and bargaining between the global North and South [20–23]. While economic bias gets much of the attention in the debate, sustainability scholars also criticize frequent environmental bias at the expense of human and social issues [4], and social bias. The latter prevailed in the Millennium Development Goals, for example [24]. Spangenberg ([18] p. 277) points out a damaging "trend towards a further fragmentation of research concerning the substance of sustainability". Skoglund and Jensen ([22] p. 124) provide a striking example of how climate policy is misguided; they refer to Chandler (2012), who showed "how different policies and non-governmental organizations rely on the 'adaptation agenda' to suggest survival strategies for the poor: thus attempting to align the marginalized with 'vulnerability to climate change', instead of addressing the broader economic and social factors that gave rise to their marginalized position". Such examples illustrate how concrete efforts and successes fade in an amalgam of overlapping and often contradictory approaches and discourses ranging from mainstream sustainability to green radicalism [25], or from weak sustainability to more radical constructions of strong sustainability [4,26,27]. As a consequence, the pre-Brundtland paradigm of growth, with its "loading-dock approach" [28] of transferring scientific and technological solutions to decision-makers, is persisting [29,30]. To break its dominance and unlock transformative potentials, sustainability advocates have begun to reclaim the emancipatory power inherent in the original conceptualizations of development in their respective disciplines and practical domains. Taking systems approaches, they strive for epistemological and practical grounding as well as for further clarification of the interfaces between diverse development concepts (see, for example, [9–11,19,31–34]).

This leads to the approach I take in this paper. My overarching question is: How can science contribute to a sustainability transformation? More specifically, I reflect on various aspects that are essential in organizing transformative research. I argue that an emancipatory and democratic construction of sustainable development is pivotal in tackling sustainability challenges. An emerging sustainability science is providing growing evidence of this fact. I further underpin my argument with experiences gained in the *Eastern and Southern Africa Partnership Programme*—a rare case of a long-term transdisciplinary research endeavour already completed. With my contribution, I intend to confirm that, if taken as the principal frame of reference, sustainable development is suited to integrate the efforts of sustainability-oriented scholars and practitioners across different profiles. It provides orientation in synchronizing development agendas and frameworks towards societal co-production of knowledge and innovation. Accordingly, the sustainability paradigm has the power to guide development and innovation policy and practice out of the current confusion and ineffectiveness.

1.2. An Emancipatory Construction of Sustainable Development

Fortunately, we can build on promising achievements in transformative research. A multitude of reviews and syntheses show how an emerging sustainability science community is establishing considerable consensus on the sustainability paradigm's epistemological and practical implications for science and research (see, for example, [8,16,18,22,27,29,35]). With a view to promoting equity-based, just development within the planetary boundaries, scholars are working to identify enabling institutional contexts and developing transdisciplinary research frameworks and procedures across scientific disciplines and at the interfaces between science and society, as well as between science and policy [32,36–40]. They conceive of sustainability as a societal future forming process [5], as it "emerges as a horizon to be approached but never reached" ([41] p. 992). Accordingly, transdisciplinary theory and practice must accommodate pluralism and experimentation. But, as Waas and colleagues ([4] p. 1645) point out, this future forming process has to be benchmarked against the "precise and unambiguous meaning" of the original conceptualization of sustainable development. They identify four fundamental principles—normativity, equity, integration, and dynamism—that "represent the interpretational limits of the concept and are essential to sustainability no matter which view and interpretation is employed" ([4] p. 1657). Such (and analogous) principles respond to the complexity and adaptiveness of human–environment systems—which are the subject under consideration [33,42]—and provide orientation for societal future forming processes and "research in a world of flux" ([5] p. 11). Ethical and equity concerns further underpin sustainable development as an emancipatory and transformative concept and open the floor for contesting existing power structures and decision-making processes [16,26,43]. Not only natural resources but also social capital and knowledge must be distributed equally [23,44–46]. This requires us to rethink our understanding of knowledge and expertise, and to revise our traditional role and (self-)conception as researchers [47–49]. Normative, democratic and procedural principles are at the core of transdisciplinary practice, in which scholars attempt to link science and civil society in joint reflexive or learning processes [17,18,26,38,40]. Building on such critical reflection, sustainability scholars are bringing together long-standing participatory, democratic, and social movements' traditions and structuring research along new, deliberate forms of science–society interaction [50–53]. In a deliberative democracy, or indeed in any deliberative system, actors participate in a communicative process and influence collective decisions [25,54]. If we understand a research framework or programme as a deliberative system, its deliberative capacity—"the extent to which a political system possesses structures to host deliberation that is authentic, inclusive, and consequential" [50]—gains utmost importance. But the deliberative capacity of individuals and institutions involved must likewise be secured for their equal and meaningful inclusion in future forming processes. As well as putting equity and power issues to the fore, this undergirds the strategic goal framed by the United Nations Educational, Scientific and Cultural Organization to develop knowledge societies by democratizing knowledge and knowledge generation [55]. Indeed, progress in the democratization of knowledge has been observed [56], and sustainability science is making headway. But transdisciplinarity is a relatively young field, and experiences of long-term transdisciplinary practice at a transnational, regional scale are particularly rare.

In the following, I will present the *Eastern and Southern Africa Partnership Programme* (ESAPP) as a research endeavour that is well-suited to help fill this gap. Running from 1999 to 2015, the programme brought together partners from Switzerland, Kenya, Ethiopia, Tanzania, Madagascar, Mozambique, and Eritrea in conducting long-term transdisciplinary research for sustainable land management and sustainable regional development. Two final publications provide substantial insights into this experience. Ehrensperger and colleagues present ESAPP's research and outcomes [57], while Ott and Kiteme [58] provide more in-depth reflections on the implementation, adaptation, and learning processes that took place within ESAPP. Taking up the arguments outlined above, I present programme features that proved to be supportive in strengthening deliberative capacity, equity-based knowledge generation, and institutional development for coherent local to global governance. I further discuss specific challenges that arose during the implementation of this transdisciplinary and transnational research programme as well as in securing its legacy.

2. Cornerstones of Transformative Research in the Eastern and Southern Africa Partnership Programme

2.1. An Enabling Institutional Context

When ESAPP was framed in the late 1990s, both public involvement and sustainability science were in their infancy. Ott and Kiteme [58] show how three contextual developments at the interface between science and policymaking had prepared the ground for ESAPP's unique and innovative programme design: First, decades of research collaborations and networking between Switzerland and countries in Eastern Africa had established trust and fruitful interaction between scientists, funding organizations, as well as governmental and non-governmental actors and institutions of the countries involved. This led to the launching of an integrative research programme that matched the scientific and political landscape of Eastern Africa. Second, since 1988, ESAPP's mother institution, the University of Bern's *Centre for Development and Environment* (CDE), had been mandated by the *Swiss Agency for Development and Cooperation* (SDC) to help prepare Switzerland's position on the 1992 Rio conventions and translate them into poverty alleviation policy and practice. Already in the 1990s, CDE had come up with integrative, participatory concepts and tools designed to support human agency, science–society interaction, and social learning [59]. Third, the programme designers could build on long-standing activities of a loose network of sustainability-oriented scholars and practitioners in Switzerland. In 1997, representatives from CDE and the Swiss Academy of Sciences and its *Commission for Research Partnerships with Developing Countries* (KFPE) drafted the KFPE's 11 Principles and 7 Questions as a guide for transdisciplinary and transnational research partnerships for sustainable development [44,60]. The KFPE guide is heavily equity-oriented and reflects state-of-the-art sustainability science even today. It underpins the choice of sustainable development, partnership, and transdisciplinarity as ESAPP's core foundations. The well-established collaboration between scientists, practitioners, and policymakers enabled SDC as the funding institution to give ESAPP's architects considerable leeway; at the same time, SDC was represented on ESAPP's advisory board—the programme's steering committee—from the outset. Such long-standing and trustful collaboration between researchers, funding organisations, and research users in the North and South, must be considered a precondition for transformative research [58].

2.2. Emancipatory Foundations: Sustainable Development, Transdisciplinarity, and Partnership

ESAPP was launched in 1999 with the mission of generating new knowledge and innovation for sustainable development on local to regional levels. The programme was aimed at mitigating sustainability challenges by making knowledge generation more democratic and accessible, increasing Southern ownership and agency, producing innovative research results, and promoting evidence-based, South-driven sustainable rural development. Transdisciplinarity as the second epistemological pillar of ESAPP was understood as an integrative approach that brings together scientific (disciplinary and interdisciplinary) and non-scientific (endogenous, indigenous, cultural, local, etc.) knowledge systems; academic, social, and political actors and institutions; and different places and scales [51,61]. This approach would guide science and society through research and learning processes in which they needed to jointly produce three types of knowledge: systems knowledge, which delineates the sustainability problem to be addressed and the associated subsystem or context ("What is?"); target knowledge, which encompasses negotiated values and goals for a shared vision of a sustainable future ("What ought to be?"); and transformation knowledge, which describes the path to follow in order to achieve a sustainable future ("How do we get there?") [39,52,60]. In such an understanding, knowledge and innovation for sustainable development are necessarily an outcome of joint learning processes that involve all societal actors. Accordingly, ESAPP framed research for sustainable development as what Gergen [5] has called a future forming practice. The programme constituted itself as a communicative space [54,62] embedded in an open framework of research partnerships. ESAPP's developers further acknowledged that partnership as a third epistemological pillar required special attention. In North–South research partnerships, disparities with regard to power, knowledge, and resources often constrain balanced exchange and cooperation, as the research is generally financed, initiated, managed, and evaluated by Northern institutions [63]. In a network as complex as ESAPP's, this calls for efforts to expand deliberative capacity, for a devolution of power, and for ensuring accountability and legitimacy towards both funding organizations and partners within and beyond the research network [8,39]. It requires management strategies and organizational structures that promote Southern partners' determination, competence, and ownership with respect to the formulation of pathways to sustainable development [43,56]. And this, in turn, calls for pragmatism [3,64]. Pursuing equity as a structural goal within ESAPP was both fundamental and innovative.

Another central conceptual element in ESAPP was its thematic and spatial concentration. In line with CDE's core competence, ESAPP focused on contextualized knowledge about sustainable land management and sustainable regional development and promoted local and regional initiatives through transdisciplinary research. Knowledge has to be generated and processed together with local actors to be robustly coupled to human-environment-system dynamics in a specific context [33,64,65]. In the African context, a vast majority of people depend on direct access to renewable natural resources, while competing claims and short-term needs at various scales tend to override environmental concerns, aggravate poverty, and inhibit economic development [66]. The result is a dwindling resource base, which often goes unnoticed for a long time. The programme's stewardship of the environment does not constitute a case of the environmental bias observed by Waas and colleagues [4]; it is a necessity. After many decades of neglect, rural areas and the livelihoods of small-scale resource users are now being reappraised based on the recognition that global governance approaches, adaptation and mitigation strategies must build on knowledge of local conditions to be effective [21,67].

2.3. Adaptive Research Structures

ESAPP's designers were well aware that the programme's transdisciplinary and transnational research framework opened up a door to many new challenges. One of these challenges is the dual role of scientists doing transformative research: they must work to provide evidence while simultaneously expanding human and institutional capacity for sustainable development by means of education and training, collaborative research and learning processes, as well as knowledge brokering activities and products [30,50,53,63]. How then should inter- and transdisciplinary research be (re-)organized and structured? A sophisticated research framework is provided by the Earth System Governance Project, which organizes research around five analytical problems: architecture, agency, adaptiveness, accountability, and allocation & access. At the same time power, knowledge, norms, and scale are regarded as crosscutting research themes that are crucial to the study of each analytical problem and also to an integrated understanding of earth system governance. Related thematic issues are embedded in flagship activities [37]. This research framework outlines, in a very useful way, the basic challenge of coherently integrating facts and values in a transdisciplinary research programme [37,47]. In ESAPP, conceptual and operational challenges or necessary trade-offs at the science–policy interface were addressed by combining the open partnership and research framework with recursive and (self-)reflexive processes that the project partners steered jointly [39]. Three structural approaches provided the necessary guidance (see also [58]):

1. *An adaptive management approach that integrates actors' agency*: Adaptive management corresponds well with a recursive and reflexive research design. Widely accepted today, adaptive management of a research programme was innovative at the turn of the millennium. ESAPP's adaptive management approach was intended to provide the necessary basic stability in the institutional fabric while allowing for goals, institutional structures, and research procedures to be reshaped in the course of the programme's implementation. It offered space for integrating feedback and research results into management decisions and securing meaningful participation and institutional development.
2. *A dual-structure approach that harmonizes concepts and action*: In development contexts, short-term priorities often override long-term sustainability imperatives. This may result in a one-sided focus on either basic research or action research, or in the latter being viewed as a mere add-on to business-as-usual science. To accommodate both need-driven and concept-driven concerns, ESAPP linked action research with basic research and capacity development. The two components were intended to interact, reinforce each other, and eventually reshape the programme. ESAPP's action research component comprised over 300 small-grant priority action projects formulated by local partners alone or in collaboration with ESAPP researchers. The basic research and capacity development component mainly served to provide support and secure programme coherence, consistency, and effectiveness through reflection, learning, and adaptation.
3. *A contextuality approach that links places and scales*: At its outset, ESAPP was mandated to build on contextualized knowledge, databases, capacities and partner networks created by CDE's predecessor programmes in Africa; to further develop their transdisciplinary character; and to make them available for decision-making support and further research. Knowledge and data for sustainable land management and sustainable regional development that are contextualized—embedded in a specific time, place, and scale—are currently high on the global development agenda. Building and consolidating bottom-up databases and linking them with regional or global observatories is critical to enhancing coherence and consistency in governance approaches from local to global levels. In addition, it is a key asset for developing countries in formulating self-determined and just national development strategies and in interacting with global development institutions [30,65].

Being at once consistent, integrative, and flexible, ESAPP's three structural approaches secured an institutional arrangement that was ideally suited for enhancing deliberative capacity, learning, and institutional development. In what follows, I will provide some insight into how indeed, they fostered equity and inclusion, the co-production of contextualized knowledge, and the development of people's and institutions' capacities, in the South and North (see also [58]).

2.4. Joint Programme Navigation for Sustainable Development

As argued above, in order to support a sustainability transformation, scientists need to strengthen the deliberative capacity of research— understood as a political system—by means of adequate structures and procedures. Adequacy in this context means that they are in line with the fundamental normative, democratic and procedural principles of sustainable development. It is in collaborative and reflexive processes that partners in research share and integrate values, norms, and perceptions, tackle dissent, and create a "common culture". This shifts the focus from research outcomes to the processes of social knowledge generation; to experimentation, learning, and constant change under an adaptive governance approach [30,53,62]. The "communicative space"—actual or virtual meeting places—and the deliberate and consequential quality of exchange become a subject of analysis: Where do researchers, partners, and actors interact, and what exactly are they doing there? But first of all, people need to be brought together. For the ESAPP as a transnational research programme, this was not only a logistical problem. Organizing joint processes among partners with different cultural backgrounds and varying institutional strength requires time, resources, and mutual trust. Over the years, ESAPP partners successfully organized an iterative process of reflection and adaptation within routine modes and places of exchange. The following elements and milestones of partners' interaction were crucial to this success:

- *Institutionalizing joint programme steering*: Like many endeavours in the field of research for development, ESAPP was North-funded and hence North-driven at its inception. The advisory board—the programme's steering body—was composed by representatives of SDC as the funding institution, of CDE, and of related Swiss institutions. Southern partners were not represented until 2011. But early assessments emphasized the need for strengthening Southern partners' capacity and ownership to increase equity and ensure research coherence, relevance, and quality for the benefit of the South. Eventually, in 2006, partners initiated annual one-week capitalization workshops in the South to overcome geographic distance, foster communication, and exchange on a regular base. The workshops immediately became the cornerstone of joint programme management. Here, ESAPP partners met for data and method sharing, deliberation and self-evaluation, strategic reorientation, and a field excursion. Here, they applied and further developed ESAPP's management tools, settled conflictive issues, and made necessary changes in the programme's organizational structure and research design.

- *Developing adequate management tools and procedures*: Of necessity and custom, at the outset of the programme, criteria for selecting research projects, as well as monitoring and evaluation mechanisms mainly reflected goals and indicators valued in the North. In the course of time, partners jointly identified new forms of process benchmarking: They developed an appropriate monitoring and evaluation system that combined reflexive elements (self-evaluation, feedback loops) with simple and easy-to-understand standard formats (project documents, catalogues of criteria, target matrices/log frames, statistical evaluations, etc.) and standard procedures (advisory board meetings, project-cycle steps, external evaluations, etc.). Being fairly consistent, lean, and procedural, ESAPP's monitoring and evaluation system served as a navigation tool [44].
- *Scaling research results up and out*: Given the high pressure for quick and effective interventions in rural development contexts, ESAPP was confronted with high numbers of priority action project proposals. To secure ESAPP's mission and scope, the partners established a process of clustering and sequencing thematically related projects. A preselection of projects was done by the coordinators in the respective partner countries. In the annual capitalization workshops, projects were further discussed, evaluated, and related to one another. Eventually, this led to the creation of thematic partnerships between countries which promoted the scaling up and out of results within the whole region. Finally, ESAPP consolidated its research in ten reference sites characterized by context-specific priorities within the region. This procedural thematic concentration made it possible to use research results of more than 300 priority action projects as evidence in an "ongoing process of evaluation, learning, adaptation and adoption" ([62] p. 492).
- *Consolidating and leveraging ESAPP's knowledge and database*: Partners jointly upgraded and made available a comprehensive long-term database that includes geo-referenced long-term measurements and observations of natural resources that links ecological and socio-economic quantitative and qualitative knowledge at local, national, and regional levels. It is a key asset for research and policymaking in Eastern Africa and the backbone of ESAPP's Southern network. At the same time, the database is a major tool for education and capacity development beyond the programme's lifetime that led to the generation of local knowledge platforms and institutions. The knowledge database also includes a set of transdisciplinary tools. Tools that combine analytical and communicative elements—that is, tools that merge empirical research with participatory assessments and social learning—proved especially successful.
- *Consolidating and leveraging ESAPP's network of partners*: In the implementation and learning processes of ESAPP, partners jointly consolidated initially broad and loose networks. Southern institutions gradually became more equal partners within the programme. Partner institutions were not equally strong in all countries—indicating a need for better integration—but in some countries they were able to initiate new strategic collaborations and networks. The ESAPP network also includes hundreds of government officials, experts, and researchers that participated in ESAPP training courses, especially in those organized by the Centre for Training and Integrated Research in Arid and Semi-Arid Lands Development (CETRAD, Kenya). CETRAD itself is a major outcome of research collaboration between Switzerland and Kenya. The Water and Land Resource Centre (WLRC) in Ethiopia is another example. But many other institutions, down to the village level, grew out of ESAPP research activities.

3. Challenges and Outlook

A sustainability transformation requires novel research frameworks and programme structures that accommodate processual and democratic features such as normativity, equity, integration, dynamism, inclusiveness, accountability, legitimacy, deliberation, and others [4,25,37]. The Eastern and Southern Africa Partnership Programme, ESAPP, was as an early transdisciplinary research endeavour that successfully endorsed inclusive, authentic, and consequential deliberation and joint programme navigation balancing local needs and sustainability demands. The programme thus fulfilled the dual role which is compulsory in transformative research: It generated contextualized knowledge and innovation at the science–society interface while at the same time securing meaningful participation and Southern agency in a co-evolutionary process [54,68]. But despite ESAPP's widely acknowledged success, the programme's final assessments list major shortcomings [57,58]. For example, research in the complex transnational and transcultural context of ESAPP was constrained considerably by standard planning and budget frameworks, which generally do not favour experimental procedures and equity approaches. Insufficient human and institutional capacities, a lack of ownership among the funding and collaborating institutions, and weak South–South engagement were other limiting factors. The jointly developed monitoring and evaluation system for guiding both action research projects and institutional development remained insufficiently coherent. Managing a comprehensive database and relating it to existing regional environmental databases and global observatories proved too ambitious and challenging for a research programme as small as ESAPP. In some countries, the number of action research projects was too small to enable meaningful clustering and scaling up of results. The programme's success in strengthening the Southern network and equitable South–South exchange was limited by differences in political and institutional backgrounds and by national interests overriding collaborative efforts. Although promising ways of tackling stumbling blocks and trade-offs at the interfaces between science, society, and policy are well-described [36,39,47] and were included in ESAPP's design, the programme's implementation was continuously contested by partners within and beyond the programme. Here, the sustainability paradigm unfolded its integrative and transformative power and helped to focus collaborative processes within the programme. Taken as a superordinate system of reference that is valid for all actors involved, it implied, and guided equity-based and democratic processes of research, learning, and innovation. A basic characteristic was that actors jointly identified research needs and approaches, and that they jointly assessed, evaluated, and reused evidence and innovations.

Such reflexive and recursive processes are well-suited for integrating different development and innovation paradigms in a fruitful way, particularly the dominant *innovation paradigm that takes science as its frame of reference*—that is, where scientists and researchers provide and transfer the "right" knowledge and solutions to decision-makers—and the fairly widespread *innovation paradigm that builds on interaction between science and society*. Both paradigms have proved to be insufficient in themselves, but they can nonetheless be an important part of solutions for sustainable development. In ESAPP's final report [57], partners provide many examples. But an important lesson learned during ESAPP is that the sustainability paradigm goes beyond the innovation paradigm building on science–society interaction. Born in the spirit of the 1980s, this innovation paradigm holds that scientists and civil society should communicate to improve the efficiency and effectiveness of development measures, enable evidence-based decision-making, and ensure an ethically sound application of knowledge. But this paradigm causes misunderstandings, resistance, and conflicts because actors in science, governmental and non-governmental institutions, business, and communities relate to different systems of reference. The concept of science–society interaction remains vague; criteria and measures of evidence and success depend on the different actors' negotiation power; and power disparities increase the commodification and economic evaluation of research [49]. By contrast, an innovation paradigm that takes sustainable development as its overarching emancipatory frame of reference—as applied in ESAPP—opens ways out of the confusion that characterizes the post-Brundtland world. It replaces unspecific interaction between science and society by integrating actors, knowledge, and value systems in joint learning processes, and supports the fundamentally novel understanding of knowledge and innovation applied in sustainability science. It enables sustainability-oriented actors from all scientific and practical fields to seek consilience [34], and synchronize their development agendas and research frameworks on behalf of societal co-production of knowledge and innovation.

But transdisciplinary practice is inherently complex, resource-consuming, and often fails. We must bear in mind that in the complexity of future forming processes, or "research in a world of flux" ([5] p. 11), achievements – but also shortcomings—are always preliminary, procedural, and gradual. Nevertheless, transformative science is a necessary counterculture to today's technocratic focus on evidence and outputs. It requires long-term commitments, collaborations and partnerships, as well as strong leadership by visionary actors in science and practice. In light of ESAPP's experience, researchers, policymakers, and funding institutions would do well to conceive of North–South research partnerships as a long-term, co-evolutional process between countries and world regions. As Garud and Geman ([41] p. 992) put it, "(...) the challenge for policy, strategy and research is not just a matter of becoming sustainable, but of sustaining the ability to embark on such journeys on an ongoing basis". If this journey ends when a programme is completed, the translation of transdisciplinarity into governance processes and institutions in partner countries in the global South will not endure.

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Challenges in Sustainability

Opinion

Making Research Matter More—Working with Action Research and Film in Sustainability Science

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Advocacy for both critical analysis of social and environmental change and a more solutions-oriented agenda has been a central mission of sustainability science since its inception [1]. To this end, integration of knowledge across disciplinary divides and inclusion of non-academic actors into the research process have been widely promoted (e.g. [2–4]). Aspirations to link knowledge to action do not only bear on processes of knowledge generation, but also on strategies for research outreach.

The short film presented here—"Making research matter—From knowledge to action with farmers in Uganda"' (Video 1)—builds on a PhD project in sustainability science [5] and is part of research outreach efforts at Lund University Centre for Sustainability Studies. It represents one attempt to explore and pursue the use of film as an alternative medium tool for research communication. At the same time, this film presents a concrete example of how action-oriented research can be employed in sustainability science to generate place-based knowledge as well as practical outcomes in favour of sustainability. More specifically, the film focuses on land degradation—a serious sustainability challenge in many parts of the world—and reflects a process in which smallholder farmers in Uganda were involved in research to jointly define problems and develop a partial solution to soil fertility problems, namely the use of human urine as fertilizer in food production.

The film provides insights into persistent problems of food insecurity and low agricultural production experienced by a smallholder community in eastern Uganda. The situation in the region reflects the generally dire conditions experienced in many parts of rural sub-Saharan Africa, which indeed is one of the "grand challenges" for sustainability science [6]. The film shows how farmers' everyday lives are affected by land degradation, in terms of nutrient depletion and erosion, and how their ability to produce enough food is seriously hampered by multiple and interlocking challenges, including environmental change, socio-economic vulnerability and rural marginalization. The film focuses not only on these challenges, but also illuminates people's agency and creativity in the way they cope with and tackle problems, with an emphasis on farmers' collective strategies in the form of self-organized community groups. Through pooling of resources, exchange of knowledge and joint experimentation, such groups serve as arenas for 'everyday politics' [7], and the creation of strategies to expand the room for manoeuvre in struggles over resources while seeking alternative development pathways. Building on farmers' existing collective action, the film, furthermore, describes the initiation of a collaborative experimentation process in which urine fertilizer was tested, positively evaluated and eventually disseminated through various strategies. The process is an example of how transdisciplinary research can guide sustainability pathways through locally-anchored knowledge, taking into account environmental and technological—as well as social dimensions.

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Video 1. Making research matter more—From knowledge to action with farmers in Uganda. The video is also available at https://www.youtube.com/v/9jc3HJ1Y4nk?rel=0.

Rather than portraying farmers as passive victims of environmental change, the film emphasizes local agency in response to change. It also demonstrates how processes of collaborative inquiry can cultivate a sense of pride and solution ownership among the participants. As one farmer expressed: “There is science now even in agriculture!” [5]. From a social learning perspective, it demonstrates that the process of inquiry is equally as important as the practical outcomes, stimulating critical reflection on problems among farmers and inspiring them to continue with experimentation. This illustrates how transdisciplinarity, in the context of sustainability science, can be “both a tool and a project” [8].

With this film we want to encourage additional efforts to pursue socially-engaged research on issues of pressing concern to people and tangibly contribute to strategies and action towards sustainability. Taking research outreach efforts seriously also reflects the ambitions of transdisciplinary research to concretely bridge science and society. The medium of film offers the potential for broad outreach and effective communication with a diversity of actors, including those who lack access to traditional forms of academic publishing. The film, therefore, is also an example of moving beyond the mere “reporting back” of findings to those directly involved in the research. To further enhance the practical use of the research findings, we have also produced a short instruction film on the use of urine as fertilizer, serving as a practical tool to disseminate knowledge about, and encourage uptake of, the practice. While publishing scientific articles will continue to be the most common method of research communication, and there are still numerous challenges associated with film as an effective form of research dissemination [9], it is positive and promising that the medium of film is increasingly welcome into the realm of academic publishing.

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Challenges in Sustainability

Research Article

Sustainability Science in the Light of Urban Planning

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Abstract: The purpose of this article is to demonstrate that, as part of its mission, sustainability science can change the way planners engage with urban problems on three points: First, that effective standard planning is an illusion, and the crucial task for urban planners should be considering—on a place-based rationale—the long-term consequences of decisions, policies and, technology change. Second,how it is necessary to develop collaborative planning and co-production of knowledge. Third, to build effective actions on the basis of collaborative planning, it is crucial to take first into account how the population and the institutions respond to and resist change. Conversely, this paper shows that urban planning is also a breeding ground for consolidating the theoretical framework of sustainability science, considering that cities can be seen as paragons of both socio-ecological systems and complex adaptive systems—a position that is discussed throughout the article. Bringing sustainability science and urban planning in closer dialogue with each other, to exploit their potential synergies, has not been done sufficiently: It is an important gap in the academic literature that this article aims at filling.

Keywords: cities; collaborative action; decision-making; knowledge building; social-ecological systems; sustainability science; urban planning; wicked problems

1. Article Statement and Argument

Addressing urban planning issues usually means confronting countless wicked problems, which is quite appropriate considering Horst Rittel and Melvin Webber coined urban planning as "inherently wicked": Namely, difficult to define, unpredictable, and defying rational decision-making [1]. More recently, Jane Jacobs observed that urban matters are neither rational problems waiting for solutions, nor a complete chaos, but rather organized complexity: "Problems which involve dealing simultaneously with a sizeable number of factors which are interrelated into an organic whole" [2]. Unlike tame problems, which lend themselves to resolution through clear definition and clear indicators and data, wicked problems challenge the very idea that it is possible to produce authoritative knowledge [3–5]. In fact, wicked problems are characterized by multiple conflicting and equally valid scientific and social solutions [6,7]. One of the core reasons why urban planning generates wicked problems is because it addresses decision-making in a context involving different socio-economic, political and biophysical systems and actors [8].

Sustainability science deals with the same kind of wicked problems. As a problem-driven endeavor addressing the boundaries and interactions between human and natural systems [9,10], sustainability science is pervaded with contested values and as such generates wicked problems of its own for three major reasons [11,12]. First, disagreement on the nature of the problem to solve is not uncommon in sustainability science, since the sustainability of a place may compromise that of others, as observed by Anthony Jakeman [13]. Second, it is likely that sustainability science will

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never reach consensus regarding dynamics of complex systems [14], due to the pervasive existence of unstated value preferences [15] and to the difficulty in incorporating values through deliberation and collective consideration of issues and answers [16]. As observed by Peter Balint, arguments in the context of environmental wicked problems are often framed around scientific uncertainty while the real issue is disagreement on values [17]. And third, it proves tricky to incorporate scientific knowledge into decision-makers' decisions and vice-versa [18]. Confronting and integrating values and knowledge from different stakeholders, in a context of high uncertainty and no "blueprint solutions" as observed by Arnim Wiek is not an easy task [19]. All these characteristics can also be applied to urban planning. A good example combining how planning and sustainability science issues may foster together wicked problems is the biofuel debate. The efforts made to push the opportunities for fossil-free fuels are backfiring: How do you decide on the sustainability of biofuel? Its development may contribute to widening of social injustice and poverty, as staple foods become economically inaccessible due to scarcity, since biofuel absorbs the largest part of land and crops [20]. As William Rees puts it in a unique and humorous style: "Human (un)sustainability is a truly wicked problem" [21].

The difficulties in adequate decision-making of wicked problems are often tied to social and political factors such as the public understanding or the politicization of data [22]. Wicked problems are most likely to yield when all the stakeholders and concerned people come together [23]. But even then, the possibility of scientific, social and political consensus on the course of an action is unlikely due to conflicting interpretations of what the real problem is and what its causes are [24], which may vary a lot with the different values and interests of the actors. It means that defining a wicked problem is inherently value-laden [25,26]. In such a situation, the planner plays a dual role of both participant and observer of the procedures [27]. As put beautifully by Jan Gehl, the actual value of a street far exceeds its assets such as pavement, traffic lights, benches, streetlights etc. [28]. The services it provides to the economy and the urban society are much more important. So city street planning is all but a technical issue concerning road widths or traffic light control. In fact it is a rather political issue, an answer to the following question: Who and what should take priority on the city's crowded streets? In this perspective street planning is typically a wicked problem: If one user group wins—by designing a new pedestrian crossing for example—another group may lose—the local stores nearby the pedestrian crossing may face slower delivery times and the residents be exposed to more noise. Therefore, designing a city street planning that allows moving and living, efficiently and equitably, for all citizens is a tricky issue.

We can distinguish with Sybille Van den Hove what can be called "science for action" and "science for science" [29]. Within such a typology, sustainability science—a use-inspired and issue-driven approach aiming at the creation knowledge for decision-making in sustainable development—is clearly "science for action" [30], as is urban planning. Both address "real-world" problems and share the necessity to build a "new social contract with science. . . that would more adequately address the problems of the current century" to quote Jane Lubchenco [31]. While the methodological framework of sustainability science is still not consolidated, Rob Swart and his colleagues clearly identify challenges for sustainability science (Figure 2 in [32]). The last one—namely, linking science with policies and action through stakeholder participation—is crucial. As put by Pim Martens, the methods required for sustainability science should be participatory, subjective, exploratory and uncertain [33]. The point is developing in the stakeholders an interest in being part of the research process and to explore solutions [34,35], which entails a strong sense of ownership about the problems they are supposed to solve [36,37]. Here too, when trying to foster participatory policies or action research, urban planning and sustainability science shares the same concerns [38]. The research process itself is likely to be twisted and contested on a regular basis by both the scientists and the other stakeholders for two main reasons. First, because there is nothing like value-free science: Every actor has its own specific interests to defend [39,40]. Second, because—to quote William Rees again—people are usually not conscious that they are "acting out of various socially constructed beliefs and ideologies acquired automatically simply by growing up in a particular culture" [41], which makes dialogue difficult.

A further connection between sustainability science and urban planning lies in the fact that,over the last twenty years, sustainability has progressively become a landmark for urban planning, leading to the emergence of so-called sustainability planning [42,43]. Many of the wicked problems that cities face are actually related to sustainability issues, or to issues concerning risk, vulnerability and tipping-points, three topics typically addressed by sustainability science [44–46].

Take, for example, the case of Ponka City in Oklahoma, where the inhabitants incriminated a nearby coal plant in an excessive amount of fine black dust in the air [47]. The state Department of Environmental Quality (DEQ) investigated and finally stated that there was no problem. Unsatisfied with this answer the City Hall brought lawsuits, which eventually prevailed: It appeared that the procedure used by the DEQ mentioned that dust crossing the property line of the plant had to be "physically seen", which obviously, is almost unfeasible. The verdict imposed to change the procedure from "physically seen" to detecting "clear evidence of fugitive dust crossing the property line, such as dust on cars", which is much easier to observe. Only a few months after the lawsuits, dust in Ponca subsequently reduced. At first sight, this case might look like a tame problem: Air standards had been established by law and could be controlled straightforwardly with the help of data and quantified information. But it was not: The real problem was that the different stakeholders disagreed on what was significant to determine the quality of air ("physically seen" vs "clear evidence of fugitive dust crossing the property line") and this difference took root in different values, which is typically wicked [48]. The DEQ had a positivist "by the book" calculation: "physically seen" concretely meant a quantitative threshold level of PM2.5 in the air. The City Hall had another approach that put the focus on the sense of ownership of the inhabitants and their local perception. What they say is: I can see black dust on my car, in my lawn or in my house, which degrade my quality of life whether the PM2.5 thresholds are exceeded or not, and this dust comes from the coal plant. This case shows that divergences, in the perception of a resource or a nuisance by different stakeholders, can result in the emergence of a wicked environmental problem as mentioned by Colleen Hiner in the case of rural-urban water fights in California [49].

There is a strong pressure on the urban planner to provide solutions to complex problems in a general context of uncertainty and permanent political, economic, social and environmental change [50]. It is really challenging since there is often no "right" answer, and all solutions usually look messy from an exterior point of view [51,52]. But still, the planner has no latitude to be "wrong", since he/she is liable for the consequences of his actions: It is a paradox. To cope with this fundamental paradox, many methodological frameworks have been designed, such as transactive planning [53], learning networks [54], deliberative planning [55], community-based participatory research and community-based planning [56], communicative rationality [57,58], or collaborative planning [59]. But finally, addressing urban problems is all about trying to provide answers to questions like: What is a city? How could we represent it so as to address effectively the wicked problems it generates [60]?

Sustainability science puts a special focus on understanding the behavior of social-ecological systems—in the sense of Elinor Ostrom [61]—to multiple, cascading and interacting perturbations [62]. Similarly, a growing number of scientists in urban planning propose to consider cities as complex adaptive systems to deal with problems encompassing multiple and interacting scales, levels, dynamics and actors [63–65]. Can we sensibly consider cities as a particular type of social-ecological systems? This is what is examined now.

2. Analysis and Discussion

2.1. Cities are Social-Ecological Systems

Urban planning research tirelessly tries to identify the nature of the cities [66–68]. It is the planner's curse—a Sisyphean task indeed. The idea that cities and urban areas could be considered as complex systems took shape in the sixties from two standpoints. On one side, Eugene Odum in his seminal book "The Strategy of Ecosystem Development", describes the urban areas as ecosystems [69]. Continuing in this vein, many authors later described cities as ecological systems with both biological and technological metabolisms [70–72]—one of the more famous being Wackernagel and Riess's book "Our Ecological Footprint" [73]. On the other side, many authors remarked that the general system theory from Ludwig Van Bertalanffy [74] combined well with Norbert Wiener's Cybernetics [75] and Warren Weaver's organized complexity [76]; providing a conceptual framework to represent the structure and functioning of the city. In this period, the big trend in social and human sciences was applying cybernetics to urban planning [77,78].

In the late seventies and in the eighties, two linked visions of cities as systems were encapsulated in two metaphors: The machine metaphor, usually associated with rigid urban projects, and hub and spoke transport models—which eventually generated dysfunctional social design, ineffective land use, pollution and congestion—and the organic one, built in analogy to organisms. Two more visions emerged: The first one considered cities as social-economic systems, as developed by Jane Jacobs [79]; the second one, supported by Manuel Castells, primarily saw cities as networks for information exchange [80]. But beyond their diversity, all these visions emphasized the five characteristics that distinguish whatever system as demonstrated by Irene Sanders: Namely heterogeneity, interconnection, scaling, circular causality, development and change over time [81].

Later, urban planners and scientists began to realize that cities could not be modeled as equilibrium systems changing smoothly and progressively. Discontinuous and chaotic change reigned everywhere in urban areas [82]. New structures and behaviors emerged constantly, in an unpredictabe way, within cities. A consequence of this new insight is that urban planners started focusing on how emergent patterns could be generated in the city, by examining how people make decisions—or even micro-decisions—and how local actions confront and aggregate into global patterns [83,84]. To do so, it proved necessary to consider cities not only as systems, but as complex adaptive systems [85,86].

Mitchell Waldrop explains in his key book "Complexity—The Emerging Science at the Edge of Order and Chaos", that complex adaptive systems can learn from experience and change accordingly [87]: The constituent agents of these systems are constantly adapting to each other and to external perturbations so that the system as a whole is prone to self-organization [88]. New structure and new functions emerge — a mechanism traditionally referred to as "emergence" [89]. The idea of self-organization has been applied to the spatial evolution of urban systems since the nineties [90,91]. Two characteristics of complex adaptive system is of significant importance to urban planning: Simple decisions made by individuals aggregate to give rise to complex global patterns, and each agent is co-evolving with the structure resulting from the actions of all the others; change stays dormant up to a tipping point at which these systems flip dramatically and irreversibly into a different state, which is almost impossible to predict. Many irreversible futures are possible.

The agents that interact in the complex adaptive systems of the cities are social and biophysical by nature. From this point of view, can they be considered as social-ecological systems, also called social-environmental systems, or still coupled human-environment systems [92]? Many authors consider that cities should be treated as such [93,94]. Marina Alberti showed that it is impossible to explain how human societies can be integrated in the ecological systems of a city, except by considering the city as a social-ecological system [95]. Nancy Grimm calls for incorporating "human decisions, culture, institutions and economic systems" in the cities [96]. In some way, her approach is echoed in the field of urban political ecology: Erik Swingedouw highlights the circulation and metabolism of nature in urban areas, the role of history in producing them, and how this production drives, and is driven, by unequal power relationships, economic inequities, and competing knowledge [97].

Even if the exact nature of social-ecological systems is still open to debate—the Resilience Alliance describes them in the very vague terms of "complex, integrated systems in which humans are part of nature" [98]—their features are well delineated. What differentiates social-ecological systems from non-human complex adaptive systems is—as mentioned by Frances Westley—that the former deals with humans who apprehend their world through abstract thought [99]. This symbolic construction is based on the ability to use language and symbols, to communicate across space and time. It has to do with the capacity of human beings to learn from the past, imagine the future, and finally materialize these thoughts in technologies, in new types of entities that only exist in the noosphere (institutions, political and economic structures, as well as values, norms and beliefs).

Sustainability science is largely about understanding the dynamics of social-ecological systems [100], especially the long-term implications of choices and policies, including possible radical and some times chaotic restructuring. It is all about developing a research that "integrates global and local perspectives to shape a place-based understanding of the interactions between environment and society" [101].

Sustainability science therefore, seems a good entry point to understand cities' sustainability, and more specifically to change the way planners engage with urban sustainability issues. Conversely urban planning can also be a breeding ground to consolidate the theoretical framework of sustainability science, since cities can be seen as paragons of both socio-ecological systems.

2.2. Changing Urban Planning in Light of Sustainability Science

Nothing is more vulnerable to rapid emergence and potential chaos than cities [102]. Thus, it is crucial for urban planning to learn how to adapt and deal with change and surprise, while avoiding changes that would threaten the life-supporting capacity of the city. The tricky issue is to strike a balance between nurturing change and maintaining the conditions that keep the system within the actual stability regime. Striking such a balance supposes to acknowledge that uncertainty and unpredictability are characteristic of cities and require adaptive planning. Addressing such problem requires learning from, working with and anticipating the dynamics within the social-ecological system of the city, which is precisely a major target of sustainability science: What determines the functional integrity and resilience of social-ecological systems? What are the networks of relationships between the different scales? What do we know about the critical variables to describe the stability range within which we want to keep the systems? These are three key issues that sustainability science address according to Robert Kates, [103] and that should help in urban planning.

Transposed into the world of urban planning, sustainability science's stress on determining networks and thresholds, underlines the fact that taking into account behaviors, relations and resources flowing across the city are of major importance. A practical example for such an approach is the BRIDGE decision support-system, which aims at connecting analytical tools with sustainability appraisal in different study sites in Europe (Firenze, Helsinki, Gilwice), so as to adapt urban planning interventions on the basis of material flow data and socioeconomic criteria [104,105]. But to do this, the planner should not only aim at obtaining information from multiple sources (such as scientists, stakeholders, practitioners, local communities, etc.), but also to accept that addressing the complexity of urban dynamics can only be achieved through co-production of knowledge with all the actors involved in the actions they plan. Such an approach goes beyond participatory planning since the knowledge and understanding of all the actors about the social-ecological system of the city nurtures the entire planning process.

For a long time, traditional urban planning considered only cause-effect relationships (i.e. housing needs and land-value), or used stochastic modeling to decide on amenities such as schools, parks or hospitals. Naturally, this often resulted in adverse effects on the urban fabric. This type of planning was endlessly providing solutions to problems "easily definable", but only apparently, and then solving the news problems created by theses solution. For example, creating sustainable neighborhoods and ecodistricts often entails the emergence of new environmental and social injustice, as mentioned by Elizabeth Burton, UK [106] and François Mancebo, France [107]. The reason is simple: The number of ecological dwellings is limited and their attractiveness is strong, which increases the rent rate and the sell rate. Such a dynamic quickly becomes toxic for the urban fabric. It is a real problem: Stephan Wheeler [108] underlines, rightly so, that for a city to move toward sustainability, it is essential to increase both affordable housing and energy efficient buildings. The lesson here is that—as mentioned by Marco Verweij and Michael Thompson—when too much emphasis is put in problem identification and solution, it usually ends in unintended negative outcomes [109].

As a matter of consequence, urban planning should be less about how to find solutions to pre-determined problems, than understanding the dynamics that give rise to desirable and undesirable phenomena: planning has to move from a prescriptive activity to a process of learning and adaption. It entails collaborative process engaging communities, professionals and other stakeholders with urban planners. Workshops, joint fact-finding and public forums, may help fostering synergistic urban lifestyles that are desirable, attainable, maintainable and reproducible—realizing what is usually called "meta design planning" [110]. An example: Sustainability science researchers from Arizona State University (ASU) led, together with various stakeholders and actors from Phoenix (city officials, business representatives, community organizations, citizens etc.), a study to develop transition strategies for sustainability that could be incorporated into the updated General Plan—city's most important guide for long-term planning. Another objective of the project was to familiarize administrative staff and citizens across Phoenix with sustainability and anticipatory governance in urban planning [111]. By integrating interactive participatory settings (public hearings, workshops, coaching sessions, and conferences), the project facilitated negotiations and reconciled the different stakeholders values and preferences, all of which resulted in a set of five sustainability-oriented intervention and transition strategies for Phoenix [112]. Co-production of knowledge is particularly relevant when coping with the Gordian knot of justice—a crucial and well-worn issue in urban planning. Besides, the notion of justice resonates strongly with sustainability [113]: From a normative perspective, everyone concerned by sustainability issues should be involved in the process of decision-making [114]; from a strategic perspective, common people have values and knowledge that are out of reach of experts, scientists or elected representatives, and may prove essential to effective sustainability decision-making [115]. Maximizing wide-scale involvement in urban planning improves justice, which is to be expected since it is impossible to define justice independently from its social context [116,117]. According to Susan Fainstein, urban planning—be it sustainable or not—should strive for outcomes only [118].

2.3. Co-producing Knowledge through Collaborative Action

Building collaborative knowledge and action is anything but obvious. The greatest difficulty lies in a structural lack of legitimacy both for the process itself and for its outcomes [119]. In the province of Limburg (Netherlands), the results of a transdisciplinary study, whose objective was to measure and develop sustainability planning, has never been adopted by the local and regional authorities that sponsored it. The reason given was that the partners of the civil society who worked within the research team "had no political mandate for defining sustainable development in this regional context" [120]. Such a situation is not uncommon: When trying to generate knowledge for collective action, the process and its outcomes often interfere with legitimized procedures and official politics [121,122]. In the case presented previously concerning the city of Phoenix, legitimacy issues proved a major obstacle to the implementation of the long-term sustainability strategies that had been delineated [123]: Since the General Plan of Phoenix was not legally binding to the City Hall and its administration, the recommendations made by the project dissolved in political debates.

But there is another important dimension to the problem of legitimacy: It may also damage the relations between practitioners and elected officials on one side, and the inhabitants and local communities on the other. In other words, the challenge is integrating bottom-up processes of knowledge and data collection and top-down agency [124]. This issue can be embodied in two questions: How can a planner know enough about the lives of local people to propose the best possible policies? How is a community motivated—or not—to collect its local information and communicate it in a way that can help planners? The example of the public water points in the city of Pune (India), developed by Luis Bettencourt, raises the following issue: How is it possible for a planner to determine how many public water points should be created in a neighborhood [125,126]? From the inhabitants' point of view, short distance and easy maintenance is essential, as well as minimal waiting time, which calls for a large number of points forming a dense network. Such a choice presents a collateral interest: Smaller groups use every point, which fosters a stronger sense of responsibility. But how does the planner know how many points are not too many? He has to learn it from the communities themselves. The inhabitants are the only ones who know the real limits—not the administrative limits—of the communities and of the neighborhoods. But they will give the information only if they perceive that it is in their best interest and if they feel they will have a seat at the decision-making table. This type of urban planning entails trust, as well as knowledge issues.

Naturally, nobody says that this "sustainability planning"—as we can coin collaborative urban planning addressing cities as social-ecological systems [127]—will replace completely prescriptive urban planning and master plans, even if scholars and planners tried [128]. The objectives and approaches taken are both different and complementary [129,130]. Prescriptive planning relies on a rational, comprehensive view of urban development that emphasizes reliance on the efficiency of technological solutions. But urban strategies focusing only—for example—on optimization of material flows without considering local knowledge as well the unpredictability of the city as a complex adaptive system, are usually hazardous: Perturbations affecting the city, such as extreme natural disasters or economic crisis, may very well result in lack of service provision, social segregation, security issues which may eventually threaten the well being of the inhabitants and lead to the collapse of the city [131].

2.4. Discussion: A Breeding Ground to Consolidate the Theoretical Framework of Sustainability Science

Embedding all-actors needs and values in sustainability planning through a collaborative approach has a big consequence, which further differentiates it from prescriptive planning: It is impossible to develop standard "one-size-fits-all" or "silver-bullet" solutions. More generally, no panaceas exist when dealing with social-ecological systems, to use the words of Elinor Ostrom [132]. The solutions always depend on the characteristics of the local communities in crafting sustainable strategies. They are typically place-based and it is crucial to build solutions adapting to the local characteristics.

This being said, the search for solutions somewhere could fruitfully learn from the experience of other places. Such consideration bring us back to the issue of knowledge building: Sharing examples, procedures and assessments of sustainability planning cases, so that the sum of the resulting knowledge can be used to understand better the common ground of urban sustainable development. Comparing and assessing different places makes sense. Moreover since this type of knowledge building is precisely a major objective of sustainability science [133,134]. This way, urban planning can contribute to consolidate the theoretical framework of sustainability science.

Cities can indeed be considered as ideal places to enact and understand the dynamics involved in sustainability policies. They concentrate three major components for successful sustainability: Human population, resource and material use, and economic activity [135]. In this sense cities are not a problem but a solution for a sustainable world. Two cities potential characteristics show the interest for sustainability science to have a focus on urban planning. First, the differences in the building compactness within urban areas and the diversity of the urban fabric converge—providing the introduction of sustainability policies—to facilitate equitable distribution of amenities on the one hand, and strong biodiversity on the other. And second, urban multifunctionality makes it easier to diminish the ecological footprint per capita by reducing energy and material needs, compared to non-urban areas [110].

3. Outlook

Urban planning can enrich significantly the understanding of social-ecological systems by sustainability science. Viceversa, sustainability science provides an effective approach for urban planning, to engage with the wicked problems presented by cities by considering them as social-ecological systems. Naturally, that is particularly true when sustainability urban planning is concerned.

There is something paradoxical when aiming at sustainability, whatever the field. On the one hand there is a need for radical change (overhauling social-ecological systems, transforming the values that drive individual actions as well as the organizations). But on the other hand there is a need to secure social, economic, ecological and political stability, so as to sustain—literally—short-term livability of the social-ecological system. As far as sustainability urban planning is concerned, it is possible to assume with Peter Allen [136] that the major issue is finding micro and macro structures which are mutually compatible and coexist, to form social-ecological systems. And it is all but obvious since—as mentioned by John Wood and François Ascher—cities are inherently unsustainable [137,138]: They are the paragon of self-organizing far-from-equilibrium dissipative structures in the sense of Ilya Prigogine [139], and as such are prone to irreversible and sudden changes.

Urban planners have long addressed chaotic environments and unpredictable emergences, as well as the tensions and potential conflicts at the intersection of human drivers and nature drivers that can be coined as "tensions in the dual mandate" [140]. These situations are well documented especially the question of the necessary trade-offs, as in the case of proactive planning [141].

But what is new when associating urban planning and sustainability science can be summarized in three points: First, the understanding that effective standard planning is an illusion, and that the crucial task for urban planners should be considering—on a place-based rationale—the long-term consequences of decisions, policies and of technology change. Second, that to do so it is necessary to develop collaborative planning and co-production of knowledge, with all the concerned actors. Third, that to build effective actions on the basis of strategic collaborative planning, it is crucial to understand first how the population and the institutions respond to and resist change. It is not enough to have an answer to a problem. What is essential is how the inhabitants and the institutions adopt these answers; how real communities can translate visions into interventions. Indeed—it is probably the bigger lesson—inertia to change result from the interaction of institutions, from the citizens to the local communities, from the city to all the actors [142].

The major objective of sustainability urban planning is now to support the critical structures, functional integrity, and capacity for regeneration of the city, so as to foster life conditions, to all the communities living there—be they human or not.

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Research Article

Methodological Challenges in Sustainability Science: A Call for Method Plurality, Procedural Rigor and Longitudinal Research

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Abstract: Sustainability science encompasses a unique field that is defined through its purpose, the problem it addresses, and its solution-oriented agenda. However, this orientation creates significant methodological challenges. In this discussion paper, we conceptualize sustainability problems as wicked problems to tease out the key challenges that sustainability science is facing if scientists intend to deliver on its solution-oriented agenda. Building on the available literature, we discuss three aspects that demand increased attention for advancing sustainability science: 1) methods with higher diversity and complementarity are needed to increase the chance of deriving solutions to the unique aspects of wicked problems; for instance, mixed methods approaches are potentially better suited to allow for an approximation of solutions, since they cover wider arrays of knowledge; 2) methodologies capable of dealing with wicked problems demand strict procedural and ethical guidelines, in order to ensure their integration potential; for example, learning from solution implementation in different contexts requires increased comparability between research approaches while carefully addressing issues of legitimacy and credibility; and 3) approaches are needed that allow for longitudinal research, since wicked problems are continuous and solutions can only be diagnosed in retrospect; for example, complex dynamics of wicked problems play out across temporal patterns that are not necessarily aligned with the common timeframe of participatory sustainability research. Taken together, we call for plurality in methodologies, emphasizing procedural rigor and the necessity of continuous research to effectively addressing wicked problems as well as methodological challenges in sustainability science.

Keywords: mixed methods; solution-orientated; transdisciplinarity; wicked problems

1. Article Statement and Argument

Sustainability science has gained increased momentum for dealing with wicked problems [1,2]. It acknowledges that cause and effects of complex problems are difficult to unravel, judgments over potential solutions are value laden, and tackling the wickedness demands integration of various knowledge domains [3]. However, often such observations remain rhetorical arguments and little attention is given to the implications this has for the practices of a science dealing with wicked problems. This contribution aims to increase clarity over the methodological challenges that sustainability science needs to address to effectively move forward in dealing with wicked problems.

The methodological challenges of sustainability science have diverse rooting. Some scholars have emphasized shortcomings in developing a new community of practices [4] that share an agreed upon set of principles [5] for generating knowledge on the interactions between nature and society. Jerneck et al. [6] noticed the tension between natural and social science. While natural science strives for scientific portrayal with little focus on matters such as justice and power, social science seeks to understand knowledge as contextually constructed, often with insufficient comprehension of natural science research [7]. In fact, much like other disciplines (e.g., health science, agricultural science) the common ground for sustainability science does not emerge from shared methods or understandings but from the problems research addresses and the purpose to developed solutions [8**?** ,9]. We hope to contribute to this debate through discussing the methodological challenges of sustainability science through the problems it addresses. Accordingly, we focus on the nature of these problems as urgent and multifaceted rather than on the specific domains in which they occur (e.g., climate change, biodiversity loss, social injustice, etc.) and guide our discussion through the solution orientation of sustainability science.

The nature of sustainability problems is best conceptualized through defining them as wicked problems [10,11]. Wicked problems are novel combinations of complex problems that are only understood after a solution is found [12]. It is controversial as to whether solutions can actually be reached or wicked problems are at best mitigated since they are likely to be continuous and have long-lasting impacts [1]. Since wicked problems depict real-world challenges, repeated solution attempts are inconceivable because working to implement a solution alters a given situation significantly, thus demanding a suite of solution attempts [13]. Furthermore, the complexity of wicked problems makes it even more challenging to develop transferable solutions because the contextual specifics of the problem vary, thereby creating novel combinations of problems features. Additional complexity is seen in the existence of 'super-wicked problems', an example of which is climate change. Research on climate change suggests that time to find a solution is running out, and the creators of the problem are also the same as those with the potential to solve it [1]. While we acknowledge the importance of super-wicked problems (e.g., [1]) our goal in this manuscript is not to address them per se, but rather focus on a more modest goal of exploring how inter- and trans-disciplinary methodological approaches can be used to progress the sustainability agenda. Particularly, because super-wicked problems as a concept does not significantly add to or change the conceptual thinking we propose in this manuscript, we find increased merits in focusing more narrowly on sustainability as a wicked problem.

Current problems such as climate change, changes in biosphere integrity, and land use change, share the key characteristics that define super-wicked problems [14]. These problems are typically multifaceted and complex, impeding comprehensive understanding and demanding solutions beyond mere panaceas [15]. While problems need to be urgently addressed, potential solutions need to be salient, credible, and legitimate to have relevance outside of science (e.g., for policy [16]) and require novel approaches because existing knowledge does not address their systemic causes [17–19]. Many of these problems span the whole globe in their impact but demand recognition of local context and the integration of stakeholder interests for approximating viable solutions [9]. For instance, while climate change occurs on a global scale, the negative impact of climate change is often observed and felt at the local scale [1]. Just as with climate change and adaptation to it, solution attempts to wicked problems leave no room for errors as only one solution attempt is possible. Yet these problems are continuous in nature and solutions can therefore only be approximated on an ongoing path [1]. Besides the practical challenges presented by wicked problems, they also require sustainability science to benefit from advances in other domains [20]. In order to effectively address wicked problems integration and cooperation between scholars and practitioners are crucial to establish a solution-oriented agenda [21] that is use-inspired and addressing real world place-based problems [22].

The tension between the disciplinary roots of sustainability science and its solution-oriented agenda creates methodological challenges, among other problems [14]. The field comprises two stands of research, the disciplinary rooted descriptive-analytical and the solution-oriented transdisciplinary science [8]. With regard to the first, research comprises disciplinary and interdisciplinary approaches that focus primarily on describing and understanding sustainability problems through descriptive analysis and advanced modeling [23]. This research follows a knowledge-first mode for understanding the root-causes and underlying mechanism, with its core interest focus on the problem [24]. Transdisciplinary sustainability science encompasses research on evidence-supported solutions generating actionable knowledge to solve and mitigate context specific problems [23]. This research focuses on transition pathways towards solutions, with its core interest laying on the solution(s) itself [24], yet we acknowledge the complexity of consolidating a project team [25]. While both strands of research have their merits for sustainability science [8], the methodological gaps between disciplinary and integrated approaches hamper efficient knowledge production. There is a need to effectively move from a mere problem analysis to creating solutions. In addition, there is insufficient exchange of methodological approaches between different fields. Thus, while necessary approaches to generate knowledge might exists in one field, they are unknown in other fields.

In this discussion paper, we focus on three aspects where we highlight methodological challenges in sustainability science.

i) descriptive-analytical research often relies on established methods despite diversity and complementary approaches that are available to address wicked problems;
ii) solution-oriented research may potentially lack the required scientific rigor in procedures and ethical standards to account for the unique features of sustainability problems;
iii) both standards of research have failed to deliver on their promise to facilitate longitudinal research which is necessary for wicked problems, as the creation of solutions does not contain stopping rules, since solution can only be approximated, but never reached.

Taken together, there is a need to consider diverse perspectives and coherent procedural frameworks in order to enable knowledge generation on a given problem state, desired futures, and solution implementation.

2. Analysis and Discussion

Solutions to wicked problems require three types of knowledge. The first is systemic knowledge that involves diagnostic understanding of the underlying dynamics and conditions. The second is normative knowledge to indicate the direction of change; and the third is transformative knowledge and solution strategies that effectively transform the problem at hand. Thus the three-fold knowledge can be pragmatically differentiated into system, normative and transformational knowledge [26]. System knowledge refers to rigorous empirical research on the multi-scalar nature, facets and complexity of wicked problems. This knowledge often has a profound disciplinary rooting and is usually generated through specific disciplinary lenses and sets of methods. Normative knowledge relates to norms, values and objectives that define how desirable a situation is, and thus provides a specific orientation and aim in decision-making and the development of solution options. Normative knowledge deals with the human perception of the situation demanding increased input from the social science and humanities for evaluating and valuing decision stakes. Finally, transformative knowledge requires development of solutions strategies and instructions to transform the analyzed problem for making progress towards greater sustainability. Transformative knowledge is least often generated and is typically unique to solution-oriented transdisciplinary research in sustainability science.

In the following sections we employ this knowledge typology in order to facilitate discussion of the methodological challenges in sustainability science. With regard to wicked problems we discuss, first, the need for diversity in methods, second, procedural and ethical challenges, and third, the demand for and necessity of longitudinal research.

3. Diversity of Methods in Times of Wicked Problems

The three types of knowledge—system, normative and transformative—foreshadow the need for diversity of approaches to work on wicked problems [27]. In fact, borders between natural and social sciences are not helpful to holistically understand environmental characteristics and societal dynamics of wicked problems (systemic knowledge) [28]. Explicit normativity in judging trade-offs in decision-making on wicked problems is crucial for orienting actions toward solutions. This requires methods that capture the multiplicity of values in order to disentangle the politics of change and clarifying whose values count (normative knowledge) [29]. Novel approaches and methods are needed for advancing "evidence-supported strategies that match the complexity of the problems they address" because the characteristics of what transformational knowledge entails and its implementation remains vague [30].

The differentiation into knowledge types illustrates the difficulties in linking results obtained through different methodological approaches because the application of specific methods and generation of knowledge are often subject to specific disciplines. A key challenge in the generation of system knowledge is that few studies apply inter- and transdisciplinary approaches. However, the use of boundary objects—which are defined as plastic objects or concepts that can integrate across different disciplines or knowledge domains [31]—can bridge perspectives and disciplines. Prominent examples of this approach include the application of frameworks such as the Ostrom framework for diagnosing and analyzing social-ecological systems [32].

Within the realms of wicked problems typical boundary objects were coined "big hairy audacious goals" [33], which indicate problems that can help to align and integrate a diversity of people towards achieving these goals. A classic example would be a lake that has collapsed and that scientists and stakeholders try to restore. While we acknowledge the existence of a wide array of methods to approach such problems, it remains a key challenge to ensure that diverse approaches are undertaken to generate a foundation for possible solutions.

Mixed method approaches (which we define as a combination of different methods, often qualitative and quantitative methods) could allow researchers to generate knowledge across different disciplines. This would, however, require research teams with competencies in and across different disciplines [34]. We therefore propose that in order to approach wicked problems the reflection on knowledge diversity, which we define as taking advantage of sources that generate a wide array of knowledge is a key component in any research project.

Normative knowledge gives rise to questions over which values are important and how to account for these [29]. In addition, solution-oriented research on wicked problems demands increased reflexivity. Researchers need to critically reflect on underlying worldviews of proponents that engage in sustainability transitions, while being sensitive to co-optation of experimentation and reflect on who benefits from solutions [35]. Besides reflexivity, a solution orientated agenda would also benefit from an increase in the accountability and legitimacy of generated knowledge [18]. A clear understanding of the different possible modes of exchange and communication needs to be facilitated. This demands an active integration of stakeholder knowledge in the research process across different scales [36], enabling joint problem framing, as well as the co-creation of solutions [34]. We recognize that for many topics and branches of science, a recognition or exploration of normative knowledge is less prevalent (e.g. [31]). However, system understanding and normative knowledge needs to be effectively linked, since most systems are managed and dominated by humans, which is why it is important to account for human perceptions of system dynamics.

Since existing knowledge has not led to addressing the systemic causes of wicked problems, transformational knowledge demands development of new methods that allow for generating of evidence-based solutions. This again is challenging since transformation per se needs also to be facilitated and the implementation of changes cannot be made by scientists, but involves a wider array of actors and recognition of power structures. Methods to support transformation are, to date, probably the weakest link within the three types of knowledge (system, normative and transformative), and we have only begun to explore the methodological approaches necessary to gain transformative knowledge and understand and act using such novel associated approaches [37].

Wicked problems demand higher diversity and complementarity in methodologies to allow generating evidence across the three knowledge types, which we propose is still widely lacking to date. As such, wicked problems might as mentioned serve as boundary objects to integrate different disciplines, raising awareness of the resources and approaches needed to approximate solutions. In order to serve as boundary objects, wicked problems would need to be sufficiently understandable to all stakeholders [38] because the recognition of a wicked problem can also be variable within a system [39]. While a concrete goal can aid to integrate diverse stakeholders, many wicked problems are more complex and harder to communicate and explain. Challenges such as the refugee crisis, resource depletion, or loss of biodiversity can be seen with this logic as wicked problems. All these problems are essentially novel, continuous, and demand the approximation of solutions. For instance, a large body of knowledge exists on climate change, yet mitigation (preventing climate change), and adaptation (implementing solutions for the impacts of climate change), remain as challenges [40].

The generation of transformational knowledge should therefore consider a diversity of methods [41] beside the development of novel methods (see above). This does not mean that system and normative knowledge do not demand recognition of available methods, however a stronger coherence and experience of knowledge generation is already at hand. While knowledge produced through disciplinary lenses is the necessary first step in better understanding wicked problems, it does not translate itself into the solutions to address them [42]. To effectively address wicked problems sustainability science needs to identify and clarify specific sets of methods that are considered suitable for: 1) generating different knowledge types; 2) facilitating pragmatic selection of appropriate methods to generate knowledge; and 3) allowing for increased coherency in future research.

The core criteria to identify suitable methods is that they help to approximate solutions, even if only indirectly. In addition, this needs to be integrated against research availability. It is clearly beyond the scope of this paper to provide criteria that help to identify suitable methods, given that solution attempts for wicked problems cannot be pre-defined following a simple checklist, yet this paper suggests some initial approaches. However, we suggest that mixed method approaches are hardly explored to date in the literature compared to the majority of papers that rely on single-method approaches.

Regarding the diversity of knowledge, claims for generating gains through interdisciplinary reach back decades [43], and knowledge from outside of academia is also increasingly demanded [34,41]. Knowledge diversity as such can thus be mapped out both within academia (i.e. between different disciplines), as well as inside and outside of academia. System thinking presents a classic approach to the integration of diverse knowledge, for instance by focusing on resources [44]. In order to realize a transformational agenda, modes of governance of the systems that need sustainability solutions [45–48] and interaction need to change [49], even going beyond established societal goals and transdisciplinary paradigms [50].

The question on sufficiency of results obtained from different methods can naturally not be easily answered due to the nature of wicked problems. Yet recent frameworks suggest that novel approaches may trigger our thinking of shorter pathways to solutions, while also considering the diversity of system, target, and transformational knowledge. A typical example is the leverage points approach proposed by Donella Meadows [51], which suggested the existence of different intervention types to tilt systems towards a more sustainable state. This represents in many aspects a solution orientated framework that may allow to approach typical problems from e.g. resilience theory. While resilience proposes shifts in systems from one state to another [52], leverage points may serve as “counter levers” to create solutions away from undesirable states of the system. Accordingly, we propose that such frameworks such as leverage points may demand further consolidation (e.g.

transdisciplinarity [41]), while recognizing the wide array of methods at hand [34]. Yet in the context of wicked problems it is especially unclear which combination of methods may allow an approximation towards solutions.

4. A Need for Rigor in Procedure and Ethics in Times of Wicked Problems

The development of solutions to wicked problems demands methodological procedures and ethical considerations to facilitate a structured approach for researching effective solutions. It would be beneficial to integrate and learn from other disciplines while advancing sustainability procedures and research ethics. Besides procedural guidelines that clearly structure and exemplify how to select and adopt suitable methods for testing solutions to wicked problems, the experimentation with real-world transformation demands explicit ethical considerations.

Procedural guidelines for solution-oriented research in sustainability science needs to facilitate the development of methodologies that are explicitly oriented towards designing and testing solutions for wicked problems [24]. Wiek and Lang [23] outlined such a methodology with the transformational sustainability research framework. Reflecting on their proposal we distill the core features to inform procedural guidelines in sustainability science:

1) Orienting the research by defining questions and goals;
2) Designing the research: selecting frameworks and methods; and
3) Testing solution options: evaluating efficiency and effectiveness.

By dividing the orientation, design and evaluation of research into these steps, we argue that necessary ethical constraints can be made more transparent, and thus explicitly considered within research projects. We agree that more reflection on the necessary ethical rigor would be needed in future research, yet propose the suggestions mentioned by Wiek and Lang [23] as a vital starting point to integrate these approaches with the necessary reflection within the research process.

The first step 'orienting the research' refers to the identification of the research objectives [53]. This involves clarifying the questions the research aims to answer as well as setting its goals. In addition, one needs to identify the wicked problem that is subject to the research and explicate its wickedness and sustainability relevance. This also helps to situate the research in relation to system, normative and transformational knowledge.

The second step 'designing the research' refers to selection of appropriate frameworks and suitable methods as well as detailing their application. This involves reflection on the limitations and virtues of the selected framework(s) with regards to the research objectives and clarification of potential biases. However, with regard to the aforementioned need for method plurality we emphasize the need for triangulation and explicit consideration of participatory setting for collecting data.

The third step 'testing solution options' refers to the application of generated knowledge to the identified wicked problem. This involves an experiential approach including base-line assessment, implementation of solutions and evaluation of observed effects [37]. The use of experimental settings provide an advantage in that solutions can be tested in small-scale settings that allow for evaluation of the effectiveness of solutions without changing the entire constellation of the investigated wicked problem. However, sustainability science needs to engage in an explicit reflection of the ethical dilemmas and consequences that this might pose, also to consider resource designation within research to focus on specific problems.

Ethical considerations of solution-oriented research in sustainability science need to account for the unique features of sustainability problems [24]. To date no clear procedure exists, which gives reason for concern, as research involves not only investigation in systems including people, but also aims to transform these systems towards sustainability. There may be trade-offs, winners and losers, and unexpected impacts to both the social and physical realms of the sustainability problem. Within other branches of science—most prominently medicine—clear and strict ethical guidelines are available, and ethical committees and checklists are often part of the research process. In sustainability science, ethical considerations are most often driven by the vigor of the disciplines included in a certain research project, yet we are not aware of any procedure that documents research projects in sustainability science under ethical concerns. We argue that such guidelines are crucial in the case of wicked problems, since in these cases, solutions can only be identified in retrospect.

Sustainability science emerged out of different disciplines, which is one reason why it is so difficult to establish a coherent ethical standard. Since researchers investigate a wide cultural and societal diversity of normative dimensions, and are often even embedded into the research process, documentation and evaluation are crucial [37]. Transformation towards sustainability can follow different trajectories, which are subject to politics of change. Since wicked problems can only have one solution approximation, numerous other trajectories are potentially less effective or can create unintended negative impacts. In order to make the research process as valid as possible from an ethical standpoint, ethical guidelines would be beneficial to ensure documentation and transparency of the research.

Prominent examples for the need of ethical considerations are the currently emerging real-world labs [54]. In these 'living labs' complex dynamics are investigated and manipulated, however, little documented consideration is given to the ethical implications of such approaches nor does consensus exist over the guidelines for such reflections. One could consider the well-known concept of 'informed consent' as suitable for such approaches where the goal and procedure is clearly communicated to participants, who are asked to agree to the research process prior to participation. The concept of informed consent is however potentially controversial in sustainability science, since identification of participants and affected stakeholders is variable if not difficult [53], particularly given the multiple spatial and temporal scales that many sustainability problems span across over. Another concept well known in medical research is "double blind studies", where both participants and scientists do not know receives a treatment and who a placebo. However, such procedures can hardly be introduced to sustainability science, the crafting of actionable knowledge relies on co-production [54]. This makes a strict planning and reviewing of research approaches necessary in sustainability science.

Another example in relation to living labs is the question of different levels of system manipulation [55]. While, for instance, some neighborhoods in a city are transformed [56], others might remain unchanged to allow for a comparison. While this certainly has merits from a statistical perspective, it may be a reason for serious concern from an ethical perspective, i.e. considering the rights of the people involved in the research. One way of overcoming this issue could be to offer to facilitate transformation after the conclusion of the research, following the three-step procedural guidance outlined above. In this way, those participants who were initially part of a control group receive the treatment once the research component is complete. On the other hand, resources are unlikely abundant enough to solve each and every single problem in sustainability science, and most definitely not every local case. Such an approach how intervention in one local system may influence a larger-scale system over a longer time period. Therefore, in order to allow for a more formalized evaluation of research processes, we call for increased attention on the ethical considerations involved in the approximation of solutions to wicked problems. Recently founded institutions such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), attempt to acknowledge this concern [57,58]. The IPBES is the intergovernmental body which assesses the state of biodiversity and of the ecosystem services it provides to society, in response to requests from decision makers (http://www.ipbes.net). The IPBES builds strongly on a transparent and coherent communication and a constant revision of their agenda. We propose that accompanying research approaches should be increasingly used by researchers and institutions, thereby allowing for an evaluation of research based on comparable ethical standards.

Rigor in the application of methods in sustainability science is challenging, since the diversity of methods is rooted in many different knowledge domains, schools of thinking, and disciplines. Sustainability science is therefore in the unique position to integrate ethical rigor based on diverse experience. While this is surely beneficial, it is vital to focus on solutions, which can be integrated with scientific rigor. In this sense, not only should our research be focused on sustainability, but it also needs to be made under sustainability standards. It is beyond the scope of this paper to discuss these standards, yet we can state that resource availability has to be balanced against the given solution approximation. While we agree that novel methods can be beneficial [1], we would also underline that a diversity of methods is already at hand, yet most methods are restricted to their given epistemological and disciplinary background and reasoning. Opening up these barriers would surely be beneficial, since diverse sampling and analysis approaches are vital, as this would theoretically increase the possibility of approximating a viable solution.

5. Long-Term Research in Times of Wicked Problems

Due to the continuous nature of wicked problems, solutions may be approximated and can only be identified in retrospect, which is why research methodologies need to allow for longitudinal research and data analyses. While we acknowledge that due to their continuous nature wicked problems may not necessarily be solved and may only be dampened, we also suggest that the implementation of solutions might cause adverse effects that were not initially considered. In addition, many wicked problems are characterized by dynamics that only become visible though decade-long observation, such as rangeland management [59]. Researchers need to embrace reflexivity in order to alter and adapt the research process. This is especially challenging when it comes to mixed method approaches, as the different grain between approaches (i.e. quantitative and qualitative) is difficult to match.

Among the most advanced approaches in sustainability science is certainly systems thinking, which taps into a wide and diverse set of data and methods [15]. While to date a large array of research has already applied systems thinking, we propose that this does not often contain mixed method approaches and often focuses too narrowly on gaining increased understanding of wicked problems thereby neglecting normative and transformational knowledge. In addition, these approaches rarely employ methods that actually allow for reflexivity. It is evident that implementing a continuous evaluation of the research process and outputs to identify the effectiveness of interventions is vital when considering wicked problems [37]. Numerous disciplinary methods are specifically designed to implement longitudinal analyses (e.g. clinical trials in medicine or greenhouse experiments in biology), while long-term approaches are also common in social sciences and urban research [60]. Matching both quantitative and qualitative methods in a mixed method framework is time consuming, and applying a wider canon of methods demands typically more resources. Yet most research projects have a much shorter funding period than what is needed to respond to sustainability problems. Projects with a backcasting approach would for instance be able to implement the approximation towards solutions of wicked problems into a sustainability science agenda. This would allow for a clear visioning process, and then enable researcher to approximate solutions, ideally based on mixed method approaches.

6. Outlook

Wicked problems are at the heart of sustainability, as many of them prominently defy justice, since the negative impact is highest in regions that contribute less to the creation of the problem. Yet while the notion of wicked problems has existed for a long time, the rise of sustainability science in the last two decades has triggered a stronger engagement in research approaching the concept of wicked problems. We propose that by embedding the framework of wicked problems more thoroughly into sustainable science, we can create a stronger argumentation to:

1) engage a diverse set of methods, including mixed methods to guide research on wicked problems and demand procedural rigor for orienting and designing sustainability research as well as testing solution options;
2) a clear documentation of research is needed to facilitate the vital ethical considerations and to increase research transparency and legitimacy that in turn allows for retrospective analysis of wicked problems; and finally,
3) a long-term research approach is vital to enable this retrospect perspective and to make it possible to engage in the whole timeline of a wicked problem.

Sustainability science is only just starting to develop an agenda on how these three challenges can be integrated and finally solved. There is already a huge portfolio of methods available, yet many of these are not sufficiently used outside of their given knowledge domain. Also, sustainability research needs to stronger shift towards solution orientation producing normative knowledge and especially transformative knowledge. With research integration and application becoming more complex, ethical procedures need to be developed, tested and applied. Only by doing this will we be able to generate transferable knowledge and facilitate long-term research, societal changes and shifts typically span across longer time scales. Initial accounts of diverse and integrated articles [37] and textbooks become increasingly available [23], paving the road for the next generation of researchers [30].

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Research Article

You Can't Eat Biodiversity: Agency and Irrational Norms in European Aquatic Environmental Law

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Abstract: Policies of the European Union cover a range of social, environmental and economic aspirations and the current environmental directives and laws have evolved from a suite of norms which have changed over time. These may be characterised loosely according to 'Three Ps': Practical, those taking an anthropocentric approach; Pure, those taking an ecocentric approach and Popular, those appealing to the general public. In this paper I use these three perspectives as a tool to analyse the complexity and identify contradictions in European aquatic environmental legislation. Some trade-offs between development and conservation are identified and used to characterise the potential qualities of more successful agency to achieve environmental goals in the governance of European aquatic environments.

Keywords: biodiversity; environmental policy; ecosystem services; transformation

1. Argument: Human Development and Evolving Norms

The normative role of sustainability science, by all modern definitions, is that of balancing conservation of the environment with sustainable use, where sustainable development is defined as meeting current needs without compromising the needs of the future [1,2]. The Sustainable Development Goals (SDGs) set out the most comprehensive suite of 17 social, economic and environmental goals and 169 targets to which sustainability science might aspire. Achieving these goals is a major challenge for humanity. At current efficiencies of resource use, and with current patterns of resource distribution in global society, the goals of eliminating poverty and hunger, promoting equality, providing jobs, economic infrastructure and growth all demand an increase in the resources available to many of the world's seven billion population. At the same time, considerations of ecological footprints suggest that many wealthier nations are living beyond sustainable levels of consumption [3,4] and will need to decrease these levels to achieve sustainability. Against this backdrop of global inequality, biodiversity globally is declining as humans continue to appropriate undeveloped areas [5]. At the core of sustainability science lie trade-offs between equitability and affluence as well as human use and non-use of natural resources. These trade-offs are 'wicked problems' which will involve winners and losers, and their solutions require moral judgments [6].

In 1992 the Convention on Biodiversity (CBD) recognised the "intrinsic value" of the diversity of life [1], which ultimately contributed to the SDGs recognising the"integrated and indivisible' balance between social economic and environmental aspects of sustainability [2].The current outlook on the role of man and nature set out in the SDGs has changed considerably since the inception of the European project following World War II. At that time, human population was approaching the peak of its growth [7] with the pop-

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ulation movement (successor to the eugenics movement and precursor to the modern environmental movement) advocating direct population control in a resource constrained planet [8–11] while the "green revolution" successfully set about improving agricultural yields [12,13]. However, this intensification of agricultural production has led to increasing environmental degradation of terrestrial and aquatic habitats [14–19] and these growing global pressures brought into focus the increasing rate of species extinctions [19,20].

The prevailing narrative in modern conservation science connects biodiversity with ecosystem processes and human well-being through ecosystem services, the benefits obtained by humans from nature. These may be divided into supporting, regulating, provisioning and cultural services [21,22]. The benefits provided by ecosystem services may be further categorised as active or passive use values as well as non-use values such as existence, option and bequest values [23]. This narrative accommodates the norms of the SDGs recognising that social systems are connected to ecological systems and viewing biodiversity as an underpinning natural resource enabling development. There remains, however, great uncertainty about the mechanisms connecting biodiversity to ecosystem processes, ecosystem services and benefits [5,24]. Despite ongoing global declines in biodiversity and ecosystem services, human well-being at the global level has continued to increase, which may be due to the reliance of well-being on food production, the decoupling of well-being from nature through technology, or time-lags between the loss of biodiversity and its consequences in terms of well-being [25].

The EU Biodiversity strategy [26], successor to the Biodiversity Action Plan [27], aims to halt biodiversity loss within Europe and stop global biodiversity loss by 2020 in line with SDGs 14 and 15, the protection and sustainable use of the oceans, and terrestrial environments respectively. The EU strategy [26] was developed to provide Europe with a mechanism to achieve its commitments under the CBD. Meeting the goals of the biodiversity strategy through the use of existing environmental legislation and the development of new legislation in Europe requires joining together many different environmental laws and policies, which have developed alongside the shifting norms described above. Norms are considered here in the general sense as sets of societal values or standards.

The shifting role of biological science in social development, through the eugenics, population and subsequent environmental movements, has left a legacy of economics, politics and legislation which have formed the current models for Earth system's governance and have potential to enable, or to hamper, productive development of environmental governance systems. Changing norms have shaped European environment and development policies over time, and the application of environmental regulation has led to social and political trade-offs, generally favouring economic development (sustainable or otherwise).

Europe has been hailed as a leader in environmental protection [28] and the quest for sustainability, yet despite a wide range of legislative measures and environmental protection policies, the European Biodiversity Strategy is failing [29]. Traditionally environmental science has been reactive [30], i.e. problems are usually identified and a solution is found to address the specific problem. Yet to achieve sustainability, it is increasingly recognised that a more proactive, transformative approach is required where there is a coherent vision of a sustainable future [31]. Normative analysis of existing policies can therefore serve as a baseline to assess the values on which existing environmental policies have developed and to compare these to current aspirations or visions such as those set out in the SDGs or under the EU Biodiversity Strategy. Explicit recognition of the multiple competing values underlying different initiatives which aspire to sustainability, can serve as a first-step to analysing policy coherence, aligning multiple policy objectives and institutional recognition of the range of divergent norms in existing policies. As such normative policy analysis can act as a useful starting point for institutional transformation.

While the SDGs 14 and 15, and the Biodiversity Strategy set the mission of achieving sustainability in terms of reducing biodiversity loss, the legal mandate for sustainability in EU member states is determined by environmental laws and directives. The pathways toward sustainability are dependent on the current levels of sustainability (the status quo) and the trajectories toward sustainability are dependent on the legacy of historic and existing practices. For practical purposes, the legal mandate of sustainability science is enshrined in the legislation and understanding how this legislation has developed is therefore critical to assessing the changes required to meet the goals of the mission.

The aim of this paper is to identify the norms informing environmental legislation in the European context with a particular focus on their relevance to the biodiversity strategy in marine and freshwater aquatic environments. Three dominant themes in European environmental legislation are identified. These norms are traced through the development of environmental legislation, and the implications for these norms in developing effective agency in environmental management is explored.

2. Analysis and Discussion

2.1. A Normative Classification of Environmental Policy

Sustainable development is often represented as having three distinct interrelated components: economy, environment and society. The model presented by Giddings et al., [32] of concentric circles with environment containing society, and society containing economy, represents an ideal frame, but in practice disciplinary silos generally result in a range of more fragmented perspectives. Some authors [33] have distinguished between the techno-economic, socio-cultural and bio-ecological elements which go into environmental decision making. This study takes the perspective that these three competing sets (economic, social and ecological elements) relate to values or norms which are transcribed into three types of environmental policy, termed here Practical, Popular and Pure respectively and that these can be distinguished by their focus on the management of different ecosystem services or on biodiversity.

Environmental policies with an anthropocentric focus may be considered *Practical*. Practical norms are largely aligned with natural resource management concepts, for example, management of stocks to meet human ends, through the exploitation or stewardship of the natural environment. These may be loosely aligned with the concept of economic well-being, where individuals seek to maximize their own profits or production. Practical policies often relate to the systematic use of provisioning ecosystem services. In this analysis policies are considered to fall into this category if their primary focus is on natural resource extraction and management.

Some components of conservation or sustainability resonate more easily with the general public than others. *Popular* norms are defined by their focus on cultural ecosystem services. This impact of these policies may be associated with non-use cultural ecosystem services for example with species that are highly visible, the "warm glow" [34] of protecting charismatic species, such as the giant panda, the polar bear or cetaceans, which elicit strong responses toward conservation. Similarly, sustainability policies which have clear impacts on direct use cultural services where, public goods are directly used by individuals without the intermediary of a specific economic sector (e.g. recreational fishing, swimming), may be considered popular as they relate to the public good rather than economic development of any particular specific sector. The values or cultural ecosystem services associated with these conservation norms may not necessarily be aligned with scientific justification (e.g. Potts et al.) [35]. Regulations and policies, which implicitly focus principally on cultural ecosystem services or components of ecosystems, which supply these services, are categorised in this analysis as Popular.

The *Pure* perspective is encapsulated by the slogan adopted by the US environmental movement of the early 1970s "we have met the enemy and he is us". This viewpoint considers human activities as inimical to ecosystem functions, juxtaposing man against nature. The norms associated with this narrative of purity seeks a return to pre-anthropogenic disturbance. This concept of naturalness or purity often represents the norm of the hard environmental conservationists and, as in the CBD, recognises the "intrinsic worth" of the natural environment. Policies which aim to minimize or eliminate human effects, principally for the sake of the environment itself or for its 'intrinsic value', are categorised as *Pure* in this analysis.

Individual pieces of European legislation may be *Hybrids* exhibiting a mixture of the three characteristics described above. Table 1 summarises the main pieces of EU environmental legislation directly related to the aquatic environments. These pieces of legislation were mapped against the norms described above based on their relation to the use of ecosystem services. Policies were classified as either Practical or Popular where they address management of provisioning, or cultural services respectively. The policies were categorised as Pure where they treat ecological integrity as an end in itself, the texts of the legislation were also analysed for explicit statements relating to economic, social, and environmental values. Figure 1 maps the legislation onto a Venn diagram of the three value sets. The following section provides an historical narrative on the development of the legislation over time, under headings of the three norms.

Table 1. Major Directives relating to the EU biodiversity Strategy in the Aquatic environment.

Policy/Directive/Regulation	Acronym	Year
Common Agricultural Policy	CAP	1962
Bathing Water Directive	BWD	1976
Birds Directive	BD	1979
Common Fisheries Policy	CFP	1983
Urban Waste Water Treatment Directive	UWWTD	1991
Nitrates Directive	ND	1991
Habitats Directive	HD	1992
Water Framework Directive	WFD	2000
Marine Strategy Framework Directive	MSFD	2008
Regulation on Alien Invasive Species	IAS	2014

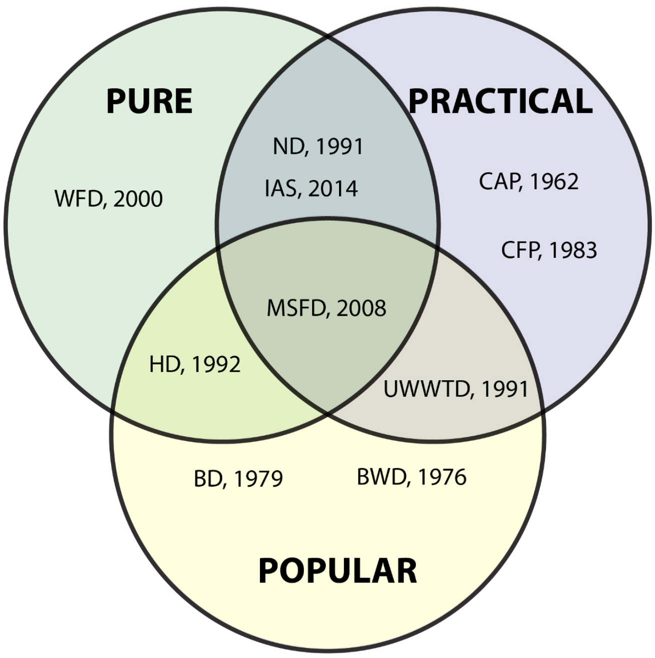

Figure 1. Venn diagram showing the overlap in values between different EU environmental directive and policies relating to the biodiversity in aquatic environments.

2.2. Practical

Though not a policy explicitly directed at the management of the aquatic environment, agricultural nutrient sources play a major role in determining European water quality [36] and for this reason the Common Agricultural Policy cannot be omitted from any analysis of aquatic environmental policy in Europe. The CAP, with the aims of achieving food security in Europe through modernization and ensuring good prices for farmers, was put in place in 1962 and since its inception food security within Europe has been maintained [37]. The CAP includes subsidies to farmers as well as import tariffs to ensure prices for European farmers. The early CAP was criticised as a protectionist policy having created price distortions in global food markets [38] but recent revisions have removed some of the more distorting subsidies [39]. The CAP has a budget of €362.8 billion (almost 40% of the EU's budget) to subsidise agriculture in the period 2014–2020 [40]. In its current form the policy is comprised of two 'pillars', direct payments or subsidies which make up 70% of the CAP budget and the European Agricultural Fund for Rural Development (EAFRD), which accounts for the remaining 30% and provides co-funding for national programmes of rural development [41]. In addition to continued food production, the most recent reforms in the CAP aimed to encourage farmers to provide public goods, enhance biodiversity and play a role in climate mitigation. 30% of direct payments are now nominally conditional on greening measures, including maintenance of permanent grasslands and crop diversification, in practice most farms, particularly smaller ones, are exempted from having to take any action to receive these subsidies [42]. This proportion of the CAP budget assigned to the production of food (a provisioning service) clearly categorises the CAP as a *Practical* policy.

A Common Fisheries Policy (CFP) began to emerge in the late 1970s as new member states joined the European Economic Community, catalysing arrangements for existing member states to gain free access to community fishing grounds. The CFP was formalised in 1983 [43] and has subsequently undergone a number of reforms [44,45]. Fisheries under the policy aim to achieve Maximum Sustainable Yield (MSY). This objective has been criticised both on an economic basis (theoretically a more efficient fishery would aim for Maximum Economic Yield) as well as on a technical basis, achieving MSY in a mixed species fishery is notoriously difficult to achieve. The operation of the CFP itself has also been heavily criticized on many fronts, in particular for the systematic rejection of scientific advice on catch levels [46]. In recent years for example catches have on average been set 20% higher than the scientific advice [47], as national political interests try to ensure the best deal for their national fishing industries. The setting of quotas has also led to the practice of discarding, which is now banned under the most recent reforms [48], which marking a shift toward Ecosystem-based management. There has been a long history of dysfunction in the CFP, currently 58% of assessed commercial stocks are considered to be at levels below levels of MSY [49] though some stocks are beginning to recover [50]. The target of MSY clearly marks the CFP as a Practical policy since the aim is to maximize the amounts of fish extracted from the seas.

The European project was designed as a free trade organisation to facilitate trade between European nations, with the goals of averting war mainly through economic means [51] and ensuring that the major policies controlling sustainable development continue to have a chiefly economic outlook. Figure 2 illustrates the budget breakdown for sustainable growth and natural resources in the EU for 2015, the total budget is over €55.9 billion. Components of the CAP combined with those of CFP make up over 99% (97.5% and 1.68% respectively) of this budget, less than 1% is assigned to other aspects (including environment and climate programs).

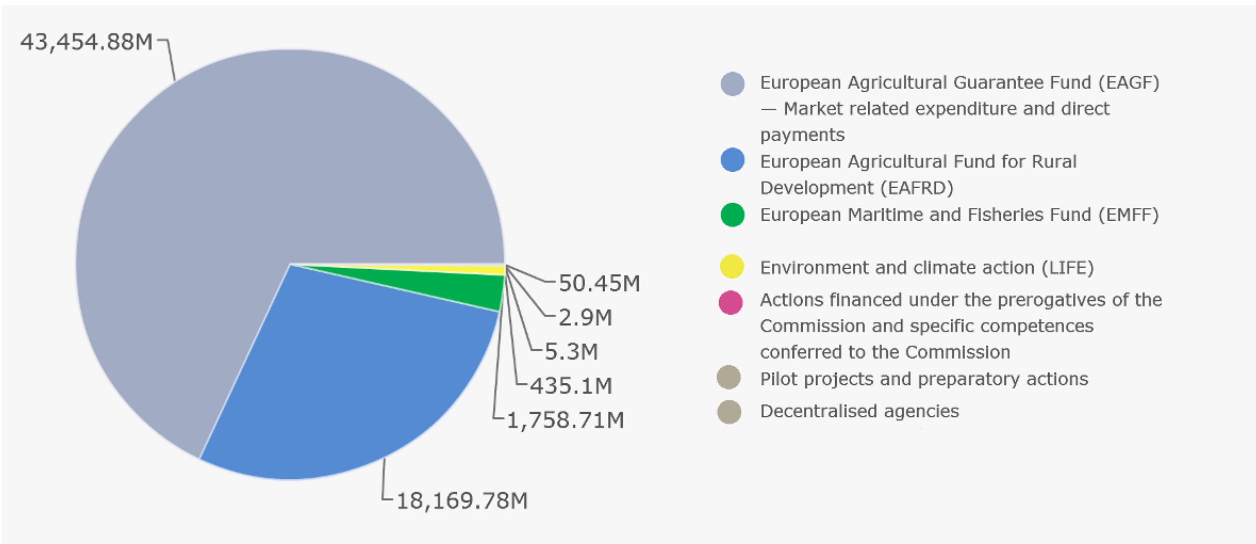

Figure 2. Sustainable growth: natural resources budget for the EU 2015 [52].

Conservation measures under "Greening of the CAP" and reformed CFP have placed the expectation on farmers and fishers to be the major agents of biodiversity conservation. Following half a century of centrally facilitated intensification administered at the level of nation states, this marks a major shift in expectation, which has not been backed up by institutional support.

2.3. Popular

The first pieces of EU law aimed at improving aquatic environmental quality was the Bathing Water Directive. It was introduced "in order to protect the environment and public health" [53]. The directive sets limits on the levels of bacteria (coliforms and enterococci) which are permitted to occur at locations designated for public bathing, in fresh and marine waters. Compliance with the directive has been supported by the European Commission since 1987 through the Blue Flag program which promotes public awareness; beaches which comply with water quality standards (and certain other criteria) are awarded a blue flag for cleanliness. The implicit focus of the directive on (direct use) cultural ecosystem services categorises the Bathing Water Directive as Popular.

The Birds Directive was established in 1979 [54] and updated in 2009 [55] to halt the decline in the numbers of wild bird species in the EU, this trend is largely ascribed to agricultural intensification [56]. The directive lists various species which must be conserved (Annex I) and others which may be harvested subject to certain conditions (Annex II) and designates Specially Protected Areas (SPAs). Both "natural balance" and "cultural heritage" are motivations for the Directive [54], the latter, illustrates the Popular nature of the directive. Article 2 of the directive mandates that bird species are maintained at *"a level which corresponds in particular to ecological, scientific and cultural requirements, while taking account of economic and recreational requirements, or to adapt the population of these species to that level"*. The perspective of the Birds Directive includes both ecological and cultural considerations but its focus on "recreational and cultural requirements", as well as its scope covering on popularly appealing, charismatic species, which provide active and passive use cultural ecosystem services, makes the case for its inclusion in the popular set. Despite its early introduction, EU avian biodiversity continues to be eroded [57].

2.4. Pure

The Water Framework Directive (WFD) was introduced [58] to harmonise the growing body of aquatic environmental legislation. This directive regulates water quality in freshwaters (rivers, lakes and groundwater) and saltwater (estuarine and coastal) areas. The goal of the directive is to achieve or maintain Good Ecological Status, which is defined with reference to a relatively clean or pristine reference condition, (determining reference conditions is itself a value laden process). The directive takes a 'deconstructing structural' approach [58,59] dealing with the characteristics of specific elements of water quality. These water quality elements are measured by a suite of indicators which include chemical parameters (concentrations of nutrients and oxygen) as well as biological parameters such as the composition of aquatic benthic flora/fauna, fauna the abundance of specific sensitive insect species for freshwater and benthic in-fauna in the marine. Given the long history of human settlement and development in Europe, aquatic ecosystems have been experiencing anthropogenic disturbance for millennia [60], and to some the goal of good ecological status is a 'dream' [61], particularly given the non-linear responses of aquatic system to relaxation of anthropogenic pressures [62]. The WFD permits the designation of heavily modified water bodies, where specified uses of water bodies (including navigation, hydro-power, and recreation) would be significantly affected by restoration measures and no feasible cost-effective option exists that would maintain these benefits [59,63]. Nevertheless, since its introduction, the directive has resulted in a major concerted effort in the measurement and monitoring for the improvement of the quality of water bodies around Europe [18]. The norms of the directive are clearly Pure as they aspire to achieving pre-anthropogenic conditions, with baseline targets set on ecological rather than anthropocentric grounds.

2.5. Hybrids

The Nitrates Directive [64] deals directly with the prevention of undesirable emissions from the "Practical" CAP for the sake of achieving environmental quality, hence its inclusion in the subset of Practical and Pure. Measures to ensure compliance with the nitrates directive include the creation of buffer strips in farm land to prevent agricultural run-off. In practice the success of the Nitrates Directive is complicated by the difficulties in enforcement of local actions over the large spatial scales covered by the Directive [65]. The nitrates directive is considered to have reduced nitrogen outputs from agriculture by between 3% and 19% depending on the species of nitrogen considered [66].

The Urban Waste-Water Treatment Directives [67], (UWWT) provides for end of pipe solutions to the release of polluted waste waters. The maintenance of clean water has elements of Practical natural resource management (supply of a provisioning service for human health) and Popular aspects in terms of supply of clean water for cultural service such as bathing and is therefore classified as a hybrid of practical and pure.

Following its commitments under the CBD, the Habitats Directive came into force [68]. The directive is concerned with the development of a network of Special Areas of Conservation (SAC) for specific habitat types and species in which biodiversity is prioritised. The Natura 2000 network, which is comprised of Habitats Directive SACs and Birds Directive SPAs, is the largest network of reserves in the world, and its development was seen as a major achievement of the Biodiversity Action Plan. Sites are designated according to the presence of particular target habitats or species listed in the Annexes of the directive. Despite its size the Natura 2000 network has had mixed success; 60% of species and 77% of habitats covered by the directive are reported to be in unfavourable condition [36]. The Natura 2000 network has also fallen far short of its targets in assigning protected status to agricultural areas. On a Europe wide basis only 11.5% of the agricultural area targeted to be designated as SAC have been assigned [69]. Though the Habitats Directive arose from the CBD, and was published in the same year, it may be considered as a hybrid of Pure and Popular in terms of its norms because it includes a mix of obscure and popularly unrecognised species (e.g. *Dytiscus latissimus* a diving aquatic beetle) which provides neither cultural nor provisioning services, as well as charismatic species (for example all species of whales are protected under the directive) and the process of designation of species for inclusion within the Annexes of the directive, through expert judgement included value based as well as ecologically based decisions [70].

The Marine Strategy Framework Directive (MSFD) [71] aims to achieve Good Environmental Status for each of 11 qualitative descriptors, uniting several environmental directives for the marine environment, these include WFD, along with the Nitrates Directive and CAP, the habitats directive and the CFP. The MSFD uses the language of the ecosystem based approach and recognises the concepts of ecosystem services and may be seen as a hybrid of all three norms, with its descriptor on fisheries being aligned with the practical focus of the CFP, the eutrophication criteria aligned with the Pure focus on the pristine environment of the WFD while the incorporation of ecosystem services (including cultural services) recognises the Popular nature of public goods. In practice, during the first round of application, the approach of many member states has been to collate the measures taken under existing directives and attribute them as measures in the implementation of the MSFD. Despite the high goals of the directive economic constraints have overridden the incorporation of new measures to incorporate ecosystem services into implementation in many cases e.g. [72].

One relatively new initiative under the EU Biodiversity strategy, and stemming from European obligations under the CBD has been the introduction of the recent regulation on Invasive Alien Species (IAS) [73]. For the purposes of the directive an alien species is *"any live specimen of a species... introduced outside of its natural range"*. The objective of the law is *"to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread of invasive alien species"*. This law obliges member states to prevent the establishment and control the spread of non-native species around Europe. The particular species to be addressed are contained within a list of European concern. The current, first list [74] differs from the "list of 100 worst alien invasive species" [75] in that it omits species, such as the Pacific Oyster (*Crassostrea gigas*), which are of economic importance but also considered invasive. While the language of the directive does recognise ecosystem service concepts, the emphasis in ecology on the concept of non-native species and the narrative of invading aliens has been heavily criticised [76], and the evolution of invasion science in the 1990s is closely linked with the coining of the term biodiversity [77]. This regulation includes some exceptions for species of economic importance in aquaculture under the Regulation concerning use of alien and locally absent species in aquaculture [78], which provides a loophole to prioritize aquaculture development over environmental integrity. While the theory behind invasive species research certainly falls into the normative category of Pure, the list of species of union concern also reflects the practical norm and the regulation may therefore be seen as a hybrid of Practical and Pure.

3. Conclusions

The use of ecosystem services concepts in the policy analysis above marks a novel development in methodology for developing explicit recognition of norms within policy. The methodology has been used retrospectively to analyse existing policies. The analysis reveals a range of competing norms and contradictory objectives in European environmental policy that have emerged reactively over the course of the formation and development of the EU.

The first EU Biodiversity Action Plan met with limited success, its target of halting biodiversity loss by 2010 was not achieved [79], the EU Biodiversity Strategy aims to halt this loss by 2020. The aim of this paper was to identify underling norms in EU environmental policy which might affect implementation of the EU Biodiversity Strategy. The competing norms underlying EU environmental law have shifted from the *"Practical"* through *"Popular"* toward *"Pure"* and increasingly represent a range of norms, but the fundamental challenges to achieving sustainability in the frame of European environmental law remain implicit trade-offs between Practical provision of food and Pure protection of nature.

Within Europe, the funding available for implementation for practical policies eclipses funding for focussed environmental legislation. The major relationship between humans and the environment promoted by EU, the two main Practical policies (CAP an CFP) is one of consumption. Efforts to reduce the amount of environmental damage of the major Practical policies have been compromised by political negotiation to ensure the economic livelihoods of small farmers and of fishers. As demonstrated by negotiations in the CAP and CFP, politicians, on a five-year re-election cycle lack the agency to impose costs on their constituents for the purposes of poorly understood concepts such as biodiversity and ecosystem services. For fisheries and agriculture, despite recent reform, economic gains are more immediately felt than environmental gains, and production of private goods is more profitable than production of public ones. Under the current system food production is favoured over biodiversity conservation, and conservation is generally economically irrational, that is, individuals do not stand to increase their own economic welfare by protecting the environment. Strategies for incorporating effective biodiversity conservation into the Practical polices are therefore a clear area for targeted further research.

The "intrinsic worth" of biodiversity, as articulated by the CBD, is not necessarily self-evident, and there are not clear links between all components of nature and well-being. Though limited data exist at the European scale, at least for the marine environment, public understanding and awareness of environmental problems is poor [36]. This imbalance could be redressed through education to develop public understanding of the benefits of nature, to better align the Popular and Pure environmental norms.

The emerging focus on ecosystem services for example in the MSFD may provide a mechanism to balance these trade-offs. While full accounting for ecosystem service values and internalisation within European policy can in theory more fully elucidate and re-balance these trade-offs, (as advocated by the MSFD) scientific understanding of the role of biodiversity in the supply of ecosystem services remains low [24,80]. Scientists therefore have a role in elucidating these links through further research and effectively communicating their findings to a policy makers and to the public.

In contrast to funding for rural development and fisheries exploitation, at the European level there is no dedicated centralised organisation for the funding enforcement of environmental legislation. While the European Environment Agency has a duty "*to support sustainable development and to help achieve significant and measurable improvement in Europes environment through the provision of timely, targeted, relevant and reliable information to policy-making agents and the public*". it has no mandate or means to enforce regulation. This responsibility instead falls to national and local governments. Existing legislation might be enforced more effectively through rebalancing the sustainable growth budget toward centralised financial support for environmental protection outside of the sectoral CAP and CFP policies.

Even within environmental legislation loopholes exist, the designation of heavily modified water bodies, the exceptions in the IAS regulation, the trade-off between economy and environment have already been made at the legislative and policy level.

4. Outlook

4.1. Agency and Irrational Trade-offs

At the individual level the goal of halting biodiversity loss, along with achieving the other indivisible SDGs come down to choices in consumption. In order to achieve these goals European individuals may be required, to make personal sacrifices for long term, greater good, to act against short-term self-interest in the cause of equity. Reducing levels of consumption may require individuals to make choices from which they personally do not benefit. This is a "wicked problem" it requires moral judgements and result in winners and losers. While science, can expose the resource constraints of a finite planet [81] it is not best suited to making moral choices or subjective decisions as it has sometimes attempted (e.g. [8,9,82]).

In this case agency requires an organisation which can effectively encourage individuals to make personal sacrifices, moral not rational choices. Markets discourage such moral behaviours [83], and the precursors of modern sustainability science has had a chequered past in this area of morality. Traditionally religious institutions could encourage or impose such choices about consumption and the major European religious institutes are beginning to engage with the environment as a moral issue [84].

This history of European environmental legislation provides evidence that European approaches toward sustainability are evolving, and that some achievements have been made, for example with the shift towards the concepts of ecosystem based management under the MSFD, it also suggests that major challenges to achieving the SDGs lie ahead. Whether the European Union (with its origins as a trading organisation) has the will, or the mandate to make the changes to key Practical policies or to force the difficult trade-offs between consumption and biodiversity that are required to meet the mission of the SDGs and of the Biodiversity Strategy remains to be seen.

The identification of competing norms and contradictory principals in this analysis provides a starting point from which European institutions can build policy coherency. The method may facilitate the proactive adaptation of existing policies and the design of new types of policy that more fully recognise and integrate the multiple Practical, Popular and Pure objectives and norms which are reflected in the SDGs and which are required to meet the goals of halting biodiversity loss in Europe.

In order to develop a truly integrated and effective approach to meeting the targets of the EU Biodiversity Strategy the norms relating to the provisioning and cultural ecosystem services of the Practical and Popular sets should be aligned with the policies of the Pure set. We need to make Pure more Popular, by improving public understanding of the environment (and thereby increasing cultural ecosystem services) and Practical more Pure by finding techniques of resource extraction that are less destructive. Explicit consideration of these differing norms provides a basis for further analysis. Ecosystem services concepts offer one potential avenue for moving past trade-offs between economic gain versus "intrinsic" worth, yet difficult trade-offs may still remain. European policy makers, scientists, educators and religious institutions all have roles to play and Europe may need to re-engage with concepts of morality rather than economy or ecology to achieve its conservation goals.

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Challenges in Sustainability

Research Article

Fostering the Next Generation of Sustainability Professionals—Assessing Field Courses in a Sustainability Science Graduate Program

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Abstract: A growing number of educational programs in sustainability science has paralleled the rise of the field itself. The educational approach of these programs follows the problem-driven, interdisciplinary, and transdisciplinary nature of the field itself. However, its effectiveness has yet to be systematically evaluated. Similarly, while ad-hoc evaluation schemes have attempted to monitor the quality of the educational programs, there is no standard method that accounts for the particularities of sustainability science programs. This study thus addresses the need for an assessment of the problem-driven approach of educational programs in sustainability science. We have conducted student self-assessments of field courses in the Graduate Program in Sustainability Science (GPSS-GLI) at The University of Tokyo, which positions its field courses at the center of its curriculum. The self-assessments were based on five key competencies identified as particularly important for sustainability professionals. Workshops and questionnaires engaged students in a reflection of the six field courses and of their own personal development through the activities offered. Our questionnaire results indicate that the majority of participants were satisfied with how the courses furthered their personal development. While some participants expressed frustration at being unable to sufficiently address the respective field's sustainability challenges due to time constraints, students generally recognized the five key competencies as important for addressing sustainability issues after participating in the courses. Moreover, participants attributed much of their learning to their active engagement in planned field research activities, rather than to passive learning. Variations in results across different course units provide material for further analysis and development of the curriculum. This study is an initial attempt at assessment, with room for ongoing improvement and further research to address additional requirements for fostering the next generation of sustainability professionals.

Keywords: curriculum development; fieldwork evaluation; higher education; competencies; sustainability professional; sustainability science

1. Introduction

Sustainability science has been promoted actively both in research and education as a vibrant response to emerging sustainability challenges such as climate change, environmental degradation, food security, energy provision, and inequality. The main disciplinary foci of sustainability science are to understand the complex interactions between natural and social systems [1–5], and to create knowledge for sustainable development [6–9]. Since challenges in sustainability generally require action to alter the status quo, the discipline's approach is problem-based and solution-oriented [10–13]. Moreover, interconnected problems [14] require researchers to go beyond their discipline of training. To reflect findings from research into actual practice, it is also necessary to cross the potential divide between academics and practitioners. Accordingly, sustainability science combines an interdisciplinary approach that employs academic knowledge from natural and social sciences to humanities, with a transdisciplinary approach that promotes co-design and co-creation of knowledge by diverse social stakeholders to address real-world sustainability challenges [15–18].

While the research dimension of sustainability science has formed its own space and landscape within academia [10,13,19,20], sustainability-related educational programs have also been promoted. According to a list from the journal Sustainability: Science, Practice, & Policy (SSPP)[21] there are more than 230 sustainability programs at the university level as of January 2016 [22]. Sustainability science education plays a key role in producing human resources with the literacy, knowledge, and skills required to actualize the recommendations of sustainability science research. Program curriculum and implementation must therefore reflect the interdisciplinary and transdisciplinary aspects of sustainability science. Students should be encouraged and trained to develop an interdisciplinary and transdisciplinary mindset, as the problems they address define the types of knowledge and methods necessary to propose possible solutions. Given the field's problem-driven and solution-oriented approach, it is also critical to have linkages not only between research and stakeholders such as industry, government, and NGOs, but also between research and education for the continuous development of sustainability professionals. More collaborative and critical research approaches are necessary to guide social transformation towards sustainability [23].

Theoretical and applied literatures address the design of educational programs. The interdisciplinary approach of sustainability science brings together academic disciplines with diverging worldviews, and this in turn creates epistemological discussions. Such inter-paradigmatic collaboration and negotiation is considered a key characteristic of the field. In line with the epistemological discussion, the idea of 'trans-epistemology' [24] was introduced [24] to better describe the dynamic integration of different methods in sustainability research. According to Scheweizer-Ries and Perkins [24], trans-epistemology is the "cooperation between different personal knowledge systems" and society as a whole is the " 'producer' of shared and socially constructed understanding of the world" [24]. The idea of sustainability is fundamentally normative and carries specific cultural values. It may also differ from person to person, so that sustainability science researchers must be able to imagine the diversity of views on a given topic and comprehend interlinkages between the viewpoints of different stakeholders. Accordingly, an educational program in sustainability must have the flexibility to accommodate awareness and tolerance of multiple epistemological views [25].

Regarding the design and operation of an educational program in sustainability science, Onuki and Mino introduced three key components: (i) knowledge and concept-oriented courses, (ii) experiential learning and skills-oriented courses, and (iii) transdisciplinary thesis research [26]. Mino and his colleagues later added the transboundary framework to emphasize the full range of scales, from the individual to the global, in order to examine subjects and problems from multiple angles [27].Tamura and Uegaki operate a sustainability science program in Ibaraki University, and raise another core concept for designing a sustainability science program, the "Mind-Skills-Knowledge" model of sustainability education [28]. In an analogy of sustainability science students with athletes who need to maintain their body, technique and spirit, the framework stresses a balance of different types of knowledge. Others have suggested declarative, procedural, effectiveness, and social knowledges, as well as their effective interaction [25].

In terms of the evaluation of sustainability science education programs, one challenge is to develop a method for investigating whether students are effectively acquiring the competencies required in order for them to actualize their knowledge as concrete actions for sustainability [28]. The work of Wiek and his colleagues provides a comprehensive discussion of five key competencies within a problem-solving framework [29]. While the proposed key competencies have been applied to assess students' learning outcomes in a transdisciplinary course [30], a general need for research on pedagogy and evaluation in sustainability science programs remains.

To address this gap in the evaluation of sustainability science programs, this study aims to examine the problem-driven approach of sustainability science through student self-assessments of six field courses at the Graduate Program in Sustainability Science (GPSS-GLI), The University of Tokyo. Field courses in GPSS-GLI are designed for students to engage in collaborative research and to address real-world sustainability challenges in various topical cases. So far, field courses have covered countries in Africa (Kenya, Nigeria, and South Africa), Asia (China, Japan, Thailand), Europe (Denmark and Sweden) and Latin America (Costa Rica), and topics such as renewable energy, biodiversity conservation, and urban informal settlement [31].

These courses also aim to equip students with practical skills such as workshop facilitation, coordination with local resource persons, and field methodologies that can be applied to their thesis research. The general structure of each field course is designed by one or two faculty members who specialize on the given topic. One unit normally accompanies a cohort of four to ten students, and one doctoral student takes a leading role in the planning. Six field courses implemented during the academic year 2014–2015 are evaluated in this study (see Table 1 for an overview of the units). Four of these are Global Field Exercises and two Resilience Exercises, but these have equal weight and significance in the curriculum and are handled as identical in this analysis.

2. Methods

The assessment began with the development of a conceptual framework and methodology, implemented systematically in a subsequent phase. The first phase took place in the Tohoku Resilience Exercise, one of six workshops assessed in this study. While the exercise itself had an educational focus of having students grapple with the complexity of issues surrounding the regional reconstruction after the Tohoku Earthquake and Tsunami of March 2011, students simultaneously engaged in a reflective analysis that laid the foundation of this assessment effort [32].

This developmental phase began with a review and analysis of the conceptual framework of key competencies for sustainability science professionals [29] that had been used in a previous assessment of the said program [33]. The chosen framework was deemed appropriate for this assessment as a focus on real-world problems is characteristic of GPSS-GLI, and the five key competencies were identified for their relevance to sustainability science research and problem solving [29,32]. Collectively, students reviewed this pre-existing framework and adapted the original definitions for use within an educational context [32]. The group then analyzed the linkages between each of the competencies and the activities and issues within the Resilience Exercise.

In order to hold pointed discussions about how different components of the field course-related activities contributed to participants' personal development, there was a need to distinguish between active and passive learning, as well as of recognizing a competence as important in professions of sustainability science. As discussed by San Carlos and colleagues [33], a review of academic literature revealed a lack of consensus and clarity on the definitions of active and passive learning [34,35]. For practical purposes, our understanding is that active learning involves active engagement of the students with the planned field exercise course activities. In other words, active learning is learning by doing, such as designing and conducting original field surveys and through firsthand interaction with stakeholders in the research topic. In contrast, passive learning is the unidirectional transmission of information through lectures and other methodologies that do not require active student engagement [35].

Table 1. Description of field course units and assessment participation rates

Type of course	Resilience Exercise		Global Field Exercise			
Unit name	Minamata	Tohoku	Oasis	Costa Rica	Bangkok	Nairobi
Main location	Minamata, Japan	Otsuchi, Japan	Zhangyo City, China	Guanacaste, Costa Rica	Bangkok, Thailand	Nairobi, Kenya
Duration of field exercise	6 days	7 days	14 days	7 days	13 days	14 days
Workshop participants / GPSS-GLI students in unit	8/10 (80% workshop participation)	8/8 (100% workshop participation)	5/5 (100% workshop participation)	5/5 (100% workshop participation)	3/3 (100% workshop participation)	7/8 (88% workshop participation)
Focus / Objective	Educational / understanding issues regarding the Minamata Disease	Educational / current situation of Tsunami affected area and applying the concept of resilience	Research / sustainable water management in semiarid region in China	Research / additionality of payments for ecosystem services for agroforestry	Educational / urban health issues (focus differed by group)	Educational / sustainability challenges and research methods in urban Africa
Primary field activities	Lectures, field, visits, group work	Lectures, field, visits, interviews	Field visits, interviews, survey	Interviews, field visits	Lectures, field visits, group work	Lectures, field research, group work
Major characteristics	Organized by faculty. Output of educational material	Organized by faculty	Student-led, participants from multiple institutions	Student-led, first time unit	Organized by faculty. Participants from multiple institutions	Organized with participation of local students

At the end of the week-long Exercise course with daily, reflective discussions, each student's personal experiences were quantified for analysis using a questionnaire with the concepts discussed. This questionnaire was used throughout the subsequent assessment. The questionnaire assumed that the respondent would have received some explanation of the competencies prior to assessment, but listed definitions as shown in Table 2. Students were asked to rate the unit's effectiveness in facilitating personal development of the respective competence beyond their baseline level. The assessment of each competence was threefold: for passive learning, for active learning, and for "recogni[tion]/agree[ment] about the importance of the competence for research on sustainability issues" (hereafter: "Recognition"). Responses were indicated according to a 5 point-Likert scale (1: very ineffective (no influence); 2: ineffective, 3: satisfactory, 4: effective, 5: very effective). Open space was provided at the end of the questionnaire with prompts encouraging comments on respondents' personal experiences or feedback on the assessment itself.

All subsequent assessments were conducted after the completion of the field courses according to the following procedure. The authors contacted student participants of the respective course unit using e-mail and/or social media to schedule a course workshop. This correspondence involved all GPSS-GLI students who had participated in the course, with one exception where the student had already graduated and left the country.

Workshops were facilitated by at least one of the authors. A brief introduction of the assessment project was followed by inquiry about the unit's educational and/or research objectives. Using a whiteboard or projected computer screen, students were then asked to list out the units' activities. Next, the competence framework was introduced using the definitions on Table 2, and students were asked to identify linkages between the competencies and the listed activities. At the end, the questionnaire was handed out either electronically or on paper for students to complete individually. The total duration of the workshops averaged about 90 minutes, and all workshops were conducted between September and November of 2015.

Table 2. Original and applied definitions of Key Competencies in Sustainability (adapted from San Carlos et al [32])

Competence	Original definition 29	Our operationalization
Systems-thinking competence	Ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global)	Competency to organize and understand the complex constellation of sustainability issues
Anticipatory competence	An ability to collectively analyze, evaluate, and craft rich pictures of the future related to sustainability issues and sustainability problem-solving frameworks	Competency to visualize future scenarios, including non-intervention and alternative sustainability visions
Normative competence	An ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets	Competency to understand the range of different values that could lead to different sustainability visions
Strategic competence	Ability to collectively design and implement interventions, transitions, and transformative governance strategies toward sustainability	Competency to design and implement strategies to achieve a particular sustainability vision
Interpersonal competence	An ability to motivate, enable, and facilitate collaborative and participatory sustainability research and problem solving	Competency to communicate, coordinate, negotiate or lead

Subsequent consultations with faculty and affiliated staff members supplement the above process as a means to consider the appropriateness of the completed assessment. To date, this process has consisted of an e-mail with a semi-structured questionnaire to faculty and staff members associated with each field course. The e-mail included a summary of the student assessments for the respective unit, as well as cross-unit average scores. Another document outlined the intent of the assessment and prompted for responses as follows: 1) explanations and interpretations of the results; 2) reflections on the exercise design; 3) comments and feedback on the assessment itself. As some unit-specific comments would be traceable to individual faculty members, the document asked faculty members to indicate their willingness to have their comments attributable to the unit in question.

3. Results

3.1. Student Workshop and Faculty Participation Rate

Field course units are referred to by the location: Minamata (Japan), Tohoku (Japan), Oasis (China), Costa Rica, Bangkok (Thailand), and Nairobi (Kenya). As shown in Table 1, the assessment had a high rate of participation, with full participation for four of six units. E-mail inquiries with faculty and staff members were followed up with reminders and reached a response rate of 86% (n = 7). As only one staff member was contacted, faculty and staff will hereafter be referred to as "respondents" to ensure confidentiality.

3.2. Student Workshop and Questionnaire Results

Figure 3 shows the questionnaire results. Columns (A) to (F) show results in each course unit by competence. Rows (1) to (5) show the results for each competence by course unit. Mean scores and standard deviations (SD) for each competence are shown by type of learning. The last column and row represent the aggregate means by competence and unit, respectively.

3.3. Results by Competence and Type of Learning

Figure 1 shows the mean scores for the five competencies by type of learning. Results indicate overall student satisfaction with the field courses, as all five competencies obtained scores higher than 3.0 ("satisfactory") for all types of learning. The highest scoring competence was Interpersonal Competence (M = 4.17). The lowest scoring competence was Strategic Competence (M = 3.38).

High scores on Recognition indicate that students generally agreed with the literature on the relevance of the key competencies for sustainability science research [29]. Recognition scored higher than the other types of learning on four of five competencies (Anticipatory Competence (M = 3.89); Normative Competence (M = 3.89); Strategic Competence (M = 3.79); Interpersonal Competence (M = 4.27)). Regarding Systems Thinking Competence, Recognition only scored marginally below the mean score of 3.88 (M = 3.86).

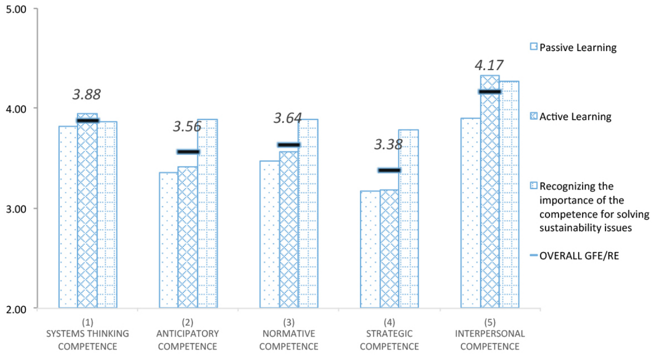

Figure 1. Aggregate scores by competence and type of learning.

Active Learning was evaluated more highly than Passive Learning for all competencies. This is intuitive, as the field courses are based on the concept of providing opportunities for active engagement in the field [36]. The difference was greatest for Interpersonal Competence, where the aggregate mean for Active Learning (M = 4.33) was 0.43 points greater than for Passive Learning (M = 3.90). In contrast, the gap between Passive (M = 3.17) and Active (M = 3.18) Learning was only 0.01 points for Strategic Competence.

Other notable results are the high scores on Interpersonal Competence (M = 4.17) and low scores on Strategic Competence (M = 3.38). Effectiveness with the development of Interpersonal Competence may be explained by GPSS-GLI students' diversity in cultural, academic, and professional backgrounds as well as demographics [36]. Lower evaluations on Strategic Competence may be due to the expectation and desire of students to have a tangible impact on the study area, despite time and resource constraints that limit such impact in reality. Student and faculty respondents alike commented that courses focused on understanding past and current situations rather than on speculating the future. This is understandable given the one to two week duration of the courses and consistent with the interpretation regarding the lack of capacity of the courses to have tangible impact.

3.4. Results by Field Course and Competence

Figure 2 shows competence and mean scores for the six field courses assessed in this study. Mean scores by course unit were also higher than satisfactory (3.0). The highest scoring course unit was the Bangkok Unit (M = 3.85). The Tohoku Unit (M = 3.46) received the lowest scorings and had high inter-student variation in each competence, a result likely attributable to the extended and critical discussions unique to this unit [32].

Results showed varying tendencies across units on student assessments' scores and standard deviations (Figure 3). Minamata Unit obtained high scores and low standard deviations for all competencies (see column (A)). Tohoku Unit yielded the lowest mean score (M = 3.46), with similar results excepting Strategic Competence (M = 2.75), which scored below “satisfactory”. However, standard deviations within each competence were high for all competencies and almost all types of learning (see column (B)). One respondent took particular note of the contrast between Minamata and Tohoku Units, as “both are designed as ‘experience-oriented’ [and with] similar concepts”.

The Oasis and Costa Rica Units were similar in their focus on research. However, evaluations by Oasis Unit students had large variation (e.g. standard deviations above 1.0 for Strategic Competence (Passive (SD = 1.30); Active (SD = 1.22); Recognition (SD = 1.58))). Students in both units were consistent in their high evaluations of the course’s impact on their Interpersonal Competence (Oasis (M = 4.87); Costa Rica (M = 4.20); see Figure 3, columns (C) and (D)). In particular, Oasis student evaluation for Interpersonal Competence was highest of all units (aggregate M = 4.87). These outcomes may be attributed to the emphasis on student leadership noted by the faculty respondents affiliated with the two units. One stated that this emphasis might have been interpreted as a lack of strategic vision in the design of the unit, explaining the lower evaluation on Strategic Competence.

General scoring patterns on the Bangkok and Africa Units are comparable. However, responses on the former unit had greater internal consistency (see Table 1, column (E), (F) and Figure 2). The Africa Unit yielded relatively high variation amongst students for Passive and Active Learning. An affiliated respondent observed that these relatively high variations might indicate that “the exercise led to variable experiences for different students”. Another respondent affiliated with the Bangkok Unit expressed surprise at the lower scores on Recognition. Regarding Systems Thinking Competence, this respondent suggested that more attention should be given to a “holistic view about the complex systems (economic, social etc.) relating to the environmental and health issues” addressed in the unit.

4. Discussion

This self-assessment of field courses in GPSS-GLI addresses both the needs of the said program, as well as academic needs to assess the development of competencies necessary for sustainability professionals [29,37]. Building upon the foundation of a previous assessment of GPSS-GLI curricular activities conducted six years ago [33], the present study provides a more detailed and in-depth assessment of field courses, a core activity in the program.

4.1. Contributions to GPSS-GLI

The self-assessment method was generated in the previous exploration of GPSS-GLI student perspectives on curricular activities and the development of their competencies [33]. Student participation in the assessment and development of GPSS-GLI is consistent with the program’s emphasis on developing student leadership skills [36] and educational practices in which students can participate [38].

Responses on the validity of the assessment are mixed, yet overall positive. Most faculty members considered the competence framework to be an appropriate assessment framework for GPSS-GLI. Five out of the six faculty members consulted considered the results insightful to varying degrees. Comments included, “the results seem accurate,” and “results are convincing”.

Nonetheless, some were skeptical of the framework and/or fundamental approach of this assessment. One respondent considered the competence framework unfit for this assessment, another expressed that their understanding of the framework was insufficient to use it, and a third considered it necessary to differentiate between the two types of field courses (Global Field Exercise and Resilience Exercise) offered in the program. A further response questioned, “the overall assessment has to be looked at with a question mark”.

4.2. Methodological Limitations

Indeed, limitations of this ongoing assessment must be carefully considered. First, students may have difficulties relating their field experiences to the development of their personal competencies. Moreover, the time between the field course and assessment varied from unit to unit. Notwithstanding the high rates of participation in the workshops (Table 1), the validity of our results must be interpreted according to the low numbers of participants per unit. Second, results depend on students’ comprehension of the competencies, and the relatively short workshops may have been insufficient to ensure adequate comprehension. One faculty member raised this issue and recommended incorporating an explanation of the competencies in the guidance before each field course.

Third, scores only reflect additional improvement of individual competencies that students considered attributable to the field courses. Accordingly, results are subject to variations in baseline levels. Individual experiences before, during and after the units play a great role in student assessment, and a respondent questioned “if [students] could really assess what outcome/impact they experienced for each key competence and by how much”.

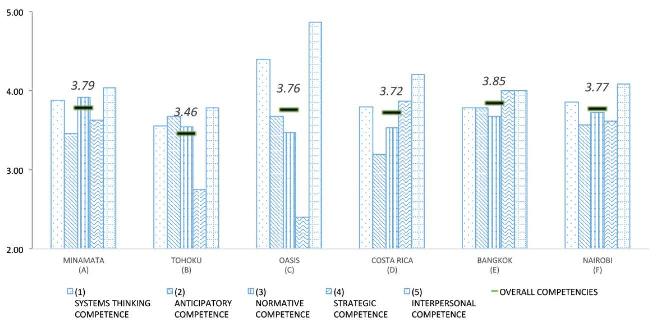

Figure 2. Aggregate scores by course and competence.

SUMMARY 2015 GFE/RE ASSESSMENT RESULTS BY UNIT

		MINAMATA (A)			TOHOKU (B)			OASIS (C)			COSTA RICA (D)			BANGKOK (E)			NAIROBI (F)			OVERALL GFE/RE (G)	
		Unit Score	SD	Unit Score (Average)	Unit Score	SD	Unit Score (Average)	Unit Score	SD	Unit Score (Average)	Unit Score	SD	Unit Score (Average)	Unit Score	SD	Unit Score (Average)	Unit Score	SD	Unit Score (Average)	Unit Score	Unit Score (Average)
(1) SYSTEMS THINKING COMPETENCY	Passive Learning	3.75	0.89	3.88	3.88	1.13	3.55	4.20	0.84	4.40	3.40	1.14	3.80	4.00	0.82	3.78	3.71	0.95	3.86	3.82	3.88
	Active Learning	4.00	1.07		3.38	1.30		4.60	0.55		4.20	0.84		3.67	1.25		3.86	0.90		3.95	
	Recognizing the importance of the competency for solving sustainability issues	3.88	0.64		3.38	1.41		4.40	0.89		3.80	1.10		3.67	0.47		4.00	0.58		3.86	
(2) ANTICIPATORY COMPETENCY	Passive Learning	3.25	1.04	3.46	3.63	1.19	3.67	3.40	0.55	3.67	3.20	0.84	3.20	3.67	0.47	3.78	3.00	1.15	3.57	3.36	3.56
	Active Learning	3.38	0.92		3.38	0.74		3.20	1.64		3.00	0.71		4.00	0.82		3.57	1.27		3.42	
	Recognizing the importance of the competency for solving sustainability issues	3.75	1.04		4.00	1.41		4.40	0.89		3.40	0.55		3.67	0.47		4.14	0.90		3.89	
(3) NORMATIVE COMPETENCY	Passive Learning	3.88	0.64	3.92	3.75	0.89	3.54	3.20	0.84	3.47	3.00	1.41	3.53	3.67	0.94	3.67	3.29	1.25	3.72	3.47	3.64
	Active Learning	3.63	0.52		3.00	1.31		3.40	0.89		3.80	0.84		4.00	0.00		3.57	1.27		3.57	
	Recognizing the importance of the competency for solving sustainability issues	4.25	0.71		3.88	1.36		3.80	1.30		3.80	1.30		3.33	0.47		4.29	0.76		3.89	
(4) STRATEGIC COMPETENCY	Passive Learning	3.25	1.04	3.63	3.13	1.13	2.75	2.20	1.30	2.40	3.60	0.89	3.87	3.67	0.47	4.00	3.14	1.07	3.62	3.17	3.38
	Active Learning	4.00	0.93		1.63	0.52		2.00	1.22		4.00	1.00		4.00	0.82		3.43	1.40		3.18	
	Recognizing the importance of the competency for solving sustainability issues	3.63	0.92		3.50	1.51		3.00	1.58		4.00	0.71		4.33	0.47		4.29	0.76		3.79	
(5) INTERPERSONAL COMPETENCY	Passive Learning	3.75	1.04	4.04	3.50	1.20	3.79	4.60	0.55	4.87	4.00	1.22	4.20	4.00	0.82	4.00	3.57	1.62	4.09	3.90	4.17
	Active Learning	4.25	0.71		4.00	1.07		5.00	0.00		4.40	0.55		4.33	0.47		4.00	1.15		4.33	
	Recognizing the importance of the competency for solving sustainability issues	4.13	0.83		3.88	1.36		5.00	0.00		4.20	0.84		3.67	0.47		4.71	0.76		4.27	
OVERALL COMPETENCIES (AVERAGE)		3.79			3.46			3.76			3.72			3.85			3.77			3.73	

Assessment of the effectiveness of this exercise for facilitating the following competences.

Score	1.00	2.00	3.00	4.00	5.00
	Very ineffective	Ineffective	Satisfactory	Effective	Very effective

Legend:
- Green: Score equal or higher than average score for that competency overall GFE/RE
- Yellow: Score lower than average score for that competency overall GFE/RE
- Pink: Standard Deviation higher than 1 point (within the 5 point Likert scale)

Figure 3. Questionnaire results.

Fourth, field courses were designed with unique objectives, none of which explicitly involved the said competencies. Nonetheless, one respondent interpreted that "assessment results show that this design was vindicated", somewhat validating the methodology even if it differed from the original intentions.

A high or low score is not necessarily good or bad, but merely a reflection of the unit design. Results thus ought to be viewed in light of the respective unit. Alternatively, future assessments should consider incorporating or reflecting the unit design in its assessment framework so as to more appropriately assess field courses designed with varying objectives in mind. For example, intended objectives of the respective course unit may be integrated into the assessment framework to provide insights more relevant to the unit in question. However, condensing the main features of each unit design into the assessment framework would be extremely challenging. Instead, the authors believe that a post-assessment discussion with students and faculty could shed light on the results obtained and allow for an open discussion that would involve the units' design.

Additional qualitative data on students' experience could offer a deeper insight into the results and how the competencies were developed in each unit. One respondent suggested "one would have to have qualitative expressions about their experiences" in order to better analyze the assessment outcome.

4.3. Fundamental Considerations

Lozano has suggested that most of the tools available for assessing sustainability do not seem adequate for immediate application to the university setting. In general, responses to this situation fall under either 1) modification of the existing tools, or 2) creation of specific tools for universities [39]. The current assessment falls under the latter approach and attempted to cater to the characteristics of the field courses in GPSS-GLI. Any application of this competence-based assessment to other programs or universities should be conducted with care and upon fundamental reconsideration of the assessment approach. Within the program, faculty members must consider the appropriateness of the framework used in this assessment, as well as whether or not and how to incorporate its outcomes in the design of future course units.

While Wiek et al.'s framework was selected for its focus on sustainability science, Wiek and his colleagues specify that pedagogy was beyond the scope of their study [29]. Thus, the application of his framework to education is so far unique to this assessment project [32,33], and the results must be interpreted with caution. For example, universal competencies other than those "key" to sustainability science have not been considered, and the list of the five key competencies so far identified has yet to be finalized [29]. The existence of other studies on sustainability in higher education suggest that attention should be also paid to competencies related to domains such as the affective learning outcomes of educational initiatives [40,41]. Further, alternative approaches to assessment could be taken into consideration, such as the Integral Framework, employed by a GPSS-GLI faculty member in the design of one course unit [42,43] but were beyond the scope of the present study.

More fundamentally, the objective and validity of an assessment need to be carefully examined. Most faculty members consulted in the assessment consider the development of an evaluation scheme for sustainability science education to be a necessary step in improving the program design. However, respondents shared the concern that an emphasis on assessment development may lead to program designs that excessively cater to evaluation. This concern is particularly relevant to the field courses, where, through direct exposure to the problems and through real-life interactions with residents of the field site, students' learning outcomes extend beyond what was originally intended or anticipated. Field courses must thus maintain a certain degree of flexibility to encompass diverse forms of learning.

5. Conclusions

This study contributes to the development of a method to assess students' learning outcomes of field courses in a sustainability science program. Through the case of six field courses in GPSS-GLI at The University of Tokyo, we address not only the development of the said program, but also academic needs to assess the key competencies for sustainability professionals. The results of the self-assessment suggest that the majority of field course participants felt satisfied with the knowledge and skills they acquired, and gained the ambition to further explore the respective topic areas. Students also recognized the importance of key competencies for sustainability professionals after participating in the field courses. Although the authors do not suggest that all courses be aligned with the key competencies, the study suggests that such alignment could raise students' awareness of the competencies they are acquiring from the program they belong to.

We expect to tackle limitations of the self-assessment method of this study in future developments. In particular, the assessment framework may be altered to reflect the variety of field course designs. In terms of implementation, the framework's concepts may be better standardized by building a common understanding of the methods and terminologies used across students and faculty. There should also be consensus within the graduate program on the role of the assessment and the appropriate level of effort dedicated to this task.

We believe that the results of this study showed enough evidence to support the usefulness and appropriateness of the deployed self-assessment. We consider the present study a successful and relevant step forward in the assessment of field exercise courses in the Graduate Program in Sustainability Science – Global Leadership Initiative of The University of Tokyo, and a contribution to the general development of mechanisms to assess key competencies for sustainability science research.

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