Global sustainability governance:
Integrated scientific assessment at a critical inflection point

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Summary

Achieving global sustainability calls for deliberate and radical transformations. Limitations in established global governance and knowledge systems require an overhaul of the international processes that can generate a widely accepted body of credible scientific advice. In the 1970s, when the concept of integrated scientific assessment was conceived, prevailing conditions and assumptions sought descriptions of the issues under scrutiny. Those conditions have changed – with a deluge of data and information to synthesize, the perils of globalization to navigate, and new inequities to confront. In the global sustainability context, expectations of assessments shifted over the decades towards a greater emphasis on, and engagement with, possible solutions. This important evolution raises serious challenges and new opportunities to improve the utility of assessments and refine their ability to influence critical decisions amidst contested and uncertain futures. This dissertation investigates how current knowledge systems across the integrated scientific assessment landscape help or hinder efforts to advance global sustainability governance. While it considers the significance of the challenges, it also explores the potential to go beyond synthesis and interpretation and to instead explicitly engage in an integrated, contextualized evaluation of solution pathways and policy performance.

The first chapter of this dissertation gives a context-setting introduction. The second chapter presents an evaluation of progress made towards achieving selected internationally agreed goals and objectives since the 1972 UN Conference on the Human Environment. The evaluation reveals very limited sustained progress (an average of less than 5% achieved of the 90 goals evaluated) and suggests that, given current trends, most internationally agreed goals are unlikely to be met or to achieve a significant measure of success within their respective commitment periods. The analysis suggests a widening incongruence, and tension, between knowledge production systems and their ability to interact with and influence international performance.

The following three chapters provide analyses and insights on the implications of the global sustainability-governance landscape, as global integrated assessments have progressed towards an increasingly demanded and already observable consideration of solutions. Chapter 3 provides a succinct overview and analysis of existing and anticipated challenges at the science-policy-society interface. Chapter 4 examines the changing role and coevolving orientation of integrated scientific assessments and the political context in which they have been embedded since their inception. Chapter 5 introduces a new conceptual framework for global integrated scientific assessments with norms for addressing the plurality of perspectives, dissent and controversy and for the treatment of uncertainty and diverging viewpoints.

The final core chapters provide practical and more specific insights into how contemporary assessment processes can be powerful platforms for collaboration beyond disciplines and between scientific and policymaking communities. Each of the two chapters presents a case study, one covering the multiple pressures on land-based ecosystems and the other examining the various components of urban food security. These chapters demonstrate that rigorous scientific assessments will be more valuable in the role of evaluating response options and informing solution pathways than as updates in the context of an endless cycle of incremental problem analysis.

In summary, the extent to which integrated scientific assessments can guide choices and influence decisions has become limited, due to their antiquated structures and processes. Remedying this will

require a new generation of tools and analytical capacities for policy assessment and for addressing increased complexity. Also needed are multiple reinforcing channels of influence and representation, including cross-national learning, and a full exploitation of digital communication and collaboration in an era of constrained resources and travel. Harnessing these opportunities offers great potential for reimagining the role and structure of integrated scientific assessments in the quest to more effectively inform governance and foster a new political economy of global sustainability.

Zusammenfassung

Um das Ziel globaler Nachhaltigkeit zu erreichen, muss ein radikaler und vor allen Dingen bewusster Wandel statttfinden. Die sich abzeichnenden Grenzen und Beschränkungen etablierter Governancesysteme zur Wissensgenerierung auf internationaler Ebene erfordern ein Neu- und Umdenken, so dass die bestehenden Prozesse weiterhin zu einer glaubwürdigen wissenschaftlichen Beratung beitragen können. Als das Konzept der integrierten wissenschaftlichen Beurteilung im Kontext der 1970er Jahre konzipiert und konkretisiert wurde, lag der Fokus auf einer Beschreibung der zu untersuchenden Thematiken. Dieser Kontext hat sich geändert, unter anderem durch die klarer zu Tage tretenden Ungleichheiten die es zu konfrontieren gilt, die negativen Rückwirkungen der Globalisierung, und eine Explosion der Verfügbarkeit von Daten und Information die es zu verarbeiten gilt. Im Kontext der Diskussion um globale Nachhaltigkeit haben sich somit die Erwartungen an wissenschaftliche Beurteilungen im Laufe der Jahrzehnte verändert, hin zu einer stärkeren Betonung auf—und Auseinandersetzung mit— möglichen Lösungen. Diese Entwicklung wirft wichtige Fragen auf und bietet zugleich neue Möglichkeiten, um den Nutzen wissenschaftlicher Assessments zu verbessern mit dem Ziel, konfliktreiche Entscheidungen in eine sinnvolle Richtung zu informieren.

Diese Arbeit untersucht, wie die etablierten Prozesse der Wissensgenerierung in integrierten wissenschaftlichen Assessments das Ziel globaler Nachhaltigkeits governance unterstützen oder behindern. Dabei werden sowohl die Herausforderungen berücksichtigt, als auch das Potenzial untersucht, über die Synthese und Interpretation von Information hinauszugehen um eine integrierte, kontext-spezifische Bewertung möglicher Lösungswege vorzunehmen. Das erste Kapitel stellt das Thema und führt in die Zusammenhänge und in die Fragestellung ein. Das zweite Kapitel beurteilt die Fortschritte zur Erreichung ausgewählter Ziele, die in der UN Konferenz über die Umwelt des Menschen von 1972 vereinbart wurden. Die Bewertung zeigt, dass nur sehr begrenzte Fortschritte erzielt wurden (durchschnittlich weniger als 5% bei 90 bewerteten Zielen) und legt nahe, dass es angesichts der aktuellen Trends unwahrscheinlich ist, dass die international vereinbarten Ziele erreicht, oder signifikante Erfolge innerhalb der Verpflichtungsfristen, erreicht werden können. Die Analyse deutet auf eine zunehmende Spannung zwischen Wissensgenerierung und ihrer angewandten Problemlösungsfähigkeit hin. Die Kapitel 2-5 analysieren, wie sich die Prozesse der Wissensgenerierung und wissenschaftlichen Assessments auf die globale Nachhaltigkeits-Governance-Landschaft auswirken, insbesondere im Zuge der globalen Nachfrage nach Lösungen und der zeitnahen Evaluierung dieser Politiken. Kapitel 3 bietet einen kurzen Überblick und eine Analyse der bestehenden und zu erwartenden Herausforderungen an der Schnittstelle zwischen Wissenschaft, Politik und Gesellschaft. Kapitel 4 untersucht die sich ändernde Rolle und Ausrichtung integrierter wissenschaftlicher Beurteilungen im politischen Kontext, in dem sie seit ihrer Einführung stattgefunden haben. Kapitel 5 führt einen neuen konzeptionellen Rahmen zur Diagnose und Bearbeitung von Konflikten im Rahmen der Erstellung gon global-integrierte wissenschaftlichen Assessments ein, der die Vielzahl von Perspektiven, Meinungsverschiedenheiten und Kontroversen berücksichtigt, als auch die Behandlung von Unsicherheit. Die letzten beiden Kernkapitel bieten praktische und spezifische Einblicke, wie zeitgemäße Assessmentprozesse leistungsfähige Plattformen für die Zusammenarbeit über Disziplinen hinweg, und zwischen wissenschaftlichen und politischen Gemeinschaften hindurch, sein können. Es werden zwei Fallstudien vorgestellt, die einerseits den vielfältigen Druck auf landgestützte Ökosysteme, und andererseits die unterschiedlichen Komponenten städtischer Ernährungssicherheit untersuchen. Diese Kapitel zeigen, dass

wissenschaftliche Assessments Lösungswegen wertvoller sind als einfache Aktualisierungen inkrementeller, technischer Problemanalysen.

Zusammenfassend zeigt die Arbeit, dass das Ausmaß in dem integrierte wissenschaftliche Assessments Entscheidungen befördern oder beeinflussen können, derzeit nochstärker begrenzt ist als notwendig, hauptsächlich aufgrund veralteter Strukturen und Prozesse. Um dies zu beheben, ist eine neue Generation von Instrumenten und Analysekapazitäten erforderlich, so dass Politikoptionen unter zunehmender Komplexität evaluiert werden können. Darüber hinaus sind andere verstärkende Einfluss- und Repräsentationskanäle erforderlich, grenzüberschreitende Lernen, und eine vollständige Nutzung digitaler Kommunikation, vor allen Dingen in Zeiten begrenzter Geldmittel und Reisemöglichkeiten. Die Nutzung dieser Möglichkeiten bietet ein großes Potenzial für eine Neugestaltung der Rolle und Struktur integrierter wissenschaftlicher Assessments mit dem Ziel Governancesysteme der globalen Nachhaltigkeit zu stärken und zu fördern.

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1. Introduction

1.1 Advancing global sustainability governance

International scientific and political cooperation has brought attention to global systemic risk and environmental change problems through the development of transnational programs that assess and monitor the state of common-pool resources and planetary change. The effectiveness of these programs, or, more precisely, their role in mitigating these problems remains highly debated.

Since the 1990s, accelerated globalization has reduced poverty rates at unprecedented scale. It has brought wide access to technologies, innovations and connectivity in all parts of the world, providing and producing insights and information based on statistical analyses and their communication. Today, vast and increasing accumulations of information, digital data, powerful algorithms and artificial intelligence influence the everyday decisions and daily routines of individuals and groups across the globe and are shaping possible development paths (Nyborg et al., 2016; Slaughter et al., 2017).

Globalization's far-reaching effects on lifestyles and global consumption patterns have intensified tendencies toward inequality, while exposing the inherent perils of ignoring social and environmental justice. These effects have intensified the threats we face as a global community, such as resource depletion, food production vulnerability, climate change, disaster risk, the spread of disease and war. The unintended consequences and drawbacks of globalization are becoming apparent in the 21st century, and they suggest that threats of global scale cannot be confronted without collective action, and, crucially, cannot be overcome without reconciling dramatic income disparities (Weiss and Thakur, 2010; Ostrom, 2010; Harper et al., 2017; Gupta, 2018; Kainuma et al., 2019). We live in a time of significant change, with the possibility ahead of great disruption but also of significant achievement.

Scientific advances have benefited from international and globalized cooperation for centuries. The advent of computerized analysis and compilation feats have enabled detailed exploration of the intricate human genome and the far edges of the Solar system. At the same time, scientific understandings of the Earth as an integrated system are challenging traditional notions of global sustainability, citizenship, political participation and governance (Slaughter et al., 2017; Steiner, 2018). Integrated assessment of scientific understanding has become the de facto tool for boundary organizations (e.g. United Nations) to inform decision-making. But can a systematic aggregation and transmission of knowledge translate the ambitions of international regimes and global narratives for enhanced sustainability into practice? Can collective knowledge, international cooperation and state behavior be reconciled to play a civilizing role in global world order, and if so, how?

The realities of national economic self-interest promote the use of growth models favoring narrow metrics of wealth creation over more inclusive indices for wellbeing. This standard makes it difficult for state actors who manage the natural resource extraction that generates environmental damage to confront the transboundary impact of their actions. It is not surprising, therefore, that the historical tendency of the nation-state system has been to 'free-ride' on the environmentally responsible efforts of other actors (Barrett, 1994; Ostrom, 1990, 2009). There are of course key exceptions, for example, the progress on reversing damage to the ozone layer through global action on science-based targets under the Montreal Protocol. But the existing disincentive effects for unilateral state action to favor any policy that addresses even the most pervasive and perilous threats, with transnational welfare impacts, remain a defining problem for global sustainable development (Finus et al., 2017).

The 2030 Agenda for Sustainable Development and its Sustainable Development Goals (SDGs) were adopted to confront these challenges. The SDG framework and its indicators and targets reflect the "integrated and indivisible" nature of society's shared aspirations for health, wellbeing, prosperity, peace and security, and are conceptualized as both preconditions for and outcomes of sustainable development. While the SGDs endorse the principle of common but differentiated responsibility, they emphasize accessibility, universal applicability and need for globally coordinated solutions. The 2015 adoption of the Paris Agreement on climate, the Sendai Framework for Disaster Risk Reduction, and the 2030 Agenda represent multilateral milestones. They provide high-level political frameworks and accountability mechanisms for global transformation to a safer, low carbon and more equitable society. Taken together, they are intended to shape policies for the next decade. However, identifying and mobilizing the appropriate policies to pursue these ambitious policy pathways and new trajectories for sustainable development, remain as shortcomings and priorities (Boucher et al., 2016; Schreurs, 2016; Höhne, et al., 2017; Gupta and Ekins, 2019).

As it is, decision-makers lack sufficient knowledge about the direct effects and co-benefits, much less, any unintended consequences, of available policy options across various dimensions: governance levels, socioeconomic contexts, and spatial and temporal scales (Carraro, et al., 2015; Edenhofer and Kowarsch, 2015; von Stechow et al., 2016; Jabbour and Flachsland, 2017). For example, policies that restrict bioenergy deployment, with the aim of protecting food security, biodiversity and water availability, increase reliance on other contested technologies as well as the costs for climate change mitigation (Kowarsch et al., 2017). While uncertainty cannot be eliminated when assessing potential effects and interdependencies, greater appreciation of uncertainties is crucial for managing these complex problems. Illuminating the benefits, trade-offs and synergies of different development pathways, ones that lead to a more sustainable society, can also foster innovative ideas and practical ingenuity in the context of global problem solving. These considerations are increasingly recognized as facets of a useful global environmental assessment (Pereira et al., 2019; UNEP, 2019).

This thesis is interested in the interaction between scientific knowledge production and emerging global political order. More specifically, it examines the role and coevolving orientation of integrated scientific assessments and the political context in which they are embedded. This dissertation seeks to better understand how current configurations and limitations of knowledge production systems (vis-à-vis integrated assessments) aid or hinder efforts to advance global sustainability governance.

It argues that integrated scientific assessment is at a critical inflection point. Calls for changes—some already underway—stress the need to ensure the ability of future assessment processes to generate fit-for-purpose information that can inform decisions and difficult choices amidst contested and uncertain futures.

This dissertation addresses ongoing reform debates concerning the need for enhanced assessment approaches that can cope with the entanglement of facts and values at the science-policy interface (Edenhofer and Minx, 2014) and still deliberate, and deliver, policy-relevant information with purpose and credibility. It asserts the need for future assessments to go beyond the synthesis of the latest scientific research and interpretation of environmental problems and priorities, to explicitly engage in integrated and contextualized evaluation of solution pathways and policy performance—including the appraisal (*ex post*) of actual policy implementation. Finally, this dissertation provides insights into

how the scientific assessment enterprise at large, can become more agile and relevant for advancing global sustainability governance in a world of environmental urgency and digital transformations.

The analysis and findings presented in the core chapters of this dissertation are based on multiple lines of evidence from different data types. A combination of primary and secondary data derived from a wide range of sources including 99 semi-structured interviews, a survey questionnaire, two focus groups, extensive literature and document review and metadata-analyses form the empirical backbone of this research. The results of this research add to a growing body of literature and pragmatic, critical reflection on cultivating the reflexivity, experimentation, deliberative social learning and international networks that knowledge systems require to evolve (e.g., Schreurs, 2008; Shapiro et al., 2010; Jordan and Lenschow, 2010; Woolley et al., 2010; Beck et al., 2014; Edenhofer and Kowarsch, 2015; Levy et al., 2016; Clark et al., 2016; Mach and Field, 2017; Pereira et al., 2019)

This introductory chapter provides a background to inform the conceptual basis for the six research pieces that form the core of this dissertation (Chapters 2, 3, 4, 5, 6 and 7). Section 1.2 presents the theoretical base from which the research evolved, discussing the authority of science and presenting selected conceptual framings on the interplay between scientific knowledge production and global environmental decision-making. Section 1.3 describes the inception and progression of integrated scientific assessment and introduces the wider context of the international sustainability agenda alongside an emerging global governance architecture. Section 1.4 briefly outlines the main methods and materials employed; and finally, Section 1.5 presents the overarching theme, research questions and assumptions that guide the chapters; and describes the structure and outline of the dissertation.

1.2 The interplay between science and policy: "Bridging the divide"

Science and policy communities operate with different cultures, interests, expectations, time-scales and worldviews. Thus, the relationship is bound to be complex. At times, communication between the two communities is fraught with tension and clashing commitments of ideology. How science, policy and society interact has been a major research focus across several disciplines and academic communities, including, for example, Anthropology, International Relations, Political Ecology, the alternative perspectives of Science and Technology Studies (STS) and, most pointedly, Sustainability Science. Each of these distinct branches of study (and consciousness) apply different epistemic framings and perspectives to examine the relationship and interplay between science and society[1].

The way that science-policy interactions are discerned and conceptualized, therefore, can vary considerably across, and even within, disciplinary communities. Similarly, competing notions on the nature of the relationship between the scientific enterprise and policy outcomes have engendered considerable debate regarding the means of knowledge transmission, the reconciliation (or non-reconciliation) of boundaries, issues of indeterminacy, disputed policy narratives (including normative value beliefs), and, the irreducible plurality of valid standpoints (Schreurs, 2003; Funtowitz et al., 2004; Van den Hove, 2007; Renn et al., 2011; Edenhofer and Kowarsch, 2015).

[1]e.g., Kuhn, 1962; Levy et al., 1995; Clark et al., 2001; Kates et al., 2001; Jasanoff et al., 2001; Levy et al., 2001; Cash et al., 2003; Haas, 2004; Steel et al., 2004; Jasanoff, 2004; Van den Hove, 2007; Pielke, 2007; McNie, 2007; Keller, 2009; Mooney et al., 2013; Wesselink et al., 2013; Saunders et al., 2017; Kurtz, 2018).

Many scholars and practitioners alike, approach the perceived divide or "gap", between science and policy as something of an impediment to overcome, eliminate or fix (e.g. Bradshaw and Borchers, 2000; Koetz et al., 2012; Sarkki et al., 2013; de Pryke 2017). In this view, the respective scholarship typically infers and/or puts emphasis on various 'obstacles', 'constraints', or 'tensions' as the driving forces separating science from policy (Eisenack, et al., 2014; Sundqvist et al., 2017). For example, Weichselgartner and Kasperson (2010) describe a series of functional, structural and social dynamics which inhibit cooperation at the science-policy interface, and that if left unchecked, can deepen the divide and friction between knowledge producers and potential users. The main factors they identify include, divergent objectives and priorities; mismatched institutional settings; and opposing cultural values, understanding and mistrust.

Another perspective, sees an overly tight (or proximate) relationship between science and policy as inherently problematic. Here, scholars argue the importance of reflexivity, allowing for alternatives in both science and policy; promoting cross-sectoral learning; an opening up of the policy debate; and fostering a plurality of strategic advice (Hoppe, 2005; Pielke, 2007; Sarewitz 2011; Wesselink et al., 2013; Cornell et al., 2013; Hoppe et al., 2013; Miller et al., 2014; Pearce et al., 2018).

In describing the diverse structures and forms of interactions between the science and policymaking communities within a given assessment process, Farrell et al., (2006, p. 13) argue that "each group must maintain its self-identity and protect its source of legitimacy and credibility" regardless of where along the spectrum of reciprocity and trust a given interaction occurs. The challenge with this assertion however—which may have been more applicable 15 or 20 years ago—is that science and decision-making communities that engage in assessments today are neither ubiquitous or entirely discrete entities. And, as such, do not necessarily represent mutually exclusive interests.

In contrast, other scholars characterize the science-policy interface as vital and inevitable junctions (or meeting points) for diverse institutions, scientists, practitioners, policymakers and other societal actors (e.g. Funtowitz and Ravetz, 1994; Jasanoff et al., 2001; Dilling and Lemos, 2011; McNie, 2012). This scholarship tends to embrace the rubric of knowledge coproduction and depicts the intersection of science and policy as a fundamentally social and cultural mélange. From an STS perspective, Sheila Jasanoff (e.g. 2009, 2004) has sought to show how the deliberate separations between science and politics become socially established; and that the entanglements of science and policy-making are both essential and unavoidable. To this end, Jasanoff (2004) rejects the notion that science is autonomous and free from moral or political choices.

Ultimately, a vast body of empirical literature and experience demonstrates (if not confirms) that there is no clear, natural or easy fit between the world of science and that of decision-making, or more precisely, the attainment of desired national, regional or international policies (e.g. Kowarsch, 2016; Jabbour et al., 2012; NRC, 2009; Young, 2008; Sarewitz and Pielke, 2007; Mitchell et al., 2006; Farrell and Jäger, 2006; Watson, 2005; Cash et al., 2003; Schreurs and Economy, 1997).

Growing concerns about the role of science-based institutions in advancing expert knowledge on the human dimensions of global environmental change, alongside rising attacks and dogmatic claims against the integrity of formal science (e.g. Carter et al., 2018; Gleick et al., 2010) have fostered new ideas on the interplay between knowledge systems, policymaking and society (e.g. Sundqvist et al., 2017; Stern et al., 2016; Edenhofer and Minx, 2014; Beck et al., 2013; Turnhout et al., 2013).

The following subsections chronicle key issues and events that helped shape the role of science in the formation of the international apparatus for environmental protection. It reflects a careful review that is both relevant to the theoretical background and context of this dissertation, and that helps illuminate how and why environmental knowledge systems, in many respects, have not kept pace with the shifting science-society interface. Relatedly, the insights presented here underscore the essential need to better understand the origins and historical development of international scientific assessments, and how the relevant institutional landscape and political context have evolved.

1.2.1 The role of science in the historic formation of the international environmental arena

The scientific enterprise is not without limitations or contested boundaries. The discipline of Science and Technology Studies (STS) has done much to illuminate that even the most rigorous scientific research is not impervious to value-laden activity (Jasanoff et al., 2004, 2001; Putnam, 2004; Weinberg, 2003). Scientists bring with them a range of inherent values, experiences, assumptions and expectations that ultimately shape the questions they pursue, the methods they apply, and the systems through which they acquire, interpret and transmit knowledge (Smith and Freeman, 2014). However, the importance of scientific knowledge and advice, including that which is reliably aggregated to inform public discourse and societal choices, has remained widely undisputed (Bronk, 1974; Carnegie Commission on Science, 1991, 1993; Selin and Eckley, 2003; Watson, 2005; Gleick et al., 2010; Kowarsch, 2016b). Decision-making structures, thus, have consistently turned to empirical research and the scientific community to provide the closest approximations of 'proof' about whether a problem in the natural world exists or could pose harm, and if so, how much (Lubchenco, 1998; Oreskes and Conway, 2010).

In the international environmental arena, the interplay between science and policy has, historically, been a particularly complex and often divisive space (Huitema and Turnhout, 2009; Wesselink et al., 2013). The way scientific advice is received and/or assigned authority is often linked to perceptions about its political neutrality (Gauchat, 2012). Jasanoff (2004) describes a crucial turning point between science and environmental public policy or government, that signaled an end to 'an age of innocence' (lasting until the early 1960s), where scientists and policymakers shared a more straight-forward relationship with delineated roles and responsibilities.

This transition coincided with increased awareness about largescale environmental phenomena (e.g. ozone depletion, climate change, persistent organic pollutants) and the imperative for society to comprehend the potential consequences and threats to their wellbeing. This societal change was attributable, in part, to a series of landmark studies starting with Rachel Carson's *Silent Spring* (1962) exposing the hidden perils and interconnectedness of various environmental problems. Carson's findings on the indiscriminate use of synthetic chemical pesticides (especially DDT) and the yet unseen dangers to human health posed by the chronic build-up of toxic substances, radically altered society's relationship with the natural world (Percival, 2007). Her work helped galvanize a new cultural and social imperative for environmental science, and, crucially, it provided a precedent for reconciling uncertainty and authority through public discourse (Shackley and Wynne, 1996).

In a speech to the National Academy of Sciences in Washington D.C. on 22 October 1963, President John Kennedy urged the scientific community, as a priority, to lend their expertise to the conservation and development of natural resources. He echoed his proposal made to the U.N. General Assembly, just weeks prior, for a worldwide program to 'protect the environment and to seize the contamination

of water and air by industrial as well as nuclear pollution, and that could facilitate the steady renewal and expansion of the natural basis of life'. He urged the scientific community to assess and reconsider its relationship with, and contribution to, government, private organizations and individual citizens—imploring that the *"Earth, the sea and the air are the concern of every nation, thus, science, technology and education must be the ally of every Nation*" (Kennedy, 1963).

These impassioned warnings were followed closely by Ehrich's *The Population Bomb* that predicted worldwide famine due to overpopulation. Ehrlich (1968) brought both the environmental crisis, and the potential for societal upheaval, to an even wider debate on the human future.

Proceeding in parallel, was the discovery of widespread presence of chlorofluorocarbons (CFCs) in Earth's the atmosphere—carried by large-scale wind motions (Lovelock, 1970). Examining the fate of CFCs and the interaction of ultraviolet radiation with CFC molecules, Rowland and Molina (1974) discovered that CFCs would eventually lead to the destruction of atmospheric ozone. Taken together, these successive political and scientific milestones exposed the direness of global environmental threats and offered the first sobering picture, within the mainstream, of society's susceptibility. Along with the momentum and receptivity fueling a counterculture movement in the US and Central Europe, they helped give rise to an emerging environmental consciousness (Cahn and Brien, 1996; Speth, 2002). By the mid-1970s a convergence in understanding among science and policy communities took hold: The uptake of empirical environmental research into the international policy sphere was no longer simply a technical matter of knowledge exchange, but also a formidable geopolitical challenge.

In December of 1972, the U.N. General Assembly established the United Nations Environment Programme (UNEP), unanimously electing Maurice Strong—founder of the Canadian International Development Agency in 1968—to be its first Executive Director and Undersecretary General. As a subsidiary organ of the General Assembly, UNEP was mandated to facilitate the impartial monitoring, reporting and scientific assessment of the global state of the environment on a continuing basis.

Over the 1974-84 decade, the creation of key international environmental agreements, treaties and other codified arrangements—largely developed and administered by UNEP—catalyzed widespread recognition for international scientific cooperation, and, the need for a permanent intergovernmental edifice to address global environmental change (Haas, 1992; Haas et al., 1993; Desai, 2003; Ivanova, 2007). At the same time, an emerging international environmental governance community, including UNEP and numerous national and transnational organizations, sought to evolve a systematic process that could at once harness an international consensus of scientific authority, and transcend divergent national allegiances. This reflected a significant shift in international relations for the environment, away from an exclusive focus on international organizations towards building regimes – specialized arrangements pertaining to well-defined principles, norms and activities around which nations' expectations could converge on a given issue by reducing uncertainties (Young, 1989).

By the late 1980s, international scientific panels, advisory bodies and similar independent expert-led structures began to coalesce around most multilateral environmental processes (Watson, 2005). Putting in place such structures to deliver informed authoritative assessments about the impacts of pervasive environmental change problems and the consequences of remedial action (or inaction) became a precondition for negotiating multilateral responses (Morrisette, 1989; Haas et al., 1993; Agarwala, 1999; Selin and Eckley, 2003; Mitchell, 2003; Grainger, 2009). The combined efforts to generate an internationally accepted body of technical and scientific knowledge on complex problems

together with a massive proliferation of international environmental regimes, marked the inception of integrated global scientific assessments (Jabbour and Flachsland, 2017). In essence, an impartial and independent (i.e. science-based) knowledge production process to reconcile uncertainty and inform decisions and policy choices arising from international environmental regimes.

1.2.2 The transmission and utility of scientific knowledge

The transmission of knowledge is a significant and often overlooked barrier—particularly within the physical sciences—for embedding scientific information into decision making (Lehmann et al., 2017). An extensive body of empirical literature, initiated in the mid-1990s, has examined the role of organized efforts to bring scientific information to bear in shaping responses to large-scale global environmental change (e.g. Kates and Clark, 1996; Cash et al., 2003; Jasanoff and Martello, 2004; Farell and Jäger, 2005; Mitchell et al., 2006; Clark et al., 2006).

This interdisciplinary research has yielded important insights on the efficacy of scientific advice in general, and expert knowledge generated through formal scientific assessment processes specifically, asserting the importance of information being concurrently credible, salient, and legitimate (Cash et al., 2003). While these criteria have been widely accepted, attempts to fulfill their simultaneous attainment, in practical terms, remains a formidable challenge (Edenhofer and Kowarsch, 2015). Moreover, achieving 'credibility' and 'legitimacy' has, increasingly, come at the expense of the uptake or tractability of assessment findings; with far fewer resources directed at understanding or realizing actual impact (Alcamo, 2017). Another dominant (and unreconciled) concern that emerged from this body of scholarship involves the inherent challenge of arriving at a common understanding of what constitutes 'effective' in the discourse on knowledge transmission. This is crucial when examining how potential changes in the conditions and conduct of efforts to assemble and mobilize knowledge could alter the course of their impacts and distributional consequences (Riousset et al., 2017).

Insights from this previous work provides the initial foundation for the research presented in this dissertation. However, the conceptual and theoretical basis for the analysis in this dissertation adopts a more critical and pragmatic approach (or orientation) to the transmission and utility of scientific knowledge. This thesis builds on the line of scholarship that argues for the incorporation of polycentric systems (with multiple nodes of authority) to help structure and conceptualize interactions between knowledge producers and potential users (e.g. Ostrom 1998; McGinnis 1999).

Building on the *Pragmatic-Enlightened Model* (PEM) proposed by Edenhofer and Kowarsch (2015), this research adopts the assumption that the interdependency of objectives, means and practical consequences—that need to be reasonably understood (or aligned) in assessment processes—are embedded in highly dynamic contexts covering political, social, scientific and individual faucets. The PEM offers a useful empirical framing that circumvents the notion of a universal ideal for scientific knowledge transmission. Instead, it conceptualizes a plurality of approaches to facilitate convergence towards a reflective equilibrium for evaluating alternative pathways; even with disputed policy narratives and different worldviews (or value systems). Conceptually, this framework provides an analytical approach that systematically seeks to deal with the inherent fact/value entanglement in assessments, and, thus, offers important insights for navigating the challenges of evaluating policy performance and alternative pathways. This is particularly relevant with respect to Chapter 4 of this dissertation that explores the limitations and opportunities of solution-oriented assessments and the shift to policy analysis; as well as Chapter 5 that examines the treatment of diverging viewpoints.

To date, most of the reflective scholarship on assessments and the efficacy of their impacts have focused on understanding the different procedures and means of conduct through which scientific information enters and influences, or fails to influence, decision-making spheres (Rowe et al., 2014; Jabbour and Flachsland, 2017; Riousset et al., 2017). In other words, 'why', 'how' and 'when' have assessments led to the adoption of political and economic choices, and/or changes in societal behavior that would not otherwise have occurred. These questions remain crucial. However, as this dissertation will assert, they represent only one side of a feedback loop (see Chapter 3).

This dissertation argues that the relationship between the intention and utility of assessments cannot be examined separate from the prevailing political and institutional circumstances in which scientific assessments are embedded in, or the knowledge systems they interact with. Figure 1.1 provides a conceptual summary of the coevolution of policy, knowledge systems and assessments over time.

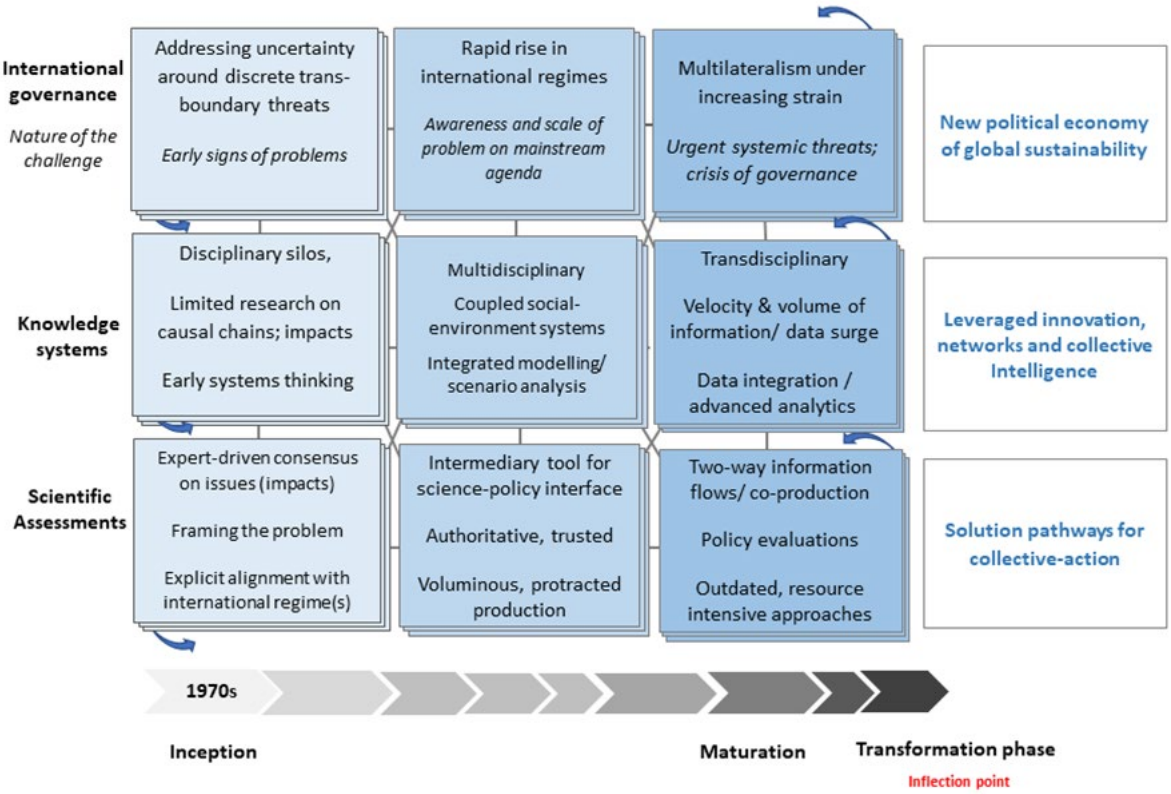

Figure 1.1. Science, policy and assessments. The interaction between international policy, scientific knowledge production and integrated assessments over time, are presented schematically as three coevolving pathways. Indicative changes in the prevailing focus of each pathway are mapped along a generalized horizon that distinguishes three phases: inception, maturation and transformation; with each phase conceptualized as parts of a continuum rather than mutually exclusive domains. In the first instance, the conceptual figure was developed to help guide and organize the review presented in Section 1.3 and to illustrate its basic structure. Taking a step further, the figure carries forward the notion of interdependency between assessment function and contexts (the proposed feedback loop) and attempts to embed two working hypotheses examined in this dissertation. The first postulates that contemporary integrated assessments have reached a critical inflection point where an alteration in their intended purpose compels conceptual and functional reconfigurations. The second predicts a widening incongruence between the emerging ambitions for knowledge production and international policy, and the available approaches and tools to cope with (and satisfy) the multiplicity of new expectations, including, integrated evaluations of solution pathways and policy performance. Acknowledging the obvious limitations with this highly simplified framework, it is not intended to be a precise or exhaustive representation of each pathway, but rather, it serves as a conceptual framework to exam these interrelated hypotheses and structuring the discussion below.

1.3 Integrated Scientific Assessments: Historical origins and key developments

Forty-five years ago, the Organisation for Economic Co-operation and Development (OECD) embarked on an international scientific collaboration to investigate transboundary air pollution. Motivated by the need to systematically build transnational consensus among Western European policymakers, the process resulted in a seminal consensus document. The *OECD Assessment of Long-Range Transport of Air Pollutants* (LRTAP) confirmed the notions that pollutants are transported over long distances and that air quality in each country is measurably affected by pollution from surrounding countries (OECD, 1977). The results of the LRTAP assessment triggered important policy on air pollution and acid rain issues far beyond Western Europe (Cowling, 1982).

The production and uptake of this unique, untried process and scientific output fueled an important breakthrough for evidence-based decision making worldwide (Alexander and Jäger, 2006). It helped galvanize international cooperation and support for the continuous monitoring, evaluation and assessment of transboundary environmental change in Europe and beyond; an essential component of the eventual creation of the LRTAP Convention and other international environmental treaties (Raustiala, 1997; Schneider and Schneider, 2004; Benedick, 2005). Crucially, the LRTAP process and its subsequent multilateral efforts to convene an international body of experts to elicit collective knowledge, marked the birth of one of the great innovations from within the scientific enterprise: *integrated scientific assessments*. In the intervening decades, a diverse landscape of 168 distinct international integrated scientific assessments, spanning a range of environmental sustainability-related issues, have been initiated, and 160 completed and published (Figure 1.2; see Chapter 4).

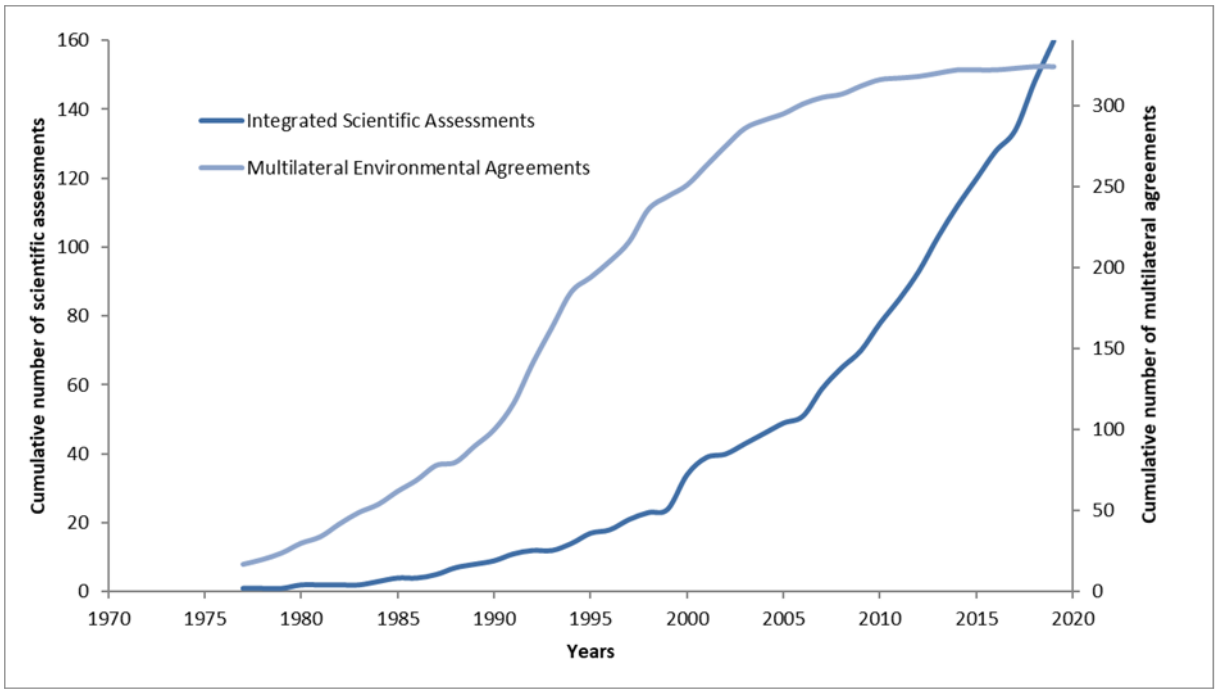

Figure 1.2. Cumulative increase of scientific assessments and multilateral environmental agreements (MEAs) exhibiting a steady growth correlation until around the early-2000s, then a sudden levelling-off of MEAs and a sharp increase in the scientific assessments from 2010 to 2020. *Sources: MEA Data from ECOLEX, 2020 and Mitchell, 2002-2020 International Environmental Agreements Database Project (Version 2020.1). Integrated Scientific Assessment data derived from author's own compilation updated from the initial dataset published in Jabbour and Flachsland, 2017, supplemental material.*

The study of international scientific assessments has long been challenged by definitional issues and a lack of conceptual clarity on the different procedures and institutional arrangements that govern their production. And yet, several scholars maintain that no single formal designation is likely to be useful, as applications (and contexts) vary from one assessment to the next (Pintér, 2002; Clark et al., 2006; Beck et al., 2014; Mach and Field, 2017; Tengö et al., 2017).

Today, the growing landscape of international science-based assessment processes relevant to environmental sustainability reflects an expansive and hugely diverse range of outputs, approaches and stakeholder expectations (Kowarsch et al., 2104; 2017). Indeed, there is no 'perfect' analogue. However, the empirical literature suggests a convergence of thinking around essential attributes that help characterize and differentiate international integrated scientific assessments.

For the purpose of this dissertation, *international integrated scientific assessments*—which are also referred to as *global environmental assessments* (GEAs)[2] in chapters 3, 4, and 5—can be understood as large-scale social processes where huge teams of experts and researchers convene to interpret, deliberate, evaluate and synthesize existing scientific knowledge on complex environmental issues with a view to inform public policy and international decision-making (Cash et al., 2003; Mitchell et al., 2006; Rothman et al., 2009; Kowarsch et al., 2016; Mach and Field, 2017).

Prominent examples of such scientific assessments include both recurring and irregular processes, typically coordinated by multilateral agencies or international bodies created through international regimes. These processes have included the *Global Environment Outlook* (GEO) series (e.g. Ullstein et al., 2012), the periodic reports of the *Intergovernmental Panel on Climate Change* (IPCC) (e.g. Stocker et al., 2013; Field et al., 2014; Edenhofer et al., 2014), the *Global Biodiversity Outlook* (e.g., CBD, 2014), the *Millennium Ecosystem Assessment* (e.g. MA, 2005), the *International Assessment of Agricultural Science and Technology for Development* (e.g. McIntyre et al., 2009), the thematic assessments of the *International Resource Panel* (e.g. UNEP, 2017) and recent assessments of the *Intergovernmental Platform on Biodiversity and Ecosystem Services* (e.g. IPBES, 2018).

Over the past four decades, integrated scientific assessments have evolved to become arguably the most elaborate, systematic, and formally structured dimension of the science-policy-society interface (Kowarsch, 2016a; Jabbour and Hunsberger, 2014). They represent a unique and formidable collective enterprise to assemble and mobilize scientific information through a deliberative, highly collaborative and international social learning process. With other external factors influencing domestic policy processes, integrated assessments have played a critical role in provoking and even shaping global policy agendas and international negotiations (Clark et al., 2006; Riousset et al., 2017; Mitchell et al., 2016; Watson, 2013; Kowarsch et al., 2017). For example, the stratospheric ozone assessments provided the scientific, economic and technical basis for the Montreal Protocol (Haas, 1992); the IPCC assessment reports effectively informed years of international policy debate, research agendas, public discourse and civil society campaigns—culminating in the Paris Agreement on climate change (Kowarsch et al., 2016; Mach and Field, 2017); and the fifth Global Environment Outlook influenced the post-2015 development agenda (Dodds et al., 2014; Rowe et al., 2014; see Chapter 3).

[2] The variation in terminology employed in thesis is owning to the fact that the middle chapters (i.e. 3, 4 and 5) were developed and published in connection with the joint research initiative: *FOGEAM –The future of global environmental assessment making*, however, for this dissertation, a broader perspective on the origins and applications of such science-based processes is taken to reflect integrated knowledge assessments for sustainability at large.

The Montreal Protocol was the first instance to institutionalize the concept of 'intergovernmental' scientific assessments in 1987. It adopted a mechanism to establish an independent international group of government-nominated experts to periodically assess relevant scientific developments to guide policy negotiators in subsequent amendments and development of the treaty (Benedick, 2005). Here, member states maintain a level of oversight and control over the assessment process itself—the *Scientific Assessment of Ozone Depletion,* which delivered its eighth report in 2018—by overseeing its structure, procedures, work program/ direction, and, expectantly, by approving and endorsing the produced assessment reports through a consensus-driven process.

By the late-1980s, coordinated integrated scientific assessments involving extensive collaborations between large numbers of scientists from various nationalities and disciplines became a driving force behind international policymaking (Young, 1989). These highly structured social processes—beyond the reports themselves—began to serve as intermediaries between science and policy (Farrell and Jäger, 2006). First-generation assessments, thus, helped forge intergovernmental cooperation and an objectively defensible means to arrive at 'international consensus' on environmental problems and policy positions that seemed irreconcilable (Mitchell et al., 2006). Over the next decade, various international assessments, most notably those of the iconic IPCC process—perhaps the single largest exercise in scientific cooperation—evolved and codified a deliberative consensus-based approach to knowledge production (Goodwin, 2009; Curry and Webster, 2013; Pearce and Raman, 2018).

The period 2000-2009 saw a 5-fold increase in the production of large-scale scientific assessments (Figure 1.2). Interestingly, a corresponding spike in the prominence of environmental and climate change issues in mass media and mainstream public discourse can be observed towards the end of the first decade of the 21st century (Pew Research Center, 2010, 2009; EC, 2009; Carter, 2018). In addition, a discernable shift in public perceptions (and improved civic literacy) worldwide about the distributional impacts and societal risks posed by systemic issues, including climate change, is also apparent (EC, 2009; Wong, 2010; Kahan et al., 2012; Poortinga et al., 2019). However, a clear picture has not yet emerged on the attribution of these international trends, or the potential links between scientific evidence and public perception (Kahan et al., 2012; Capstick et al., 2015; Engels, 2016).

In 2007, the IPCC was jointly awarded the *Nobel Peace Prize* (with former US Vice President Al Gore) for their efforts in assembling and disseminating greater knowledge about climate change. Earning this accolade had the dual effect of garnering international praise and attention for the IPCC's work, while also making it a target for denigration. In 2009, the legitimacy of its content came under harsh attack, mostly by climate deniers—following high-profile errors discovered in the Fourth Assessment Report—which sparked debate over the openness and transparency of its procedures and structures (Valsileiadou et al., 2011; Shapiro et al., 2010).

These events precipitated new deliberations on both the role of international scientific cooperation, and the challenge of producing expert advice under conditions of heightened political and public scrutiny. Reflecting on how the IPCC has coped with increasing scrutiny, Beck (2012) explains the paradoxical nature of the authority ascribed to a scientific endeavor whose work is both "delegated" by, and has direct bearing on, a community entrenched in an increasingly sensitive geopolitical context with competing interests and agendas. This peculiar state of affairs has, in many respects, forced narrower conceptions (and superficial tradeoffs) between integrated analysis and analytical rigor—thereby creating a false dichotomy between credibility and legitimacy (Sarkki et al., 2015).

Today, global environmental crises are growing in number and severity and are now central to public policy and business discourse. The number of international scientific assessments addressing various dimensions of environmental sustainability continues to surge. At the same time, a lively discussion has emerged on how future information flows and knowledge systems can affect change. Observers and assessment practitioners reflecting on past experiences, have become increasingly vocal in recent years and have put forth appeals for a range of assessment reforms in various intergovernmental fora, as well as numerous opinion articles, commentaries and editorial features. Many of these discussions go beyond procedural and structural issues raised previously, but rather, are motivated by more fundamental concerns over the efficacy of scientific assessments, in their current form, and their ability to deliver fit-for-purpose information that can inform decisions and difficult choices.

A few examples serve to illustrate the nature and variety of issues raised in the recent debates. For instance, observers highlight challenges arising from the protracted and increasingly cost-and time-intensive assessment processes, which endeavor to review all available scientific literature, placing significant strain on available academic resources (Nature, 2013; Stocker, 2013; Griggs, 2014; Mach and Fields, 2017). Meanwhile, the volume and velocity of relevant data streams and environmental information that scientific assessments are expected to engage has risen exponentially (Chapter 3). Related, perhaps, is a growing sentiment that assessments have become inefficient in curating and communication knowledge—and have not kept pace with the technological advancements of the digital revolution (e.g. bigdata analytics, machine learning tools, artificial intelligence etc.) and/or the way and speed at which society consumes information (Jensen and Campbell, 2018; Minx et al., 2017; Joppa, 2017; Kitchin, 2014; Christy, 2010).

Other commentators point to a need to build capacity to understand and reshape the prevailing systems of 'knowledge governance' which continue to limit the use, access and sharing of information; which, in turn, are exacerbating knowledge-to-action challenges (Clark et al., 2016; Mach and Field, 2017). Another area of growing concern involves the way critical 'science' questions are conceptualized and framed. Here, observers caution that assessment framings—which often reflect an underrepresentation of social science and humanities—continue to favor analysis that prohibits systematic learning on solutions; giving emphasis to narratives that become 'lost in the problem', and potentially amplifying the issue of political inertia (Minx et al., 2017; Becks et al., 2014; Griggs, 2014; Hoppe et al., 2013; Stocker, 2013).

In addition to these reflective deliberations, boundary organizations that facilitate assessments, not least UNEP and its sister agencies within the Secretariat (e.g. the UN Department of Economic and Social Affairs), have recently conducted internal evaluation processes, commissioned whitepapers and convened focused groups to reflect on past assessment experiences and explore possible new directions. Many of these processes are ongoing or have only just begun, and thus, can hopefully benefit from this research.

1.3.1 An emerging governance architecture for the global commons

The international environmental governance context in which assessment processes are embedded, has changed significantly over the past four decades. Towards the end of the 20th century, a transition from environmental protection to environmental sustainability was taking shape. The concept of sustainable development expanded the international environmental governance agenda by stressing

the imperative to simultaneously address social, economic and environmental issues with policies and frameworks that emphasize interdependence and the interactive effects between them (Kanie, 2014). Up until the late 1990s, international agreements for environmental protection were conceived and negotiated separately, and treated as independent entities—thus, lacking 'systemic integration' with existing structures for economic development (Krishna et al., 2017; Shah, 2014). By the mid-2000s, a multiplicity of largely autonomous multilateral environmental agreements (MEAs) and environmental regimes, with limited and increasingly dispersed authority, was seen as a main contributor to an increasingly fragmented and inadequate framework for governance (Kanie, 2014; Biermann et al., 2012; Bernstein et al., 2008). Consequently, the proliferation of MEAs experienced a sudden and sharp levelling off, with a gradual decline beginning in 2010 (Figure 1.2). The need for a more dynamic governance model, geared to addressing collective-action problems has since emerged (Young, 2013).

Today, most systemic and global environmental change issues are now viewed within the broader framework of sustainability. Similarly, many contemporary assessments are conducted in a wider context of the international agenda on sustainability and the emerging governance system for the global commons, where the environment is increasingly recognized as an equal and indispensable dimension of sustainable development (see Chapters 2).

Another clear signal for the preeminence of the 'environmental sustainability' agenda is the recent institutional strengthening and 'partial' upgrading of UNEP, following the call by Heads of State and Governments at the close of the Rio+20 summit; and later endorsed by the UN General Assembly at the 67th session in 2013. In practical terms, this decision affords UNEP universal membership of its governing body and enables access to more predictable, stable and increased funding from the UN Regular Budget. In principle, it also signals increasing confidence in the capacity and role of the organization to deliver support to the global sustainable development apparatus (Ivanova, 2013; Rangreji, 2013) not least through its scientific assessment activities that were recognized favorably—as articulated in *paragraphs 90 and 88d* of '*The Future We Want*: UN Conference on Sustainable Development' outcome document (UN, 2012).

As the world becomes more interdependent, Nation States have become far more susceptible and predisposed to policies and activities outside their jurisdictions that invariably influence the global commons: intensified economic globalization, increasing migration, trade and capital flows, and global environmental change (UN, 2013). On the one hand, this new context has influenced thinking on the intrinsic connection between environmental sustainability and development pursuits. This was evidenced in the SDG negotiations, where the prominence of environmental pressures and resource scarcity, above any other factor, shaped the post-2015 development agenda (UN, 2015). However, persistent gaps in international regimes and complex multi-level governance (the so-called 'crisis of global governance') has reinforced rather than reduced global imbalances (Biermann, 2014; UN, 2013; Park et al., 2008). These dynamics represent a significant departure from the international discourse and framing that informed first-generation assessments (i.e. in the 1970s) when the concepts of global environmental change and international environmental governance were in their infancy (Jabbour and Flachsland, 2017; Persson et al., 2016; Ivanova, 2013).

A new era of international cooperation is emerging. Both the 2015 Paris Agreement and the adoption and early implementation of the global Sustainable Development Goals (SDGs) compel a complex suite of policy interactions and tradeoffs. The aspirations and commitments articulated in these

agreements mark a significant milestone for international cooperation, which, in and of itself, is an essential factor for the required course-correction in global governance. However, these agreements are about targets and not explicit mechanisms or a codification of specific international, regional and/or national means of implementation (Maxwell et al., 2015; Colglazier, 2015; Elder et al., 2016; Persson et al., 2016; Griggs et al., 2017; Biermann et al., 2017; Nilsson and Persson, 2017).

The challenge now is to ensure that these agreements are informed by a robust and scientifically rigorous analysis of potential choices such as an interdependent mix of financial resources; capacity-building; technology development and transfer; inclusive and equitable trading systems, including realistic and effective carbon pricing mechanisms; regional integration; and the establishment of enabling institutional and national policy conditions.

The comprehensive consideration of these (and other) options and their interdependencies marks a significant shift from environmental problem analysis to the exploration of specific solutions and synergistic response options in international debates on the governance of the global commons. It is within this emerging narrative-and within the dynamically changing political context that integrated assessments are embedded, this dissertation will argue, that contemporary assessment processes have reached a 'maturation'. And, the assessment enterprise must actively undergo a transformation and reorientation toward mobilizing response options, policies and solutions (Chapters 3 and 4).

In this emergent institutional and policy context, the analysis and potential utility of future assessment processes takes on greater significance for advancing governance. As assessments have become an established feature of the international policy landscape for sustainability, decision-makers and practitioners are advocating for more explicit information and knowledge about the suitability of specific strategies, pathways and actions that range from technology and behavioral change policies, regulatory measures and new market-based instruments (Kowarsch et al., 2017; Jabbour and Flachsland, 2017; Carraro et al., 2015; Lee, 2015; Perrings et al., 2011).

1.3.2 Scientific assessments at a Crossroads: Rethinking their foundations and purpose

Historically, analysis of policy options in scientific assessments has often been dominated by the need to maintain political neutrality while building consensual knowledge around aggregated impacts and the need for responses (Rothman et al., 2009; Watson, 2005). Moreover, the organizing frameworks and approaches of those assessments, mostly predating 1995, and to lesser extent those occurring before 2005, often tended to frame issues in less tractable ways, producing narratives and findings that were detached, more generalized and less conducive to action (see Chapter 2 and 4). While various assessments have effectively exposed environmental problems, drivers and the need for action, the evaluation of responses has not reached its full potential (Miller et al., 2014; Kowarsch et al., 2017). The recent developments in multilateralism and international cooperation likely suggest that expectations for scientific knowledge, innovation and technology, and their interaction with decision-making processes, have shifted considerably (see Chapters 3 and 4) (Clark et al., 2016).

There is increasing awareness of the need for improved integration across all spheres and domains of sustainability, both in governance and in integrated assessments (see Chapter 3). There is also an inclination to shift the focus in assessments toward policy alternatives, practical consequences and plausible future pathways (Kowarsch, 2016; Jabbour and Flachsland, 2017). The adoption and early

implementation of the 2030 Agenda and the SDGs particularly, suggest that a better understanding of the interactions, interdependencies and co-evolutionary pathways required to achieve shared goals will require enhanced policy integration. The SDGs also reflect the reality that a more balanced and integrated approach cannot be isolated from the imperative to address social and environmental inequalities (Martinez and Mueller, 2015). This is an area that most integrated scientific assessments have struggled to cope with (e.g. Scoones, 2009; Ullstein et al., 2012; Pereira et al., 2019).

As has been argued elsewhere, some of these challenges can be conceptually linked to perceptions of credibility, legitimacy and salience—widely accepted criteria for assessment effectiveness (Kowarsch et al., 2017a; Mitchell et al., 2016; van der Hel and Biermann, 2017). However, a more nuanced examination of their challenges and interdependencies, as described in the review presented above, suggests that such criteria need to be specified; and that they need to be continuously adapted to the changing policy contexts in which integrated scientific assessments are embedded (Jabbour and Flachsland, 2017; Haas, 2017; Riousset et al., 2017). As such, investigating how and why elements of organizational design, assessment objectives, and the evolving political backdrop interact with on one another becomes crucial.

Furthermore, an improved understanding of the enabling conditions and prospects for advancing more explicit and contextualized engagement with solutions requires a closer examination of the indicative future challenges and constraints, including, for example, the pervasive uncertainty of policy-related knowledge and the disputed normative implications of aggregating and mobilizing such research. A critical examination of how existing assessment frameworks handle dissent, controversy and a plurality of perspectives and divergent viewpoints, can also be instructive for thinking about the conditions most conducive to framing and communicating *ex post* policy analysis; and can help inform the successful facilitation of collective learning on domestic policy lessons.

Practical lessons and important insights must also be gleaned from the development and analysis of tools and approaches to catalyze policy learning, and inspire new ways to frame and inform choices. Similarly, extracting lessons from actual cases, or real-world attempts to mainstream science into sectoral policies through facilitated dialogue and interaction between experts and decision-makers (e.g. policy planners) can offer essential learnings; including, for example, how inclusive interactions can foster mutual understandings of the "policy-relevant questions to which assessed knowledge can productively contribute" (Mach and Field, 2017, p558), and how leveraging existing social structures can help translate narratives and enable practical means of implementation at the national level (Larsen et al., 2012; Stringer and Dougill, 2013).

An emerging scholarship on new methods, tools and conceptual framings to support environmental public policy assessment and scenarios analysis (e.g. Craft and Howlett, 2013; Turnpenny et al., 2014; Hoppe, 2018; Pereira et al., 2019), together with novel applications to fundamentally transform knowledge provisioning capabilities, for example, by leveraging the power of networks and collective intelligence systems (Benkler, 2006; Malone et al., 2009; Woolley et al., 2010) also offer new insights on navigating the solution space and a decisive push toward renewed policy relevance.

Similarly, major advancements in computing, environmental statistics, analytics and data collection, particularly in the metadata and geospatial realms, have inspired a rush of new ideas and potential for advancing knowledge discovery, integration and communication through analytics, machine learning algorithms, and public-private partnerships for innovation (e.g. Jacob and Mangalagiu et al.,

2019; Joppa, 2017; Minx et al., 2017; Rasmussen et al., 2007). In its current form, the scientific assessment enterprise has yet to leverage and catalyze on this potential. However, in the last couple years, experts and practitioners within the assessment community have begun to explore the prospects of a so-called digital ecosystem – a convergence of big data and frontier technologies such as machine learning and artificial intelligence—as a powerful avenue for generating and embedding information more efficiently and effectively in today's knowledge systems (Daguitan et al., 2019; UNEP, 2018; Jensen and Campbell, 2018).

1.4 Materials and methods

The analysis and findings presented in the core chapters of this dissertation are based on multiple lines of evidence from different data types. A combination of primary and secondary data derived from a wide range of sources including 99 semi-structured interviews, a survey questionnaire, two focus groups, extensive literature and document review and metadata-analyses form the empirical backbone of this research. The transcripts from the interviews were coded in Max-QDA and analyzed following the Grounded Theory methodology and Constant Comparative techniques (Strauss and Corbin, 1998; Ritchie and Spencer, 2002).

An extensive dataset, bringing together comparable metadata for 20 large-scale integrated scientific assessments—spanning the period of 1977 to 2015—was developed specifically for this thesis and together with the interviews, serves as the empirical primary conduit through which insights were derived (particularly for chapters 3, 4 and 5). This metadata catalogue was instrumental in facilitating the retrospective analysis of the evolution of the assessment landscape, and the context in which they have been conducted and delivered over the past four decades. To the best of my knowledge, this is the first such effort to generate and assemble a dataset of this kind. The research analyzed a wide range of documents including, scientific assessment reports themselves, scoping papers, procedural guidelines, meeting reports, independent evaluations, and official United Nations documentation—some of which was not in the public domain. In addition, a systematic literature review on the scholarship of assessment-making was conducted and forms an important element of this research. Crucially, the analysis in this dissertation was also corroborated by observation and experiential data, from direct involvement with large-scale integrated scientific assessment processes[3]. A more detailed elaboration of the concepts, approaches, data sources and specific methods employed for the various analyses is presented in Section 8.2.

1.5 Research objectives, questions and structure

The review provided in Sections 1.2 and 1.3 suggests that integrated scientific assessments and the political context in which they are embedded have reached a turning point. The interface between science, policy and society is in a state of flux. A new phase in the 'democratization of knowledge' has emerged and is pushing new limits.

[3] J. Jabbour has been closely involved the coordination of the Global Environment Outlook (since 2007) and various other UNEP-led scientific assessments including the Emissions Gap Report and the Climate Change Science Compendium.

Meanwhile, the traditional boundaries between sectors have become blurred, with a less direct role for national governments, and a wider governance role for civil society, private enterprise and sub-state actors. The transformational change required to achieve sustainability (not least the SDGs) present new opportunities and new responsibilities for each sector and, increasingly, a shared set of interests in harnessing the contributions of science, technology and innovation. Arguably, responding to these changes, there has been a shift in demand for greater emphasis on, and engagement with, the policy and solution-space.

While many aspects of the interaction between scientific knowledge and decision-making have been investigated, a deeper understanding of the coevolution of integrated scientific assessments and global sustainability governance remains incomplete. A key point of departure for this research rests on the assertion that shifting international policy contexts, in and of themselves, exert influence on how scientific assessment processes evolve. This important yet scarcely studied dynamic provides both the motivation and the conceptual framing for the analysis in this dissertation.

This thesis is guided by the underlying assumption that achieving sustainability, globally, will require fundamental and deliberate changes in our knowledge production systems, including a vastly improved orientation toward societal concerns and collective action, and crucially, new tools, approaches and norms for meaningful engagement with the solution-space. Whether the scientific assessment enterprise can play a role in informing these norms, and continue to deliberate, and deliver, policy-relevant information with purpose and credibility remain vital questions. Ultimately, this dissertation seeks to identify and understand contextual factors and mechanisms that can help guide future assessments to generate more impactful and accessible information, to inform decision-making and influence transformational change.

This thesis aims to contribute to the literature by exploring the following overarching research theme: How do the current configurations and limitations of the scientific assessment enterprise interact with international decision-making? Will the shift towards explicit and contextualized engagement with policy performance and the solution-space serve to benefit or hinder efforts to guide and advance global sustainability governance?

The question about whether policy focused assessments could have a counterproductive effect on global governance (and international cooperation) has implications on the future prospects of how international regimes and scientific advice interact. It also poses important challenges for how we conceptualize, understand and implement our environmental regimes and goal-setting efforts to tackle global problems going forward. Understanding whether the prevailing constraints are owing to a conceptual impasse (i.e. incompatibility with the basic configuration of our international governance architecture), versus epistemic limitations of existing knowledge domains (i.e. deficits in empirical aggregation and systematic learning on solutions) is crucial. This differentiation could provide new insights on whether a systematic aggregation and transmission of solution-oriented knowledge can translate the ambitions of international regimes and global narratives for sustainability into practice.

1.5.1 Research questions

The six core chapters of this dissertation explore this overarching theme from different perspectives, each addressing one or more of the following specific research questions.

1. How have integrated scientific assessments evolved over the past four decades? How do the current reform debates relate to their historic development?
2. Has the scientific assessment enterprise shifted towards a policy focus and a more explicit engagement with solutions; and if so, how and why?
3. What practical lessons and insights can be drawn from developing and analyzing tools for knowledge aggregation on policy analysis, building on and required for use in scientific assessments?

1.5.2 Thesis structure

At its core, Chapter 2 represents an ex post analysis of international environmental goal-attainment since the 1972 Conference on the Human Environment in Stockholm that precipitated the creation of a dedicated UN agency for the protection of the Environment (i.e. UNEP). The chapter investigates different aspects of global-scale environmental deterioration in relation to a series of biophysical trends and conditions, against the proliferation of international and multilateral agreements. The key finding reveals very limited sustained progress (i.e. <5%) across the 90 goals evaluated and indicates crucial flaws in the global sustainability governance architecture including the international goal-setting processes themselves. The research identifies new insights and lessons from comparing the international goal-setting efforts of the past four decades (1972-2012) with actual environmental performance over that same period. The chapter also analyzes the evolution of international regimes and institutions and shows how a series of critical misalignments between science and policy; between the fragmentation of governance and the need for integrated approaches (and collective action); and between complex systems and the desire for measurable outcomes are inhibiting goal-attainment. It offers an interpretation of key transformations required to address these gaps and accelerate progress including the need to improve integrated policy responses for sustainability governance. The text has been published in *Environmental Development*[4].

Chapter 3 provides a 40-year retrospective analysis of the integrated scientific assessment enterprise and the changing character, orientation, and dominant focus of contemporary processes. The chapter examines how and why elements of organizational design, objectives, and the evolving political backdrop depend on one another. The research offers a hypothesis that the prevailing conditions and assumptions that originally gave rise to the scientific assessment concept have changed. It shows how the evolving international sustainability governance context, in and of itself, has exerted influence on how assessment processes evolved. The research draws on multiple lines of evidence including interviews, focus group workshops and extensive metadata analysis (from 20 assessments spanning 1977 to 2014). It analyses how assessments and their political contexts continue to coevolve, and discusses the need for future assessments to be more reflective of political integration and the need to develop a new generation of tools and analytical capacities for policy assessment and for addressing increased complexity. The text has been published in *Environmental Science & Policy*[5] as part of a special issue on Global Environmental Assessments.

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[4] Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Schwarzer, S., 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development*, 3(2):5-24.

[5] Jabbour, J., and Flachsland, C., 2017. 40 years of global environmental assessments: a retrospective analysis. *Environmental Science & Policy,* 77(1), pp.193-202.

Building on the results of the retrospective analysis, Chapter 4 examines the increasing demand for solution-oriented scientific assessments within the evolving architecture for global sustainability. The chapter provides a systematic overview and analysis of existing and anticipated challenges at the science-policy-society interface for advancing a more explicit and contextualized evaluation of policies and solution pathways. The chapter discusses a substantive refinement to existing assessment making approaches and identifies reform options to help facilitate an integrated evaluation of the multi-dimensional effects of policies, an enhanced treatment of divergent normative viewpoints (inherent to solution-oriented assessment processes). Finally, the research discusses emerging opportunities and new insights for enabling more inclusive, interactive and deliberative learning. The text has been published in *Nature Climate Change*[6].

Chapter 5 examines the systematic treatment of divergent viewpoints in scientific assessments alongside the related (and inherent) entanglement of disputed facts and values, with an emphasis on contemporary solution-oriented processes. The chapter offers a novel conceptualization of 'divergent viewpoints' for integrated assessment processes extending to both scientific and the normative political dimensions, focusing on practitioners' framing of environmental policy problems and/or on the suitability of particular response options. The research identifies and evaluates nine simplified ideal-type approaches, distilled from previous research and experience. Reflecting on the emerging landscape of sustainability governance, the research provides a structured comparison of three assessment processes[7] to understand and critically evaluate the limitations, strengths and conditions for success, for each proposed approach. The analysis here suggests that for policy-relevant divergent viewpoints, highly disputed both on normative and scientific grounds, collaboratively exploring the practical implications of policy alternatives through assessment processes is a particularly promising approach, although practical challenges remain. The text has been published in *Environmental Science & Policy*[8] as part of a special issue on Global Environmental Assessments.

Chapter 6 provides a practical example for developing and analyzing tools for knowledge aggregation (and its uptake) in integrated scientific assessments. This research examines the application of an adapted visualization technique known as Kiviat diagramming to both investigate and communicate complex, coupled systems and human-environment interactions. The chapter posits that the strategic use of such techniques can foster an accessible and deeper mutual understanding of assessment knowledge, and specifically help in linking scientific analysis with policy narratives. The chapter presents a theoretical discussion about the potential role of integrated assessments processes to serve as knowledge intermediary platforms to catalyze policy learning and inspire new ways to frame and inform choices. The findings from Chapter 6 suggest the need to rethink the current knowledge deficit model and the prevailing assumption that decisionmakers require more comprehensive information with high confidence levels before they can act, and/or engage and thereby narrow the 'usability' gap. The analysis adds to a growing body of research that suggest that mechanisms that

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[6] Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T.J., Watson, R., Haas, P.M., et al., 2017. A road map for global environmental assessments. *Nature Climate Change* 7, 379–382.

[7] The three assessment processes used in the comparative analysis include: (1) the *Global Environment Outlook* series; (2) the *International Assessment of Agricultural Knowledge, Science and Technology for Development*; and (3) the fifth assessment report of the *Intergovernmental Panel on Climate Change*, IPCC – Working Group III.

[8] Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J., Riousset, P., 2017. The treatment of divergent viewpoints in global environmental assessments. *Environmental Science & Policy*, 77, pp.225-234.

enhance communication, mutual understanding, integration and engagement on both ends of the producer-user-knowledge spectrum have a crucial role to play in improving the interface between science and policy for global environmental change. The text has been published in *Natural Resources*[9].

Chapter 7 applies a comparative case study example of ex-post policy analysis aggregation building on, and required for use, in integrated scientific assessments. Here, key environmental sustainability and governance dimensions of urban and peri-urban agriculture (UPA) in rapidly growing cities in Africa and Asia are examined. The results indicate that local decisionmakers (e.g. municipal planners and city managers) perceive the use of retrospective frameworks and *ex-post* analysis as practical tools to improve the formulation of assessment framings in a way that relates to local realities and helps anticipate unforeseen circumstances that can influence the viability and efficacy of potential UPA interventions. Chapter 7 illustrates how contemporary scientific assessment processes, beyond the reports, can serve as an effective platform to facilitate and incorporate two-way interactions and cross-sectoral coherence (and unity) through informal but systemic learning on the solutions for specific issues. A key finding of is that response options need to be rooted in the potential to optimize integration across boundaries and the imperative to be synergistic across sectors and scales. The research supports the notion that predictive, problem-focused scientific assessments are inherently limited in the extent to which they can guide policy development and that rigorous scientific assessments can be much more valuable by advancing norms and tools to support *ex post* policy evaluation. The text has been published in *Urban Climate*[10]

Chapter 8 summarizes the results of the six core chapters (2-7) and discusses their contributions to the overarching research theme and how the overall dissertation adds to the literature. It also provides more detailed reflections on the approaches and methods used in the dissertation, and the limitations of the research. Finally, it provides an outlook on possible future research and personal reflections going forward.

[9] Jabbour, J., Hunsberger, C., 2014. Visualizing relationships between drivers of environmental change and pressures on land-based ecosystems. *Natural Resources,* 5(4), pp.146–160.

[10] Padgham, J., Jabbour, J. and Dietrich, K., 2015. Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. Urban Climate, 12, pp.183-204.

1.6 References

Alexander, E.F., Jäger, J., 2006. Assessments of Regional and Global Environmental Risks: Designing Processes for the Effective Use of Science in Decision making. Resources for the Future Press, Washington, DC.

Barrett, S., 1994. Self-Enforcing International Environmental Agreements. *Oxford Economic Papers*, 46, Special Issue on Environmental Economics pp. 878-894.

Beck, S., Borie, M., Chilvers, J., Esguerra, A., Heubach, K., Hulme, M., Lidskog, R., Lövbrand, E., Marquard, E., Miller, C. and Nadim, T., 2014. Towards a reflexive turn in the governance of global environmental expertise. The cases of the IPCC and the IPBES. *GAIA-Ecological Perspectives for Science and Society*, *23*(2), pp.80-87.

Bergman, N., 2018. Impacts of the fossil fuel divestment movement: effects on finance, policy and public discourse. *Sustainability,* 10(7), p.2529.

Biermann, F., Kanie, N. and Kim, R.E., 2017. Global governance by goal-setting: the novel approach of the UN Sustainable Development Goals. *Current Opinion in Environmental Sustainability*, 26, pp.26-31.

Biermann, F., 2014. Earth System Governance: World Politics in the Anthropocene. Cambridge, MA. MIT Press.

Biermann, F., Abbott, K., Andresen, S., Bäckstrand, K., Bernstein, S., Betsill, M.M., Bulkeley, H., Cashore, B., Clapp, J., Folke, C. and Gupta, A., 2012. Transforming governance and institutions for global sustainability: key insights from the Earth System Governance Project. *Current Opinion in Environmental Sustainability*, 4(1), pp.51-60.

Bernstein, S., Bernstein, S.F. and Pauly, L.W. eds., 2008. Global liberalism and political order: toward a new grand compromise?. SUNY Press.

Boucher, O., Bellassen, V., Benveniste, H., Ciais, P., Criqui, P., Guivarch, C., Le Treut, H., Mathy, S. and Séférian, R., 2016. Opinion: In the wake of Paris Agreement, scientists must embrace new directions for climate change research. *Proceedings of the National Academy of Sciences*, 113(27), pp.7287-7290.

Bradshaw, G.A. and Borchers, J., 2000. Uncertainty as information: narrowing the science-policy gap. *Conservation ecology*, 4(1).

Bronk, D.W., 1974. Science advice in the White House. *Science,* 186(4159), pp.116-121.

Carnegie Commission on Science and Government, 1991. Science, Technology, and Congress: Expert Advice and the Decision-making Process. Carnegie Commission on Science, Technology, and Government.

Carraro, C., Edenhofer, O., Flachsland, C., Kolstad, C., Stavins, R., Stowe, R., 2015. The IPCC at a crossroads: opportunities for reform. *Science,* 350 (6256), 34–35.

Carter, J., Markham, A., Clement, J., Heid, M. and Worth, P. 2018. Science under Siege at the Department of the Interior America's Health, Parks, and Wildlife at Risk. Union of Concerned Scientists.

Carter, N., 2018. The politics of the environment: Ideas, activism, policy. Cambridge University Press.

Cash, D., Clark, W., Alcock, F., Dickson, N., Eckley, N., Jäger, J., 2002. Salience, credibility, legitimacy and boundaries: linking research, assessment and decision making. KSG Working Papers Series RWP02-046.

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J. and Mitchell, R.B., 2003. Knowledge systems for sustainable development. *Proceedings of the national academy of sciences*, *100*(14), pp.8086-8091.

CBD (Secretariat of the Convention on Biological Diversity), 2014. Global Biodiversity Outlook 4. Montréal. Available online: https://www.cbd.int/gbo/gbo4/publication/gbo4-en.pdf.

Clark, W.C., Van Kerkhoff, L., Lebel, L. and Gallopin, G.C., 2016. Crafting usable knowledge for sustainable development. *Proceedings of the National Academy of Sciences,* 113(17), pp.4570-4578.

Clark, W.C., 2007. Sustainability Science: A room of its own. *Proceedings of the National Academy of Sciences*, 104 (6) 1737-1738.

Clark, W.C., Kerkhoff, L.v., Lebel, L., and Gallopin, G.C., 2016. Crafting usable knowledge for sustainable development. *Proceedings of the National Academy of Sciences*, (113)17: 4570–4578.

Colglazier, W., 2015. Sustainable development agenda: 2030. *Science,* 349(6252), pp.1048-1050.

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J.D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P. and Otto, I.M., 2013. Opening up knowledge systems for better responses to global environmental change. *Environmental Science & Policy*, 28, pp.60-70.

Cowling, E.B., 1982. Acid precipitation in historical perspective. *Environmental Science and Technol*ogy 16(2), 110–123.

Craft, J. and Howlett, M., 2012. Policy formulation, governance shifts and policy influence: Location and content in policy advisory systems. *Journal of Public Policy,* 32(2), pp.79-98.

Daguitan F., Mwangi, C., Tan, M., Clark, G., Cooper, D., Donovan, J.M., Gutierrez, S., Kruglikova, N., Lehohla, P., Seager, J. and Sonntag, W., 2019. Future Data and Knowledge Needs-Global Environment Outlook (GEO-6): Healthy Planet, Healthy People. *Chapter 25*. Cambridge Press.

De Pryck, K., Wanneau, K., 2017. (Anti)-boundary work in global environmental change research and assessment. *Environ. Sci. Policy*. http://dx.doi.org/10.1016/j.envsci.2017.03.012.

Dietz, T., 2013. Bringing values and deliberation to science communication. *Proceedings of the National Academy of Sciences*, 110(Supplement 3), pp.14081-14087.

Dilling, L., Lemos, M.C., 2011. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. *Global environmental change,* 21(2), 680-689.

Dijkstra, E.M. and Goedhart, M.J., 2012. Development and validation of the ACSI: measuring students' science attitudes, pro-environmental behavior, climate change attitudes and knowledge. *Environmental Education Research*, 18(6): 733-749.

Dodds, F., Laguna-Celis, J., Thompson, L., 2014. From Rio 20 to a New Development Agenda: Building a Bridge to a Sustainable Future. Routledge, London.

Edenhofer, O., Kowarsch. M., 2015. Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy,* 51: 56-64.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Minx, J.C., Farahani, E., et al. 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Eisenack, K., Moser, S.C., Hoffmann, E., Klein, R.J., Oberlack, C., Pechan, A., Rotter, M. and Termeer, C.J., 2014. Explaining and overcoming barriers to climate change adaptation. *Nature Climate Change*, 4(10), p.867.

Elder, M., Bengtsson, M. and Akenji, L., 2016. An optimistic analysis of the means of implementation for sustainable development goals: Thinking about goals as means. *Sustainability,* 8(9), p.962.

Engels, A., 2016. Anthropogenic climate change: How to understand the weak links between scientific evidence, public perception, and low-carbon practices. *Energy Emiss. Control Technol*, (4) 17–26.

European Commission, 2009., Europeans' attitudes towards climate change. A survey coordinated by Directorate-General for Communication, Research and Political Analysis Unit. November 2009.

Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., et al. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Finus, M., Cooper, P. and Almer, C., 2017. The use of international agreements in transnational environmental protection. *Oxford Economic Papers,* 69(2), 333-344.

Funtowitz, S.O., Ravetz, J.R., 1994. Uncertainty, complexity, and post-normal science. *Environmental Toxicology and Chemistry,* 13(12), 1881-1885.
Garard, J., Kowarsch, M., 2017. If at first you don't succeed: evaluating stakeholder engagement in global environmental assessments. *Environmental Science & Policy,* 77, pp.235-243.
Gauchat, G. 2012. Politicization of science in the public sphere a study of public trust in the United States, 1974 to 2010. *American Sociological Review,* 77(2), 167-187.
Gleick, P.H., Adams, R.M., Amasino, R.M., Anders, E., Anderson, D.J., Anderson, W.W., Anselin, L.E., Arroyo, M.K., Asfaw, B., Ayala, F.J. and Bax, A., et al., 2010. Climate change and the integrity of science. *Science*, 328(5979), pp.689-690.
Griggs, D.J., Nilsson, M., Stevance, A. and McCollum, D., 2017. A guide to SDG interactions: From science to implementation. International Council for Science, Paris. DOI:10.24948/2017.01.
Gupta, J., 2018. Globalization and sustainable development. Handbook on the Geographies of Globalization, p.96.
Harper, C., Harper, C.L. and Snowden, M., 2017. Globalization, inequality, and sustainability. *(In) Environment and society: Human perspectives on environmental issues*. Routledge.
Haas, P.M., 2017. The epistemic authority of solution-oriented global environmental assessments. *Environ. Sci. Policy*. http://dx.doi.org/10.1016/j.envsci.2017.03.013.
Haas, P.M., 2004. When does power listen to truth? A constructivist approach to the policy process. *Journal of European Public Policy* 11(4): 569-592.
Haas, P.M., 1992. Introduction: epistemic communities and international policy coordination. *International organization*, 46(1), pp.1-35.
Haas, P.M., Keohane, R.O., Levy, M.A. and Gasser, L. eds., 1993. Institutions for the earth: sources of effective international environmental protection. Mit Press.
Herrick, C. and Sarewitz, D., 2000. Ex post evaluation: a more effective role for scientific assessments in environmental policy. *Science, Technology, & Human Values*, 25(3), pp.309-331.
Höhne, N., Kuramochi, T., Warnecke, C., Röser, F., Fekete, H., Hagemann, M., Day, T., Tewari, R., Kurdziel, M., Sterl, S. and Gonzales, S., 2017. The Paris Agreement: resolving the inconsistency between global goals and national contributions. *Climate Policy*, 17(1), pp.16-32.
Hoppe, R., 2005. Rethinking the science-policy nexus: from knowledge utilization and science technology studies to types of boundary arrangements. *Poiesis & Praxis,* 3(3), pp.199-215.
Hoppe, R., 2018. Knowledge, power, and participation in environmental policy analysis. Routledge.
Hoppe, R., A. Wesselink, and R. Cairns. 2013. "Lost in the Problem: The Role of Boundary Organisations in the Governance of Climate Change." Wiley Interdisciplinary Reviews: Climate Change, 4 (4): 283–300.
Huitema, D., Turnhout, E., 2009. Working at the science–policy interface: a discursive analysis of boundary work at the Netherlands Environmental Assessment Agency. *Environmental Politics*, 18(4), pp.576-594.
IPCC, et al., 2013. Climate change 2013: the physical science basis. In: Stocker, T., Qin, D., Plattner, G.-K., Tignor, M., Allen, S., Boschung, J. (Eds.), Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
Jabbour, J., Flachsland, C., 2017. 40 years of global environmental assessments: a retrospective analysis. *Environmental Science & Policy,* 77(1), pp.193-202.
Jabbour, J., Hunsberger, C., 2014. Visualizing relationships between drivers of environmental change and pressures on land-based ecosystems. *Natural Resources,* 5(4), pp.146–160.
Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Singh, A., Levy, M.A., Schwarzer, S., 2012. Internationally agreed environmental goals: a critical evaluation of progress? *Environ. Dev*. 3 (2), 5–24.
Jasanoff, S., 2009. The fifth branch: Science advisers as policymakers. Harvard University Press.
Jasanoff, S. 2004. The idiom of co-production. In Jasanoff, S. (Ed), States of knowledge: The co-production of science and social order, pp. 1-12. London, UK: Routledge.

Jasanoff, S. and Martello, M.L. eds., 2004. Earthly politics: local and global in environmental governance. MIT press.
Jasanoff, S., Markle, G.E., Peterson, J.C. and Pinch, T. eds., 2001. Handbook of science and technology studies. Sage publications.
Jordan, A. and Lenschow, A., 2010. Environmental policy integration: a state of the art review. *Environmental policy and governance,* 20(3), pp.147-158.
Kanie, N., 2014. Governance with Multilateral Environmental Agreements: A Healthy or Ill-equipped Fragmentation?. *Green Planet Blues: Critical Perspectives on Global Environmental Politics*, p.137. Norichika
Kainuma, M., Mangalagiu, D., Asrar, G. R., Jacob, K., Pereira, L., Rocamora, A., ... and King, P. (2019). The Way Forward-Global Environment Outlook (GEO-6): Healthy Planet, Healthy People Chapter 24. Global Environment Outlook (GEO-6): Healthy Planet, Healthy People.
Kates, R.W. and Clark, W.C., 1996. Environmental surprise: Expecting the unexpected?. *Environment: Science and Policy for Sustainable Development*, 38(2), pp.6-34.
Keller, A.C., 2009. *Science in environmental policy: The politics of objective advice*. MIT Press.
Kennedy, J.F., 1963. Address at the Anniversary Convocation of the National Academy of Sciences (22 October 1963).
Kennedy, J.F., 1963. Speech to the General Assembly of the United Nations. (21 September 1963).
Kitchin, R., 2014. Big data, new epistemologies and paradigm shifts. *Big data and society,* 1(1)
Koetz, T., Farrell, K.N., Bridgewater, P., 2012. Building better science-policy interfaces for international environmental governance: assessing potential within the Intergovernmental Platform for Biodiversity and Ecosystem Services. *International environmental agreements: politics, law and economics*, *12*(1), pp.1-21.
Kowarsch, M., Flachsland, C., Jabbour, J., Garard, J., Riousset, P., 2014. The future of global environmental assessment making (FOGEAM): reflecting on past experiences to inform future choices. In: MCC Working Paper Prepared for UNEP's IGMS Consultation on GEO-6. Oct 2014, Berlin. www.mcc-berlin.net/fileadmin/data/events/FOGEAM_Preliminary_Draft_Report_17102014.pdf
Kowarsch, M., Garard, J., Riousset, P., Lenzi, D., Dorsch, M., Knopf, B., et al., 2016. Scientific assessments to facilitate deliberative policy learning. Palgrave Commun. 2, 16092.
Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T., Watson, R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P. and Pintér, L., 2017a. A road map for global environmental assessments. *Nature Climate Change* 7, 379–382.
Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J., Riousset, P., 2017b. The treatment of divergent viewpoints in global environmental assessments. *Environmental Science & Policy, 77, pp.225-234.*
Kowarsch, M., 2016a. Policy assessments to enhance EU scientific advice. *Nature Climate Change,* 6 (1), 15–17.
Kowarsch, M., 2016b. A pragmatist orientation for the social sciences in climate policy. Boston Studies in the Philosophy and History of Science. Springer.
Kahan, D.M., Peters, E., Wittlin, M., Slovic, P., Ouellette, L.L., Braman, D. and Mandel, G., 2012. The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature climate change,* 2(10), pp.732-735.
Krishna, I.M., Manickam, Shah, A., and Davergave, N., 2017. Environmental Management: Science and Engineering for industry. Butterworh-Heinemann.
Kuhn, T.S., 1962. The structure of scientific revolutions. University of Chicago press.
Kurtz, D.V., 2018. Political anthropology: power and paradigms. Routledge.
Larigauderie, A., 2015. The intergovernmental platform on biodiversity and ecosystem services (IPBES): a call to action. GAIA 24 (2), 73–74.
Lee, H., 2015. Turning the focus to solutions. Science 350 (6264) 1007–1007.

Lehmann, A., Chaplin-Kramer, R., Lacayo, M., Giuliani, G., Thau, D., Koy, K., Goldberg, G., 2017. Lifting the information barriers to address sustainability challenges with data from physical geography and earth observation. *Sustainability,* 9(5), p.858.

Levy, M et al., 2016. GEO-6 North American Regional Assessment. United Nations Environment Programme, Nairobi, Kenya.

Levy, M.A., Haas, P.M. and Keohane, R.O., 2016. Institutions for the Earth: Promoting International Environmental Protection (1992). The Globalization and Environment Reader, p.262.

Levy, M.A., Young, O.R. and Zürn, M., 1995. The study of international regimes. *European journal of international relations*, 1(3), pp.267-330.

Levy, M.A., Cavender-Bares, J., Clark, W.C., Dinkelman, G. and Nikitina, E., 2001. Goal and strategy formulation in the management of global environmental risks. See Ref, 55, pp.87-113.

Li, Y., and Oberheitmann, A. (2009). Challenges of rapid economic growth in China: reconciling sustainable energy use, environmental stewardship and social development. *Energy Policy*, 37(4), 1412-1422.

MA (Millennium Ecosystem Assessment), et al., 2003. In: Alcamo, J. (Ed.), Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington DC. http://pdf.wri.org/ecosystems_human_wellbeing.pdf.

Malone, T.W., Laubacher, R. and Dellarocas, C., 2009. Harnessing crowds: Mapping the genome of collective intelligence.

Martinez, C., Mueller, M., 2015. The SDGs: opportunities for conservation. *Environ. Policy Law* 45 (6), 239.

Maxwell, S.L., Milner-Gulland, E.J., Jones, J.P., Knight, A.T., Bunnefeld, N., Nuno, A., Bal, P., Earle, S., Watson, J.E., Rhodes, J.R., 2015. Being smart about SMART environmental targets. *Science,* 347 (6226), pp.1075-1076.

McGinnis, M.D., 1999. Polycentric governance and development: Readings from the workshop in political theory and policy analysis. University of Michigan Press.

McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T. (Eds.), 2009. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD): A Synthesis of the Global and Sub-Global IAASTD Reports. Island Press, Washington DC.

McNie, E.C., 2007. Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environmental science & policy*, *10*(1), pp.17-38.

McNie, E.C, 2008. Co-producing Useful Climate Science for Policy: Lessons from the RISA Program. Phd, University of Colorado.

McNie, E.C., 2012. Delivering climate services: organizational strategies and approaches for producing useful climate-science information. *Weather, Climate, and Society,* 5(1), pp.14-26.

Miller, T.R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D., Loorbach, D., (2014). The future of sustainability science: a solutions-oriented research agenda. *Sustainability Science,* 9 pp. 239-246.

Minx, J.C., Callaghan, M., Lamb, W.F., Garard, J., Edenhofer, O., 2017. Learning about climate change solutions in the IPCC and beyond. *Environmental Science and Policy,* http://dx.doi.org/10.1016/j.envsci.2017.05.014.

Mitchell, R.B., Clark, W.C., Cash, D.W., Dickson, N.M. (Eds.), 2006. Global Environmental Assessments: Information and Influence. MIT Press, Cambridge, MA.

Molina, M.J., Rowland, F.S., 1974. Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. *Nature,* 249(5460), p.810.

Mooney, H.A., Duraiappah, A. and Larigauderie, A., 2013. Evolution of natural and social science interactions in global change research programs. *Proceedings of the National Academy of Sciences*, 110(Supplement 1), 3665-3672.

Nilsson, M. and Persson, Å., 2017. Policy note: Lessons from environmental policy integration for the implementation of the 2030 Agenda. *Environmental Science & Policy*, 78, pp.36-39.

Norgaard, R.B., 2008. Finding hope in the millennium ecosystem assessment. *Conservation Biology,* 22 (4), 862–869.
OECD, 1977. The OECD Assessment on Long-Range Transport of Air Pollutants: Measurements and Findings. Organization for Economic Cooperation and Development (OECD), Paris.
Ostrom, E., 1990. Governing the commons: The evolution of institutions for collective action. Cambridge University Press. Cambridge.
Ostrom, E., 1998. Scales, polycentricity, and incentives: designing complexity to govern complexity. Protection of global biodiversity: Converging strategies, pp.149-167.
Ostrom, E., 2009. A polycentric approach for coping with climate change. World Bank: Policy Research Working chapter WPS 5095. Washington, DC.
Ostrom, E., 2010. Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, 20(4), pp.550-557.
Park, J., Conca, K., Finger, M. (eds)., 2008. The crises of global environmental governance: Towards a new political economy of sustainability. Routledge.
Pearce, W., Mahony, M. and Raman, S., 2018. Science advice for global challenges: Learning from trade-offs in the IPCC. *Environmental Science & Policy,* 80, pp.125-131.
Pereira, L., Asrar, G.R., Fisher, L.H., Hsu, A., Nel, J., Sitas, N., Ward, J., Vervoort, J., Selomane, O., Trisos, C. and Malone, T., 2019. Bottom-up Initiatives and Participatory Approaches for Outlooks-Global Environment Outlook (GEO-6): Healthy Planet, Healthy People Chapter 23. Cambridge University Press.
Percival, R.V., 2007. Environmental law in the twenty-first century. *Virginia Environmental Law Journal*, pp.1-35.
Perrings, C., Duraiappah, A., Larigauderie, A., Mooney, H., 2011. The biodiversity and ecosystem services science-policy interface. *Science* 331 (6021), 1139–1140.
Persson, Å., Weitz, N. and Nilsson, M., 2016. Follow-up and Review of the Sustainable Development Goals: Alignment vs. Internalization. *Review of European, Comparative & International Environmental Law*, 25(1), pp.59-68.
Pew Research Center, 2010. Rising environmental concern in 47-nation survey. Conducted by pew Global Attitudes.
Pew Research Center, 2009. Public praises science; scientists fault public, media. Public Survey. July, 9, 2009.
Pielke Jr, R.A., 2007. *The honest broker: making sense of science in policy and politics*. Cambridge University Press.
Poortinga, W., Whitmarsh, L., Steg, L., Böhm, G. and Fisher, S., 2019. Climate change perceptions and their individual-level determinants: A cross-European analysis. *Global environmental change*, 55, pp.25-35.
Putnam, H., 2004. The Collapse of the Fact/Value Dichotomy and Other Essays. Harvard University Press, Cambridge, MA.
Rasmussen, S., Mangalagiu, D., Ziock, H., Bollen, J. and Keating, G., 2007, April. Collective intelligence for decision support in very large stakeholder networks: The future US energy system. In 2007 *IEEE Symposium on Artificial Life* (pp. 468-475). IEEE.
Renn, O., Klinke, A., & van Asselt, M. (2011). Coping with complexity, uncertainty and ambiguity in risk governance: A synthesis. *AMBIO: A Journal of the Human Environment*, 40, 231–246.
Riousset, P., Flachsland, C., Kowarsch, M., 2017. Global environmental assessments: impact mechanisms. Environ. Sci. Policy. http://dx.doi.org/10.1016/j.envsci.2017.02.006.
Rowe, A., Ng'eny, N., Carbon, M., 2014. Terminal Evaluation of the Project Fifth Global Environmental Outlook: Integrated Environmental Assessment. UNEP Evaluations Office, Nairobi.
Sarewitz, D. 2011. Does Climate Change Knowledge Really Matter? *Wiley Interdisciplinary Reviews: Climate Change* 2(4), 475–481.

Sarkki, S.; Niemelä, J.; Tinch, R.; van den Hove, S.; Watt, A. and Young, J. 2014. Balancing credibility, relevance, and legitimacy: A critical assessment of trade-offs in science-policy interfaces. *Science and Public Policy* 41(2): 194-206.

Sarkki, S., Tinch, R., Niemelä, J., Heink, U., Waylen, K., Timaeus, J., Young, J., Watt, A., Neßhöver, C. and van den Hove, S., 2015. Adding 'iterativity'to the credibility, relevance, legitimacy: a novel scheme to highlight dynamic aspects of science–policy interfaces. *Environmental Science & Policy*, 54, pp.505-512.

Saunders, F.P., Gilek, M. and Linke, S., 2017. Knowledge for environmental governance: probing science–policy theory in the cases of eutrophication and fisheries in the Baltic Sea. *Journal of Environmental Policy & Planning*, 19(6), 769-782.

Schmalzbauer B., Visbeck M. (Eds.) 2016. The contribution of science in implementing the Sustainable Development Goals. German Committee Future Earth, Stuttgart/Kiel.

Schreurs, M.A., Economy, E. and Smith, S. *eds.,* 1997. The internationalization of environmental protection (Vol. 54). Cambridge University Press.

Schreurs, M.A., 2003. Environmental Politics in Japan, Germany, and the United States. Cambridge University Press.

Schreurs, M.A., 2008. From the bottom up: local and subnational climate change politics. *The Journal of Environment & Development*, *17*(4), pp.343-355.

Schreurs, M.A., 2016. The Paris climate agreement and the three largest emitters: China, the United States, and the European Union. *Politics and Governance,* 4(3), pp.219-223.

Shackley, S., Wynne, B., 1996. Representing uncertainty in global climate change science and policy: Boundary-ordering devices and authority. *Science, Technology, & Human Values*, 21(3), 275-302.

Shah, M.M., 2014. Sustainable Development. *In* Encyclopedia of Ecology, Eds. Jorgensen, S.E. and Fath, B.D. 2014. Newnes.

Schneider, T. and Schneider, J., 2004. EMEP: Backbone of the Convention. *In* Clearing the Air: 25 years of the Convention on Long-range Transboundary Air Pollution (No. 8). *Eds*. Sliggers, J. and Kakebeeke, W. 31-44. New York: United Nations.

Scoones, I., 2009. The politics of global assessments: the case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *The Journal of Peasant Studies*, 36(3), pp.547-571.

Slaughter, M., 2017. The Chessboard and the Web: Strategies of Connection in a Networked World. Yale University Press.

Steel, B., List, P., Lach, D. and Shindler, B., 2004. The role of scientists in the environmental policy process: a case study from the American west. *Environmental Science & Policy*, 7(1), pp.1-13.

Steiner, A., 2018, Statement to the UNDP Executive Board, New York, 6 September 2018.

Stern, P.C., Sovacool, B.K. and Dietz, T., 2016. Towards a science of climate and energy choices. *Nature Climate Change,* 6(6), p.547.

Stocker T.F., Qin, D., Plattner, G-K., Tignor, M., Allen, S.K., et al. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge Univ. Press

Stringer, L.C. and Dougill, A.J., 2013. Channeling science into policy: enabling best practices from research on land degradation and sustainable land management in dryland Africa. Journal of Environmental Management, (114), 328-335.

Turnhout, E., Stuiver, M., Klostermann, J., Harms, B. and Leeuwis, C., 2013. New roles of science in society: different repertoires of knowledge brokering. *Science and public policy,* 40(3), pp.354-365.

Turnpenny, J., Radaelli, C.M., Jordan, A. and Jacob, K., 2009. The policy and politics of policy appraisal: emerging trends and new directions. *Journal of European Public Policy*, 16(4), pp.640-653.

Turnpenny, J., Russel, D. and Jordan, A., 2014. The challenge of embedding an ecosystem services approach: patterns of knowledge utilisation in public policy appraisal. *Environment and Planning C: Government and Policy,* 32(2), pp.247-262.

UNEP, 2017. Strengthening the Science-Policy Interface: A Gap Analysis. United Nations Environment Programme. Nairobi, Kenya.

UNEP, et al., 2017. In: Ekins, P. (Ed.), Resource Efficiency: Potential and Economic Implications. A Report of the International Resource Panel. UNEP, Nairobi, Kenya.

Gupta, J. and Ekins, P. 2019. Forward (Co-Chairs; Eds.) *In* UN Environment, 2019. Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Cambridge University Press.

Ullstein, B., de Mattos, H., Hawkins, C., McMullen, C.P., Jabbour, J., Scharlemann, J. (Eds.), 2012. The Fifth Global Environment Outook (GEO-5): Environment for the Future We Want. United Nations Environment Programme, Nairobi.

Valsileiadou, E., Heimeriks, G., and Petersen, A.C., 2011. Exploring the IPCC Assessment Reports on science. *Environmental Science & Policy*, 14(8): 1052-61.

van der Hel, S. and Biermann, F., 2017. The authority of science in sustainability governance: A structured comparison of six science institutions engaged with the Sustainable Development Goals. *Environmental Science & Policy*, *77*, pp.211-220.

Van den Hove, S., 2007. A rationale for science–policy interfaces. *Futures,* 39(7), pp.807-826.

von Stechow, C., Minx, J.C., Riahi, K., Jewell, J., McCollum, D.L., Callaghan, M.W., Bertram, C., Luderer, G. and Baiocchi, G., 2016. 2 C and SDGs: united they stand, divided they fall?. *Environmental Research Letters*, *11*(3), p.034022.

Watson, R.T., 2013. The value of knowledge and the importance of global assessments. In: CGFRA Seminar Biodiversity for Food and Agriculture. United Nations FAO Rome: 13 April.

Weiss, T.G. and Thakur, R., 2010. Global governance and the UN: an unfinished journey. Indiana University Press.

Weichselgartner, J., Kasperson, R., 2010. Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. *Global Environmental Change*, 20(2), 266-277.

Wesselink, A., Buchanan, K.S., Georgiadou, Y. and Turnhout, E., 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. *Environmental Science & Policy,* 30, pp.1-9.

Wong, K.K., 2010. Environmental awareness, governance and public participation: public perception perspectives. International Journal of Environmental Studies, 67(2): 169-181.

Yamineva, Y., 2017. Lessons from the Intergovernmental Panel on Climate Change on inclusiveness across geographies and stakeholders. *Environmental Science & Policy,* 77, 244-251.

Young, O.R., 1989. International cooperation: building regimes for natural resources and the environment. Ithaca: Cornell University Press.

2. Internationally agreed environmental goals: A critical evaluation of progress*

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Abstract

The number of international environmental institutions, goals and agreements has increased greatly since the United Nations Conference on the Human Environment in 1972. However, the results of this proliferation for environmental protection have been mixed. The "Rio +20" conference, offers world leaders an opportunity to reaffirm the importance of achieving a sustainability agenda and to revisit their strategies for doing so. To inform this process it is crucial to learn from the ambitions, achievements and shortcomings on goal attainment to date. Drawing on the United Nations Environment Programme's fifth Global Environment Outlook report (GEO-5), this paper presents an evaluation of progress made on globally agreed environmental goals in relation to a series of biophysical trends. The analysis suggests a picture of patchy achievements rather than sustained progress. The most encouraging results have occurred where measurable targets were established on problems with relatively straightforward causes and courses of action. Key obstacles to the achievement of goals include a series of mismatches: between narrow objectives and the need for integrated approaches; between types of problems and types of solutions; between the fragmentation of governance and the need for collective action; between science and policy; between the responsibilities and resources of environmental institutions; and between complex systems and the desire for measurable outcomes. Overcoming these obstacles will require not only learning from past successes and failures but also adapting this knowledge to environmental, political and economic circumstances that have changed considerably over the past 40 years.

Keywords: environmental agreements, internationally agreed goals, sustainable development, Rio+20, sustainability, integrated environmental assessment, UNEP

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2.1 Introduction

Since the 1972 United Nations Conference on the Human Environment in Stockholm there has been a growing recognition of the importance of multilateral cooperation in addressing environmental issues, resulting in an ever-increasing number of environmental institutions, goals, and agreements. Despite this, environmental conditions have continued to degrade at an alarming pace, exacerbating existing vulnerability, poverty, and food insecurity (UNEP, 2012a, b; UNEP, 2011a, b; UNEP, 2007; Butchart et al., 2010; IPCC 2007; MA 2005). Taken as a whole, the magnitude, extent, and rate of change of environmental conditions are without precedent during human history (Zalasiewicz et al. 2011). Earth systems are being pushed toward their biophysical limits; strong signals suggest these limits are close, and have in some cases been exceeded (Lenton et al., 2008; Fabry et al., 2008; Rockström et al., 2009; Smith et al., 2009).

In June 2012, state, market, and civil society leaders will gather in Rio de Janeiro for the second Earth Summit, dubbed "Rio+20''. The aim is to renew political commitments, assess progress made since the first Earth Summit of 1992, and reflect on real and tangible challenges that continue to obstruct the achievement of sustainability objectives at local through global scales. The Rio+20 conference will provide an opportunity to take a critical look at environmental institutions and policies in the 21st century. The difficult question facing the international community is why, in aggregate, the goals agreed through the policies and principles put in place over the past 40 years have not been met.

Through the process of producing its fifth Global Environment Outlook report (GEO-5), the UN Environment Programme (UNEP) has recently undertaken a collaborative assessment of progress in relation to a broad range of internationally agreed environmental goals. This paper draws on the findings of GEO-5 as well as recent environmental governance literature. It seeks to identify lessons learned from comparing the goal-setting efforts of the past several decades with actual environmental performance over the same period.

We begin with an historical overview of the establishment of international environmental institutions, goals and agreements. The second part presents analysis from GEO-5, using biophysical trends in the domains of atmosphere, land, water, biodiversity, chemicals and waste to critically evaluate progress towards–and gaps in–goal achievement. The third part discusses challenges and constraints that inhibit goal attainment. The article concludes by offering suggestions to Rio+20 participants and others regarding areas where opportunities exist to enhance enabling factors.

2.2 International environmental goals: a brief history

The first global conference on the environment, held in Stockholm in 1972, set in motion four decades of intensive debate and multilateral negotiations on environmental policy. This historic gathering, the United Nations Conference on the Human Environment, raised awareness of an issue hitherto little talked about–the 'global environment'–thus securing a lasting, albeit often precarious, place for the environment on the international governance agenda.

Twenty years after Stockholm, because of vastly improved knowledge about the state of the environment and the extent to which environmental conditions were deteriorating–a reality much worse than previously understood–world leaders gathered in Rio de Janeiro at the 1992 UN

Conference on Environment and Development (UNCED), also known as the Earth Summit. Flush with the hopes of investing the post-Cold War 'Peace Dividend', UNCED delegates discussed how to combine the imperative of economic development for the world's poor with protection of the environment to ensure a sustainable future.

The 1987 Brundtland Commission report Our Common Future (Brundtland, 1987), which paved the way to Rio, was widely attributed with popularizing the term 'sustainable development' (Langhelle, 1999), first articulated as ''development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs''. Over the years, the discourse of sustainable development has given rise to considerable debate over its many interpretations, influences, transformations, and shortcomings (Zaccai, 2012). Despite inherent and persistent definitional ambiguities, at a basic level, the notion of sustainable development continues to be the acknowledged goal for many policy domains, including the environment.

The outcomes of the 1992 Earth Summit were the Rio Declaration and Agenda 21, important steps towards sustainable development. The former included 27 principles that nations committed to and the latter articulated a comprehensive plan of action for the achievement of sustainable development in the 21st century. It covered socio-economic and environmental issues, and suggested roles for a wide variety of stakeholders – engaging actors beyond the state and across scales – including international non- governmental organizations, communities, local government and civil society organizations (Andonova and Hoffmann, 2012).

Further dimensions of environmental goals emerged through the negotiating agenda of the General Agreement on Tariffs and Trade (GATT), at first with the concern that environmental legislation could be interpreted as a non-tariff trade barrier and thereby impute the environment as a last refuge of protectionism (Hoekman and Kostecki, 1995; Jackson, 1997). But in the lead-up to the 1992 Rio Earth Summit, serious consideration was undertaken of international trade's potential contribution to addressing environmental problems. In 1994, the GATT parties established a Committee of Trade and Environment that was tasked to examine interactions between trade measures and environmental measures to promote sustainable development. The result was a series of recommended reforms to the provisions of the multilateral trading system, feeding eventually into the GATT's metamorphosis to the World Trade Organization in 1995 (WTO 2011; Demaret, 1995). These deliberations also foreshadowed an important discourse about trade policies as a means of enforcing environmental regulations (Xing and Kolstad, 1996).

In September 2000, leaders from 193 countries agreed to the Millennium Development Goals (MDGs). These represented another important addition to the existing set of sustainability goals and targets. The MDGs aim for a future with less poverty, hunger, and disease; greater survival prospects for mothers and their infants; better educated children; equal opportunities for women; a healthier environment; and a world in which developed and developing countries work in partnership for the betterment of all (UN 2000). The eight MDGs provide a framework of 21 time-bound targets by which progress can be assessed along with 60 indicators to measure and show progress by the year 2015. While environmental themes cut across several MDGs, they are most prominently highlighted in MDG-7: Ensuring Environmental Sustainability. MDG-7 is divided into four targets that emphasize sustainability principles: reversing natural resource degradation, reducing biodiversity loss, increasing access to safe drinking water and sanitation, and improving slums.

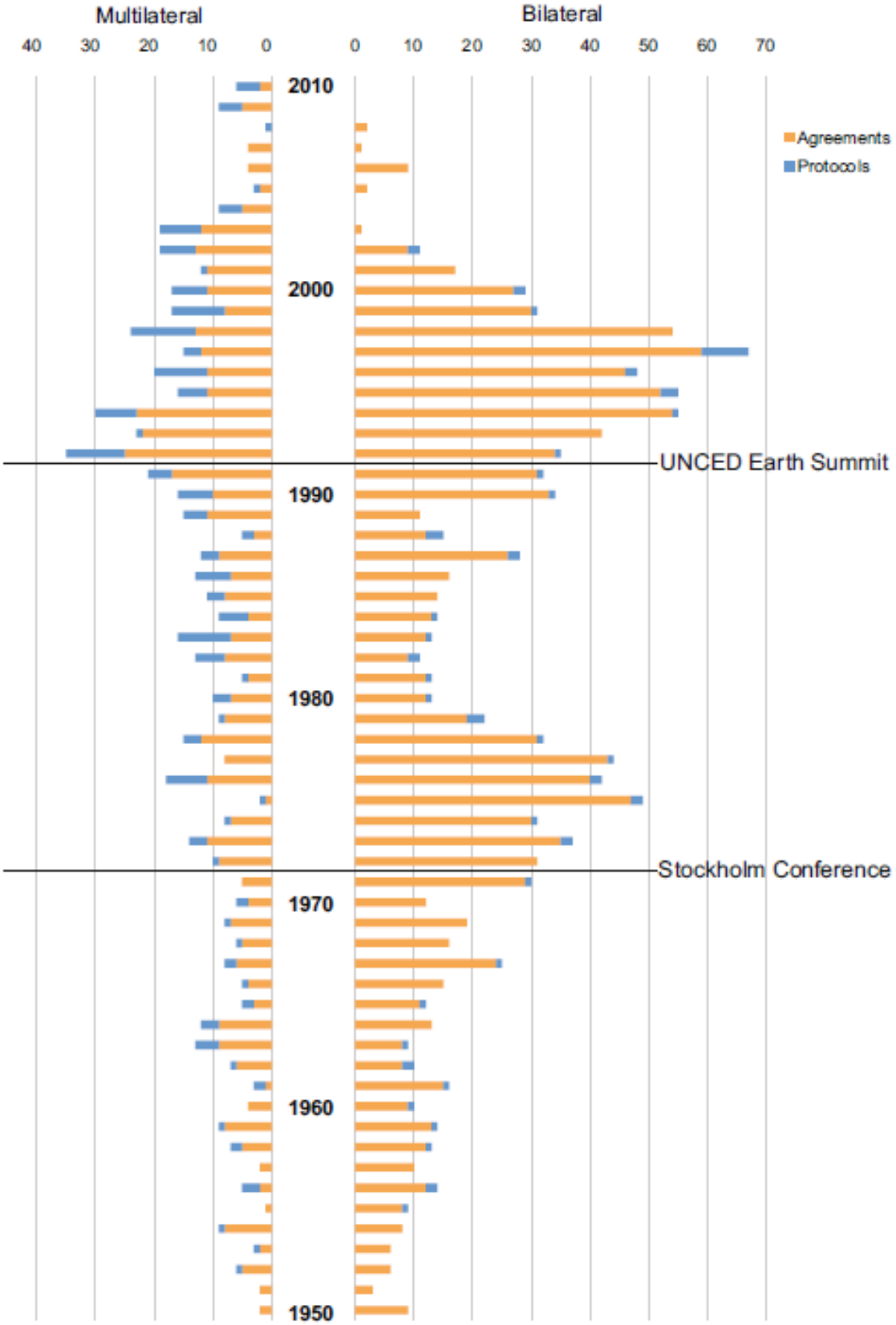

Figure 2.1. International environmental agreements and protocols since 1950: environmental agreements are understood here as intergovernmental legally binding documents with a primary purpose of preventing or managing human impacts on natural resources.

Environmental targets were also adopted in 2002 at the World Summit on Sustainable Development (WSSD) in Johannesburg (UN, 2002). With the Johannesburg Declaration on Sustainable Development, world leaders reaffirmed their commitment to advance the three pillars of sustainable development – environmental protection, social development and economic development – and further committed themselves to expedite the achievement of the time-bound targets contained within a new Plan of Implementation for the Johannesburg Declaration on Sustainable Development. Unlike Agenda 21, the Johannesburg outcome was intended to go beyond debate and catalyze a move to action and results by instituting targets and timetables; however, most of the goals and targets remained broad and in some cases virtually un-measurable.

2.2.1 The current landscape of environmental agreements

Since 1972, there has been a proliferation of environmental treaties and other agreements (global, regional and bilateral) designed to help achieve sustainable development (Figure 2.1). The International Environmental Agreement (IEA) Database Project managed by the University of Oregon lists some 560 IEAs (Mitchell, 2012), of which 350 came into existence between 1972 and the early 2000s. The number of agreements becomes even higher when the protocols and amendments built around the main agreements are included. As of 2010, an inventory of IEAs approximates 60 related to the atmosphere; 155 related to biodiversity; 180 addressing chemicals, hazardous substances, and waste; 45 related to land use; and another 195 that are broadly related to water resource issues (Knigge et al., 2005; Najam et al., 2006; Mitchell, 2012).

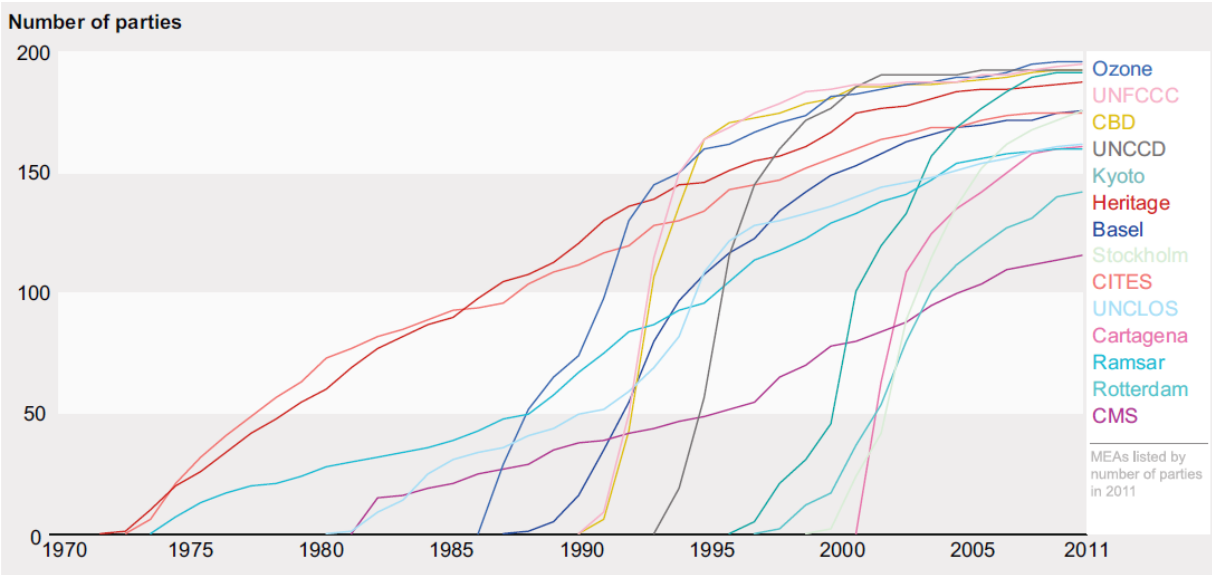

Figure 2.2. Growth in ratification of environmental treaties, 1971–2011.

The United Nations has also registered more than 500 multilateral environment agreements (MEAs), in a programme called ECOLEX (ECOLEX 2012). The core of the global environmental legal framework, however, is made up of a more limited number of treaties with a growing number of ratifications (Figure 2.2). While the creation of the various environmental conventions and protocols can be viewed as an achievement, it also raises the need for continuing support in developing countries when

national administrations become overloaded with reporting requirements and countless international meetings (Najam et al., 2006; Biermann, 2007). On one hand, the rapid growth of MEAs and establishment of other shared goals could be seen to signal a collective appreciation of the scope and severity of environmental issues (Roch and Perrez, 2005; Kanie, 2007; Oberthür and Stokke, 2011). On the other hand, despite – or perhaps because of – the proliferation in the number of environmental agreements, the political will required to ensure global environmental protection has been suboptimal. The resulting patchy achievement of goals and agreements is illustrated in the following section.

2.3 Analysis of goals and gaps

Over the past 15 years, UNEP has published four flagship assessment reports – the Global Environment Outlook (GEO) series – as part of its mandate to keep the state and trends of the global environment under review. Using a consultative and collaborative process involving hundreds of scientific and policy experts, GEO aims to help bridge the gap between science and policy by translating the best available scientific knowledge into policy-relevant information for decision-makers. An important focus of GEO assessment reports has been on identifying and analyzing environmental problems and solutions through the DPSIR framework consisting of Drivers, Pressures, States, Impacts and Responses along a continuum (Stanners et al., 2007). One of GEO's strengths is its integrated assessment approach, which allows for a comprehensive, multidisciplinary overview across different environmental themes in the global and regional context.

The fifth edition in the GEO series, GEO-5, contains an additional element: the state and trends analysis is linked to a review of the progress made towards the achievement of selected key internationally agreed goals. Relevant goals and objectives were identified from a range of sources including legally binding instruments (i.e., international treaties, conventions, or protocols); and nonbinding instruments, including outcomes of United Nations summits and world conferences, and conferences convened under the auspices of specialized agencies. The outcome of the GEO-5 assessment is expected to provide a key input to the intergovernmental deliberations leading up to the UN conference on Sustainable Development in Rio de Janeiro in June 2012.

In this attempt to measure the state of the environment against the backdrop of internationally agreed goals, key indicators and time-series datasets were used, where available, to measure progress. GEO-5 collaborators and experts in each region first identified a subset of key regional priority themes for analyses (Table 1) through a series of surveys and expert-lead consultations. For each issue, a comprehensive inventory of existing internationally agreed goals, compiled by UNEP with the support of the Government of Switzerland, was then considered. The selection process was initiated in July 2010, with questionnaires being sent out to a wide range of key stakeholders in each region to gather preliminary information. Respondents were asked to identify priority environ- mental challenges in their respective regions, and the way these challenges relate to regionally relevant international goals. With this information, regional consultations with various policy and environmental experts were held from September to October 2010. Each consultation resulted in a report that included key recommendations and target audiences, in addition to the selected priority themes and internationally agreed goals.

The international goals selected to guide the analysis in GEO-5 cover a broad spectrum of issues and vital targets related to food security, poverty reduction, vulnerability, ecosystem resilience, human well-being and environmental sustainability. For this analysis, goals have been classified vis-a-vis their achievement in terms of: 'significant progress'; 'some progress'; 'very little to no progress'; and 'further deterioration'. Provisions are also made to report whether there is 'insufficient data to evaluate progress' or it is 'too soon to assess the goal'.

Table 2.1. GEO-5 Priority themes by region*

	Africa	Asia and the Pacific	Europe	Latin America & the Caribbean	North America	West Asia
Environmental governance						
Climate Change						
Energy						
Air pollution						
Land						
Freshwater						
Oceans and seas						
Biodiversity						
Chemicals and waste						

Selected as a theme Selected as a cross-cutting theme

**Regional consultations identified which themes were the highest priorities for each region. Some chose to highlight additional themes that cut across the priority themes.*

The analysis of environmental agreements conducted by GEO-5 authors revealed several difficulties in applying straight compare-and-contrast techniques. It also shed light on the complexity and limitations of such an investigation in the face of scarce data and limited monitoring and evaluation frameworks. The analysis found that it is exceedingly difficult to assess the progress of many goals due to lack of verifiable indicators, quantifiable targets, and reliable data-especially regarding biodiversity, chemicals and hazardous wastes, and several aspects of land use and conservation of terrestrial ecosystems. Reliable baselines, against which to measure progress, and robust monitoring systems that can collect data at regular intervals, need considerable improvement for many themes, and in some cases, are absent.

The task of assessing progress in meeting internationally agreed goals is further complicated by the fact that most goals cannot be considered in isolation. Due to complex tensions and synergies among them, progress towards one goal must be viewed considering implications to other goals. For example, the analysis of goals related to land highlights friction between MDG 1, on reducing hunger, and MDG 7 on ensuring environmental sustainability. Increasing food production through agricultural expansion directly compromises the protection of forests, wetlands, and other ecosystems providing services for human well-being that are less obvious than food, but no less important. Another example of such friction is found in targets for freshwater: dams may interfere with protection and restoration of ecosystems but they also may improve the availability of freshwater to communities. Thus, an integrated perspective on goal achievement is necessary but complex. With these caveats in mind, the following sections summarize GEO-5's assessment of progress toward internationally agreed goals related to the themes of atmosphere, land, water, biodiversity, and chemicals and waste. Table 2.1. provides an overview of the progress towards the goals for each of these themes.

2.3.1 Atmosphere

Atmospheric goals include those related to air pollution, climate change, and stratospheric ozone depletion. The GEO-5 analysis studied a total of nine internationally agreed atmospheric goals. Of those, two goals show significant progress, five show some progress, and two shows very little or no progress. Differences in progress on the goals reflect variables such as the size of the economic sector targeted for change, type of behavioral shifts required by solutions, complexity of the issues, relative costs, and degree of concern.

The two goals demonstrating significant progress are the Montreal Protocol to the Vienna Convention to eliminate production of chlorofluorocarbons (CFCs) that destroy the stratospheric ozone layer, and the campaign to remove lead from automobile fuel, successful in all but six countries of the world. The Montreal Protocol has resulted in an almost 100% reduction in the consumption of CFCs globally. Removal of lead from gasoline reduces the damage to children's brains and central nervous systems at high exposures and to their immune, reproductive, and cardiovascular systems at lower exposures. A reduced level of lead in children's blood can be detected because of the change in petrol composition. In contrast, the targets and goals set for climate change mitigation remain far from being achieved, and emissions continue to rise (Figure 2.3). A small reduction in the rate of CO_2 emission increase in 2009, due to the global financial crisis, is overshadowed by the 2010 increase in emissions that rivaled the highest rates of the last decade. The 2010 rate of emissions from fossil fuel burning and cement production was the highest ever recorded and the atmospheric concentration of CO_2 at the end of 2010 was 398.6 ppm (parts per million), about 39% more than the 278 ppm in preindustrial 1750. The GEO-5 analysis considered this as very little to no progress.

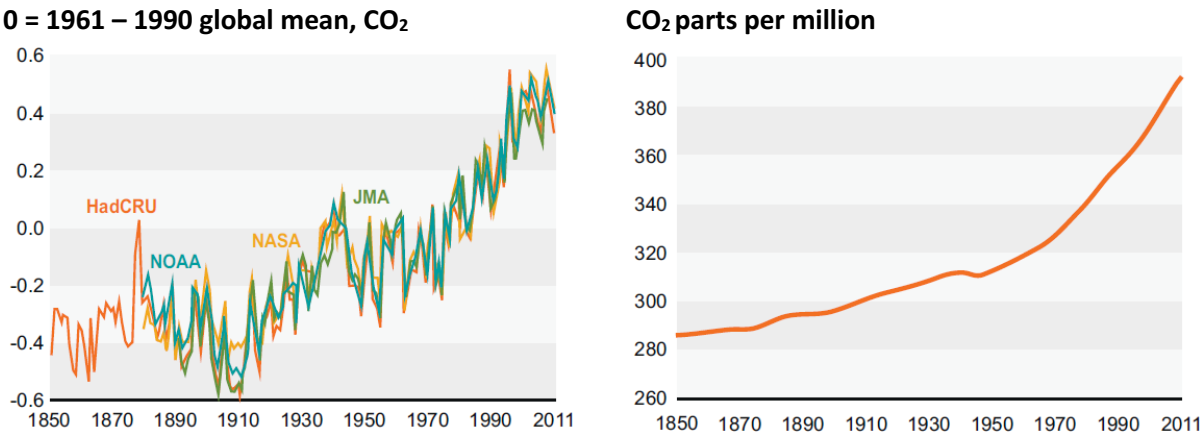

Figure 2.3. Trends in temperature change and atmospheric CO2 concentrations, 1850–2010. *Source:* Left panel–NOAA NCDC; NASA GISS; Hadley Climatic Research Unit at the University of East Anglia(HadCRU); Japan Meteorological Agency(JMA); Right panel–Scripps Institute of Oceanography, NOAA.

The non-binding Copenhagen Accord of 2009- 'noted' by 114 countries-recognized the need for emission targets that will hold the increase in global temperature below 2°C a concentration level of 450 ppm of carbon dioxide in the atmosphere. However, under the current levels of promised cuts, a gap of at least 5 GtCO2e will be left by 2020. Compared to concentrations that result in a 2°C increase in global average temperature, this gap is equal to the total emissions of the world's cars, buses and trucks in 2005 (UNEP, 2010). This situation illustrates a problem that is becoming more apparent as negotiations to address environmental degradation bog down for years and even decades.

2.3.2 Land

Internationally agreed goals related to land issues include those relating to protecting temperate and tropical forests, preserving and restoring wetlands, combating desertification, valuing ecosystem services, and increasing agricultural productivity. Of the nine internationally agreed land goals examined in GEO-5, four show some progress, including MDG 1 to 'eradicate extreme poverty and hunger,' which is closely related to food production through agriculture. The number of undernourished people, while increasing overall, has decreased as a proportion of population. However, while food per capita is increasing, a large gap between regions remains. Goals related to soil fertility, rate of soil loss, land use and land cover change are not showing significant progress.

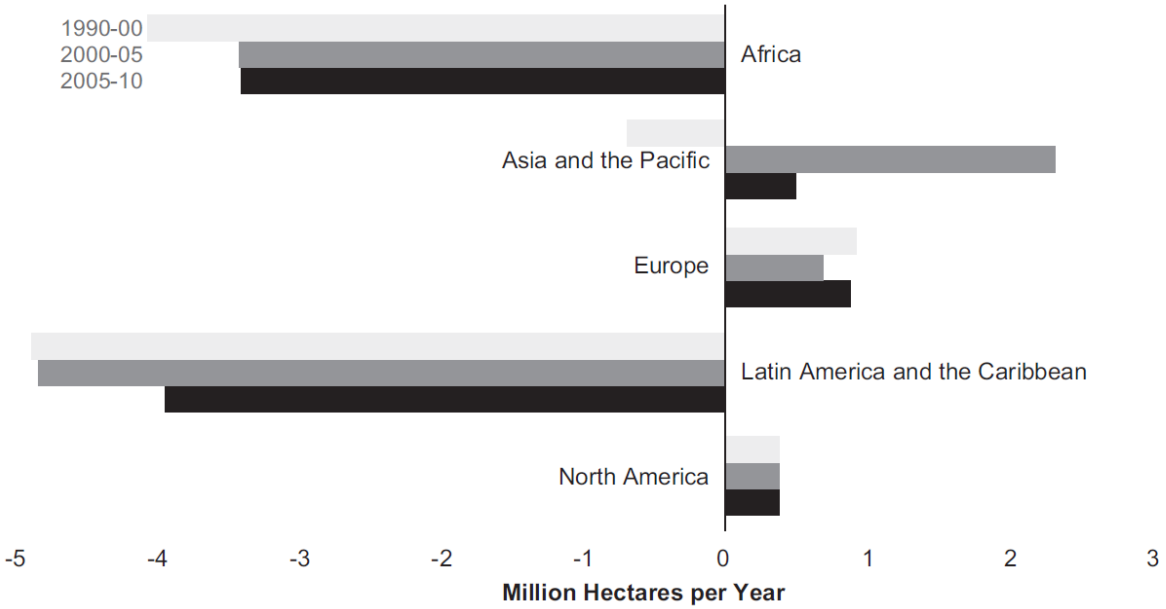

Figure 2.4. Change in forest area by region, FAO 2010.

Overall, competing demands for land make conservation increasingly difficult, with deforestation rates still dangerously high (mostly in the tropics) despite a slight decrease or even forest regrowth in the northern hemisphere (Figure 4). The GEO-5 analysis revealed the need to acknowledge the interactions between different components of social and ecological systems at different scales, emphasizing the fact that goals cannot be considered independently of each other. Also, the analysis of land related goals found that many important issues are not reflected in the current landscape of international goals. For example, there are no land-related goals or targets that reflect the unique vulnerabilities and challenges that exist in polar areas. Issues of capacity building and stakeholder participation are also inadequately represented in international goals. At the same time, several of the land-related goals that do exist lack quantifiable targets, complicating the task of assessing progress towards their achievement.

2.3.3 Water

Of the 30 environmental goals and objectives examined in relation to water in the GEO-5 assessment, only one goal shows 'significant progress', 12 goals are represented by 'some progress', there are four goals for which 'very little to no progress' has been achieved, and seven goals for which there is

'further deterioration'. The world is currently on track to achieve the MDG target of providing 87% of the global population with access to an improved water supply by 2015. Despite this achievement, more than 1 in 10 people (800 million) will still be without access to improved water sources in 2015, and 3.5 million people still die each year from water-related diseases. Over 2.5 billion people still lack access to improved sanitation, and the MDG goal for improved sanitation by 2015 appears to be out of reach. Much remains to be done in vulnerable rural communities, especially in Africa and South Asia, which require solutions different from those for urban communities, including increased use of ecosystems for water purification. It is estimated that $72 billion is required in developing countries annually to meet the MDG target 10 on water supply and sanitation.

There has been very little or no progress in improving water security and equitable access to water. Against a background of continuing degradation and over-exploitation of water resources, the need for sustainable water supplies remains one of humanity's most critical resource needs (Figure 2.5). There has also been little progress in reducing nutrient loads to freshwaters and coastal areas, or towards effective governance of areas beyond national jurisdictions, such as on the high seas. Furthermore, global scale monitoring of water quality, quantity, and ecosystem health has been reduced. As a result, there are increasing uncertainties associated with assessing the water environment, due both to data gaps and the rapidly-changing nature of water issues, including those related to climate change. The complexity of the drivers and associated pressures on the water environment is a key barrier to attaining internationally agreed goals. Lack of quantifiable targets for many environmental, socioeconomic and governance goals makes assessment of progress towards achieving water-related goals and sustainable ecosystems especially challenging. Other barriers include inadequate capacity, limited access to technology and funding, and information and data gaps.

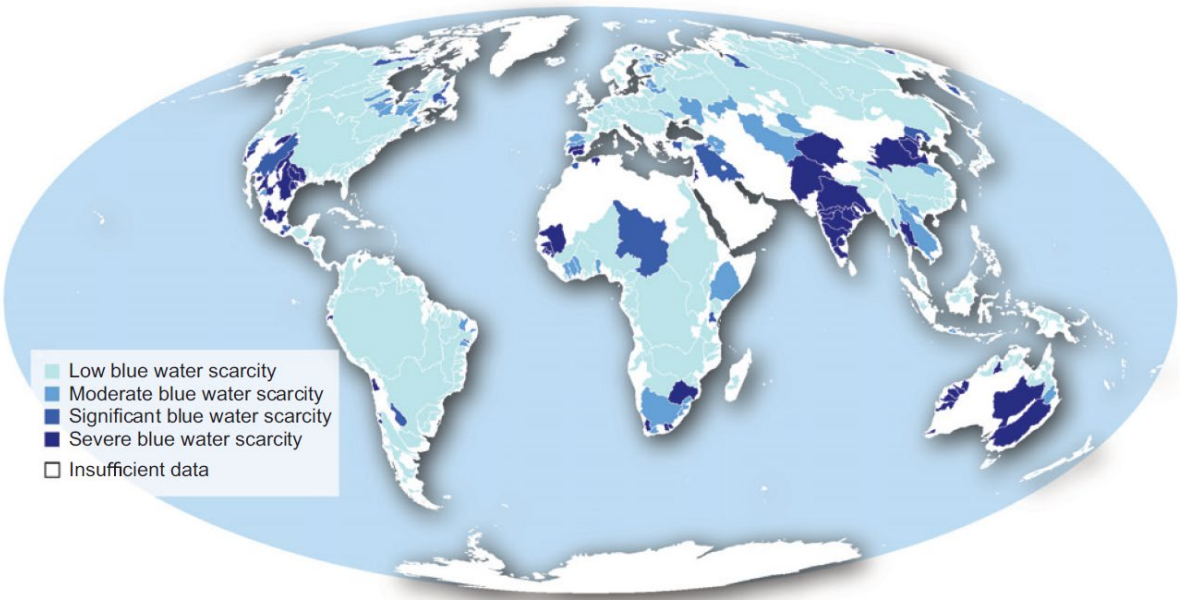

Figure 2.5. Annual average water scarcity in major river basins, 1996–2005. *Note: The annual average is calculated from monthly values (Adapted from Hoekstra and Mekonnen, 2011).*

2.3.4 Biodiversity

Internationally agreed goals related to biodiversity issues include those relating to habitat loss and degradation, fish stock, invasive alien species, extinction risk of species, sustainably managed

production areas, protected area, equitable use of natural resources, and access and benefits sharing, and traditional knowledge. Of the 19 internationally agreed biodiversity goals and objectives examined in GEO-5, ten goals show 'little to no progress'. Although there has been much global interest in halting the loss and degradation of biodiversity, there has not been much success. The overall outlook reveals little evidence of improvement; biodiversity loss continues at a dangerous rate (Figure 2.6). At the species level, current trajectories indicate that even more species are threatened by extinction, with extinction ranges from 13– 63% and averaging almost 20% for vertebrates. The levels of threat are increasing fastest for corals—where the global decline of coral reefs since 1980 is nearly 38%. The condition and extent of natural habitats continue to decline, with some areas experiencing declines of 20% or more since 1980. The proportion of overexploited, depleted or recovering marine fish stocks has more than tripled between 1974 and 2008.

There is a general increase in the pressure from pollutants although some progress is seen in the reduction of pressure from certain pollutants in some regions. There are also detectable trends in the impacts of climate change that include increasing disruption in phenology, abundance, distribution, and community composition in all ecosystems.

Areas where goals are being partially met include: increases in the designation of protected areas (now covering nearly 13% of land area, but less than 1.5% of marine area); increasing recognition of indigenous community managed areas; adoption of policies and actions for managing invasive alien species and genetically modified organisms, regulating sustainable harvests and reducing pollution; specific cases of species recoveries and habitat restoration. There is also some progress towards enhancing the equitable access and benefit sharing of genetic resources.

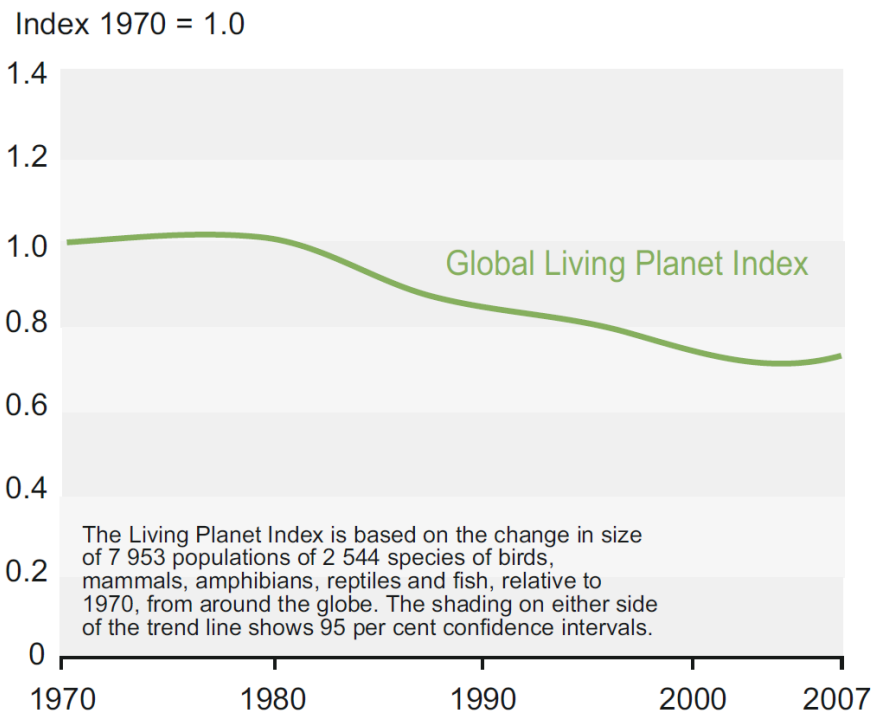

Figure 2.6. Global Living Planet index based on the change in size of 7953 populations of 2544 species of birds, mammals, amphibians, reptiles and fish, relative to 1970, from around the globe. *Note: Dotted lines show 95% confidence intervals (Loh, 2010).*

2.3.5 Chemicals and Waste

Internationally agreed goals related to chemicals and waste include those relating to protection of marine environments, control of persistent organic pollutants, shared responsibility and cooperation related to the international trade of hazardous chemicals, approaches to managing radioactive wastes, and technical and capacity support for countries in need. Of the 23 goals and objectives related to chemicals and waste analyzed in the GEO-5 assessment, significant progress was made in the achievement of only one goal: improving research to prevent, eliminate and reduce pollution of the marine environment. There were 11 goals for which some progress has been observed and three goals for which there is very little or no progress. The remaining eight goals could not be properly assessed due to insufficient information.

Where better management of toxic and other hazardous chemicals is needed, the lack of information is of paramount concern. While there is a growing body of scientific knowledge on the impacts of chemicals and wastes on humans and the environment, this knowledge remains incomplete and in some cases seriously lacking due to limited data and information on uses, emissions, exposure pathways and effects of chemicals mixtures. The results suggest that long-term monitoring programs for persistent organic pollutants in environmental media and human tissue need to be maintained and expanded, particularly in the southern hemisphere. These initiatives are essential for a better understanding of the time trends of global chemical pollution and for the effectiveness evaluation of the Stockholm Convention on persistent organic pollutants. In addition to scientific knowledge gaps, sound chemicals and waste management is also hampered by the lack of resources, capacity, and compliance monitoring, as well as the lack of education and training on the appropriate management of chemicals and wastes in many developing countries. Furthermore, increased trade resulting from free trade agreements is complicating this picture as it may well exert even more pressure on emerging economies with respect to regulating or restricting chemical use.

Table 2.2. Summary of progress toward environmental goals.

	Deterioration	Very little to no progress	Some progress	Significant progress	Insufficient data	Too soon to assess	**Total**
Atmosphere	0	2	5	2	0	0	**9**
Land	0	5	4	0	0	0	**9**
Water	7	4	12	1	6	0	**30**
Biodiversity	0	10	8	0	1	0	**19**
Chemicals & waste	0	3	11	1	7	1	**23**
Total	**7**	**24**	**40**	**4**	**14**	**1**	**90**

Results of GEO-5 thematic chapters in assessing progress toward selected environmental goals and objectives based on the latest available data

2.4 Discussion: challenges in meeting internationally agreed goals

Building on the analysis from GEO-5 presented above, the following sections discuss key obstacles that have hindered the achievement of internationally agreed environmental goals. These can be considered as a series of mismatches or discontinuities that interfere with adopting the integrated approaches, long-term perspectives and collaborative actions that would be needed to attain these goals. The analysis of the combined effect of these mismatches can help us understand the limitations of current approaches to meet internationally agreed goals.

2.4.1 Focus on economic priorities over environmental ones in the operationalization of development

The continuous search for economic growth has dominated international, national, and local development agendas. Policies have been oriented to support economic growth and governments have shifted from a managerial to an entrepreneurial orientation often neglecting environmental priorities (Jackson, 2009a, b). The mismatch between economic and environmental priorities is one of the elements that help in understanding the pace and scale of global environmental change. In the view of some scholars, this change is challenging the resilience of the earth system and the ability to maintain livelihoods and support human development (Rockström et al., 2009; Steffen et al., 2011).

Despite international attention given to sustainable development since 1992 as a normative concept seeking to balance – and ideally, integrate – economic, social, and environmental priorities, 20 years later that attention has diluted and societies are in search of new paradigms to improve their interactions with the environment. There have been positive contributions to improving the balance between economic and environmental priorities (Pearce and Turner, 1990; Cropper and Oates, 1992; Pearce and Atkinson, 1993; Daly and Cobb, 1994; Hawken, 1994; Ayres, 1996; Ayres and Ayres, 1996; Stahel, 1997, 2006; Ostrom et al., 1999; MA, 2005; Cato, 2009; Kumar, 2010). For example, the emergence of environmental economics as a subdiscipline seeking to provide an economic value to environmental considerations, ecological economics as an effort to address the interactions between economic systems and ecosystems over time and space, and the Millennium Ecosystem Assessment raising awareness of the importance and value of ecosystem services, are positive steps in this direction. More recently, the OECD's Measuring the Progress of Societies initiative (Hall et al., 2010) and UNEP's Green Economy Initiative (UNEP 2011b) have stimulated important discussion on the development of environmental and social indicators and aggregate indices to complement GDP and traditional national accounts that are now beginning to be applied.

Despite these and other contributions, environmental concerns continue to be subordinated to economic growth in national and local development plans, policies, and strategies. At the same time, the implementation of MEAs is constrained by limited political will, the dominance of free trade ideology, economic and financial crises, and the still embryonic emergence of new governance approaches to foster sustainable development processes.

2.4.2 Types of problems vs. types of responses

Responses to sustainability challenges are often not well matched to the kinds of problems that these challenges represent. This mismatch has two dimensions: (1) response strategies do not sufficiently address the complexity of the problems; and (2) problems and solutions frequently play out over different spatial, temporal and jurisdictional scales while cross-scale interactions are not adequately considered.

Zaccai (2012) describes how the types of ''iconic'' issues dominating the international environmental governance agenda have changed over time. In the 1980s and 1990s an emphasis on pollution and waste problems meant that it was relatively easy to define the source of the problem and design corrective action. In contrast, challenges currently considered as most urgent are more complex and diffuse issues such as climate change and biodiversity loss (Zaccai, 2012). One consequence of this shift is that strategies that led to past successes in controlling specific pollutants, such as ozone

depleting substances or lead in gasoline, are not as applicable to issues with more dynamic patterns of causality and interactions between drivers.

For some issues, the changing nature of environmental problems means that responses are absent altogether. One such area where strategies are lacking involves anticipating and handling the non-linear changes associated with tipping points, another, concerns addressing the unique challenges presented by emerging technologies (Biermann et al., 2012). The mismatch between problems and strategies extends to issues of scale in environmental governance.

Tensions between problems and responses are evident on temporal, spatial and jurisdictional scales (Hisschemöller and Gupta, 1999; Cash et al., 2006; Nilsson and Persson, 2012). Regarding temporal scales, governments and private sector actors tend to be driven by short-term electoral or financial cycles, giving them little incentive to act on problems that are expected to unfold over long time periods (Cash et al., 2006). At the same time, ''slow-motion'' responses are not keeping up with quickly changing biophysical and socio-economic processes.

The alignment of spatial and jurisdictional levels, particularly for transboundary environmental problems, tends to be poor. In terms of jurisdictions, top-down and bottom-up responses are generally not well connected. Much of the work on multilateral environmental agreements has taken the form of a global, top-down approach. There has been relatively little attempt to link efforts at the local, national and international levels, in terms of both information about impacts and compliance. A decentralization of power in many parts of the world has occurred without the creation of clear links between the different levels of government and international bodies (Dodds, 2002), and to a large extent without changing the existing patterns of influence by centralized actors (Young, 2006).

Economic globalization and its accompanying influence on transnational corporations since the 1992 Rio Earth Summit has produced a challenge for environmental governance across jurisdictional levels. While regulation on companies' behaviour to control negative impacts on the environment may be acceptable at a national level, at a global level it is incredibly challenging to regulate industrial activities in the name of environmental protection (Dodds, 2002). Integration across jurisdictional levels is discussed further in the section on the fragmentation of governance below (Section 2.4.5).

2.4.3 Responsibilities vs. resources of environmental institutions

Environmental institutions at different levels are expected to bear great responsibility for implementing agreements. This is, however, out of proportion to the level of power, resources and in some cases capacity that these institutions often have. Global institutions that are working to promote sustainability face challenges related to authority and coordination, while at the national level, ministries of the environment frequently lack the capacity and clout needed to fully engage in the implementation of environmental agreements.

One of the two main themes for the Rio+20 Earth Summit is the 'institutional framework for sustainable development'. This primarily refers to the system of global governance for sustainable development, which includes the global institutions charged with developing, monitoring and implementing policies on sustainable development across its three pillars—social, environmental and economic (Young, 2010). The two main institutions governing sustainable development at the global level are the United Nations Environment Programme (UNEP), established in 1972 because of the

Stockholm Conference, and the Commission on Sustainable Development (CSD), created in 1992 to ensure effective follow-up to the Rio Earth Summit. Many attempts have been made to clarify the roles and relationships between and among the CSD, UNEP, the UN Development Programme, and other UN programmes and agencies (Roch and Perrez, 2005), as well as the various other mechanisms within the UN such as the Inter-Agency Committee on Sustainable Development; the interagency mechanisms of UN Oceans, UN Water, and UN Energy; and the Environmental Management Group (UNCSD, 2011).

A considerable amount of analysis has assessed the effectiveness of global governance for sustainable development, not all of it favorable. Many stress that the failure to halt or reverse global environmental degradation is evidence of the inherent adequacies of the global governance system (Oberthöur and Stokke, 2011; Galaz et al., 2012). Due to its limited mandate and status as a UN 'Programme' rather than a Specialized Agency, UNEP has lacked the necessary authority to mainstream environmental considerations throughout the UN system. There has also been a certain overlap of scope and mandate between the CSD and UNEP, encouraging competition rather than collaboration, yet with neither possessing the necessary status to accelerate the required global changes to achieve sustainable development (Andresen, 2007a; Biermann, 2011).

Discussion and debate about the reform of International Environmental Governance in the context of Global Governance for Sustainable Development is ongoing (Ivanova, 2007; Ivanova et al., 2007; Ellyard, 2011; Ivanova, 2011; HLPGS, 2011a,b,c; Biermann et al., 2012; Andonova and Hoffmann, 2012; Ivanova, 2012; UNCSD, 2012; Zaccai, 2012; UNEP, 2012a). Since the World Summit on Sustainable Development (WSSD) in 2002, little progress has been made in relation to the required institutional architecture that would propel global environmental and sustainable development issues into the 21st century. While the World Summit on Sustainable Development heralded a new era of action-orientated 'partnerships' for sustainable development, it is recognized that despite the considerable success of some of these partnership programmes, they have not delivered the systemic change needed in global governance. It is therefore hoped that the focus on 'the institutional architecture for sustainable development' for Rio+20 presents an unprecedented opportunity to spur progress towards a more effective global system for delivering sustainable development objectives (Biermann et al., 2012).

2.4.4 Country Capacity

In the Millennium Report, the Secretary-General of the United Nations highlighted that ''Support for the rule of law would be enhanced if countries signed and ratified international treaties and conventions'', but that many countries are unable to engage effectively owing to ''the lack of institutional capacity and resources'' (UN, 2011). The lack of sufficient capacity and authority of environmental ministries in most countries hinders the effective implementation of global policy instruments at the national level and prevents countries from seizing the constructive opportunities that international mechanisms can provide.

States, especially developing countries, struggle to meet institutional demands as the number of institutions increases. Participation in global environmental governance represents a challenge as countries use scarce resources to participate in negotiations and meetings, and to satisfy reporting requirements and other MEA demands. Overstretched human and financial resources needed for global governance leave developing countries with fewer resources for implementation or the

mitigation of environmental threats of most concern to them. For example, harmonizing national reporting on biodiversity-related conventions has been pursued, but this has been difficult, and given the structure of the ‘‘harmonized’’ process, it remains unclear exactly how it improves the implementation of conventions at the national level or saves national resources (Najam et al., 2006).

Many instruments have failed to develop implementation mechanisms that consider the different capacity level of countries. Countries at different levels of development require different kinds of institutional support and financial and technical assistance to implement convention obligations. This aspect has been increasingly recognized as important, and in recently negotiated instruments the linkage between assistance by developed countries and compliance by developing countries and countries in economic transition has been more strongly stated. For example, the Stockholm Convention on Persistent Organic Pollutants Article 12 on technical assistance states that ‘‘The Parties recognize that rendering of timely and appropriate technical assistance in response to requests from developing country Parties and Parties with economies in transition is essential to the successful implementation of this Convention’’.

Access to a proper funding mechanism under a convention has a direct impact on its implementation; conventions with a dedicated financial mechanism tend to be more successful than others. The Montreal Protocol on ozone depleting substances, one of the most successful agreements to date, has its own Trust fund, which provides support to developing countries and countries in economic transition at both institutional and industrial investment levels. Four other MEAs (the Convention on Biological Diversity, the UN Framework Convention on Climate Change, the UN Convention to Combat Desertification and the Stockholm Convention on Persistent Organic Pollutants) use the Global Environment Facility (GEF) as a financial mechanism and experience some degree of implementation, which paves the way to success. The Ramsar Convention of Wetlands of International Importance has established three targeted funding mechanisms to assist Parties in implementing the convention: (1) a Small Grants Fund for Wetland Conservation and Wise Use (a global program), (2) Wetlands for the Future (a program for Latin America and the Caribbean), and (3) the Swiss Grant Fund for Africa. In addition, private sources and bilateral donors frequently provide financial resources to protect and manage wetlands. These funding mechanisms can help to address shortfalls in capacity for environmental governance at the country level and increase the chances that environmental agreements will be successfully implemented.

2.4.5 Disconnect between science and policy

The science-policy interface in the field of international environmental governance reveals a fundamental mismatch between the empirical evidence for a call to action on environmental issues by the science community and the inertia of environmental policy-making processes. As demonstrated in numerous ongoing intergovernmental negotiations (e.g., the UNFCCC process), the challenge of transforming the near-consensus recommendations from science into practical policies and actions is formidable.

The scientific community has created significant contributions improving the state of knowledge about global environmental change. Yet only a fraction of that knowledge is used in the design of policies and strategies to address international, regional, and local environmental problems. The science and policy communities operate with different cultures, interests, ideologies, expectations, and time-scales, and communication between them is often scarce, fragile or inexistent. Better knowledge of

global environmental problems has not fostered more effective MEAs or better national and local environmental strategies and policies.

A vast body of literature and experience demonstrates that there is no clear, natural or easy fit between the world of science and that of environmental decision-making processes, or more precisely, policy (Sarewitz and Pielke, 2007; Young, 2008; National Research Council (NRC) 2009; UNEP 2011b). However, concerns about the role of science in the study of global environmental change have fostered fresh ideas for reducing the divide between science and policy/practice. These efforts recognize the need to transcend disciplinary boundaries and reductionist and positivist approaches to science for a new approach to the generation of knowledge that includes a balanced and dynamic participation of stakeholders (Dietz et al., 2003; Robertson and Hull, 2003; Bammer, 2005, 2008; Næss et al., 2006; Roux et al., 2006; Turnhout et al., 2007; Huitemaa and Turnhoutb, 2009; Rosa et al., 2010). Although there are encouraging initiatives illustrating the benefits of a close collaboration between the scientific and policy communities (for example in building climate change mitigation and adaptation actions in some urban areas), much remains to be done to make a broader use of available knowledge in addressing global environmental change.

The proliferation of environmental agreements has contributed to an increasingly fragmented landscape of governance institutions and proposed solutions which has arguably become as daunting a challenge as the problems that the solutions were designed to address (Najam et al., 2006; Andresen, 2007b; Kanie, 2007; Bernstein and Pauly, 2008; Biermann et al., 2009; Zelli et al., 2011). When negotiating existing agreements, there was little recognition of relationships between the different areas. Instead, an atmosphere of competition – for funds, staff, and attention – was in some instances even encouraged. This has resulted in considerable fragmentation of the sustainability agenda (Dodds, 2002; Zelli, 2011). Most of the new agreements have established independent bureaucracies and this proliferation has dispersed authority in international environmental governance.

The fragmentation of environmental institutions not only relates to issues of geographical dispersion, but also to such problems as inconsistency of norms and rules, and of differing political and normative contexts. Fragmentation thus relates to discrepancies and overlaps between the agendas of thematically equivalent regional and world-wide bodies as much as it relates to problems of duplication of work between global institutions with very different agendas (Knigge et al., 2005).

Although the establishment of environmental agreements and institutions is to be welcomed, it has become increasingly clear in recent years that the plethora of instruments and actors concerned with environmental protection gives rise to problems of governance. While governments may often agree with the principles promoted in the agreements and have the good will and desire to implement their obligations, the reality has been that many have felt overwhelmed by the multiplicity of obligations they have incurred under multilateral environmental agreements. Not surprisingly, in many countries with limited international policy capacity, this multitude of forums has hampered implementation.

Synergy can be achieved through strengthening cooperation between institutions and administrations involved in implementation and enforcement, development of coordinated legislation, improved information provision and exchange between Secretariats, governments, industry and civil society, coordination among focal points in monitoring and enforcement, coordinated capacity building and trainings. One recent effort to achieve synergy between MEAs was implemented in 2010 by the three Conventions (Basel, Rotterdam and Stockholm Conventions) that promote sound management of

hazardous chemicals and wastes under the auspices of UNEP. The process aims to strengthen ties between the conventions, and better target resources for chemicals and waste management on regional and national level. It is anticipated that this joint effort will lead to enhanced implementation of the Conventions and compliance by Parties.

2.4.6 Complex systems vs. measurability of outcomes

Those environmental agreements for which specific, numerical targets were set have been relatively successful. Already in the 1960s, for example, the World Commission on Protected Areas (WCPA) set a target of 10% of global land area to be designated as formally protected; today, nearly 13% of the world's surface has been set aside as protected. Similarly, the Montreal Protocol on Substances that Deplete the Ozone Layer defines mandatory targets and specific timeframes within which the required reductions must be met and it conducts regular reviews of phase-outs in accordance with scientific updates. It is critical to have baseline information to allow progress towards the targets to be tracked. One of the obstacles to achieving environmental goals in many cases is the lack of sufficient data and monitoring systems to measure progress. Every GEO-5 author team noted the lack of availability of basic data sets. Even when data is available, analysis and interpretation within appropriate contexts are often lacking.

Relatively little measurable progress has been made – or can be demonstrated – towards the WSSD target to ''reverse the loss of biodiversity by 2010'', where there is no reliable baseline information on the amount of biodiversity on which to base trends and assess progress. More recently the Nagoya targets set under the Convention of Biological Diversity also have no clear numerical goals. When specific quantitative goals are absent, targets may read more like recommendations. When goals incorporate numerical levels or values, the required achievement is more clearly defined and potentially obtainable. In fact, empirical evidence shows that goal-setting can work when clear quantitative targets are set (UNEP, 2012a; UNEP, 2011c).

However, the presence of clear and quantified targets is no guarantee of success. Climate change mitigation has had numerical targets for many years in the form of greenhouse gas emission reductions spelled out in the Kyoto Protocol, but the clear majority of countries that adopted these legally binding targets have not come close to meeting them. This example highlights another lesson learned from the history of environmental target-setting: that it works best for well-defined issues, such as the phasing out of Ozone Depleting Substances or leaded gasoline, and for issues related to industrial chemicals for which technologies exist or can be developed. In other words, the nature of environmental problems themselves influences how easily they can be governed using international goals and strategies. Since efforts to reduce greenhouse gas emissions rely on changing energy and land use patterns that are deeply embedded, pervade many human activities and for which a technological substitution is not always readily available, numerical targets alone have not been enough to motivate action to the level of goal achievement on this issue.

Compliance and verification tools

Few of the Multilateral Environmental Agreements (MEAs) have specific compliance mechanisms, and even the ones that exist are relatively weak, as few countries are prepared to submit themselves to an independent review of compliance with convention requirements.

There is a lack of support for countries to create the adequate laws, or to set up proper verification mechanisms for the enforcement of MEAs. Enactment of agreements depends on 'political will' by countries to do their 'best'. This does not work in most cases. Even if it is possible to show that a country has not complied it is unlikely that the convention secretariat will call them to account. The principle pressure comes from those stakeholders who can use the media or publish reports, which embarrass countries in front of their peer group. There are mechanisms outside the environment sector that have formalized this (e.g., CEDAW). The situation will only change if the environmental conventions develop legally binding agreements on compliance that can be enforced internationally with proper sanctions—a 'rules-based governance' system.

Assessing the effectiveness of international environmental agreements requires verification of compliance, agreements that are verifiable being more likely to succeed than others. The process of verification builds confidence and improves the prospects for future cooperation. Verification produces information that can provide the technical basis for future agreements and shared understanding as well as the basis for sanctions. MEAs recognize the importance of this process and many employ some form of implementation review in which the performance of governments in implementing their commitments is evaluated. The reviews however use different methods, ranging from loose compilation of national reports to stricter compliance mechanisms, based on monitoring, reporting, and assessing environmental and socio-economic statistical data.

The ''non-compliance'' provisions have been difficult to get agreement on in MEAs negotiations and have often remained inconclusive or weak, excluding formal arbitration mechanisms. In the absence of enforcement mechanism, governments in both the industrial and developing world can evade responsibility for the environmental consequences of their actions. The less rigorous national reporting in place for most MEAs is usually performed through gathering and distribution of national reports by the relevant secretariat, with little or no analysis.

The Montreal Protocol and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) contain the most extensive and formalized review institutions and the Convention on Migratory Species and the Convention to Combat Desertification the least. The first two agreements are often cited as the most successful ones (Raustiala, 2001).

Newer MEAs exhibit a greater tendency toward the development of review processes, and there is evidence that review mechanisms are most developed where MEA commitments are most specific. The Stockholm Convention on Persistent Organic Pollutants includes a provision for effectiveness evaluation of the convention, which encompasses a global monitoring program of POPs in the environment. The UNFCCC has also begun with the negotiation of the Kyoto Protocol to create more specific, concrete commitments and is now beginning to establish the institutions necessary to review compliance with them.

One of the interesting findings of GEO-5 suggests a tendency in the last twenty years for some environmental agreements to use trade mechanisms to ensure compliance. Two such treaties are the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer and the 1991 Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal. In some cases, individual nations have tried to enforce their environmental standards using trade sanctions (e.g., the U.S. embargo on tuna products from Mexico). Some authors consider this could provide an argument for stronger enforcement for future conventions (Dodds, 2002). However, other authors doubt trade

sanctions would result in environmental benefits (Muradian and Martinez-Alier, 2001; Yu et al., 2002). Despite the attention provided to interactions between trade and the MEAs during the last decade, there is still need for a broader understanding of this complex relationship. This is particularly relevant considering current efforts to create more efficient approaches to address global environmental change.

2.5 Conclusions

In the 40 years between Stockholm and Rio+20, environmental concerns have been identified, solutions drafted and commitments made many times over. In May 2011, IUCN President Ashok Khosla stated that Rio+20 needs to review 40 years of unfulfilled commitments and explore genuine alternatives to current practices. Such unfulfilled commitments are reflected in a deterioration of environmental conditions in many areas including climate change, biodiversity loss and disruptions to the nitrogen cycle, all of which carry a risk of irreversible changes.

In its analysis, GEO-5 demonstrates that the international community has, over the past 40 years, typically concentrated on reducing pressures, the symptoms of degradation. There are, however, compelling reasons to take a fresh look at the fundamental drivers of environmental change as an appropriate focus in redefining the approach to address persistent environmental problems. The analysis of biophysical trends in GEO-5 helps connect these problems with the limited success so far in achieving internationally agreed environmental goals.

The analysis presented in this paper reiterates the clear need for improved policy responses. It finds that several critical mismatches are impeding the achievement of environmental goals. Improving this situation is likely to require considerable transformations, not only in thinking, but in the ways people live their lives. Moving on to such a path will require substantial political leadership combined with the application of adaptive approaches in governance - at every level from the local to the global. Redefining the approach to addressing global environmental problems should also consider how internationally agreed goals are defined, how closely they match environmental and social needs, and how they could be updated to reflect dynamic changes in biophysical and social processes.

A new approach could focus on a realistic number of goals that can be monitored and encourage the development of enforcement mechanisms to increase the number of countries meeting them. International organizations (the UN family, GEF, The World Bank and others) can play a key role in creating new approaches for addressing global environmental change. Closing the gap between the science and policy communities will be a crucial step in helping to define new patterns of green growth and opportunities for sustainable development.

Overcoming the obstacles outlined here is both the opportunity and the challenge for Rio+20. This will require achieving an improved understanding of the transformations needed to tackle the fundamental drivers of environmental change, mobilizing the necessary political will, and identifying, targeting and coordinating the resources needed to begin the process of transformational change. The cost of inaction is high, the global environment and the people who depend on it cannot wait another 40 years before decisive and coordinated action is taken.

2.6 References

Andonova, L.B., Hoffmann, M.J., 2012. From Rio to Rio and beyond: innovation in global environmental governance. *Journal of Environment and Development* 21 (1), 57–61.

Andresen, S., 2007a. The effectiveness of UN environmental institutions. international Environmental Agreements: Politics, *Law and Economics* 7 (4), 317–336.

Andresen, S., 2007b. Key actors in UN environmental Governance: influence, reform and leadership. International Environmental Agreements: Politics, *Law and Economics* 7 (4), 457–468.

Ayres, R.U., 1996. Limits to the growth paradigm. *Ecological Economics* 19 (2), 117–134.

Ayres, R.U., Ayres, L.W., 1996. Industrial Ecology: Towards Closing the Materials Cycle. Edward Elgar, Cheltenham, UK.

Bammer, G., 2005. Integration and implementation sciences: Building a new specialization. *Ecology and Society* 10 (6), 6.

Bammer, G., 2008. Enhancing research collaborations: Three key management challenges. *Research Policy* 37 (5), 875–887.

Bernstein, S. and Pauly, L.W. (Eds), 2008. Global Liberalism and Political Order: Toward a New Grand Compromise? SUNY series in Global Politics. State University of New York Press.

Biermann F., Abbott, K., Andresen, S., B¨ackstrand, K., Bernstein, S., Betsill,M.M., Bulkeley, H., Cashore, B., Clapp, J., Folke, C., Gupta, A., Gupta, J., Haas, P.M., Jordan,M., Kanie, N., Kluva´nkova´ -Oravska´, T., Lebel, L., Liverman, D.,Meadowcroft, J., Mitchell, R.B., Newell, P.,Oberth¨ur, S., Olsson, L., Pattberg, P., Sa´nchez-Rodrı´guez, R., Schroeder, H., Underdal, A., Vieira, S.C., Vogel, C., Young, O.R., Brock, A., Zondervan, R., 2012. Transforming Governance and Institutions for Global Sustainability: Key Insights from the Earth System Governance Project, Current Opinion in Environmental Sustainability, http://dx.doi.org/10.1016/j.cosust.2012.01.014.

Biermann, F., 2011. Reforming global Environmental Governance: The Case for a United Nations Environment Organisation (UNEO), Stakeholder Forum, Feb. 2011.

Biermann, F., Pattberg, P., van Asselt, H., Zelli, F., 2009. The fragmentation of global governance architectures: a framework for analysis. *Global Environmental Politics* 9, 14–40.

Biermann, F., 2007. Reforming global environmental governance: from UNEP towards a world environment organization', in lydia swart and estelle. In: Perry (Ed.), Global Environmental Governance: Perspectives on the Current Debate. Center for UN Reform Education, New York.

Brundtland, G., 1987. Our Common Future: The World Commission on Environment and Development. Oxford University Press, Oxford.

Butchart, S.H.M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J.P.W., Almond, R.E.A, Baillie, J.E.M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K.E., Carr, G.M., Chanson, J, Chenery, A.M., Csirke, J., Davidson, N.C., Dentener, F., Foster, M., Galli, A., Galloway, J.N., Genovesi, P., Gregory, R.D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M.A., McRae, L., Minasyan, A., Hernández Morcillo, M., Oldfield, T.E.E., Pauly, D., Quader, S., Revenga, C., Sauer, J.R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S.N., Symes, A., Tierney, M., Tyrrell, T.D., Vie, J.-C., Watson, R., 2010. Global biodiversity: indicators of recent declines. *Science* 328 (5892), 1164–1168.

Cash, D.W., Adger, W., Berkes, F., Garden, P., Lebel, L., Olsson, P., Pritchard, L., Young., O., 2006. Scale and cross-scale dynamics: governance and information in a multilevel world. *Ecology and Societ*y 11 (2), 8.

Cato, M.S., 2009. Green Economics: An Introduction to Theory, Policy and Practice. Earthscan, London.

Cropper, M.L., Oates, W.E., 1992. Environmental economics: a survey. *Journal of Economic Literature* 30 (2), 675–740.

Daly, H.E., Cobb, J.B., 1994. For the Common Good: Redirecting the Economy toward Community, the Environment, and a Sustainable Future. Beacon Press, Boston.

Demaret, P., 1995. The metamorphoses of the GATT: from the Havana charter to the world trade organization. *Columbia Journal of Transnational Law* 34, 123.

Dietz, T., Ostrom, E., Stern., P.C., 2003. The struggle to govern the commons. *Science* 302 (5652), 1907–1912, http://dx.doi.org/10. 1126/science.1091015.

Dodds, F., 2002. Interlinkages Among Multilateral Environmental Agreements. United Nations University, Tokyo.

ECOLEX, 2012. The gateway to environmental law. Rome. http://www.ecolex.org

Ellyard, P., 2011. Designing 2050: imagining and building a global sustainable society. *Journal of Future Studies* 15, 3.

Fabry, V.J., Seibel, B.A., Feely, R.A., Orr, J.C., 2008. Impacts of ocean acidification on marine fauna and ecosystem processes. *ICES Journal of Marine Science* 65, 414–432.

FAO, 2010. Global Forest Resources Assessment 2010. FAO Forestry Paper No. 163. Food and Agriculture Organization of the United Nations, Rome.

Galaz, V., Biermann, F., Crona, B., Loorbach, D., Folke, C., Olsson,P., Nilsson,M., Allouche, J., Persson, A., Reischl, G., 2012. 'Planetary boundaries'—exploring the challenges for global environmental governance. *Current Opinion in Environmental Sustainability* 4(1),80–87.

Hall, J., Giovanni, E., Morrone, A., Ranuzzi, G., 2010. A Framework to Measure the Progress of Societies. Organisation for Economic Co-operation and Development (OECD), Paris.

Hisschemöller, M., Gupta, J., 1999. Problem-solving through international environmental agreements: the issue of regime effectiveness. *International Political Science Review* 20, 2.

HLPGS, 2011a. Sustainable development for Brundtland to Rio+20: Background Paper. http://www.un.org/wcm/content/site/climatechange/pages/gsp/documents_1.

HLPGS, 2011b. Input to the High-level Panel on Global Sustainability: Paradigms. http://www.un.org/wcm/content/site/ climatechange/pages/gsp/documents_1S.

HLPGS, 2011c. NGLS Summary Report: Civil Society Consultation Conducted for the Global Sustainability Panel. www. un.org/wcm/content/site/climatechange/pages/gsp/documents_1S

Hoekman, B.M., Kostecki., M.M., 1995. The Political Economy of the World Trading System: From GATT to WTO. Oxford University Press, New York.

Hoekstra, A.Y., Mekonnen, M.M., 2011. Global Water Scarcity: Monthly Blue Water Footprint Compared to Blue Water Availability for the World's Major River Basins. Value of Water Research Report Series No. 53. UNESCO-IHE, Delft.

IPCC, 2007. Climate change 2007: impacts. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK, pp. 976.

Ivanova, M., 2007. Designing the United Nations Environment Programme: a story of compromise and confrontation. *International Environmental Agreements* 7, 4.

Ivanova, M., 2011. Financing Environmental Governance: Lessons from the United Nations Environment Programme. Governance and Sustainability Issue Brief Series: Brief 1. Center for Governance and Sustainability, University of Massachusetts Boston, Boston.

Ivanova, M., 2012. Institutional design and UNEP reform: historical insights on form, function and financing. *International Affairs* 88 (3), 565–584.

Ivanova, M., Gordon, D., Roy, J., 2007. Towards institutional symbiosis: business and the United Nations *In* Environmental Governance. *Review of European Community and International Environmental Law* (RECIEL) 16, 2.

Hawken, P., 1994. The Ecology of Commerce: A Declaration of Sustainability. Harper Collins, NewYork.

Huitemaa, D. and Turnhoutb, E., 2009. Working at the science—policy interface: a discursive analysis of boundary work at the Netherlands Environmental Assessment Agency. *Environmental Politics* 18(4),576–594. http://dx.doi.org/10.1080/ 09644010903007427.

Jackson, J.H.., 1997. The World Trading System: Law and Policy of International Economic Relations, 2nd ed. MIT Press, Cambridge, MA 1997.

Jackson, T., 2009a. Prosperity without growth? The Transition to a Sustainable Economy. Sustainable Development Commission, London.

Jackson, T., 2009b. Prosperity without growth? Economics for a finite planet. Earthscan, London.

Kanie, N., 2007. Governance with Multilateral Environmental Agreements: A Healthy or Ill-Equipped Fragmentation? Global Environmental Governance: Perspectives on the Current Debate, edited by Walter Hoffmann and Lydia Swart: 67–86. New York: Center for UN Reform Education.

Knigge, M., Herweg, J., Huberman, D., 2005. Geographical Aspects of International Environmental Governance: Illustrating Decentralisation. Ecologic Institute for International and European Environmental Policy, Berlin.

Kumar, P. (Ed.), 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, Washington.

Langhelle, O., 1999. Sustainable development: exploring the ethics of our common future. International Political Science Review April 1999 20, 129–149.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S., Schellnhuber, H.J., 2008. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences* 105, 1786–1793.

Loh, J. (Ed.), Living Planet Report, 2008. WWF, Gland, Switzerland.

MA, 2005. Ecosystems and Human Well-being: Synthesis. Millennium Ecosystem Assessment. Island Press, Washington, DC.

Mitchell, R.B., 2012. International Environmental Agreements Database Project (Version 2012.1). http://iea.uoregon.edu/

Muradian, R., Martinez-Alier, J., 2001. Trade and the environment: from a 'Southern' perspective. *Ecological Economics* 36, 281–297.

Næss, L.O., Norland, I.T., Lafferty, W.M., Aall, C., 2006. Data and processes linking vulnerability assessment to adaptation decision-making on climate change in Norway. *Global Environmental Change* 16 (2), 221–233.

Najam, A., Papa, M., Taiyab, N., 2006. Global environmental governance: a reform agenda. International Institute for Sustainable Development, Winnipeg, IISD, 124.

National Research Council (NRC), 2009. Informing Decisions in a Changing Climate. National Academies Press, Washington, DC.

Nilsson, M., Persson, A., 2012. Can Earth system interactions be governed? Governance functions for linking climate change mitigation with land use, freshwater and biodiversity protection. Ecological Economics 75, 61–71.

Oberthür, S., Stokke, O.S. (Eds.), 2011. Managing Institutional Complexity: Regime Interplay and Global Environmental Change, 2011. MIT Press, Cambridge, MA.

Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., Policansky, D., 1999. Revisiting the commons: local lessons, global challenges. *Science* 284 (5412), 278–282.

Pearce, D.W., Turner., R.K., 1990. Economics of Natural Resources and the Environment. Johns Hopkins University Press, Baltimore. Pearce, D.W., Atkinson., G.D., 1993. Capital theory and the

measurement of sustainable development: an indicator of ‘‘weak’’ sustainability. *Ecological Economic*s 8 (2), 103–108.

Raustiala, K., 2001. Reporting and Review Institutions in 10 Selected Multilateral Environmental Agreements. UNEP, Nairobi.

Robertson, D.P., Hull, R.B., 2003. Public ecology: an environmental science and policy for global society. *Environmental Science and Policy* 6 (5), 399–410.

Roch, P., Perrez, F.X., 2005. International Environmental Governance: the strive towards a comprehensive, coherent, effective and efficient international environmental regime. Colorado *Journal of Environmental Law and Policy* 16, 1.

Rockström, J., Steffen, W., Noone, K., Persson, ˚ A., Chapin III, F.S., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Nykvist, B., de Wit, C.A., Hughes, T., van der Leeuw, S., Rodhe, H., S¨ orlin, S., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. Planetary boundaries: exploring the safe operating space for humanity. *Nature* 461, 472–475 (24 September 2009). Published online 23 September 2009.

Rosa, E.A., Diekmann, A., Dietz, T., Jaeger, C., 2010. Footprints on the Earth: Threats to Sustainability. MIT Press, Cambridge, MA.

Roux, D., Roggers, K., Biggs, H., Ashton, P., Sergeant, A., 2006. Bridging the science-management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing. *Ecology and Society* 11 (1), 4.

Sarewitz, D., Pielke., R.A., 2007. The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science and Policy* 10, 5–16.

Smith, J.B., Schneider, S.H., Oppenheimer, M., Yohe, G.W., Hare, W., Mastrandrea, M.D., Patwardhan, A., Burton, I., Corfee- Morlot, J., Magadza, C.H.D., Fussel, H.-M., Pittock, A.B., Rahman, A., Suarez, A., van Ypersele, J.-P., 2009. Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC), ‘reasons for concern’. *Proceedings of the National Academy of Sciences, USA* 106, 4133–4137.

Stahel, W.R., 1997. The service economy: wealth without resource consumption? *Philosophical Transactions of the Royal Society* 355 (1728) 1309–1319.

Stahel, W.R., 2006. The Performance Economy. Palgrave MacMillan, London.

Stanners, D., Bosch, P., Dom, A., Gabrielsen, P., Gee, D., Martin, J., Rickard, L., Weber, J.-L., 2007. Frameworks for environmental assessment and indicators at the EEA. In: Ha´ k, T., Moldan, B., Dahl, A. (Eds.), In Sustainability Indicators—A Scientific Assessment. Island Press, Washington, DC.

Steffen, W., Grinevald, J., Crutzen, P., McNeill, J., 2011. The Anthropocene: conceptual and historical perspectives. *Philosophical Transactions of the Royal Society A* 369 (1938): 842–867. http://dx.doi.org/10.1098/rsta.2010.0327.

Turnhout, E., Hisschemöller, M., Eijsackers, H., 2007. Ecological indicators: between the two fires of science and policy. *Ecological Indicators* 7(2), 215–228.

UN, 2000. United Nations Millennium Development Goals. /http//:www.un/millenniumgoals.

UN, 2011. The Millennium Development Goals Report 2011. United Nations, New York. http://www.un.org/millenniumgoals/ 11_MDG%20Report_EN.pdfS.

UN, 2002. Johannesburg Plan of Implementation. World Summit on Sustainable Development. http//:www.un.org/esa/susdev/documents/wssd_poi_pd/English/wssd_planimpl.pdf.

UNCSD, 2011. Discussion Paper: Strengthening the Institutional Framework for Sustainable Development. High-Level Dialogue on the Institutional Framework for Sustainable Development. Solo, Indonesia. July 19–21, 2011.

UNCSD, 2012. The Future We Want. Zero Draft of the Outcome Statement, January 10.

UNEP, 2012a. Global Environment Outlook: GEO-5. United Nations Environment Programme, Nairobi.

UNEP, 2012b. 21 Issues for the 21st Century: Results from the UNEP foresight Process on Emerging Environmental Issues. In: Alcamo, J., Leonard, S.A. (Eds.), United Nations Environment Programme, Nairobi, pp.56.

UNEP, 2011a. The Emissions Gap. United Nations Environment Programme, Nairobi.

UNEP, 2011b. Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication—A Synthesis for Policy Makers. United Nations Environment Programme, St-Martin Bellevue.

UNEP, 2011c. Keeping Track of our Changing Environment: From Rio to Rio+20 (1992–2012). United Nations Environment Programme, Nairobi.

UNEP, 2007. Global Environment Outlook GEO-4: Environment for Development. United Nations Environment Programme, Nairobi.

UNEP, 2010. The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to limit Global Warming to 2°C or 1.5°C? United Nations Environment Programme, Nairobi.

WTO, 2011. Early Years: Emerging Environment Debate in GATT/WTO.

Xing, Y., Kolstad, C.D., 1996. Environment and trade: a review of theory and issues, University of California, Santa Barbara. Working Papers in Economics: 02/96.

Young, O., 2006. Vertical interplay among scale-dependent environmental and resource regimes. *Ecology and Society* 11 (1), 27.

Young, O.R., 2008. The architecture of global environmental governance: bringing science to bear on policy. *Global Environmental Politics* 8, 14–32.

Young, O.R., 2010. Institutional Dynamics: Emergent Patterns in International Environmental Governance. /http://mitpress. mit.edu/catalog/item/default.asp?ttype=2&tid=12318S

Yu, D.W., Sutherland, W.J., Clark., C., 2002. Trade versus environment'. *Trends in Ecology and Evolution* 17, 341–344.

Zaccai, E., 2012. Over two decades in pursuit of sustainable development: influence, transformations, limits. *Environmental Development* 1,1.

Zalasiewicz, J., Williams, M., Haywood, A., Ellis, M., 2011. The Anthropocene: a new epoch of geological time? *Philosophical Transactions of the Royal Society A,* 369(1938):835-841http://dx.doi.org/10.1098/rsta.2010.0339.

Zelli, F., 2011. The fragmentation of the global climate governance architecture. WORES *Climate Change 2*, 255–270.

Zelli, F., Biermann, F., Pattberg, P., van Asseslt, H., 2011. The consequences of a fragmented climate governance architecture: a policy appraisal. In: Biermann, F., Pattberg, P.H., and Zelli,F. (Eds.). In Global Climate Governance Beyond 2012: Architecture, Agency and Adaptation 2010. Cambridge University Press.

3. 40 years of global environmental assessments: a retrospective analysis[1]

Jason Jabbour
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Abstract

This paper provides a retrospective analysis of global environmental assessment (GEA) processes and their changing character, focus and political context over the past 40 years. We examine how and why elements of organizational design, objectives, and the evolving political landscape have interacted and changed, with a view of informing the design and conduct of future processes. We find that the historical genesis of GEAs is closely connected to the emergence of environmental multilateralism. However, the prevailing conditions and assumptions which originally gave rise to the GEA concept have changed significantly over time, giving rise to an increasing demand for a focus on response options and policies. We also find that the epistemic and process complexity of GEAs has increased substantially, without a corresponding expansion in the magnitude and composition of GEA management teams. We suggest that developing analytical capacities for policy assessment as well as ensuring sufficient resources and tools to manage increasingly complex GEAs is essential to ensure their future relevance and success. This article is part of a special issue on solution-oriented GEAs.

Keywords: global environmental assessments; science-policy-society interface; SDGs; environmental policy; international governance; sustainable development

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3.1 Introduction

Future scholars studying global environmental governance are likely to point to the year 2015 as a breakthrough in the evolution of multilateralism and international cooperation. On 13 December 2015, 196 governments—despite the exigencies of war and economic and social upheaval—agreed the world's first universal and legally binding climate treaty, the Paris Agreement. The same year also witnessed the adoption of the *2030 Agenda for Sustainable Development*, the global Sustainable Development Goals (SDGs), and the Sendai Framework for Disaster Risk Reduction. Of course, the full, effective and sustained implementation (and enforcement) of these global compacts is far from guaranteed (Aitsi-Selmi et al., 2016; Deacon, 2016; Rogelj et al., 2016; Schleussner et al., 2016). Nonetheless, these multilateral agreements represent a culmination of some forty years of intergovernmental negotiations and remarkable scientific progress (Robbins, 2016; Rogelj and Knutti,

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2016; Savaresi, 2016). They also build on a landscape of global environmental assessments (GEAs) that have served to inform, provoke and even shape complex international deliberations (Clark et al., 2006; Jabbour et al., 2012; Kowarsch et al., 2017).

To date over 140 such GEAs have been initiated since their inception 40 years ago[2]. We define GEAs as largescale, highly deliberative processes where experts are convened to distill, synthesize, interpret and organize existing scientific knowledge (on environmental issues) to inform decision-making. Well-designed GEA processes are widely viewed as powerful, legitimate tools with the potential to catalyze cooperation and arrive at consensual evidence-based knowledge (Clark et al., 2006; Rothman et al., 2009; Watson, 2013; Kowarsch et al., 2016). Climate change, stratospheric ozone depletion, and biodiversity loss are among the most iconic examples. For each of these global challenges, a succession of GEAs has provided the scientific foundations and evidentiary basis for multilateral intervention (Watson, 2013). Today, GEAs have become an established feature of the international policy landscape and the global architecture for sustainability governance.

Over a four-decade span, the production of GEAs has given rise to several conceptual, normative and institutional obstacles. How to reconcile the vast, sometimes diverging perspectives (and/or vested interests) that different actors bring to bear has been a universal challenge (Kowarsch et al., 2017). Hrabanski and Pesche (2015) suggest that the organizational structure of a given GEA is closely linked to the distribution of power and the challenges and balancing acts inherent in the assessment process itself. At the broadest level, the GEA enterprise has shared a complex, if at times uneasy, coexistence with international negotiations, where scientific debates and political ones, not surprisingly, often overlap and clash.

Amidst the growing presence and prominence of GEAs in high-stakes international affairs, discussions around their future function and utility have emerged. Key actors—within and beyond the assessment communities— question whether GEAs can deliver fit-for-purpose information that can inform decisions on the deployment of effective actions at national and subnational levels. Related concerns over the compatibility (or incompatibility) between existing assessment structures and their capacity to analyze benefits, costs and risks of specific policy options and management alternatives have also surfaced (Creutzig et al., 2012; Rowe et al., 2014; Carraro et al., 2015; von Stechow et al., 2016). These questions have elicited critical thinking on the future role of GEAs. In recent years, scientists and governments alike have engaged in reflective dialogue on potential restructurings and key reform opportunities (e.g., Hulme et al., 2010; Shapiro et al., 2010; IPCC, 2014; Carraro et al., 2015 Victor, 2015; Chan et al., 2016).

Given the changing international environmental governance (IEG) context and the growing complexity in the models of science-policy-society interactions (Buizer et al., 2011; Koetz et al., 2012; Kauffman and Arico, 2014), the GEA enterprise now finds itself at crossroads. Four decades offers a good vantage point to reflect on the broader assessment landscape and to draw from the collective and individual experiences to date. This paper sets out to provide a retrospective analysis of the GEA enterprise and the evolution of assessment approaches with a view of informing future processes.

[2] The first GEA was the 1977 OECD-led Assessment of Long-Range Transport of Air Pollutants (LRTAP); see Supplementary Materials *(Table S1)* for a compressive inventory of GEAs completed to date.

Most of the reflective scholarship on GEAs and the efficacy of their impacts have focused on understanding the different procedures and means of conduct through which GEA-generated information enters and influences, or fails to influence, decision-making spheres (Rothman et al., 2009; Rowe et al., 2014; Riousset et al., 2017). In other words, 'why', 'how' and 'when' have assessments led to the adoption of political and economic choices, and/or changes in societal behavior that would not otherwise have occurred. These questions remain crucial. However, we believe that they represent only one side of a feedback loop. In this paper, we argue that the relationship between assessment approaches and effectiveness cannot be examined separate from the prevailing political and institutional circumstances in which GEA processes are embedded, and shaped by. A key point of departure for this research, thus, rests on the assertion that shifting international policy contexts in and of themselves, exert influence on how GEA processes evolve.

Building on the seminal body of GEA research that emerged in the early 2000s—pioneered by the *Social Learning Group* and the *GEA Harvard Project*—this work examines how and why elements of organizational design and objectives of GEAs and their evolving political backdrop depend on one another. The discussion presented in this paper draws heavily from a broader interdisciplinary body of work developed through a collaborative research project: *The Future of Global Environmental Assessment Making* (FOGEAM). With reference to that work, we provide evidence to support two key assertions. First, GEA processes have been increasingly hampered by a discernible rise in epistemic and process complexity. Second, the GEA enterprise is undergoing a fundamental reorientation from a focus on problems toward solutions.

The remainder of the paper is organized as follows. Section 3.2 describes the materials and the methods employed, including a retrospective analysis of metadata from 20 GEAs spanning 1977 to 2014. Section 3.3 begins with a contextual narrative summarizing our extensive systematic literature and document review on the historical origins of global environmental assessments. Tracing key developments in the lead up to first-generation assessments (those occurring before 1995), we reveal that the genesis of GEAs is closely connected to the birth of environmental multilateralism. We then present and discuss results from various analyses which demonstrate that the prevailing conditions and assumptions which originally gave rise to the GEA concept have changed. Specifically, there is a significant increase in the epistemic and process complexity of GEAs; and a shift in demand for greater emphasis on, and engagement with, the solution-space. Section 3.4 concludes with reflections and recommendations on how to further develop GEAs to meet future decision-making needs.

3.2 Methods and materials

Our analysis is based on multiple lines of evidence including interviews, focus group workshops, extensive literature and document review/ meta-analysis, and direct GEA experience[3]. Given the socially constructed nature of assessment processes, direct experience serves as both an important mode of learning (challenging preconceptions and deepening understanding) while facilitating direct and unmediated access to process dynamics that are otherwise impossible to document. At the same time, care needs to be taken to control for subjective bias. Our strategy to do so was to collect the empirical data as described below; regularly discuss findings and interpretations within the FOGEAM

[3] *J. Jabbour has been closely involved the coordination of the GEO process and C. Flachsland with IPCC AR5 WGIII*

research team and colleagues at our respective institutions, and other researchers and practitioners at scientific conferences and workshops (see below); and by comprehensively reviewing the GEA literature.

The analysis presented in this paper draws on the results of 99 semi-structured interviews conducted between August 2013 and April 2015. The interviews were carried out with a broad spectrum of GEA stakeholders including authors, advisory experts, reviewers, governmental representatives, and practitioners. Interview candidates were largely drawn from a pool of individuals involved in the production of either the UNEP-led fifth Global Environment Outlook (GEO-5) assessment (n=73), or the IPCC Fifth Assessment Report, Working Group III: Mitigation of Climate Change (n=16). The interviews lasted between 20 to 120 minutes and averaged ~60 minutes. Where possible, interviews were digitally recorded, with the consent of each interviewee, and transcribed. The interviews were piloted and guided by an interview topic guide organized around eight clustered areas of investigation (see *Supp. Mat. 3.2.2*). The interview transcripts were coded in Max-QDA and analyzed using the Grounded Theory and Constant Comparative techniques (Strauss and Corbin, 1998; Ritchie and Spencer, 2002).

Two focus groups of experts and assessment practitioners in the field of global environmental change convened in October 2013 and September 2015 in Berlin (Germany) provided valuable experiential data, perspectives, and interpretations including feedback on our early research findings; and helped further shape the research design. Focus group discussions are commonly employed for the elicitation of specific refining information and for the generation of experiential data and insights which are more readily gleaned through direct interaction between participants (Morgan, 1996; Krueger and Casey, 2014). The first group consisted of 13 experts from the *Global Environment Outlook* (GEO) community, engaged in a two-day workshop comprising a series of semi-guided discussions on procedural and methodological issues, impact channels, institutional and political contexts, and GEA design options. The participants shared insights on the inner workings of assessment processes including the deeply embedded (and often dismissed) norms and culture, self-perceptions and social dynamics that shape the assessment-making experience.

The second focus group brought together 18 distinguished scholars and practitioners, including senior representatives from the science-policy community, to reflect on and deliberate over the challenges and future opportunities of contemporary assessments, and particularly the shift towards solution-orientated processes. These discussions confirmed the direction of our initial findings, and helped to further refine and extend our analysis (see *Supp. Mat. 1.2.3* for additional information).

3.2.1 GEA metadata catalogue, 1977-2014

As described in the introduction to this special issue of *Environmental Science and Policy*, an extensive dataset (or catalogue), bringing together comparable metadata for 20 assessments was developed as a core component of the FOGEAM collaborative research initiative and the analysis presented here (see *Supp. Mat. 1.2.1*). The purpose of the catalogue was to facilitate comparative analysis of key attributes and epistemic properties across a range of largescale GEA processes spanning the period of 1977 to 2014. In this paper, we present results and discuss the analyses of key data derived from the catalogue that highlight the changing character of GEAs and the associated rise in process and

epistemic complexity. This paper presents comparative analyses of the following attributes: respective lengths and scope of GEA reports, references and information sources, composition and distribution of participants, review comments, authorizing mandates, objectives and key messages.

Three selection criteria were employed to evaluate the inclusion of a given assessment: (1) aiming to achieve a representative sample of recurring and non-recurring (or irregular) GEAs; (2) sufficient access to information regarding relevant preparatory and background documentation; and (3) largescale assessments that are 'global' in their scope in terms of thematic and geographic coverage, and participation. We also strove to capture an indicative sample consistent with the relative temporal distribution (frequency) of GEAs published across the 40-year inclusion period. Extensive discussions with the FOGEAM research team and focus-group feedback (as described above) helped inform the criteria and the final selection of GEAs. The ability to satisfy the specific inclusion/ exclusion criteria (e.g., access to information) had a major impact on the available sample size.

A broad range of materials and document types were analyzed as part of the data-gathering exercise for developing the GEA metadata catalogue. They include background documents, assessment scoping papers, meeting reports, independent evaluations, authorizing mandates, participants' lists, and crucially, a range of United Nations (UN) documentation including official proceedings of the UN General Assembly, subsidiary organs of the UN or specific UN conferences, UN Resolutions and Decisions of governing bodies and/or subsidiary organs, verbatim or summary records of the meetings, annexes and supplements. Information from national government publications, newspaper articles, peer-reviewed paper, and of course, the assessment publications themselves were also integrated into the GEA catalogue. The development of the catalogue was initiated in March 2013 and completed in July 2016. The processes involved collecting, collating, and integrating data—across numerous heterogeneous sources—coding information, and, where necessary, digitizing selected texts from earlier GEAs (e.g. key messages, assessment objectives etc.).

The selection of attributes and the information categories included in the catalogue was informed by the academic literature, specialized reports and independent reviews on assessment practices (e.g., InterAcademy Council's Review of the IPCC), the authors' own personal experiences with GEAs, anecdotal and informal evidence, and a series of exploratory focus-group discussions within the FOGEAM research team, assessment practitioners involved in the October 2013 two-day expert workshop as described above.

To the best of our knowledge this is the first attempt to generate such a catalogue of comparable GEA metadata. Not surprisingly, we encountered several challenges in assembling the database, related to the diffusion (and volume) of relevant information and in some cases its limited availability or accessibility. Similarly, issues of confidentiality and restricted disclosure—including intergovernmental deliberations and proceedings—also presented difficulties. In some instances, and particularly for the assessments that predate the internet, relevant information (e.g. participant lists, budgets etc.) are poorly documented, if at all. Finally, harmonizing heterogeneous datasets across different assessment processes was also a challenge. These obstacles underscore the inherent difficulties of studying GEA processes and cultivating the reflexivity and deliberative learning that assessment structures require to evolve (Rowe et al., 2014; Shapiro et al., 2010).

3.3 Results and discussion

The results of our study show that the character and orientation of global environmental assessments (GEAs) has shifted considerably since their inception, and particularly in recent years. We commence our analysis with a discussion of the historical origins and key developments that gave rise to GEAs. We then discuss the nature, importance and implications of these shifts in relation to an evolving international environmental scene and changing political context. Finally, we present and discuss results from various analyses which illustrate a discernible rise in epistemic and process complexity in contemporary assessments; and an increasing emphasis on, and engagement with solutions.

3.3.1 Tracing the origins and early development of GEAs

In 1972, the United Nations Environment Programme (UNEP) was established as subsidiary organ of the UN General Assembly and given the mandate to facilitate the monitoring, reporting and ongoing assessment of the state of the global environment (Ivanova, 2007). The rise in awareness over largescale environmental phenomena (e.g. ozone depletion, persistent organic pollutants) and the imperative to comprehend the potential consequences and threats to human wellbeing, alongside the creation of UNEP, resulted in a significant expansion of environmental literacy and multilateralism (Young, 1997; Desai, 2010). Over the 1974-84 decade, the proliferation of global environmental treaties, regimes, and processes catalyzed widespread recognition for international scientific cooperation (Haas, 1992; Desai, 2003). The emerging international environmental governance community sought to evolve a systematic process that could at once harness an international scientific consensus and transcend divergent national allegiances (Jabbour et al., 2012). Scientific panels, expert advisory bodies and similar independent structures began to coalesce around most multilateral environmental processes (Watson, 2005). Putting in place such structures to evaluate and deliver informed collective judgments about the impacts of pervasive environmental problems and the consequences of remedial action (or inaction) became a precondition for negotiating multilateral responses (Morrisette, 1989; Agarwala, 1999; Selin and Eckley, 2003; Mitchell, 2003; Grainger, 2009). The combined efforts to generate an accepted body of scientific knowledge on complex environmental problems to support the legitimatization and edifice of international regimes marked the birth of international scientific knowledge assessments.

The Montreal Protocol[4] was the first instance to institutionalize the concept of scientific assessments in1987. It adopted a mechanism establishing an independent international group of experts to periodically assess relevant scientific developments and guide policy negotiators in subsequent revisions and adjustments of the treaty (Benedick, 2005). By the late-1980s, coordinated global scientific assessments involving extensive collaborations between large numbers of scientists from various nationalities became a driving force behind international policymaking (Young, 1989). These highly structured social processes—beyond the reports themselves—began to serve as knowledge intermediaries between science and policy (Farrell and Jäger, 2006). First-generation GEAs helped forge intergovernmental cooperation and an objectively defensible means to arrive at consensus on environmental problems and policy positions that seemed irreconcilable (Mitchell et al., 2006). Over the next decade, various largescale GEAs (notably the IPCC reports) evolved and codified a deliberative consensus-based approach to knowledge production (Goodwin, 2009; Curry and Webster, 2013). By

[4] The Montreal Protocol on Substances That Deplete the Ozone Layer is a landmark international agreement, originally signed in 1987, designed to protect the stratospheric ozone layer.

the early-1990s, there was widespread recognition in the international community that the most pervasive environmental issues extended beyond strict geopolitical confines, and could no longer be analyzed or resolved in isolation (Haas, 1990). This thinking gave way to new levels of international dialogue and cooperation, including new roles for international institutions in the production of scientific knowledge on a range of environmental sustainability issues (Raustiala, 1997; Watson, 2005).

The rise in awareness and political attention on the issue of sustainable development catalyzed the 1992 Earth Summit in Rio de Janeiro. The Earth Summit marked the beginning of a ten-year surge in multilateral treaties and new governance structures (Desai, 2003; Elsig et al., 2011). The Earth Summit also brought to light several critical implementation challenges for IEG, including uncertainties in scientific knowledge and the need to remove North-South information asymmetries. These challenges reinforced the importance of monitoring, technology transfer and scientific assessments—cornerstones of the Summit's voluntary action plan *Agenda 21*. Beyond a rapid succession of multilateral environmental agreements (MEAs) in the post-Rio period, were increasing appeals from the international science-policy community to redress ongoing deficits of reliable scientific information to support these agreements (Haas *et al.,* 1992; Parson, 1993; Boehmer-Christiansen, 1994; Levy et al., 1995).

Table 3.1. Figurative representation for the evolution of international environmental scene

Selected features of the environmental scene	**Pre-sustainable development era (1970s and 1980)**	**Current situation (last ten years)**
1. Iconic policy instruments	Command and control instruments (e.g. *Montreal Protocol*)	Economic/ market-based instruments (e.g. *The Paris Agreement*)
2. Key actor(s) relied on	Predominantly Government (*heavy reliance on public sector*)	Mix of Government and Stakeholders (*growing role for non-state actors*)
3. Dominant modalities of action/ implementation	Emphasis on industrial sectors; technology-driven interventions (*e.g. agricultural intensification)*	Working with industry and consumers, through technology, innovation, finance (e.g. *renewable energy incentives*)
4. Knowledge about the Environment	Superficial, or limited to specialists in a narrower range of fields	Extensive, mainstreamed, diffused in many realms of society
5. Information, data and knowledge management	Limited public access, expensive, inadequate or highly propriety national data flows	Proliferation of digital, open access data platforms and networks;
6. Main disciplines; fields of scientific engagement	Predominantly natural science researchers; observational sciences (*chemistry, biology and physics*)	Trans-disciplinary research; integrated approaches; projections and futures (*social, natural, economic and holistic)*
7. Iconic environmental problems; most urgent	Wastes, water pollution (*easier to define/ narrower point sources*)	Climate change, loss of biodiversity (*more complex and diffuse*)
8. Main actors/regions seen to be drivers of adverse change	Industries, production patters OECD (*United States*)	Consumers, consumption patters Emerging economies (*China, Brazil*)
9. Social equity issues and environmental equality	Superficial, or neglected concerns (*peripheral to mainstream debate*)	Key goal of many environmental policies (*core aspect of 2030 Agenda and SDGs*)
		Adapted from Zaccai, 2012

3.3.2 Shifting political and institutional orientations

The environment now represents the second most common area of international rulemaking, only after international trade (Muñoz et al., 2009). Moreover, from being a niche topic, environmental concerns have moved to become an equal and indispensable dimension of sustainable development. Zaccai (2012) describes a series of changes in the constellation of actors, discourses, modes of action, and the nature of problems themselves, that characterize the evolution of the "environmental scene" and to a large extent, shaped the discursive struggle over sustainable development. Building on his analysis, we enumerate an expanded selection of features relevant to the evolving international

environmental scene contrasting the pre-sustainable development era with the current situation. These prevailing shifts offer a useful background for examining how GEAs have been influenced by, and responded, to the context in which these have transformations occurred (Table 3.1).

The most demanding issues on today's IEG agenda are characterized by highly dynamic patterns of causality and complex interactions between environmental drivers and pressures (Jabbour and Hunsberger, 2014). Regarding key actors, roles and dominant modalities for action, the emphasis has shifted away from a pure focus on the state, towards wider stakeholder engagement, shared responsibility and collaborative private-public actions (Lozano, 2012). A similar shift has occurred at the science-policy-society interface with a move towards greater inclusivity, and efforts to transcend traditional reductionist approaches (Vogel et al., 2007; Wesselink et al., 2013). This thinking has influenced the direction of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and other recent GEAs efforts (e.g. GEO-6) to institutionalize synergies across knowledge systems by introducing a series of functioning mechanisms and procedures (Tengö et al., 2014; Perrings et al., 2011).

Many of the transformations reflected in Table 3.1 manifested in the deliberations on the 2030 Agenda and the SGD framework, in contrast to the expired Millennium Development Goals (MDGs). For example, the SDGs reflect a more balanced and integrated treatment of the global environment and the imperative to address both social and environmental inequalities (Martinez and Mueller, 2015). Regarding environmental sustainability, the SDGs place greater importance on the need to promote equitable access to increasingly scarce resources and energy, and to minimize the vulnerability of the poor. In this regard, debates were centered on how existing international agreements can address equitable, inclusive low-carbon growth. A similar discourse-shift is reflected in the narratives of many recent GEAs that call attention to the notion that the science of global environmental change can no longer be divorced from fundamental issues of fairness, equity and social justice (e.g. Green Economy, 2011; GEO-5, 2012; IPCC, 2014). Another important difference between the MDGs and the SDGs–bearing witness to the evolution

of geopolitics and the environmental scene—is that emerging economies and lower-income countries, created the impetus for the 2030 Agenda and were deeply involved its formulation. This resulted in an SDG framework that better reflects the principles of universality and accountability, while respecting the need for adaptability. This is a drastic shift from the pre-sustainable development era, and even the 1990s, when northern economies dominated most multilateral fora including IEG, while low and middle-income states (i.e. G-77) and the BRICs (Brazil, Russia, India and China) had much less political, economic and scientific clout (Papa and Gleason, 2012). Investments in technology and scientific research in the global south are accelerating at a rapid pace. It comes as little surprise, therefore, that developing-country[5] participation rates in GEAs have experienced a 10-fold increase (>250% proportionally) from 1977 to 2014. The enhanced involvement and greater influence that middle and low-income countries have acquired, as a result, could mean more legitimacy and impact for the SDGs, and similarly, the future uptake of GEA findings – particularly in countries facing lower scientific capacity and limited data flows.

While important advances in bringing international treaties and related aspects of IEG into a more coherent and stable institutional framework have taken place, the current constellation of MEAs—the

[5] Including low- and lower-middle-income economies as defined by the World Bank classification lists

international legal basis for cooperation—has become increasingly complex and disconnected from GEA processes (Rothman et al., 2009). The historical function and objectives of first-generation GEAs (occurring before 1990) were comparatively narrower in scope, and could thus uphold a stronger coupling with existing policy-relevant structures and international regimes. Selin and Eckly (2003) describe how the GEAs on persistent organic pollutants (POPs) from the mid-1980s possessed more fluid boundaries between science and policy and were directed at a "specific context of policy application, with mutual construction and evolution of scientific and policy agendas" (2003:21). Consequently, these first-generation GEAs, which they describe as expressions of 'regulatory science' played a prominent role in establishing POPs as an issue of international concern, and influencing intergovernmental deliberations on their management and mitigation. Findings generated from the chronology of GEAs titled *Scientific Assessment of Ozone Depletion*—the reoccurring assessment process mandated by the Montreal Protocol (Article 6)—have not only informed deliberations of the 'Conference of Parties' to the MEA, but have provided the scientific and evidentiary basis for seven crucial amendments to the Protocol since its inception (e.g. accelerating phase-out schedules), including the most recent Kigali Amendment on hydrofluorocarbons. In this view, early GEAs played a more explicit role in framing relevant environment issues around problems and building the necessary consensual knowledge and international cooperation—at a time when the underlying problems were uncertain and governments were selective and reticent on specific multilateral commitments.

Much has changed since the inception of GEAs forty year ago. The political setting for the environment, including institutional contexts and the international governance architecture that GEAs are operating in, while more robust and more empowered, is now subject to a variety of challenges including but not limited to a separation of political ambition (or will) and the means of implementation (Aitsi-Selmi et al., 2016; Deacon, 2016; Rogelj et al., 2016; Schleussner et al., 2016). As the political context has evolved, our analysis indicates that the prevailing conditions and assumptions that gave rise to the GEA concept have also shifted. In the following sections (3.3 and 3.4) we present and discuss results that demonstrate a significant increase in the epistemic and process complexity of GEAs; and an increasing demand for greater emphasis on, and engagement with, the solution-space.

3.3.3 *Rising epistemic and process complexity*

The most obvious attribute-change in GEAs over the last four decades concerns both the depth and breadth of their contents. Across all assessment processes examined, GEAs have consistently become increasingly voluminous reports. Successive iterations of IPCC reports, for example, have experienced a nearly fivefold increase in length since their inception, despite efforts to set page limits. The *Fifth* and latest IPCC assessment (across three volumes) totals over 4,300 pages, 60 chapters, and 16 annexes totaling approximately 3.26 million words. To put this in perspective, it would take the average person nearly eight uninterrupted work-weeks to read the report, never mind digest or comprehend the material. The Global Environment Outlook (GEO) series and the supporting material produced alongside its underlying assessments have increased four and 7-fold respectively from 1997 to 2015.

These changes reflect the impacts of a rise in epistemic complexity. This trend is manifested, in part, by a dramatic increase in the number of relevant publications that assessments draw upon. As illustrated in Figure 3.1, comparing the number of source materials used in the five iterations of the

GEO and IPCC reports, reveals seven and 13-fold increases respectively, from the first reports to the most recent; with the latest IPCC report containing nearly 31,300 citations. Conversely, the first IPCC assessment included only 2,284 citations. In addition to this massive upsurge in the number of source materials used, more crucially, the citation-to-content ratio (i.e. the average number of citations per page), has also increased from 2.1 to 5.6 for GEO and from 2.5 to 6.9 for the IPCC assessments. In contrast, of the first-generation GEAs examined (predating 1995), the average citation-to-content ratio was 1.7:1. These results are consistent with recent bibliometric studies that highlight the exponential growth of relevant peer-reviewed literature since inception of the IPCC, where in 2015 alone, more articles were published (>30,000) than the entire 12-year period between the first and third assessment reports (Minx et al., 2017). The rapid advancements in environmental science and global-change research in recent years, compounded by the increasingly multiscalar and multidimensional nature of relevant information, has served to complicate what was already an inherently demanding and complex task for GEA experts.

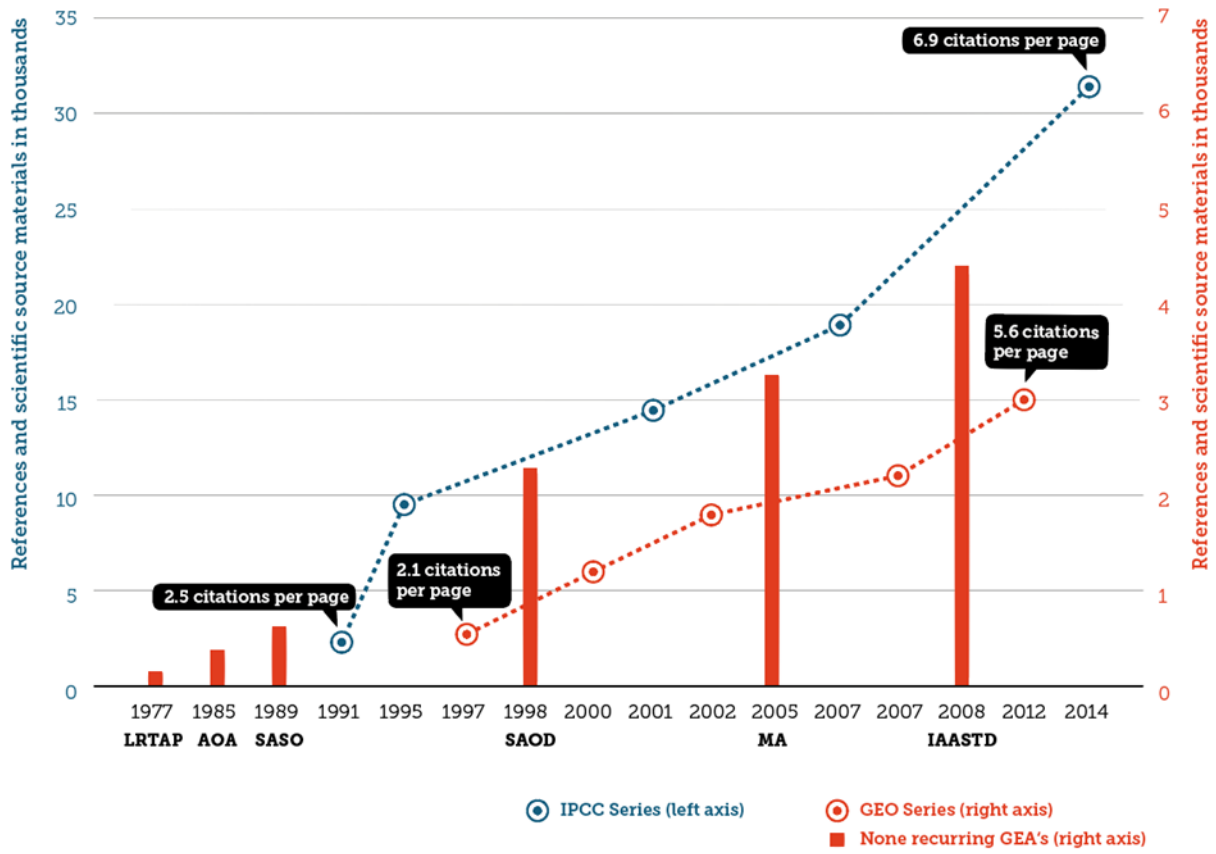

Figure 3.1. Trends in the number and proportion of source materials used (i.e., average citations per page expressed as a ratio) in two recurring assessments: the GEO series (right axis), and the IPCC series (left axis) over five successive iterations; as well as six nonrecurring GEAs assessments (right axis).

In addition to the substantial increase in scientific publications, the magnitude and complexity of the assessment task has also been exacerbated by significantly greater demands and rising expectations. Our results indicate that GEAs have experienced a significant expansion in their substantive and operational scope in the last decade. A broadening of thematic coverage, for example, is evident if one compares earlier assessments (e.g. LRTAP, 1977 or Atmospheric Ozone, 1985) that dealt with

more narrowly defined environmental problems, compared with more recent GEAs (e.g. IPCC and GEO) that encompass much more diffuse, interrelated and multi-factorial issues (Flachsland et al., 2015; OECD 2015; Minx et al., 2017; Riousset et al., 2017).

This is manifest in the sharp rise in the number of individual objectives per assessment, and the number (and range) of specific framing questions that assessments are expected to address (Figure 3.2). More crucially, of the 20 GEAs analyzed in our database, there was no evidence of deliberate prioritization or ranking of such objectives in any one of them; thus, leaving their relative importance open for interpretation. Eleven interview respondents referred to this theme. One of the interviewees stated, for example, that the widening the scope of attention with no clear alignment to the prevailing GEA storyline "*diminishes the intensity of analyses and creates confusion and friction among* [*experts*]" while exposing the assessment processes to be diverted by peripheral issues (December 2013; L5). Another respondent described feeling overwhelmed by *"the mystification of purpose [of the GEA]"* resulting from *"mission-creep and [this] gradual shift in emphasis [in the course of production]"* (September 2014; LL2). In the absence of specific guidance or stricter measures on the development of GEA objectives, assessment processes are at risk of being overwhelmed by their own mandates and unwieldy bulk.

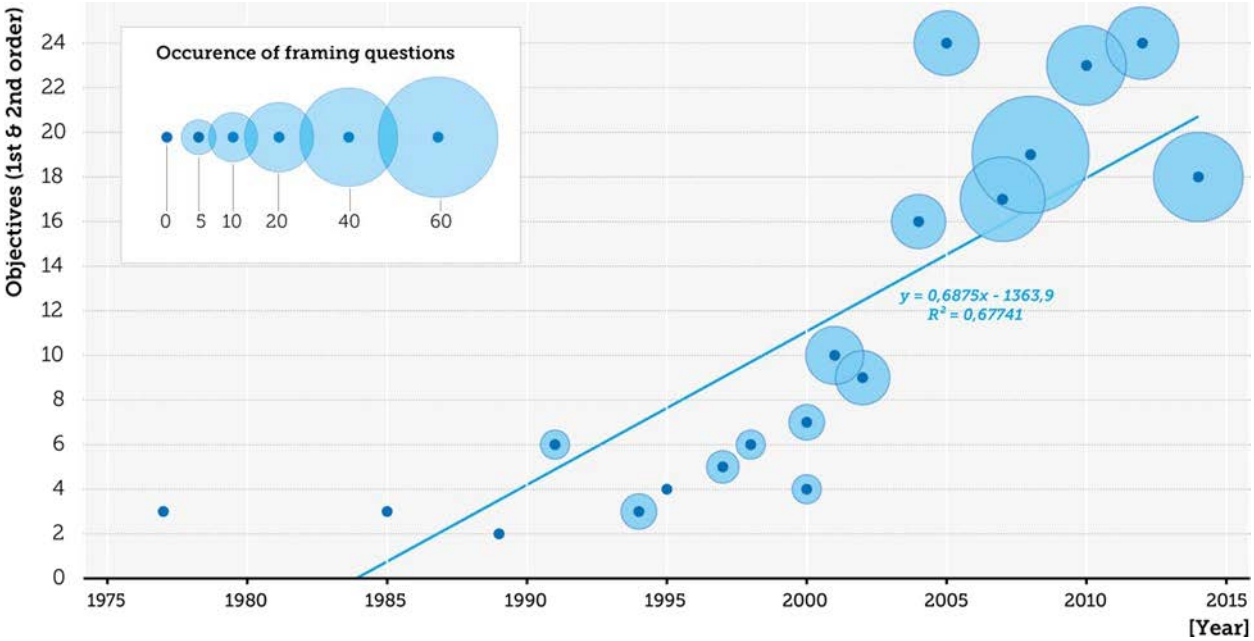

Figure 3.2. Broadening in the extent and scope of assessment objectives of GEAs, 1977—2014; the relative size of data points represents the occurrence of additional framing questions. (*See Supp. Mat. 4.1.2.4 for details*).

Another important trend contributing to the rise in process and epistemic complexity of GEAs is the sharp increase in the number of participants actively engaged in producing a given assessment. We observe parallel shifts in the type and distribution of stakeholders and their respective roles. The GEO and IPCC recurring assessment processes, as well as six non-recurring GEAs examined (spanning 1977 to 2014) have experienced a significant rise in the number of authors and 'expert' contributors over their evolution. In the case of GEO, the segment of participants effectively responsible for content-development rose from 186 individuals in the first GEO (1997), to 863 in GEO-5 (2012) and well over 1000 experts for GEO-6 (*forthcoming*). For the IPCC, a total of 607 authors and expert contributors

were involved in delivering the first assessment in 1990, compared with 2,330 individuals for fifth assessment report delivered in 2013-2014. If one considers the full spectrum of stakeholders involved in the development and production of the latest GEO and IPCC assessments (i.e. expert advisors, reviewers, government representatives, production staff, editorial teams, technical support) the number of participants rises to 2,018 and 4,905 respectively. Considering that the first GEA in 1977 (LRTAP) comprised of fewer than 80 individuals, contemporary GEAs have become enormously more complex, resource-intensive processes to coordinate. The complexity of interconnections—interpersonal, group and institutional dynamics—brought about by interfacing hundreds (sometimes thousands) of actors towards a process of 'negotiated' knowledge production remains poorly understood (Wesselink et al., 2013). This is complicated by the heightened sensitivity to the concerns of political neutrality, particularly given the shift to solution-oriented analyses (see section 3.3), which has increased GEAs' exposure to divergent viewpoints requiring active management (Kowarsch et al., 2017).

Despite the exponential rise in GEA participants and the increase in process complexity, interestingly, the administrative structures of GEAs (i.e. management/ production support staff) have diminished or remained largely unchanged over time. These actors, who typically belong to the boundary organizations facilitating a given GEA, play an important coordination and knowledge-intermediary role (Jones et al., 2012). For first-generation assessments, production support, on average, accounted for approximately 6% of the total pool of GEA participants. More recently, this segment has been reduced to less than 2% (e.g. GEO-5, MA, IPCC and IAASTD). This difference is not trivial, given the additional burden of responsibility these actors face in having to manage the procedural and organizational structures that can handle the vastness and diversity of inputs, data-flows, contributions and critical reviews. Rigorous multi-stage review processes, for example, which comprise more stringent protocols for ensuring transparency and scientific credibly (Shapiro et al., 2010), have become far more onerous exercises to coordinate. Assessment processes have also experienced a substantial increase in the proportion of reviewers engaged in GEAs in the last four decades (Figure 4.3).

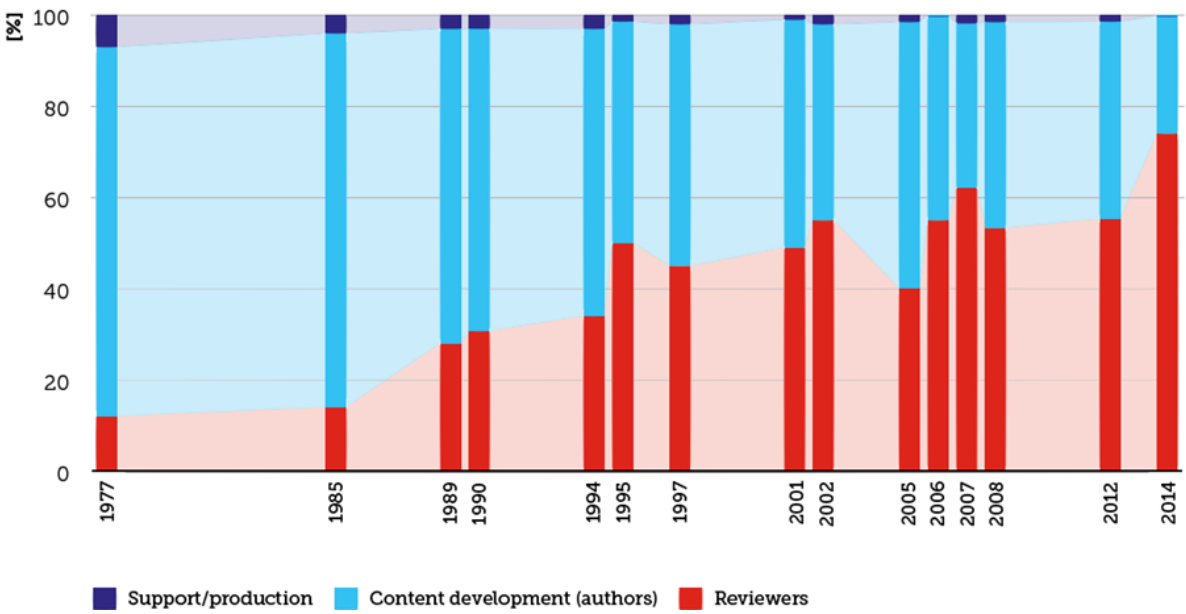

Figure 3.3. Reviewers as a percentage of total GEA participants (N=15; from 1977 to 2014)

For the most recent GEAs examined (those occurring in the last 10 years), reviewers constituted the largest segment of stakeholders involved (between 40 and 63%). This has led to a commensurate increase in the number of revisions requested of author teams. In the latest IPCC assessment, the total number review comments that draft manuscripts received and dealt with (across all working groups), was in the order of 143,000. Similarly, the number of review comments in the GEO process has increased 6-fold from 3,893 (GEO-3, 2002) to 23,772 (GEO-5, 2012).

3.3.4 The shift to solutions-oriented assessments

We find that contemporary assessments put increasing emphasis on considering future outlooks, response strategies, action-oriented narratives, and to varying degrees, public policy analysis relative to analyzing the biophysical and ecological problems underlying global environmental challenges. This is reflected in both the institutional objectives and the actual content in the underlying reports. In the case of the IPCC, its new Chair has declared explicitly that 'the next cycle of assessments should be more focused on opportunities and solutions' (Tollefson, 2015).

While some of these variants and attribute-shifts have been institutionalized in the authorizing mandates and formal objectives of GEAs, others remain much harder to quantify. Our analysis of core GEA messages articulated in the summaries or stand-alone key messages pooled from eight GEAs[6] published between 1985 and 2012 reveals a ten-fold and eight-fold increase in the use of the terms *"political action"* and *"policy response(s)"* respectively. Similarly, the use of the word *"solutions"* in the GEO assessment series reports has risen consistently with nine instances in GEO-1, to 99 instances in in GEO-5. Quantitative text analyses of 320 source materials[7] of four GEAs[8] from 1985, 1995, 2008, and 2012, reveals an increasing reliance on solution-focused information with 0%, 12%, 47% and 55% respectively. Similar trends are occurring in other assessment-related fields, for example, environmental risk assessment. Finkel (2011) describes evidence for an emerging reversal in the functional and conceptual practice of traditional risk assessment; where the focus has shifted away from dissecting problems, and increasingly towards evaluating management pathways and tangible solutions to mitigate risks.

Table 3.2 – Examples of authorizing mandates of recent GEAs that exhibit a focus on solution analysis

GEA	Year	Mandated solution-oriented objective	Design innovation
TEEB-D1	2010	*"Identification of opportunities for action, such as applying new or reforming existing policy tools"*	Applying new economical valuation methodologies
GEO-5	2012	*"..analysis of case studies of policy options, that incorporates environmental, economic, social and scientific data and information and their indicative costs & benefits to identify promising policy options."*	Assessing progress against internationally agreed goals and objectives
IPBES	2012	*"supports policy formulation and implementation by identifying policy-relevant tools and methodologies, such as those arising from assessments…"*	Conceptual Framework explicitly includes co-design and multiple knowledge systems

[6] *Atmospheric Ozone, 1985; Scientific Assessment of Stratospheric Ozone, 1989; Global Biodiversity Assessment, 1995; Global Environment Outlook (GEO-1), 1997; GEO-2, 2000; GEO-3, 2002; GEO-4, 2007; IAASTD, 2008; GEO-5, 2012.*

[7] *'Source materials' refers to all sources of information and data used in the report including scientific peer-reviewed papers, as well as scientific research reports and materials produced by organizations and governments cited in the GEAs examined.*

[8] *Atmospheric Ozone, 1985; Global Biodiversity Assessment, 1995; IAASTD, 2008; GEO-5, 2012.*

Our results also indicate an increasing demand by decision-makers and scholars for solutions-oriented GEAs. A review of the authorizing mandates of contemporary GEAs (e.g. Table 3.1) and subsequent experimental approaches and design-innovations introduced suggest growing demand for policy analysis and more integrative response options. An analysis of the recent IPCC reform debate explicates this desired shift and the call for more explicit and meaningful assessments of possible solutions and action-oriented knowledge in GEAs (Figure 3.4).

Of the 32 government responses submitted to a 2014 IPCC survey on the future work of the Panel, 20 (62%) indicated the need for greater emphasis on response options including more explicit assessments of policies. The survey, which invited inputs on both the IPCC's future reports and the structure and modus operandi for producing the assessments, elicited nearly 100 different recommendations, representing 72% of the total respondents (across various actor groups), were aligned with a solution-orientation shift. These results are consistent with similar findings from the independent evaluation of the fourth GEO assessment (UNEP, 2009; Koetz et al., 2012), and the more recent evaluation of the fifth GEO (Rowe et al., 2014), which describe explicit changes in the demand for and supply of information that better supports 'policy options', and not only 'problem identification'.

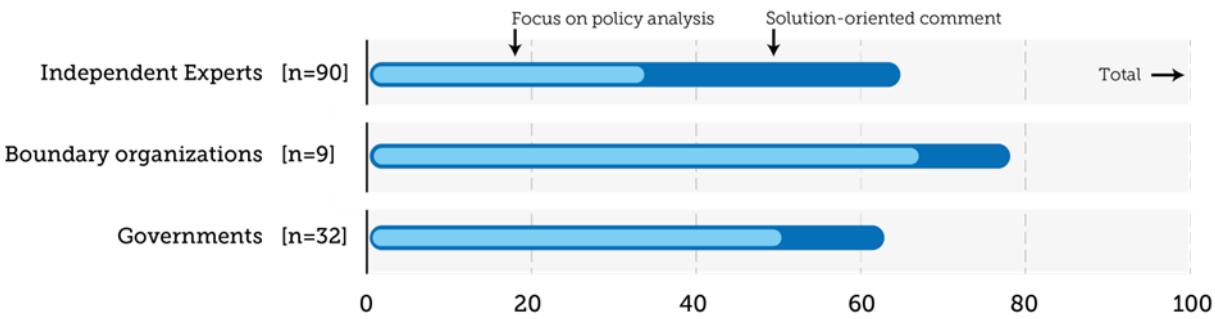

Figure 3.4. Results of a 2014 survey on IPCC reforms illustrate the increased demand for solution-oriented assessments (across three GEA actor groups) with an emphasis on actionable knowledge and means of implementation, (n=131).

Taken together, the emphasis of solution- and policy-orientation of GEAs in a changing political context (Sections 3.3.1 and 3.3.2) has led many experts to postulate that GEAs are and should increasingly focus on exploring solutions to global environmental problems (Edenhofer and Kowarsch, 2015; Carraro et al., 2015; Bulkeley and Kok, 2016; Kowarsch et al., 2016; Le Quéré and Minns, 2016; Beck and Mahony, 2017; Kowarsch et al., 2017).

3.4 Conclusions

The objective of this study was to provide a retrospective analysis of the GEA enterprise and the coevolving context in which assessment processes are embedded. Our results demonstrate that the prevailing conditions and assumptions which originally gave rise to the GEA concept have changed significantly since the mid-1970s when GEAs were conceived.

Arguably responding to these changes in the IEG context of GEAs, there has been a shift in demand for greater emphasis on, and engagement with, the solution-space. At the same time, GEAs have

experienced a perceivable increase in epistemic and process complexity. As a result, knowledge producers and boundary institutions facilitating these highly complex deliberative processes are expected to address and manage an ever-expanding and increasingly inter- and trans-disciplinary knowledge base, extraordinarily large numbers of participants who represent increasingly diverse and diffuse actor-groups, more varied spatial, time and institutional scales, and new dynamics between the scientific and policy spheres.

One possibility for responding to these challenges is to advance a new generation of tools, models and frameworks better able to assemble, streamline, manage and integrate information, including those generated through different paradigms, to better support policy-relevant analysis (e.g., Minx et al., 2017, Flachsland et al., 2015).

One option that is currently being explored at UN Environment is to adapt aspects of integrated assessment processes to more networked, dynamic and inclusive knowledge generation through the use of digital-based knowledge platforms (e.g., Environment Live). Such efforts promise to enable better organization of information and streamlining of data flows, and provide GEAs with a vehicle for promoting open access, inclusivity and a more reflexive approach towards knowledge provisioning. Also, responses to the challenges stemming from increasingly complex process management requirements (Carraro et al., 2015) might include the provision of adequate GEA management resources (e.g. operating budgets, number of dedicated staff) and capacities (e.g. ensuring skills upgrading and training of GEA practitioners and support staff, including in the area of policy assessment). Finally, some have suggested deliberately scaling-back the complexity of GEAs in terms of a proliferation of their objectives, and instead focusing on shorter and more targeted products and processes (Hulme, 2010).

Ultimately, as our retrospective analysis has shown, for GEAs to be effective, assessment processes themselves must change over time, and there are no one-size fits all analogs. GEAs must therefore be reflexive and respond to context-specific demands for knowledge. This is particularly pertinent in the new global setting for sustainability governance, where many of the SDGs will be attainable only if the environmental knowledge production community together with the GEA enterprise, can effectively contribute to their realization, and is transformed by them (Nossum, 2017).

It appears that global environmental assessment processes are at a crossroads: On the one hand, they could continue down the path of predominantly focused problem analysis and remain reticent to fully engage with the solution space. In that case, their future relevance to policy is at risk of diminishing gradually over time. On the other hand, assessment processes could increasingly engage with a complex solution space, and strive to develop and cultivate a widely accepted set of methods and tools to do so in a way that informs evidence-based policymaking by rigorously synthesizing and assessing available research. Reflecting on the first 40 years of GEAs and the current international governance context, we believe that the latter option deserves more practical and theoretical consideration, including in policy research as well as in the empirical literature analyzing GEAs. Our hope is that more future research will be dedicated to this field.

3.5 References

Agrawala, S., 1999. Early science–policy interactions in climate change: lessons from the Advisory Group on Greenhouse Gases. *Global Environmental Change,* 9(2): 157-169.

Aitsi-Selmi, A., Murray, V., Wannous, C., Dickinson, C., Johnston, D., Kawasaki, A., Stevance, A.S. and Yeung, T., 2016. Reflections on a science and technology agenda for 21st century disaster risk reduction. *International Journal of Disaster Risk Science*, 7(1), pp.1-29.

Beck, S. and M. Mahony. 2017. The IPCC and the politics of anticipation. *Nature Climate Change*, 7, 311–313.

Benedick, R.E. 2005. The Case of the Montreal Protocol: Science Serving Public Policy; The Role of Science in Environmental Policy Making. U.S. Senate Committee on Environment and Public Works. September 2005.

Boehmer-Christiansen, S., 1994. Global climate protection policy: the limits of scientific advice: Part 1. *Global environmental change*, *4*(2), pp.140-159.

Bulkeley, H. and Kok, M., 2016. Knowledge, policy, and expertise: the UK royal commission on environmental pollution 1970–2011, by Susan Owens, Oxford, Oxford University Press.

Carraro, C., Edenhofer, O., Flachsland, C., Kolstad, C., Stavins, R. and Stowe, R., 2015. The IPCC at a crossroads: Opportunities for reform. *Science*, 350 (6256): pp.34-35.

Carson, R. 1962. Silent Spring. Houghton Mifflin Co., Boston.Chan, G., Carraro, C., Edenhofer, O., Kolstad, C. and Stavins, R., 2016. Reforming the IPCC's Assessment of Climate Change Economics. *Climate Change Economics,* 7(01), p.1640001.

Clark, W.C., Mitchell, R.B. and Cash, D.W., 2006. Evaluating the influence of global environmental assessments. Global environmental assessments: information and influence. MIT, Cambridge, pp.1-28.

Creutzig, F., Von Stechow, C., Klein, D., Hunsberger, C., Bauer, N., Popp, A. and Edenhofer, O., 2012. Can bioenergy assessments deliver?. *Economics of Energy & Environmental Policy*, 1(2): 65-82.

Curry, J.A. and P.J. Webster. 2013. Climate change: no consensus on consensus. *CAB Reviews*, 8(1): 1-9

Deacon, B., 2016. SDGs, Agenda 2030 and the prospects for transformative social policy and social development. *Journal of International and Comparative Social Policy*, 32(2): 79-82.

Desai, B.H., 2003. Mapping the Future of International Environmental Governance. *Yearbook of international environmental law,* 13(1), pp.43-61.

Desai, B.H. 2010. Multilateral environmental agreements: legal status of the secretariats. Cambridge University Press.

Edenhofer, O. and Kowarsch, M., 2015. Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy,* 51, pp.56-64.

Ehrlich, P.R. 1968. The population bomb, New York: Sierra Club, Ballantine.

Elsig, M., Milewicz, K. and Stürchler, N. 2011. Who is in love with multilateralism? Treaty commitment in the post-Cold War era. *European Union Politics,* 12(4), 529-550.

Farrell, A.E. and J. Jäger. 2006. Assessments of Regional and Global Environmental Risks. Washington, D.C.: Resources for the Future.

Farrell, A.E., S. D. VanDeveer, and J. Jäger. 2001. Environmental assessments: Four underappreciated elements of design. *Global Environmental Change,* 11: 311-333.

Finkel, A.M., 2011. Solution-Focused Risk Assessment: A Proposal for the Fusion of Environmental Analysis and Action. *Human and Ecological Risk Assessment: An International Journal*, 17(4), pp.754-787.

Flachsland, C. Kowarsch, M., Jabbour, J. and Riousset, P. (2015). Public policy assessment in global environmental assessments. Working paper: Presented at the *International Conference on Public Policy*, Milan.

Goodwin, J. 2009. The Authority of the IPCC First Assessment Report and the Manufacture of Consensus. Paper presented at the National Communication Association conference, Chicago, November.

Grainger, A. 2009. The role of science in implementing international environmental agreements: the case of desertification. *Land Degradation and Development,* 20(4): 410-430.

Haas, P.M. 1992. Introduction: epistemic communities and international policy coordination. *International Organization,* 46: 1.

Haas, P.M., Levy, M.A. and Parson, E.A. 1992. How Should We Judge UNCED's Success?. *Environment: Science and Policy for Sustainable Development,* 34(8): 6-33.

Hrabanski, M. and D, Pesche. 2015. From the GBA to the IPBES: A comparative analysis of science-policy interfaces for biodiversity. International Conference on Public Policy, July 2015. Milan, Italy. Advancing public policy assessment in global environmental assessments.

Huitema, D. and Turnhout, E., 2009. Working at the science–policy interface: a discursive analysis of boundary work at the Netherlands Environmental Assessment Agency. *Environmental Politics*, *18*(4), pp.576-594.

Hulme, M., Zorita, E., Stocker, T.F., Price, J. and Christy, J.R., 2010. IPCC: cherish it, tweak it or scrap it. *Nature*, 463(11), pp.730-732.

Hulme, M., 2010. Split into three panels. *Nature,* 463: 730-731.

IPCC 2014. Future work of the IPCC. A report presented by the Task Group on the Future Work of the IPCC. TGF-II/INF.1 (1.IX.2014) Geneva, Switzerland, September 2014.

Ivanova, M. 2007. Designing the United Nations Environment Programme: a story of compromise and confrontation. *International Environmental Agreements: Politics, Law and Economics,* 7(4): 337-361.

Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Singh, A., Levy, M.A. and Schwarzer, S. 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development,* 3(2):5-24.

Jabbour, J. and Hunsberger, C. 2014. Visualizing Relationships between Drivers of Environmental Change and Pressures on Land-Based Ecosystems. *Natural Resources,* 5(4): 146-160.

Jones, H., Jones, N., Shaxson, L. and Walker, D. 2012. Knowledge, Policy and Power in International Development: A Practical Guide. The Policy Press, Bristol.

Kauffman, J. and Arico, S., 2014. New directions in sustainability science: promoting integration and cooperation. *Sustainability Science*, *9*(4): pp.413-418.

Koetz, T., Farrell, K.N. and Bridgewater, P., 2012. Building better science-policy interfaces for international environmental governance: assessing potential within the Intergovernmental Platform for Biodiversity and Ecosystem Services. *International environmental agreements: politics, law and economics*, 12(1), pp.1-21.

Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T.J., Watson, R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P., Pintér, L., Langford, C., Yamineva, Y., Stechow, C.V., O'Reilly, J. and Edenhofer, O., 2017. Global environmental assessments and the path to solutions. *Nature Climate Change,* 7(6): 379-382.

Kowarsch, M. 2016. Policy assessments to enhance EU scientific advice. *Nature Climate Change,* 6(1): pp.15-17.

Kowarsch, M., Garard, J., Riousset, P., Lenzi, D., Dorsch, M.J., Knopf, B., Harrs, J.A. and Edenhofer, O., 2016. Scientific assessments to facilitate deliberative policy learning. Palgrave Communications, Vol. 2, 2016.Krueger, R.A. and Casey, M.A., 2014. Focus groups: A practical guide for applied research. *Sage publications*.

Le Quéré, C. and Minns, A., 2016. Where next for global environmental research? The answer is Future Earth. In Annales des Mines-Responsabilité et environnement (No. 3, pp. 72-77). FFE.

Levy, M.A., Young, O.R. and Zürn, M., 1995. The study of international regimes. *European journal of international relations*, *1*(3), pp.267-330.

Lozano, R., 2012. Towards better embedding sustainability into companies' systems: an analysis of voluntary corporate initiatives. *Journal of Cleaner Production,* 25, 14-26.

Martinez, C. and Mueller, M., 2015. The SDGs: Opportunities for Conservation. *Environmental Policy and Law,* 45(6): 239.

Minx, J.C., Callaghan, M., Lamb, W.F., Garard, J., and Edenhofer, O., 2017. Learning about climate change solutions. *Environmental Science and Policy, submitted*

Mitchell, R.B., 2006. Global environmental assessments: Information and influence. MIT Press.

Morgan, D.L., 1996. Focus groups. *Annual Review of Sociology* 22, 129-152

Morrisette, P.M. 1989. The evolution of policy responses to stratospheric ozone depletion. *Natural Resources Journal*, 29: 793-820.

Muñoz, M., Thrasher, R. and Najam, A. 2009. Measuring the negotiation burden of multilateral environmental agreements. *Global Environmental Politics,* 9(4): 1-13.

Nossum, J., 2017. Into the great wide open: Trends and tendencies in university collaboration for development. North–South Knowledge Networks.

Oberthür, S. 2009. Interplay management: enhancing environmental policy integration among international institutions. *International Environmental Agreements: Politics, Law and Economics,* 9(4), 371-391.

OECD, 2015. Scientific Advice for Policy Making: The Role and Responsibility of Expert Bodies and Individual Scientists. OECD Science, Technology and Industry Policy Papers, No. 21, OECD Publishing, Paris. http://dx.doi.org/10.1787/5js33l1jcpwb-en

Papa, M. and Gleason, N.W. 2012. Major emerging powers in sustainable development diplomacy: Assessing their leadership potential. *Global Environmental Change,* 22(4): 915-924.Parson, E.A. 1993. Protecting the Ozone Layer, in: P.M. Haas; R.O. Keohane and M.A. Levy (*eds*.): Institutions for the Earth. Sources of Effective International Environmental Protection, Cambridge, Mass.: MIT Press, pp. 27-73.

Perrings, C., Duraiappah, A., Larigauderie, A. and Mooney, H., 2011. The biodiversity and ecosystem services science-policy interface. *Science,* 331(6021): pp.1139-1140.

Raustiala, K. 1997. States, NGOs, and international environmental institutions. *International Studies Quarterly,* 41(4): 719-740.

Riousset, P., Flachsland, C. and Kowarsch, M. 2017. Global Environmental Assessments: Impact mechanisms. *Environmental Science & Policy,* http://dx.doi.org/10.1016/j.envsci.2017.02.006

Ritchie, J. and Spencer, L., 2002. Qualitative data analysis for applied policy research. *The qualitative researcher's companion*, *573*(2002), pp.305-329.

Robbins, A. 2016. How to understand the results of the climate change summit: Conference of Parties21 (COP21) Paris 2015. *Journal of public health policy, 37*(2): pp.129-132.

Rogelj, J. and Knutti, R., 2016. Geosciences after Paris. *Nature Geoscience*, *9*(3): pp.187-189.

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K. and Meinshausen, M., 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 C. *Nature,* 534(7609), pp.631-639.

Rothman, D.S., C. van Bers, J. Bakkes, C. Pahl-Wostl, 2009. How to make global assessments more effective: lessons from the assessment community. *Current Opinion in Environmental Sustainability,* 1: 214-218.

Rowe, A., Ng'eny, N. and M. Carbon, 2014. Terminal Evaluation of the Project Fifth Global Environmental Outlook: Integrated Environmental Assessment. UNEP Evaluations Office, Nairobi.

Savaresi, A., 2016. The Paris Agreement: a new beginning?. *Journal of Energy & Natural Resources Law,* 34(1), pp.16-26.

Selin, H. and Eckley, N. 2003. Science, politics, and persistent organic pollutants: The role of scientific assessments in international environmental co-operation. *International Environmental Agreements,* 3(1): 17-42.

Shapiro, H.T., Diab, R., de Brito Cruz, C.H., Cropper, M.L., Fang, J., Fresco, L.O. and Zakri, A.H., (2010). Climate change assessments: Review of the processes and procedures of the IPCC. *InterAcademy Council,* Amsterdam.

Strauss, A. and Corbin, J., 1998. Basics of qualitative research: Procedures and techniques for developing grounded theory.

Tengö, M., Brondizio, E.S., Elmqvist, T., Malmer, P. and Spierenburg, M., 2014. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio,* 43(5), 579-591.

Tollefson, J. and Weiss. K.R., 2015. Nations adopt historic global climate accord Agreement commits world to holding warming 'well below' 2°C. *Nature,* 528 (315-316):10.1038/528315a

Tollefson, J., 2015. Climate-panel chief Hoesung Lee wants focus on solutions. Nature, 526 (October 15, 2015). doi:10.1038/nature.2015.18556.

UNEP, 2009. Findings of the review of the initial impact of the fourth global environment outlook: Environment for development report and the self-assessment survey. UNEP/GC/25/INF/13.

UNGA (United Nations), 2012. Resolution adopted by the General Assembly on 27 July 2012: A/RES/66/288. *The future we want.* UNGA, 11 September 2012, New York.

Victor, D. 2015. Embed the social sciences in climate policy. *Nature* 520, 27–29.

Vogel, C., Moser, S.C., Kasperson, R.E., Dabelko, G.D. 2007. Linking vulnerability, adaptation, and resilience science to practice: pathways, players, and partnerships. *Global Environmental Change,* 17:349–364.

von Stechow, C., Minx, J.C., Riahi, K., Jewell, J., McCollum, D.L., Callaghan, M.W., Bertram, C., Luderer, G. and Baiocchi, G., 2016. 2° C and SDGs: united they stand, divided they fall?. *Environmental Research Letters*, 11(3), p.034022.

Watson, R.T. 2013. The value of knowledge and the importance of global assessments. CGFRA Seminar Biodiversity for food and agriculture. United Nations FAO Rome: 13 April 2013.

Watson, R.T., 2005. Turning science into policy: challenges and experiences from the science–policy interface. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 360(1454): 471-477.

Wesselink, A., Buchanan, K. S., Georgiadou, Y., and Turnhout, E. 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. *Environmental Science and Policy*, 30: 1-9.

Young, O.R., 1989. International cooperation: Building regimes for natural resources and the environment. Cornell University Press.

Young, O.R., 1997. Global governance: drawing insights from the environmental experience. MIT press.

Zaccai, E., 2012. Over two decades in pursuit of sustainable development: Influence, transformations, limits. *Environmental Development,* 1(1): 79- 90.Jabbour, J. and Flachsland, C., 2017. 40 years of global environmental assessments: A retrospective analysis. *Environmental Science & Policy 71,* 193-202.

3.6 Annex A: Supplementary Information

3.6.1 Mapping the landscape of global environmental assessments: A comprehensive inventory

As defined in the main text, Global Environmental Assessments (GEAs) are highly structured mechanisms to organize and integrate existing scientific knowledge on the drivers and impacts of, and responses to, pervasive environmental issues for the purposes of informing local, national and/or transnational decision-making, and even international environmental governance (Clark et al., 2006; Rothman et al., 2009; Díaz et al., 2015). The development and preparation of a GEA typically involves large numbers of experts with varying backgrounds, convened around a deliberative process to distill, synthesize, interpret and organize environmental knowledge, information and data into a careful sequence of indicator-based narratives.

The GEA inventory presented in Table S3.1 represents the most complete and comprehensive compilation to date, and the first attempt of its kind. The inventory was conducted by the authors over a 3-year period (2013-2016) with inputs and reviews by leading GEA experts and practitioners; it relies heavily on the careful analysis and surveying of other related repositories and databases (e.g., IPBES 2016; UN DESA 2016; UNEP 2016). The criterion for inclusion in this inventory was informed by the aforementioned definition and characterization of GEAs, specifically: (1) the thematic and/or geographic scope of assessment being global in nature; and (2) a multidisciplinary and multinational composition of independent experts (or multiple expert groups) working in a highly collaborative, structured and integrated setting through a pre-defined process.

The 1977 OECD *Assessment of Long-Range Transport of Air Pollutants* (LRTAP), to the best of our knowledge, represents the first GEA ever undertaken. Since then, over 143 distinct GEAs have been initiated, of which, 136 have been completed. With respect to scope, although some of the GEAs identified are concerned primarily with specific political boundaries (i.e., the OECD Assessment series) we consider these processes to be "global" as their outlook and analysis reflect developments and interactions with issues outside their geographic scope and how they (OECD countries) can better cooperate on global environmental problem-solving. Of all GEAs produced or currently under development, roughly 60% (86) are reoccurring, in other words, are part of a continual process with a dedicated assessment platform, and released on a semi-regular (or irregular) basis. More than half (56%) all GEAs produced over the 40-year span since their conception have been initiated in the last decade.

Finally, of the 143 GEAs identified in the inventory, nearly 25% (37) are formally recognized as intergovernmental assessments. While many, if not most of the known GEAs are produced or administered by an intergovernmental organization (whose mandates are typically governed by an intergovernmental process), the assessment processes themselves are not necessarily deemed to be "intergovernmental". The important distinction is that intergovernmental scientific assessment processes are not only administered under the auspices of the United Nations, and are set up at the request of member governments; they also possess a formal intergovernmental body or panel that oversees the overall production of the GEA and its process and procedures.

Table S3.1. A comprehensive summary of all known GEAs initiated to date, including 7 anticipated or currently under production; the inventory includes both recurring and non-recurring GEAs and those formally recognized as intergovernmental

	Assessment title	Year Published	Recurring assessment	Inter-governmental	Lead Organization(s)
1	Global Assessment of Long-Range Transport of Air Pollutants: Measurements and Findings *	1977			OECD
2	First Global Forest Resources Assessment	1980	✓		FAO
3	Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1984: Atmospheric Aerosol Optical Depth	1984	✓		WMO
4	Atmospheric Ozone: Assessment of Our Understanding of the Processes Controlling Its Present Distribution and Change (Three volumes)*	1985			WMO, UNEP, NASA/NOAA
5	Our Common Future: World Commission on Environment and Development	1987			UN WCED
6	Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data for 1985. Vol 1: Atmospheric Aerosol Optical Depth	1987	✓		WMO
7	Interim report on the global state of forest resources	1988	✓		FAO
8	Global Ozone Research and Monitoring: Report of the International Ozone Trends Panel 1988 (two volumes)	1988			WMO, UNEP, NOAA
9	Scientific Assessment of Stratospheric Ozone, 1989 (Two volumes) 1989*	1989	✓	✓	WMO, UNEP, NASA/NOAA
10	Second Global Forest Resources Assessment 1990	1990	✓		FAO
11	Scientific Assessment of Ozone Depletion: 1991	1991	✓		WMO
12	Intergovernmental Panel on Climate Change- First Assessment Report (FAR) (Three volumes)*	1991	✓	✓	IPCC
13	World Resources Report: Guide to Global Environment	1992	✓		WRI
14	Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios	1994		✓	IPCC
15	Scientific Assessment of Ozone Depletion: 1994	1994	✓		WMO, UNEP
16	World Resources Report 1994-95: People and the Environment	1995	✓		WRI, UNEP, WB
17	Global Biodiversity Assessment (GBA)*	1995			UNEP
18	Intergovernmental Panel on Climate Change (IPCC-SAR) (Three volumes) 1995*	1995	✓	✓	IPCC
19	World Resources Report: The Urban Environment	1996	✓		WRI, UNEP
20	State of the World's Forests 1997	1997			FAO
21	The Regional Impacts of Climate Change: An Assessment of Vulnerability	1997			IPCC
22	Global Environment Outlook (GEO-1)*	1997	✓		UNEP
23	World Resources Report: Environmental change and human health	1998	✓		IPCC
24	Scientific Assessment of Ozone Depletion: 1998	1998	✓	✓	WMO, UNEP
25	Aviation and the Global Atmosphere	1999			IPCC
26	Land Use, Land-Use Change, and Forestry	2000			IPCC
27	Global Forest Resources Assessment 2000 (FRA 2000)	2000	✓	✓	FAO
28	The 2000 IUCN Red List of Threatened Species	2000	✓		IUCN
29	Global Key Biodiversity Areas Assessment	2000			IUCN
30	World Energy Assessment: The Challenge of Sustainability	2000	✓		UNDP, WEC, DESA
31	Methodological and Technological Issues in Technology Transfer	2000			IPCC
32	Global Emissions Scenarios	2000			IPCC
33	The World Database on Protected Areas (WDPA)	2000			IUCN
34	State of the World's Plant Genetic Resources for Food and Agriculture	2000			FAO
35	Global Environment Outlook (GEO-2) 2000*	2000	✓		UNEP

36	Intergovernmental Panel on Climate Change (IPCC - TAR) (Three volumes) 2001*	2001	✓	✓	IPCC
37	OECD Environmental Outlook 2001	2001	✓		OECD
38	Global Assessment of Human-induced Soil Degradation	2001			FAO, UNEP, WRI
39	World Resources Report 2000-2001 -- People and ecosystems: The fraying web of life	2001	✓		WRI, UNEP, WB
40	Global Biodiversity Outlook (GBO 1) 2001*	2001	✓	✓	CBD, UNEP
41	Scientific Assessment of Ozone Depletion: 2002	2002	✓	✓	WMO, UNEP
42	World Water Development Report 1: Water for People, Water for Life (2003)	2003	✓	✓	UNESCO
43	World Resources Report: Decisions for the Earth - Balance, voice, and power	2003	✓		WRI
44	World Energy Outlook 2003	2003	✓		OECD/ IEA
45	Global Environment Outlook (GEO-3) 2002*	2002	✓	✓	UNEP
46	Species Survival Commission and the 2004 IUCN Red List of Threatened Specie	2004	✓		IUCN
47	Global Fishery Independent Survey	2004			ICES
48	Global Biodiversity Outlook (GBO 2) 2004*	2004	✓	✓	CBD/ UNEP
49	World Resources Report 2005 - The Wealth of the Poor: Managing Ecosystems to Fight Poverty	2005	✓		WRI, UNEP, WB
50	World Energy Outlook (WEO-2005)	2005	✓		OECD/ IEA
51	Global Marine Species Assessment	2005			IUCN
52	Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons	2005		✓	IPCC
53	Global Forest Resources Assessment 2005	2005	✓		FAO
54	Carbon Dioxide Capture and Storage	2005			IPCC
55	Special Report on Carbon Dioxide Capture and Storage	2005			IPCC
56	Millennium Ecosystem Assessment (4 Volumes)*	2005			UNEP, WB
57	World Water Development Report 2: Water, a Shared Responsibility	2006	✓	✓	UNESCO
58	Scientific Assessment of Ozone Depletion: 2006	2006	✓	✓	WMO, UNEP
59	World Energy Outlook (WEO) 2006	2006	✓		OECD/ IEA
60	Global Land Degradation Assessment in Drylands	2006		✓	FAO/LADA
61	Global International Waters Assessment	2006			UNEP
62	Water Quality for Ecosystem and Human Health	2006			UNECSO, UNEP
63	The World's Mangroves 1980-2005	2007			FAO
64	State of the World's Animal Genetic Resources for Food and Agriculture	2007			FAO
65	Comprehensive Assessment of Water Management in Agriculture	2007			IWMI
66	Intergovernmental Panel on Climate Change (IPCC AR4) Fourth Assessment Report (3 Volumes)*	2007	✓	✓	IPCC
67	Global Peatlands Assessment	2007			UNEP-GEF, APN
68	Large Marine Ecosystem Report: Changing Conditions in the World's Regional Seas	2007			UNEP
69	Global Environment Outlook (GEO-4): Environment for Development 2007*	2007	✓	✓	UNEP
70	International Assessment of Agricultural Science and Technology for Development (IAASTD)*	2008		✓	UNEP
71	The Economics of Ecosystems and Biodiversity (TEEB) Global Assessment	2008			UNEP
72	Health environment: Managing the linkages for sustainable development - a toolkit for decision-makers	2008			WHO, UNEP
73	World Energy Outlook (WEO-2008)	2008	✓		OECD/ IEA

74	World Resources Report 2008: Roots of Resilience - Growing the Wealth of the Poor	2008	✓		WRI, UNEP, WB
75	Wildlife in a Changing World: An Analysis of the 2008 IUCN Red List of Threatened Species	2008	✓		IUCN
76	OECD Environmental Outlook to 2030	2008	✓		OECD
77	Towards Sustainable Production and Use of Resources: Assessing Biofuels (2009)	2009			UNEP/ IRP
78	Impacts of Ocean Acidification on Marine Biodiversity	2009			UNEP-WCMC
79	Global assessment report on disaster risk reduction	2009	✓		UNISDR
80	Climate Change Science Compendium 2009	2009			UNEP
81	World Water Development Report 3: Water in a Changing World	2009	✓	✓	UN
82	Assessment of Assessments (AoA): Regular process for global reporting and assessment of the state of the marine environment, including socio-economic aspects	2009	✓	✓	UNEP, UNESCO/ IOC
83	Global Forest Resources Assessment 2010	2010	✓		FAO
84	The Emissions Gap Report	2010	✓		UNEP
85	Assessing the Environmental Impacts of Consumption and Production: Priority Products and Materials (2010)	2010			IPR/ UNEP
86	World Resources Report 2010-2011: Decision Making in a Changing Climate	2010	✓		WRI, UNEP, WB
87	Global Biodiversity Outlook (GBO 3) 2010*	2010	✓	✓	CBD, MEA
88	Global Land Degradation Assessment in Drylands 2	2010	✓		FAO
89	World Energy Outlook (WEO-2010) International Energy Agency	2010	✓		OEC/ IEA
90	Scientific Assessment of Ozone Depletion: 2010	2010	✓	✓	WMO, UNEP
91	The IUCN Global Assessment Red List of Ecosystems	2011	✓		IUCN
92	Bridging the Emissions Gap Report 2011	2011	✓		UNEP
93	Towards a GREEN economy: Pathways to Sustainable Development and Poverty Eradication	2011			UNEP
94	World Resources Report 2010-2011: Decision Making in a Changing Climate	2011	✓		WRI, UNEP, WB
95	Cities and Climate Change: Global Report on Human Settlements	2011			UN-Habitat
96	Global Water Footprint Assessment Standard	2011			GFN
97	Renewable Energy Sources and Climate Change Mitigation	2011			IPCC
98	OECD Environmental Outlook to 2050: The Consequences of Inaction	2012	✓		OECD
99	World Energy Outlook (WEO-2012)	2012	✓		OECD/ IEA
100	Mediterranean Wetlands Outlook	2012	✓		Ramsar/MedWet
101	Global Environment Outlook (GEO-5) 2012*	2012	✓	✓	UNEP
102	Understanding Relationships between Biodiversity, Carbon, Forests & People: A Global Assessment Report	2012			IUFRO
103	Responsible Resource Management for a Sustainable World: Findings from the International Resource Panel	2012			UNEP/ IRP
104	Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation	2012		✓	IPCC
105	The Emissions Gap Report 2012	2012	✓		UNEP
106	The Economics of Ecosystem and Biodiversity (TEEB) for Water and Wetlands	2013			UNEP
107	Global Soil Biodiversity Assessment (GSBA)	2013			EC, CSU
108	World Energy Outlook (WEO-2013)	2013	✓		OECD/ IEA
109	World Resources Report 2013-2015: Creating a Sustainable Food Future	2013	✓		WRI, UNEP, WB
110	City-level Decoupling: Urban Resource Flows and the Governance of Infrastructure Transitions (2013)	2013			UNEP/ IRP
111	The Emissions Gap Report 2013	2013	✓		UNEP
112	Global Chemicals Outlook report: Towards Sound Management of Chemicals	2013		✓	UNEP
113	The IUCN Red List of Ecosystems	2013	✓		IUCN

114	Global assessment report on disaster risk reduction 2013	2013	✓		UNISDR
115	Intergovernmental Panel on Climate Change (IPCC-AR5) - Three Volumes 2013/14*	2013	✓	✓	IPCC
116	Scientific Assessment of Ozone Depletion: 2014	2014	✓	✓	WMO, UNEP
117	Global Sustainable Development Report *(Prototype)*	2014	✓		UNDESA
118	The Emissions Gap Report 2014	2014	✓		UNEP
119	UN World Ocean Assessment	2014	✓	✓	UN
120	World Energy Outlook (WEO-2014)	2014	✓		OECD/IEA
121	Assessing Global Land Use: Balancing Consumption with Sustainable Supply (2014)	2014			UNEP/ IRP
122	Global Biodiversity Outlook 4 (GBO-4)	2014	✓	✓	UNEP-CBD
123	World Water Development Report: Water and Energy	2014	✓		UN
124	World Resources Report 2013-2014: Creating a Sustainable Food Future	2014	✓		WRI
125	World Energy Outlook - 2015	2015	✓		IEA OECD
126	First Global Integrated Marine Assessment	2015			UN
127	Global Sustainable Development Report, 2015 edition	2015	✓		UN DESA
128	Assessment on Food Systems and Natural Resources	2015			UNEP/ IRP
129	The 2015 Global Forest Resources Assessment (FRA)	2015	✓		FAO
130	Global assessment report on disaster risk reduction	2015	✓		UNISDR
131	The Economics of Ecosystems and Biodiversity for Agriculture and Food GLF 2015	2015			UNEP
132	International Trade in Resources: A biophysical assessment	2015			UNEP-IRP
133	Global Assessment of Sand and Dust Storms	2016			UNEP, WMO, UNCCD
134	Global Sustainable Development Report, 2016 edition	2016	✓		UN DESA
135	Global Gender and Environment Outlook	2016		✓	UNEP
136	Global assessment on pollinators, pollination and food production	2016		✓	IPBES
	GEAs currently under production/ initiated	***Anticipated***			
137	*Special Report on Climate change and the oceans and the cryosphere*	*2017**		✓	IPCC
138	*The first Global Land Outlook (GLO)*	*2017**	✓		UNCCD
139	*Global assessment on biodiversity and ecosystem services (IPBES) First Global Assessment*	*2018**	✓	✓	IPBES, UNEP
140	*Special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways*	*2018**		✓	IPCC
141	*Global Environment Outlook (GEO-6)*	*2019**	✓	✓	UNEP
142	*Global Sustainable Development Report, 2019 edition*	*2019**	✓		UN DESA
143	*Intergovernmental Panel on Climate Change (IPCC-AR6) – Three Volumes*	*2022**	✓	✓	IPCC

3.6.2 Methods and materials

GEA metadata catalogue

To facilitate a comparative retrospective analysis of GEAs, a subset of 20 assessments were selected from the 136 identified in the inventory presented in Table S4.1 (those indicated with an asterisk '*') spanning the period of 1977 to 2014. Comparable metadata of key attributes and epistemic properties for these 20 assessments were collected (from March 2013 to July 2016) and analyzed. These metadata form a key component of the empirical evidence underpinning our retrospective analysis and that support the conclusions of this paper. In particular, we present a comparative analysis of

metadata that highlight the changing character and orientation of GEAs—in their 40-year evolution—with respect to a discernable rise in both process and epistemic complexity.

Table S3.2 – Key GEA attributes and sub-attributes collected for the subset of 20 assessments

Attribute / *Sub-attribute*	Description
Lengths of assessment - *Volumes, pages, word count, chapters/ sections*	Quantity of content including all visual, graphical and data content presented in each published assessment
Authorizing mandates	Intergovernmental obligation and/or directive, in any, that authorize/ request and define mandate
Purpose and objectives	Defined overarching aim, purpose(s), aim, objectives/ sub-objectives; guiding, and/or framing question(s)
Scope - *Subject area(s); environmental domains coverage* - *Spatial, temporal, jurisdictional (e.g. geographic) and/or institutional, extent or range investigation*	Geographic, thematic/ domain scope, outlook and extent of the assessment undertaking; rationale of intended scope/ range of investigation.
Coordination and administration - *Sponsorship, cooperation, Secretariat, governance and management**	Organization(s) and institutional structures (e.g. Secretariat) in place/ involved in the overall production, administration and sponsorship of the assessment
Contributors involved in GEA production - *Different roles of GEA participants* - *Governments/ national-level representation**	Number, types (e.g. authors, expert advisors, reviewers etc.), distribution of all participants involved
Source materials - *Reference/ citation counts; types, distribution of disciplinary sources*	All information, data and knowledge sources used (i.e. considered and synthesized) in the assessment
Key messages	Synthesized presentation of main findings
Target audiences	Pre-defined stakeholder/ particular group(s) which assessment is aimed
International policy-relevant context	Political, institutional or multilateral milestone, event aligned with given GEAs
Review process	Number, type and distribution of review comments; procedural and guidance documents
Operating budgets*	Known expenses, anticipated/incurred costs, and/or in-kind financial resources needed to produce the GEA

**Note*: *completeness of attribute data varied from one assessment to the next and in some cases, was missing as function of limited accessibility and/or incomplete records / documentation of certain processes*

A broad range of document types was analyzed as part of the data-gathering exercise for developing our GEA metadata catalogue. They include background documents, scoping papers, meeting reports, independent evaluations, official United Nations (UN) documentation (e.g., resolutions of the UN General Assembly, and/or decisions from the Governing Bodies of subsidiary organs of the UN, official UN information documents in support of inter-governmental meetings etc.), official proceedings of the principal organs of the UN or certain UN conferences; including verbatim or summary records of the meetings of the organs concerned, annexes and supplements.

The development of the catalogue, which was initiated in March 2013, involved collecting, collating, synthesizing and coding information, and, where necessary, digitizing selected texts from earlier GEAs (e.g., key messages, assessment objectives etc.) to facilitate comparative discourse analysis. The selection of attributes and the information categories included in the catalogue was informed by several discussions within the FOGEAM research team, various GEA practitioners, as well as the outcomes of a two-day experts' workshop reflecting on the experiences of conducting GEAs, systematic literature and document review, and authors' direct experience with global assessment processes. Comments on a draft attributes lists were made to the FOGEAM research group and GEA practitioners through multiple exchanges. A preliminary draft was also presented to a subset of the group targeted focus groups of experts and assessment practitioners convened in October 2013. The full list of GEA attributes (or properties) and sub-attributes collected for our research are presented in Table S3.2.

Interview materials and analysis

The analysis presented in this paper draws on the results of 99 semi-structured interviews conducted between August 2013 and April 2015. The interviews were carried out with a broad spectrum of GEA stakeholders including authors, advisory experts, reviewers, governmental representatives, and practitioners. Interview candidates were largely drawn from a pool of individuals involved in the production of either the UNEP-led fifth Global Environment Outlook (GEO-5) assessment (n=73), or the IPCC Fifth Assessment Report, Working Group III: Mitigation of Climate Change (n=16). For the purposes of analysis, we grouped the interview respondents into three broad 'informant' groups or stakeholder profiles: (1) scientific experts, comprised of GEA authors, subject-area experts, advisors, contributors and reviewers from the scientific research community; (2) government representatives, including official national representatives and other civil servants engaged in GEAs; and (3) target audience comprised a range of relevant GEA stakeholders from civil society, media, academia, decision-making entities (i.e., government), and relevant non-government organizations deemed to be potential consumers or users of GEA findings. A summary of the interviews completed along with response rate, by group, is presented in Table S3.3. The highest response rate (31.5%) came from the scientific experts group, who arguably, were the most vested in the outcome of the process. The interviews lasted between 20 to 120 minutes and averaged ~60 minutes and were digitally recorded and transcribed with the consent of each interviewee. The flexibility of the semi-structures interview approach employed, allowed for the discovery and elaboration of information that was important to participants but not previously thought of as pertinent by the research team. The interviews were piloted and guided by an interview topic guide—a pre-developed set of question areas, probes and prompts—organized around eight clustered areas of investigation (Table S4). The initial ideas for the interview topic guide were generated iteratively drawing on a combination of the experiences of the FOGEAM researchers and their respective research areas; as well as extensive literature review; citing empirical and/or antidotal evidence of key design elements for assessment making. Ideas were further refined and tested using a targeted focus group of experts and assessment practitioners convened in October 2013 in Berlin. The extended list of guiding questions used during the interviews along with anonymized data, coding information, and a list of consenting interviewees can be made available from the corresponding author upon reasonable request. The data generated from these interviews is not publicly available due to the sensitive nature of topics discussed and in order to protect the privacy of interviewees.

Table S3.3 – Summary of interviews completed and response rates, by group (N=99)

Interviewee/ informant group	Interviews completed	Response rate
Scientific experts (e.g., authors, advisors, reviewers)	76	31.5%
Government representatives	13	19.4%
Target audience (non-involved individuals)	10	12.7%

Table S3.4 – Clustered question areas/ lines of investigation used to inform the semi-structured interviews

Question area/ e.g. lines of investigation	No. of probing questions
Background, scene-setting: general experience, motivation to engage	3
1. Impact, Objectives and Context: direct/indirect impact channels	6
2. Stakeholders engagement: methods, engagement processes, profiles	4
3. Means and Obstacles: institutional, personal challenges	3
4. Policy appraisal: engagement, approach, methods, challenges	4
5. Multi-scalar issues: decision-making support, organizing frameworks	4
6. Divergent Viewpoints: broad areas of disagreement, dynamics, conflicting interests	4
7. Reflecting back: shifting orientation, political context, exogenous factors	3
8. Future role of GEAs: key design, procedural aspects, motivation, ambition	3

The FOGEAM research team met frequently during and after the interviewing phase to analyze data. The interview transcripts were coded in Max-QDA and analyzed using the Grounded Theory and Constant Comparative techniques (Strauss and Corbin, 1998; Ritchie and Spencer, 2002). Interview data were tabulated under clustered themes to facilitate comparison and interpretation (see above). We specifically looked for dissonant cases: informants who gave views contrary to the majority.

3.6.3 Expert Workshops in Berlin, 2013 and 2015

Two focus groups of experts and assessment practitioners in the field of global environmental change convened in October 2013 and September 2015 in Berlin, Germany, and provided valuable experiential data, perspectives, and interpretations including feedback on our early research findings. The first workshop assembled distinguished researchers with substantial experience in designing and carrying out UNEP's flagship Global Environment Outlook (GEO) series and other comparable assessments, to facilitate a series of focus-group discussions and critical reflections on their experiences (in particular with GEO-5). The group, which consisted of 13 participants, deliberated on a range of topics—through semi-guided focus group discussions—including procedural and methodological issues, impact channels, institutional and political contexts, and GEA design options, reforms and enhancements.

The workshop agenda combined plenary sessions, brief inputs from the FOGEAM research team, and parallel focus group discussions which feed back into the plenary. The focus group discussions included three topic areas: (1) political context and impacts of GEO; (2) objectives, means and procedures; and (3) the evolution, performance and conceptual design of GEAs. The applied insights and practical relevance shared during the expert workshop formed a key empirical component of the FOGEAM research design and analysis; and in particular helped informed the qualitative analysis presented in this paper regarding the inner workings of assessment-making processes.

The second focus group brought together 18 distinguished scholars and practitioners, including senior representatives from the science-policy community, to reflect on and deliberate over key aspects of contemporary assessment-making. The central purpose of this second expert workshop was to facilitate fruitful and critical discussions about key challenges of and opportunities for GEAs, and practically solution-oriented global assessments, from different disciplinary and experiential perspectives. This workshop was used to also to test key FOGEAM hypotheses confirm the direction of our initial findings. It was instrumental in further refining and extending our analysis presented in this paper. The workshop agenda consisted of five focused sessions including: (1) the changing GEA landscape and political context: Shift to solutions, new challenges; (2) Policy assessment paradigms, complexity and research organization; (3) Re-thinking the potential for impacts of GEAs on policy processes; (4) Legitimacy, multiple stakes and divergent viewpoints; and (5) What GEAs could contribute to the Sustainable Development Goals.

3.6.4 Background and method underlying Figure 3.2

Global environmental assessments vary not only in their content and coverage, but also in their level of ambition and their scope of intention (i.e., the types, range and number of questions they seek to answer). The breadth of their envisioned audience and their associated sphere of influence also varies considerably between GEAs (Mitchell et al., 2006; Jabbour et al., 2012; Ling et al., 2015; Kowarsch et al., 2017). As a result, the specific roles and functions that characterize a given assessment are highly heterogeneous across the GEA landscape. Based on anecdotal evidence and personal experience, we established a working hypothesis that the magnitude and complexity of the assessment task, in large part, has been exacerbated in recent years by significantly greater demands and rising expectations. We set out to test the hypothesis by studying the extent and scope of assessment objectives of 20 GEAs spanning 1977—2014, by carefully analyzing a range of supporting documents. These included, but were not limited to: (1) official authorizing mandates; (2) meeting reports and background papers associated with the preparatory (or scoping) phases of the assessments; (3) explicit directives and/or operation guidance provided to authors and experts; (4) preamble materials; and (5) the assessment documents themselves. We developed a hierarchical clustering of "assessment objectives" to logically characterize and measure the substantive and operation scope of each GEA examined, consisting of 'first' and 'second-order' objectives and third level which we called 'framing questions'. Table S4.5 provides descriptions for each category in and an example of how the hierarchy was applied.

Table S4.5 – Hierarchical clustering used to analyze the extent and scope of assessment objectives

Hierarchical clustering	Description	Example
First-order objectives	*Overarching goals, typically aspirational in nature and often connected to the underlying mandate(s) and/or aim of the assessment.*	'Strengthen policy relevance'
Second-order objectives	*These are instructional objectives typically formulated as statements (or directives) which clearly describe an anticipated outcome and/or course of action to achieve one or more specific 1st order objectives.*	'Review and assess case studies of policy options that incorporate environmental, social and economic data and information that have facilitated and/or have the potential to facilitate speeding up achievement of internationally agreed goals by providing their indicative costs and benefits.'
Framing/ scoping questions	*Specific / focused questions typically linked to 2nd order objectives to offer indicative guidance on the scope and/or framing of an objective (i.e., narrowing of investigation).*	'What specific policy options can be most successfully applied in each region to help speed up meeting internationally agreed goals?'

3.6.5 Material and method underlying Figure 3.4

The underlying data for the analysis presented in Figure 3.4 was derived from the collated inputs of a questionnaire (and accompanying report) commissioned by the Intergovernmental Panel on Climate Change (IPCC) in 2013 carried out by the Task Group on the Future Work of the IPCC. The report compiled 137 official comments submitted from Governments, IPCC authors, contributing authors and review editors, and relevant international organizations on the future work of the Panel including proposed suggestions/ options and recommendations for reform. The results of our analysis are presented as an indicative illustration of the current thinking regarding the utility, perceived function and demands or expectations of future GEAs across a range of state and non-state actors in the assessment community. To facilitate our analysis, responses were grouped into 3 responded groups: independent experts (n= 90); governments (n=9); and boundary organizations (n=32). We analyzed the complete text contents of 137 responses with respect to explicit and implicit alignment of recommendations/ suggestions with greater solution and/or response oriented focus for the future work of the IPCC; including a deeper engagement with policy analysis and the assessment of solutions. The analysis began with the identification of relevant keywords and word sets (see indicative list below) and the partitioning of text into coherent segments or groupings. Four sets were initially identified and further grouped into two main sets: a 'focus on policy-analysis' set and 'solution-oriented response' set. Comments were evaluated and grouped based on their inclusion of keywords (for the respective sets/groupings). The analysis also considered, to the extent possible, the specific context(s) in which keywords occurred to ensure a more differentiated interpretation of the comments.

S4.6 – Indicative list of keywords, word sets and groupings

Keywords	Solution-oriented comment	focus on policy-analysis/ response
Solution(s)/ solution pathway; transition pathways	✓	
Technology/technologies, practice(s), technology transfer	✓	
Capacity/building/ development	✓	
Measure(s), means	✓	
Mitigation/adaptation potential/option(s)/effort		✓
Policy-relevant, demanded by policy-makers, addressed to policymakers	✓	
Economic analysis, sectors/ analysis		✓
Development alternatives	✓	✓
Achieving/transition to SDGs	✓	
Building resilience, sustainable infrastructure	✓	
Synergy/synergies, win-win, co-benefits	✓	✓
Policy, policy instrument(s), analysis, tool(s), design, alternative(s)	✓	✓
Incentives, market-based approach	✓	✓
Policy/ response, response measure, strategy/ processes	✓	✓
Strategy, approach(es), adaptive measures, adaptive strategies	✓	
Governance, management	✓	
Action, actionable knowledge, actionable/ implementation plan, priorities-actions, political action	✓	
Address(ing) options, mitigation and adaptation	✓	
Recommending/recommendation(s)	✓	
Implementing/implementation; means of implementation	✓	
Good/best practice(s); experience(s); demonstration activities	✓	✓
Climate finance/financing; financial instrument(s); investment	✓	✓

3.7 References

Alexander E.F. and Jäger, J., 2006. Assessments of regional and global environmental risks: designing processes for the effective use of science in decision-making. Resources for the Future Press. Washington, DC.

Clark, W.C., Mitchell, R.B. and Cash, D.W., 2006. Evaluating the influence of global environmental assessments. Global environmental assessments: information and influence. MIT, Cambridge, pp.1-28.

Cowling, E.B., 1982. Acid precipitation in historical perspective. *Environ. Sci. Technology,* 16(2), pp.110-123.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. (2015). The IPBES conceptual framework - connecting nature and people. *Current Opinion in Environmental Sustainability,* 14: pp.1-16.

IPBES 2016. Catalogue of Assessments on Biodiversity and Ecosystem Services. Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). http://catalog.ipbes.net/

Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N. and Schwarzer, S. 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development,* 3(2):5-24.

Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T.J., Watson, R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P., Pintér, L., Langford, C., Yamineva, Y., Stechow, C.V., O'Reilly, J. and Edenhofer, O. 2017. Global environmental assessments and the path to solutions. *Nature Climate Change,* 7(6): 379-382.

Ling, M., Coppens, L., MacDevette, M. and Mapendembe, A. 2015. An introduction to environmental assessment. UNEP World Conservation Monitoring Centre. United Nations Environment Programme.

Mitchell, R.B., 2006. Global environmental assessments: Information and influence. MIT Press.

OECD, 1977. The OECD assessment on long-range transport of air pollutants: Measurements and findings. Organization for Economic Cooperation and Development (OECD), Paris, France.

Ritchie, J. and Spencer, L., 2002. Qualitative data analysis for applied policy research. The qualitative researcher's companion, 573(2002), pp.305-329.

Rothman, D.S., C. van Bers, J. Bakkes, C. Pahl-Wostl, 2009. How to make global assessments more effective: lessons from the assessment community. *Current Opinion in Environmental Sustainability,* 1: 214-218.

Strauss, A. and Corbin, J., 1998. Basics of qualitative research: Procedures and techniques for developing grounded theory.

UN DESA, 2016. Annex 2: Database of UN Flagship Report under consideration for the GSDR prototype process. https://sustainabledevelopment.un.org/content/documents/4259Annexes2.pdf

UNEP, 2016. Environment Live: Assessment/ knowledge portal. https://uneplive.unep.org/assessments

4. A road map for global environmental assessments[1]

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Abstract

Increasing demand for solution-oriented environmental assessments brings significant opportunities and challenges at the science–policy–society interface. Solution-oriented assessments should enable inclusive deliberative learning processes about policy alternatives and their practical consequences.

Keywords: environmental assessments, intergovernmental processes, IPCC, science-policy interface, solutions, sustainable development

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4.1 Introduction

More than 140 global environmental assessments (GEAs) have been initiated over the past four decades (Jabbour and Flachsland, 2017). There is ongoing demand for these diverse, large-scale, multi-stakeholder, typically intergovernmental processes that distil and synthesize knowledge to inform decision-making. GEAs are time-consuming, demanding processes often facing institutional and political constraints. Nevertheless, compared with alternative science–policy–society interfaces, well-

[1]Published as Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T., Watson, R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P., Pintér, L., Langford, C., Yamineva, Y., von Stechow, C., O'Reilly, J., and Edenhofer, O. 2017. A road map for global environmental assessments. *Nature Climate Change*, *7*(6), pp.379-382.

designed GEAs have higher potential for legitimacy, governmental buy-in and generating credible syntheses across disciplines and approaches (Mitchell et al., 2006; Kowarsch, 2016; Norgaard, 2008), particularly regarding 'wicked problems' (Kowarsch et al., 2016). GEAs have provoked and sometimes even shaped international negotiations (Mitchell et al., 2006; Jabbour et al., 2012). For example, the assessments of the IPCC informed and catalysed support for the Paris Agreement (Kowarsch et al., 2016), and the fifth Global Environment Outlook (GEO-5) assessment influenced the 2030 Development Agenda (Dodds et al., 2014).

4.2 A desirable shift to solutions

Notwithstanding these successes, it is widely recognized that GEAs must evolve to improve their utility in integrating scientific and other expertise with policy processes (Mitchell et al., 2006; Norgaard, 2008; Perrings et al., 2011). Crucially, while many GEAs have effectively exposed environmental problems and drivers, the existing assessment of possible solutions has not yet reached its full potential. More clearly and extensively than ever before, decision-makers and scholars are demanding a deeper and more explicit focus on assessing different possible solutions in GEAs, including policies, in particular (for example, regulatory measures or market-based instruments) (Perrings et al., 2011; Halle et al., 2013; Carraro et al., 2015; Lee, 2015; Victor, 2015). Recent IPCC reform discussions help illustrate this (Figure 4.1).

Extensive policy assessment stands to reason given the recent developments in international environmental governance. The universal adoption of the Sustainable Development Goals (SDGs) and the Paris Agreement in 2015 were historic milestones in multilateralism and environmental governance. However, identifying and mobilizing the appropriate policies to pursue ambitious climate policy pathways or multiple SDGs remains a shortcoming and a priority. To this end, decision-makers are lacking sufficient knowledge about the direct effects, co-benefits and unintended adverse consequences of available policies across various dimensions, including multiple policy fields, governance levels, socioeconomic contexts, and time scales Carraro et al., 2015; Edenhofer and Kowarsch, 2015; von Stechow et al., 2016). For example, policies restricting bioenergy deployment to protect food security, biodiversity and water availability increase the reliance on other contested technologies and the costs for climate change mitigation (von Stechow et al., 2016). While uncertainty cannot be eliminated when assessing potential effects and interdependencies, their greater appreciation is crucial for managing these wicked problems. The GEA enterprise could become more relevant for advancing global sustainability by going beyond the (still necessary) assessment of environmental problems and priorities to explicitly engaging an integrated, contextualized evaluation of different environment-related policies and their complex effects. GEAs could, for instance, explore the implications of multilateral regimes or the global diffusion of domestic and regional policy lessons. Co-producing application-oriented, trans-disciplinary knowledge with an extended community of actors is crucial here (Garard and Kowarsch, 2017; Funtowicz and Ravetz, 1993; Nowotny et al., 2001; Fabricius et al., 2006).

However, to be successful, such solution-oriented GEAs must first address three profound challenges (see Supplementary Section C.a): integrating multiple policy dimensions, treating divergent normative viewpoints, and influencing policy. These challenges are intertwined, and are amplified by the evolving international environmental governance landscape. This evolving landscape has become

characterized by the proliferation of consensual environmental goals without appropriate policies for their achievement, and by new constellations of actors (and power) increasingly including non-state actors at multiple scales (Jabbour and Flachsland, 2017). Drawing from a larger interdisciplinary research project (Supplementary Section C.a), we provide a systematic overview of challenges and opportunities for contemporary solution-oriented GEAs in this evolving governance landscape. In particular, going beyond the largely fragmented literature on individual GEAs, this includes a unique synthesis — and substantive refinement — of some emerging GEA design approaches that may help address the challenges.

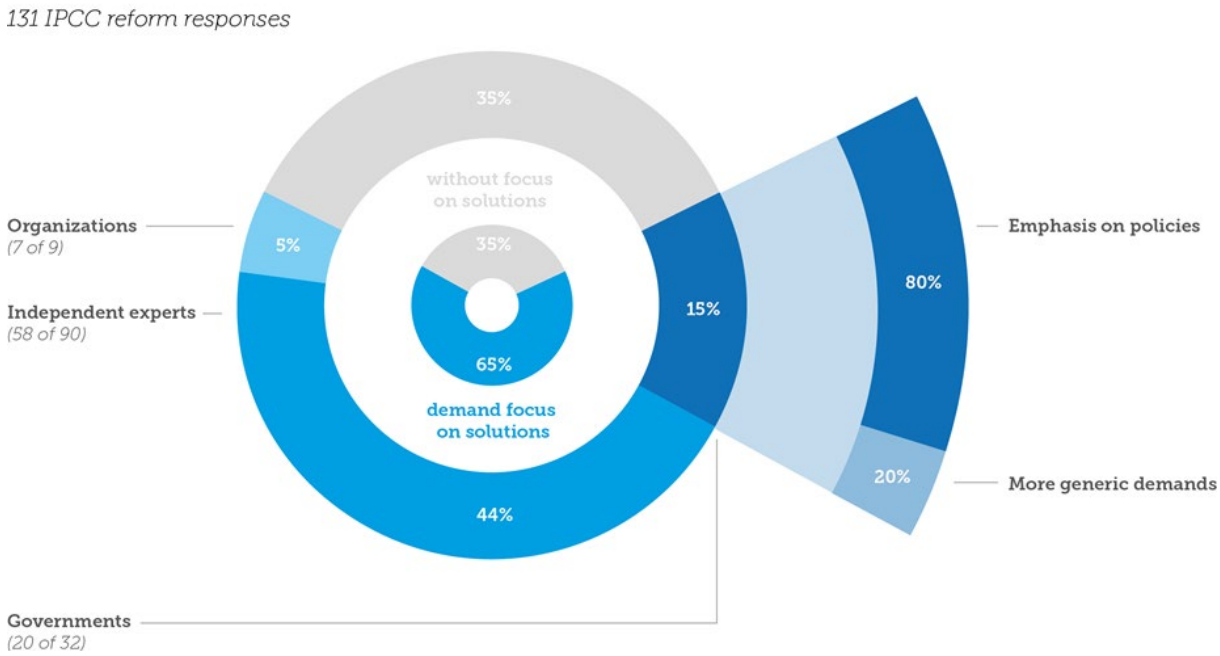

Figure 4.1. Various actor groups demand more solution-oriented IPCC assessments. ***Building on Jabbour and Flachsland (2017), further analysis of 131 comments submitted to the IPCC by governments, organizations and independent experts in 2014 for the IPCC reform discussions reveals the extent of the demand (percentages are rounded) for more explicit assessment of solution options in future IPCC reports, and specifically of policies (demanded by 80% of the 20 solution-oriented government submissions).*** *Note: See Supplementary Materials, Annex A (Section 4.9)*

4.3 Three challenges of solution-orientation

The first challenge is assessing the various multi-dimensional effects of policies in a rigorous and highly integrated manner (without necessarily reconciling them). This has proven an onerous and sometimes overtaxing methodological undertaking thus far (Norgaard, 2008). It is difficult enough to frame and scope suitable policy options in a complex solution space, as experienced in the Millennium Ecosystem Assessment (MA) and in GEO-5. The profound multi-dimensionality of the SDGs and the Paris Agreement goals create unprecedented complications for GEAs assessing options for achieving them.

Closely related is a second challenge: treating controversial normative viewpoints inherent to solution-oriented GEA processes that could undermine their legitimacy. Normative assumptions are inevitable in scientific research (Edenhofer and Kowarsch, 2015). While explicitly incorporating them through inclusion of divergent worldviews, policy priorities, and so on of diverse stakeholders

(Supplementary Section C.b) is an essential opportunity for GEAs, polarization can be triggered by divergent viewpoints — not only between author teams and other stakeholders, but also among authors themselves. For example, in the impressively inclusive International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), disagreements over the impacts of genetically modified organisms resulted in some private sector authors and members of the Bureau resigning. More recently, some governments resisted an *ex post* evaluation of national policies by the IPCC (Edenhofer and Minx, 2014). The evolving governance landscape, involving a growing diversity and number of disputed policy priorities and stakeholders, has resulted in amplified tension in GEA processes.

The third challenge is facilitating meaningful GEA influence, mainly in terms of mutual learning (Mitchell et al., 2006; Victor, 2015; Riousset et al., 2017). Conventional thinking maintains that scientific consensus is a precondition to directly influencing policy decisions by governments. However, the complexity of current policy issues and the diversity of actors involved in the evolving governance landscape make a consensus on 'best' policy options virtually impossible. Fostering influence requires an improved understanding of the potential causal influence (that is, outcome and impacts in the policy arena) of solution-oriented GEAs in the evolving governance landscape, resulting from both their processes and outputs.

4.4 Enabling multi-dimensional policy assessment

The following interventions may be part of a strategic response to the first challenge of integrating multiple policy dimensions.

Given the proliferation of objectives for many contemporary GEAs because of the increasing multi-dimensionality (Jabbour and Flachsland, 2017), a deliberate focus on a limited number of collaboratively determined, specific policy questions of particular relevance to decision-makers (for example, distributional effects of policies) is a first step towards improving the feasibility of many GEAs, as already practiced by the UN Environment Emissions Gap reports and the IPCC special reports. Yet, the selected policy issues should be assessed in a way that also informs governance processes about key interdependencies and indirect effects across policy fields.

Following the example of the integrated scenario modelling community, the main organizational principle of solution-oriented GEAs could be to more resolutely assess coherent future policy pathways, including potential policies, their various effects and specific requirements. This would improve policy-relevance. Multiple (qualitative and quantitative) criteria and various (for example, agent-based) model types should be employed to assess different policy dimensions, disciplinary insights, and approaches in an integrated manner. This would also help better embed the social sciences and humanities in some GEAs, including the IPCC (Victor 2015).

The aggregation of research results could be improved outside of assessment processes (as observed in the health and education sectors), through meta-analyses and systematic reviews, particularly in the peer-reviewed social-science literature. This should be organized along the multiple policy dimensions explained above, and would help GEAs deal with the rapidly growing body of literature (Figure 3.2). Equally important is addressing key research gaps outlined in previous solution-oriented

GEAs, particularly regarding empirical *ex post* policy analysis to enable learning from past experiences for future policy design. A systematic *ex post* meta-study on existing policies for sustainability could be organized, for instance, analogous to Elinor Ostrom's comparative analysis (Ostrom, 1990) of local common-pool resource management. This would help identify empirical factors conducive to successful environmental management in the context of multiple societal goals rather than continuing theoretical disputes in the social sciences.

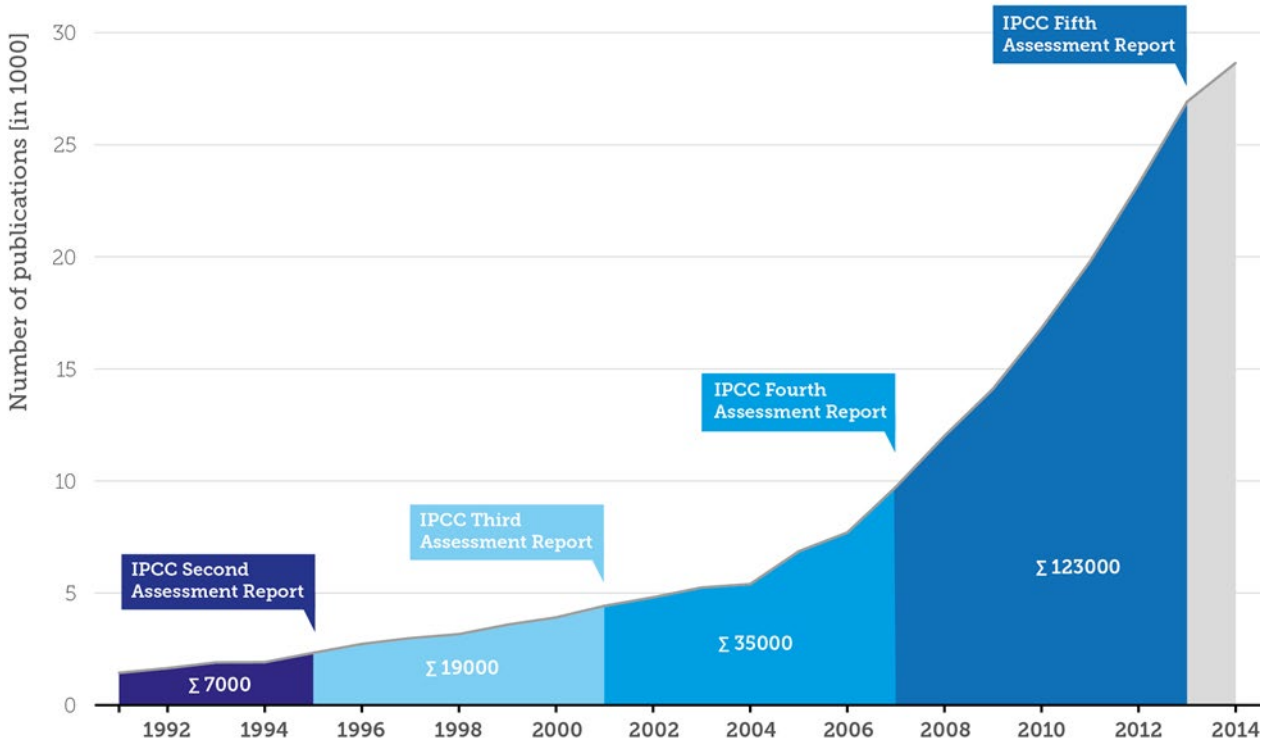

Figure 4.2. Rapid growth of annual publications on 'climate change'. We considered publications between 1990 and 2014 (212,000 in total) as listed in Web of Science, following Grieneseisen and Zhang (2011). Numbers are rounded. In 2014 alone, more papers (29,000) were published than in the entire period between Assessment Report 1 (AR1) and Assessment Report 3 (AR3) by the IPCC (26,000). *Note: See Supplementary Materials, Annex B (Section 4.10).*

4.5 Accommodating divergent normative viewpoints

To address the second challenge, GEAs must avoid polarization (of issues and stakeholders) and technocratic policy prescriptions while still constructively addressing controversial policy issues. The Intergovernmental Platform for Biodiversity and Ecosystem Services, for example, is deliberately positioned to become a learning opportunity for the meaningful inclusion of multiple worldviews, knowledge and value systems through diverse stakeholders (Supplementary Sections C.b and C.c).

More specifically, solution-oriented GEAs, through inclusive and transparent processes, may collaboratively select, scientifically explore and critically assess alternative policy pathways including their diverse practical implications (Edenhofer and Kowarsch, 2015), taking into account a diversity of knowledge systems and perspectives (Fabricius et al., 2006). No consensus on specific problem

framings or solutions is needed, but consistency in approaches is required to facilitate comparison (Edenhofer and Kowarsch, 2015). Only a few past GEAs have seriously explored alternative policy pathways, including the recent IPCC Working Group III assessment (Edenhofer and Kowarsch, 2015), and, to a lesser degree, the MA. The pathways explored should represent alternative policy narratives and objectives. Through the exploration of alternative pathways, GEAs can also reveal tensions between developing and developed countries and address them more explicitly (Carraro et al., 2015; Petersen et al., 2015). GEAs should identify and communicate the underlying reasons for disagreement when evaluating policy pathways. These approaches can significantly increase the legitimacy of GEAs and enable iterative, deliberative learning processes (Norgaard, 2008; Kowarsch et al., 2016; Dietz, 2013) among different stakeholders about policy alternatives while making it harder for interest groups to steer GEAs in a particular direction.

Acknowledging the multiplicity of approaches through which stakeholders can be engaged within GEA processes, a simple but effective measure for many solution-oriented GEAs to improve these methods would be to better align them with their objectives (*Supplementary Materials Section 3.11*) and available resources. This could be done, for example, by strengthening and formalizing the protocols and institutions guiding stakeholder selection and methods of engagement (for example, the Multi-Stakeholder Bureau supporting the 2008 IAASTD assessment) to ensure clear objectives, fair representation, cohesive engagement approaches, and use of outputs in GEAs (Garard and Kowarsch, 2017).

4.6 Interacting with new target groups

Addressing the third challenge requires better recognizing and fostering of the broad range of possible GEA influences on policy discourses. These include often-concealed forms of influence that solution-oriented GEAs exert through co-production of knowledge and interactive deliberations with various stakeholders (Riousset et al., 2017). Examples include: agenda-setting, shaping networks in international negotiations, the diffusion of programmatic policy ideas (for example, carbon pricing), and bidirectional learning between scientists and policy-makers. Thus, a potential, desirable and often underestimated outcome of solution-oriented GEAs in the evolving governance landscape is the enrichment of policy discourses among various state and non-state decision-makers through open multi-stakeholder learning processes around policy alternatives. Different measures may help realize this outcome.

Solution-oriented GEAs should recognize new and diverse target groups (Petersen et al., 2015). International environmental governance processes typically include, for instance, coalitions of local governments (for example, C40 Cities Climate Leadership Group) and business associations concerned with sustainability (for example, World Business Council for Sustainable Development). Depending on available resources, GEAs could organize separate dialogue forums with each group before, during and after GEA processes.

By encouraging direct interactions between these groups, GEA processes can enhance mutual learning, enable researchers to identify windows of opportunity, re-animate environmental debates, and facilitate discussions about relevant socio-economic and political conditions (Riousset et al., 2017) Inspiring approaches to structure such encounters include: co-producing different summaries with

different target audiences (for example, GEO-5) (Garard and Kowarsch, 2017); positioning special experienced translators between scientific expertise and policy (for example, UN Chief Scientists); and organizing regular face-to-face dialogues between scientists and policy-makers, such as the successful Structured Expert Dialogue on international climate policy involving IPCC experts (2014–2015).

4.7 Reforms embedded in a learning process

To conclude, future assessments should, in contrast to current populist ideas, facilitate inclusive, interactive and deliberative learning processes about actual policy alternatives and their different implications and interdependencies. Then, GEAs can more meaningfully contribute to policy discourses, which are a major factor contributing to policy change (Riousset et al., 2017) — particularly when emphasizing solution options. In this sense, GEAs can take advantage of the current solution-orientation in environmental governance and may help decision-makers make more robust policy decisions given multiple objectives, complexity and uncertainty.

Given the vast diversity of GEAs and their important distinctions from traditional assessment approaches, our recommendations are not blueprints and require contextualization. These promising GEA reform options must be (further) tested in adaptive learning processes where feedback is openly obtained and the GEA strategies are appropriately adjusted, for instance in the upcoming sixth IPCC assessment cycle. To facilitate learning from experimental phases of GEA design, scientifically robust investigations into GEA impacts and their enabling conditions should become routine after every GEA, incorporating more nuanced and comparable impact metrics than standard user surveys. This would provide the responsible scientific and policy communities, including assessment practitioners, various stakeholders and governments who are mandating assessment processes, with a transparent basis for judging, comparing and adjusting GEA methodologies and processes. This will help GEAs to effectively contribute to better governance of pressing global threats (Haas, 2015).

4.8 References

Jabbour, J. and Flachsland, C., 2017. 40 years of global environmental assessments: A retrospective analysis. *Environmental Science & Policy 71,* 193-202.

Mitchell, R. B., Clark, W. C., Cash, D. W. and Dickson, N. M., 2006. (eds) *Global Environmental Assessments: Information and Influence.* MIT Press.

Kowarsch, M., 2016. Policy assessments to enhance EU scientific advice. *Nature Climate Change*, *6*(1), 15-17.

Norgaard, R.B., 2008. Finding hope in the millennium ecosystem assessment. *Conservation Biology*, *22*(4), 862-869.

Kowarsch, M., Garard, J., Riousset, P., Lenzi, D., Dorsch, M.J., Knopf, B., Harrs, J.A. and Edenhofer, O., 2016. Scientific assessments to facilitate deliberative policy learning. *Palgrave Communications* 2, 16092.

Dodds, F., Laguna-Celis, J. and Thompson, L., 2014. *From Rio+ 20 to a new development agenda: Building a bridge to a sustainable future*. Routledge.

Perrings, C., Duraiappah, A., Larigauderie, A. and Mooney, H., 2011. The biodiversity and ecosystem services science-policy interface. *Science*, *331*(6021), pp.1139-1140.

Halle, M., Najam, A. and Beaton, C., 2013. The future of sustainable development: Rethinking sustainable development after Rio+ 20 and implications for UNEP. *International Institute for Sustainable Development (IISD), Winnipeg*.

Carraro, C., Edenhofer, O., Flachsland, C., Kolstad, C., Stavins, R. and Stowe, R., 2015. The IPCC at a crossroads: Opportunities for reform. *Science* 350(6256), 34-35.

Lee, H., 2015. Turning the focus to solutions. *Science* 350(6264), 1007-1007.

Victor, D.G., 2015. Embed the social sciences in climate policy. *Nature,* 520, 27-29.

Edenhofer, O. and Kowarsch, M., 2015. Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy* 51, pp.56-6

von Stechow, C., Minx, J.C., Riahi, K., Jewell, J., McCollum, D.L., Callaghan, M.W., Bertram, C., Luderer, G. and Baiocchi, G., 2016. 2° C and SDGs: united they stand, divided they fall?. *Environmental Research Letters,* 11(3), p.034022.

Garard, J. and Kowarsch, M., 2017. If at first you don't succeed: Evaluating stakeholder engagement in global environmental assessments. *Environmental Science & Policy* 77, 235-243. http://doi.org/b6rt

Funtowicz, S. O. and Ravetz, J. R., 1993. Science for the post-normal age. *Futures* 25(7), 739–755.

Nowotny, H., Scott, P. and Gibbons, M., 2001. *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty.* Polity Press.

Fabricius, C., Scholes, R. and Cundill, G., 2006. In *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment* (eds Reid, W. V., Wilbanks, T., Capistrano, D. and Berkes, F. 165–182, World Resources Institute, Washington D.C.

Edenhofer, O. and Minx, J., 2014. Mapmakers and navigators, facts and values. *Science*, *345*(6192), pp.37-38.

Riousset, P., Flachsland, C. and Kowarsch, M., 2017. Global environmental assessments: Impact mechanisms. *Environmental Science* & Policy, 77: 260-267.

Ostrom, E., 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge University Press.

Petersen, A., Blackstock, J. and Morisetti, N., 2015. New leadership for a user-friendly IPCC. *Nature Climate Change*, *5*(10), pp.909-911.

Dietz, T., 2013. Bringing values and deliberation to science communication. *Proceedings of the National Academy of Sciences,* 110(Supplement 3), pp.14081-14087.

Haas, P. M., 2015. *Epistemic Communities, Constructivism and International Environmental Politics.* Routledge, 2015.

Grieneisen, M.L. and Zhang, M., 2011. The current status of climate change research. *Nature Climate Change*, *1*(2), pp.72-73.

4.9 Annex A: Supplementary Information on method underlying Figure 1

According to the principles governing the work of the Intergovernmental Panel on Climate Change (IPCC), these as well as the procedures shall be revised periodically to constantly improve the IPCC's operations, procedures and products. Upon conclusion of the fifth assessment cycle, during its 37th session in Batumi, the IPCC plenary initiated a task group on the future of the IPCC, calling for input from governments, observer organizations and scientists involved in the IPCC process[2]. This process resulted in the comments that underlie Fig. 1 and provide information about the 'demand side' of global environmental assessments (GEAs). While the authors acknowledge that the IPCC context cannot be generalized to other GEAs, these results are presented as illustrative for current thinking about GEAs.

In total, 137 official comments were submitted from Government[3], Authors, Contributing Authors and Review Editors, International and other Organizations[4] 32 of which were submitted by governments, 90 by independent experts, and 9 by organizations. The nature of the comments illustrates the explicit demand across various actor groups for future IPCC reports to more explicitly assess solutions in general, and to focus on policy analysis (see Figure S1 for a comprehensive overview). This result was obtained by analyzing the comments with respect to their orientation towards 'solutions' (column "Solution-oriented comment" in Tables S.1, S.2 and S.3) and with respect to their focus on policy analysis (column "Emphasis on policies" in Tables S.1, S.2 and S.3). Comments were judged to be solution-oriented if they included key words such as:

- Solution(s)
- Technology/technologies, practice(s)
- Measure(s)
- Technical potential
- Engineering
- Mitigation/adaptation potential/option(s)/effort
- Policy-relevant, demanded by policy-makers, addressed to policymakers
- Governments define topics
- Economic analysis, sectors
- Decision(s)
- Development alternatives
- Growth potential
- Achieving/transition to SDGs, building resilience
- Synergy/synergies, win/win
- Co-benefits
- SREX *(Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation)*

Similarly, comments were judged to focus on policies if they included key words such as:

- Policy
- Policy instrument(s), analysis, tool(s), design, alternative(s)
- Incentives

[2] https://www.ipcc.ch/meetings/session37/p37_decision_future.pdf

[3] https://ipcc.ch/apps/eventmanager/documents/11/280220141142-inf1_future_of_ipcc_govt_comments.pdf

[4] https://ipcc.ch/apps/eventmanager/documents/17/090920140449-INF.1,%20Add.1%20-%20Future%20Work%20of%20IPCC%20-%20Compilation%20of%20submissions.pdf

- Response, respond to climate change
- Response measure, strategy
- Strategy
- Priorities
- Governance
- Action, actionable knowledge
- Address(ing) (options, salient questions, climate change mitigation and adaptation etc.)
- Recommending/recommendation(s)
- Implementing/implementation
- Experience(s)
- Approach(es)
- What works…? What do we do…?
- Good/best practice
- Climate finance/financing
- Financial instrument(s)
- Investment

While these keywords played a central role in analyzing the comments, this analysis (building on, but refining and amending the analysis presented by Jabbour and Flachsland, (2017) also considered the specific contexts in which the keywords occur which enabled a more appropriate and differentiated interpretation of the comments. Please note that based on personal conversations and the high-level involvement of some of the co-authors of this paper in the recent IPCC assessment process, we know that IPCC reform comments suggesting "more focused" IPCC reports (e.g., "SREX"), for instance, typically have in mind more solution-orientation and higher relevance of IPCC reports for decision-making processes.

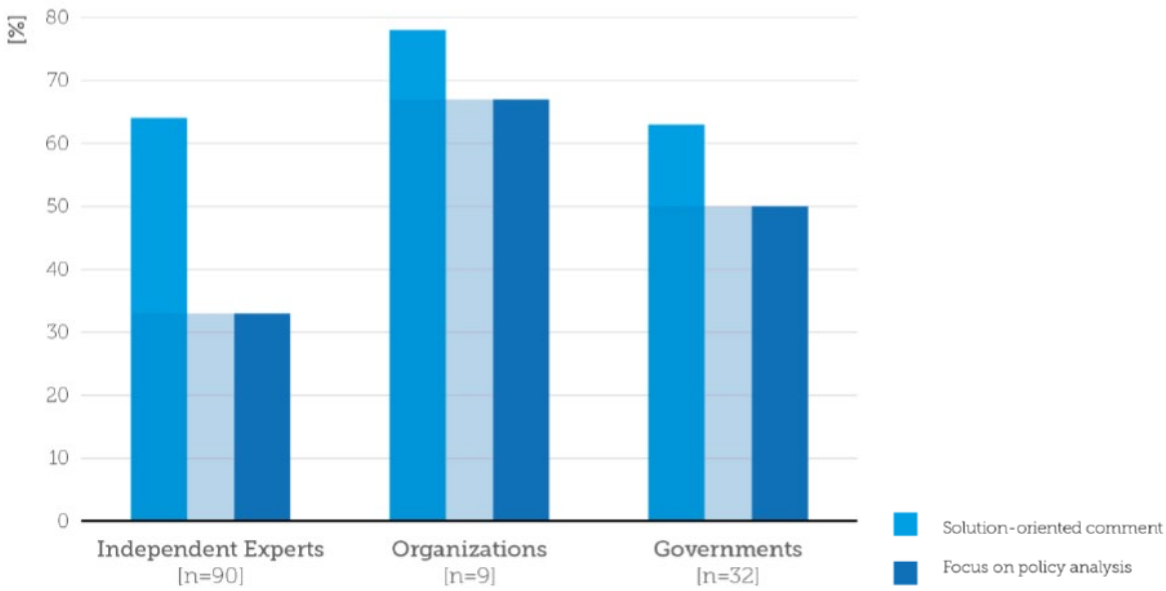

Figure S1. High demand for more assessment solutions. The share of comments of governments, independent experts and organizations that submitted solution-oriented comments (light blue) and with an emphasis on policies (blue). This figure summarizes all results while Figure 1 in the main text focuses particularly on the comments by governments.

Table S1. Summary table of extracted verbatim comments supporting the analysis of submissions with clear orientation towards 'solutions' and emphasis on policies – Independent Experts

Stakeholder type	Verbatim comments (*relevant excerpts extracted*)	Solution-oriented	Emphasis on polices
Independent expert	"...A distinction between the problem and the solutions …and the need to address options, experiences, syn**ergies, win-win and co-benefits and tradeoffs between adaptation and mitigation with the goal to enhance sustainable development** for all and to properly assess questions of justice."	1	1
Independent expert	"…offer an assessment of scientific literature on the reasons for lack of success in realizing the goals and implementing to previous decisions adopted…**assess the scientific policy alternatives** to multilateral treat-based climate diplomacy…address promising unilateral and multilateral pathways towards a transition to SDG"	1	1
Independent expert	"**A clear shift in focus to solutions.** The IPCC has been very successful in defining the threat of climate change and raising awareness. Governments, business and the public are now looking for information on how they might respond" – what works and what doesn't work. This can be done in a manner that is not policy prescriptive"	1	1
Independent expert	"**Direction and strategy for mitigation and adaptation measures …solutions for potential climate changes**. Link the activities of IPCC to MDGs and improvement of energy access through investment for energy efficiency and renewables"	1	1
Independent expert	"Greater focus on climate finance needs, flows, policy/financial instruments and their effectiveness"	1	1
Independent expert	"A special report which central focus is assessing these links as well as the multiple strands of existing literature on climate resilient pathways linking adaptation and mitigation will be of great value for any UNFCCC decisions made in 2015."	1	0
Independent expert	"…publish an annual (or biennial) bulletin that incorporates: updated factors, new methods and examples of good practices….examples of application of good practices can be prepared according to difficulties experienced by countries in implementing…"	1	1
Independent expert	"the IPCC should call for more research on [energy] development alternatives for [countries in transition] and then summarise the achieved results in AR6."	1	0
Independent expert	"…structure reports or emphasis on particular types of content to persuade the intransigent economic groups"	1	0
Independent expert	"…taking a more proactive role in developing and implementing climate change policies/laws, in particular, policies/laws related to mitigation opportunities and emissions constrains. As a basis for such policies and to better understanding the GHG emissions and removals"	1	1
Independent expert	"Midterm report …on policy and economic aspects before integrated into the AR should be considered"	1	1
Independent expert	"[Future] IPCC Assessment Reports [should] represent in a condensed form the available knowledge and reflect the scientific consensus on the climate change in future and **the availability of solutions**."	1	0
Independent expert	"there is a need for a transition of sorts… surely the questions change to "what do we do about it?" There is now an imperative to recognize that climate change is with us and we must plan for it in every way possible. Part of this relates to what does develop under GFCS and climate services"	1	1
Independent expert	"...regional reports **to enable better localization of climate change** problems **and solutions in concrete locations**."	1	0
Independent expert	"The IPCC …requires new policy oriented yet scientific leader….Awareness of what is and what is not societally relevant is a matter of framing issues in specific ways.	1	1
Independent expert	"Shorter, more focused reports that answer specific emerging **questions ….arising from the policy process**"	1	1
Independent expert	"a hiatus from the comprehensive reports should be taken for a number of years. The focus for a few years should be placed on …special reports that are carefully targeted to address specific, salient questions that are of high scientific, policy and social importance."	1	1
Independent expert	"Special reports where governments define topics…"	1	0
Independent expert	"Shorter reports on select topics as demanded by policy makers"	1	0
Independent expert	"specific guidance for those countries to be able to go from Tier 1 guidance to Tiers 2 or 3 including suggested approaches and potential sources and costs of acquiring the necessary data and synthesis."	1	1

Independent expert	“evolution towards assessments that focus more on what has changed in our understanding…need to strengthen participation from the private sector …evolution towards clearly-defined quantitative metrics [for] mitigation cost and investment..”	1	1
Independent expert	“Policy briefings and information with practical information”	1	1
Independent expert	"as Ars have matured, there has naturally been an evolution towards clearly-defined quantitative metrics (….) and estimates of their uncertainty…their role in informing risk management could help the next assessment….[need for] **greater flexibility in assessing economics literature on options and policies.**."	1	1
Independent expert	"…[need for a an improved] systematic co-exploration where the science of regional responses are evaluated through the lens of WG2/3 concerns…"	1	0
Independent expert	"…more focused …limited reports focused on progress achieved since previous report"	1	0
Independent expert	“Topical reports, answering concrete policy relevant questions”	1	0
Independent expert	"product should be aimed at actionable knowledge and directly address critical issues…more user-relevant scales…emphasis should be given to synthesizing the findings and mapping them to applicable knowledge"	1	1
Independent expert	"Relatively frequent special reports indicating major changes in understanding or developing a them (e.g. SREX) and occasional executive and technical summaries of the state of the science"	1	0
Independent expert	“I suggest the development of new information **products oriented to society, and focused on simple facts and actions**.”	1	1
Independent expert	“…disconnect between assessment of the costs of climate change, evaluated in WG II (though usually not in economic terms) and assessment of the costs of mitigation, evaluated in WG III. This undermines the cost-benefit analyses that are sorely needed for the world to make rational decisions, as much as possible, on how to respond to climate change.”	1	1
Independent expert	“Examples of application good practices can be prepared according to difficulties experienced by countries in implementing them or where areas of further clarification are identified”	1	1
Independent expert	“issue-specific reports … particularly targeted toward informing sector-specific adaptation/mitigation efforts authored by smaller task forces”	1	0
Independent expert	"advocate a series of topic reports, similar to SREX…"	1	0
Independent expert	"…the main conclusions from old assessment reports are mainly the same…focus on important new insight we need new ways to avoid [a situation' where every sentence has to be approved…	1	0
Independent expert	"…unified quantification approach for emissions and sequestration… management approaches"	1	0
Independent expert	"…identification of the regions that will be most directly affected and recommendations about remediation (engineering approaches).."	1	0
Independent expert	"…IPCC spend too much time discussing model projections… economic analysis of AR5 was perhaps the most important new information that was provided.."	1	0
Independent expert	“focused regional level reports on mitigation and adaptation options, strategies and responses at 5-10 year intervals"	1	1
Independent expert	“focus on assessment and evaluation of adaptation plans and actions implemented. Specific plans and actions are more likely to have been reported in government documents and grey literature….”	1	1
Independent expert	“these major reports have outlived their value. Future products ...should therefore be targeted on specific areas in climate science adaptation, mitigation and –perhaps most importantly - specific economic sectors and aspects of the human economy”	1	0
Independent expert	"[future reports] should be focus how to go about building resilience at all scales"	1	0
Independent expert	“Sector-based products may well be more useful than more ‘business as usual’ reports”	1	0
Independent expert	“…address promising unilateral and multilateral pathways towards a transition to sustainable development goals addressing the need to drastically reduce GHG emissions by a progressive decarbonization of the energy, transportation, agriculture, production and housing sectors and the potential peace dividend of such a policy strategy that aims resource efficiency and a replacement of fossil energy sources with renewables”	1	1

Independent expert	"Focused sectoral reports on learnings from adaptation and mitigation actions for the advancement of the global community knowledge."	1	1
Independent expert	"produce summary reports spot on the LDCs enclosed recommendations and advices to decision maker could be more valuable."	1	1
Independent expert	"one WG focusing on the physical science aspects and impacts of climate change from global to regional, and a second WG focusing on the solution space, including adaptation and mitigation."	1	0
Independent expert	"…highlighting specific challenges and opportunities related to climate system variability and changes on which place-based actions are possible."	1	1
Independent expert	"Increased attention is therefore suggested on strengthening the assessment of what emissions inventories mean in terms of impacts… A further consideration for the appropriate structure and modus operandi for the production of the IPCC products, focuses on the important role of involving experts from the energy sector. These experts are critical in a number of areas, including: in addressing technologies for mitigation; assessing practices for adaptation; methodologies for emissions estimation."	1	0
Independent expert	"deliver [assessments that] provide the scientific evidence for synergistically addressing: climate change adaptation and mitigation, food security, combating land degradation and desertification, while maintaining ecosystems services, including biodiversity."	1	1
Independent expert	"[Future IPCC] Report must be further developed and strengthened to help identify current priorities and adaptation needs in specific countries and societies, especially in highly vulnerable regions."	1	0
Independent expert	"Develop... a repository of successful (and not-successful) policy experiences and options, technologies, financing mechanisms, and educational/awareness raising actions…"	1	1
Independent expert	"The IPCC needs to commit to the eligibility of assessing regional policies and emissions in the reports. Climate change and climate policies cannot be sensibly assessed without regional specificity"	1	1
Independent expert	I feel we have become so concerned about the scientific validity of our reports that, while perhaps technically accurate, our reports have very little capacity to be digested and discussed among non-scientists (including policymakers), much less motivate social responses.	1	0
Independent expert	"More focused reports on questions of immediate interest to policy makers. SREX provides an example…geoengineering as an abatement strategy, ….food security, and the role of shale gas in carbon mitigation….evaluating leakage issues.	1	0
Independent expert	"…more guidance to capture their carbon footprint…National GHG inventories, increased use of multimedia	1	0
Independent expert	"Ranking for cost effectiveness of mitigation options in each sector."	1	0
Independent expert	"**Reports focused on Adaptation and Mitigation should receive stronger focus**. Consider the 2020 climate change agreement for planning the report publication."	1	0
Independent expert	"Updated analysis of renewable energy options highlighting both technology needs and economic investments needed to transform our current energy systems to a low carbon state"	1	1
Subtotals		**58**	**30**

Table S2. Summary table of extracted verbatim comments supporting the analysis of submissions with clear orientation towards 'solutions' and emphasis on policies – Boundary Organizations

Stakeholder type	Verbatim comments (*relevant excerpts extracted*)	Solution-oriented	Emphasis on polices
International Organization (*Climate Action Network*)	"...**increase understanding of alternative models of economic growth** that are decoupled from greenhouse gas emissions, the IPCC should call for **more research on development alternatives** for these countries and then summaries the achieved results in AR6...include a short description and analysis of this situation on governance..."	1	1
(State of Palestine - Environment Quality Authority)	"... crosscutting issues require special attention for example, climate financing and response measures.."	1	1

International Organization *(START Sec.)*	"… [new focu] on low carbon growth potential and related incentives-tradeoffs might foster better opportunities for concerted actions by IPCC member nations. Likewise special reports that deal with urban-rural linkages seem most timely."	1	1
International Organization *OECD*	Understanding of climate science and climate impacts has evolved considerably since the IPCC's First AR. Focusing future reports on areas that are currently less certain could allow for the structure of future ARs to be streamlined, e.g. by merging assessments on the physical science basis and assessing the risks and impacts of climate change (i.e. working groups 1 and 2). The OECD considers "special reports" useful, and supports their continued preparation. These are particularly useful as they can be prepared on a shorter timescale than the assessment reports. Possible topics for upcoming special reports could include the economic impact of inaction, impact of climate change on achieving sustainable development goal(s), or SRs on the expected climate and economic impacts on a specific region.	1	0
International Organization *(UNCCD)*	"UNCCD recommends that further attention be given to [adaptation measures] in the future IPCC work. Constraints on implementation of adaptation are coming from uncertainty in the impacts, limited resources to develop effective policies, lack of guidance on principles and priorities, limited coordination of governance, different perceptions of risks, competing values, absence of adaptation leaders and advocates and limited tools to monitor adaptation effectiveness. Addressing adaptation throughout the world will ultimately require a diverse set of local-level, **context-specific solutions and the blending of traditional and modern knowledge and technologies**. **We recommend that these issues be given due attention in future IPCC reports**..."	1	1
International Organization *(UNEP)*	"IPCC Assessment Report must be further developed and strengthened to help identify current priorities and adaptation needs in specific countries and societies, especially in highly vulnerable regions. A shorter cycle report...[with a] focus on emerging science, especially when there are new trends or developments, **and solutions** and reflect the issues/developments relevant to the three IPCC working groups. The feature focus of the report might as well be chosen based on the demands from UNFCCC parties/IPCC member states."	1	1
University of Nijmegen	"Develop – in cooperation with other UN agencies - a repository of successful (and not-successful) **policy experiences and options, technologies, financing mechanisms**, and educational/awareness raising actions/campaigns."….Each of these groups consists of subject experts, **climate policy experts**, governmental representatives... Focus on special areas of societal and policy relevance, new insights and controversial issues."	1	1
Subtotals		7	6

Table S3. Summary table of extracted verbatim comments supporting the analysis of submissions with clear orientation towards 'solutions' and emphasis on policies – Governments

Stakeholder type	Verbatim comments (*relevant excerpts extracted*)	Solution-oriented	Emphasis on polices
Argentina	"important to move forward to cross-cutting approaches among different Working Groups...Group III evaluates adaptation strategies and mitigation, enabling, at the same time, analysis of synergies"	1	1
Austria	"A high priority for the IPCC to produce fact track products to respond to urgent needs at the policy level"; "responses to the climate change risks, including adaptation and mitigation, should be addressed by the second Working Group."	1	1
Belgium	"Providing information that is useful for the policy processes and underpinning policy development without being policy prescriptive; ...the challenge of how to be more policy-relevant without being policy prescriptive;" ...The IPCC might have to consider a modification in the assessment cycle, the type of products useful for policymakers, ...A re-organization of the 3 current working groups (keeping the TFI as it is) in 2 new groups: Group 1 - Mechanisms: climate and impacts; physical climate change impacts on ecosystems and human activities - **Group 2 - Solutions: Mitigation, adaptation and vulnerability:** Scenarios, role of socio-economic drivers in shaping emissions, mitigation potential, adaptation potential, and vulnerability; Technical potential; Costs Transition, links with sustainable development"	1	1

Brazil	"For the next decade, emphasis should be placed on …the needs arising from the implementation of the post-2020 agreement under the Convention. Focus should be placed on "fast track" products, such as …the necessary **inputs and tools for** … further **developing and implementing their policies and actions**."	1	1
Canada	"provide information that would support a future UNFCCC review of long-term globa climate, mitigation goals. Canada encourages the Task Group and/or Secretariat to consult with the UNFCCC early in these deliberations…. [concerns regarding lack of policy utility] "Canada is open to exploring suggestions for other WG structures …such as a **structure oriented towards articulating the "challenge" and "solutions"** to climate change. Canada sees merit in this type of structure.	1	0
EU	"physical science basis and the assessment of associated impacts, risks and vulnerabilities' while the second part should **focus on the 'response measures: adaptation and mitigation'.** Such an approach will allow for a more coherent treatment of cross-cutting issues, m**ark a clearer distinction between 'diagnostics' and 'solutions/proposed measures' and also make it easier for policy makers to extract relevant information.** It will also cover adaptation and mitigation in an integrated manner –which is highly pertinent for policy making- and also facilitate the final synthesis of the assessment report.	1	1
Finland	"Although many key decisions in international climate policy are still to come, there is a lot of material for policy analysis during a 6-7 year assessment cycle. "	1	1
Germany	"IPCC assessment reports (ARs) and Special Reports (SRs) should become more concise with an **increased focus on policy relevant topics**. This would increase their usefulness for policy makers and reduce the workload for authors… enhancing the flexibility and the **responsiveness of the IPCC to policy needs**, in particular of the Parties to the UNFCCC."	1	1
Japan	"As overall tasks for the future, … reports focusing on practical and applicable mitigation and adaptation measures in each region or sector, taking the post-2020 international regime on climate change into consideration. Those reports should contribute especially to increasing knowledge of mitigation and adaptation measures applicable to developing countries. ...normative studies as well as empirical knowledge become important in relation to issues such as an assessment of geo-engineering. **…increased emphasis on response strategies.**"	1	1
Latvia	"More information compilations addressed to the policymakers"	1	0
Mali	"Strengthen adaptation and vulnerability measures, especially for developing countries..."	1	0
Nether-lands	"**Informing the international community about the scale of the problem and the availability of solutions and providing legitimacy for national climate policies**… recognizes and supports a growing demand for information that can support local decisions." ...**Both adaptation and mitigation solutions could be included**, which require different practical hand-on protocols, assessment methods and decision tools (e.g. **risk profiles; economic appraisal tools; finance tools; methodology for producing mitigation road maps**; portfolio management for adaptation and mitigation)."	1	1
Norway	"IPCC could exploit pre-policy analyses of audiences and user groups, as part of the scoping."	1	1
Saudi Arabia Kingdom of	"some crosscutting issues require special attention for example, climate financing, response measures, emerging issues	1	1
South Africa	"The IPCC should focus far more strongly on encouraging advancing the technologies and tools of impacts and adaptation assessment	1	0
Spain	"...consider grouping IPCC work in two main WGs: (i) physical science of climate change....and (ii) **responses/proposal to climate change challenge** in the field of adaptation and mitigation. The latter group – responses- can address some sectors with a clear win-win approach (agriculture, forestry, soils, health…), and others with a more independent way between adaptation and mitigation. This **WG on solutions can be structured according to a sectoral approach**."	1	1
Switzerland	"We propose to improve the IPCC products and to expand the activities [of the IPCC] …Assistance in the **elaboration of Policy Tools such as**: Manual for Adaptation Planning; Manual for Technology Assessment; **Optimization of Policy Design; Optimization of Environmental Synergies**"	1	1
Thailand	**"Increased [focus] on the solution side, best practice and** examples of current problems and adaptation in each region should be included… reports should be developed to identify … adaptation in specific countries, in particular in high	1	1

	vulnerability regions. IPCC should provide the pilot projects that illustrate m**anagement [tools] and technologies**"		
UK	"..the need for policy makers to have answers to policy relevant questions, which don't readily map to specific WG reports.	1	1
USA	"**Re-work the substance on adaptation and mitigation options currently contained in WG2 and WG3 into a report on the "solution space" (i.e., mitigation and adaptation) for climate change**. Such a report could still be on a 5-7 year cycle, but more staggered from the WG1 report to ensure the scientific communities have sufficient time to digest and publish the results from the WG1 literature."	1	1
Subtotals		20	16

4.10 Annex B: Supplementary Information on Method underlying Figure 2

Scientometric / bibliometric studies of the climate change literature remain relatively scarce. The study by Grieneisen and Zhang (2011) is a first attempt to provide a comprehensive overview of the field of climate change research based on a systematic and sophisticated search query. The study showed an exponential increase in publications between 1991 and 2009.

We apply the same search query to extend the analysis to understand whether this trend has continued in subsequent years. A complete description of the research methodology is included in the paper by Grieneisen and Zhang (2011) and does not need to be replicated here. We can closely reproduce the results for the period 1991-2009. We find that the exponential growth in the climate change literature has continued between 2009 and 2014. In fact, 2014 provides first evidence that this trend may start to break in the near future and continue at decreasing rates. However, no conclusions can be drawn from a single data point on this matter and only time can tell whether this really marks a change in the growth pattern.

The Intergovernmental Panel on Climate Change (IPCC) assesses the state of climate change research every five to seven years. These assessments ought to be undertaken on a comprehensive, objective, open and transparent basis. We roughly approximate the magnitude of the new literature that has accumulated over an assessment cycle by assigning all studies that have appeared before the year of publication of the synthesis report summarizing the findings across IPCC Working Groups. This is a coarse approach: for example, we assign all publications of the year 2013 to the Fifth Assessment Report cycle even though the Working Group I contribution was already published that year. However, this pragmatic procedure is justifiable as we only want to show orders of magnitude that remain unaffected.

Our results show that the total number of new studies that had to be considered for the Second and Third Assessment Report was about 26,000. In the most recent years of analysis, this amount of new literature is published annually. This highlights the challenges for current global environmental assessments – in particular, the IPCC, with its precise mandate. New avenues need to be explored for dealing more systematically with this 'literature explosion' making the organization of the assessment process more complex. For example, bibliometric and scientometric methods need to be applied systematically during the scoping and assessment process of global environmental assessments. There is an increasing dependence on synthesis efforts within the research community that can be built upon within the assessment process. In many communities – particularly the social sciences – such meta-analytical approaches are still underdeveloped.

Table S4. Data on climate change literature

Year	Number of publication	New literature for IPCC Assessments
1991	1,442	
1992	1,650	Second Assessment Report:
1993	1,907	**6,918**
1994	1,919	
1995	2,333	
1996	2,729	
1997	2,989	Third Assessment Report:
1998	3,166	**18,718**
1999	3,589	
2000	3,912	
2001	4,429	

2002	4,810	Fourth Assessment Report:
2003	5,248	**35,064**
2004	6,014	
2005	6,863	
2006	7,700	
2007	9,738	
2008	12,009	
2009	14,113	
2010	16,824	Fifth Assessment Report:
2011	19,796	**122,659**
2012	23,255	
2013	26,924	
2014	28,651	

4.11 Annex C: Background on the challenges and stakeholder engagement

4.11.1 Substantiating the three challenges

Although contemporary GEAs are facing many more challenges, we claim that the three challenges presented in the main paper belong to the most important and profound ones for contemporary, solution-oriented GEAs facing wicked problems[5]. This claim is based on both empirical and theoretical grounds. The empirical evidence inter alia stems from 99 semi-structured expert interviews on challenges and opportunities for contemporary GEAs, conducted as part of a larger research project on GEAs[6] that underlies the commentary. The interviewees highlighted particularly these three challenges. The empirical evidence cited in the commentary furthermore includes relevant observations of GEA processes published by experienced assessment practitioners.

Moreover, also the theoretical and conceptual literature on GEAs strongly supports our selection of the challenges. While the specific characterization of these three problems as major challenges for contemporary GEAs in their current political context (i.e., the evolving governance landscape) is relatively new, core aspects of each of these challenges have been discussed before in the literature, usually in more generic terms.

For instance, as Kowarsch and Jabbour (2017) explain in more detail, the first of the three challenges identified in our commentary is basically about the 'salience' (in terms of the need for addressing those aspects that are highly relevant to decision-making processes) as well as the scientific 'credibility' (i.e., rigor and soundness) of policy evaluation; the second challenge is mainly about (civic) 'legitimacy' issues; and the third challenge is related to GEA influence overall, as a function of credibility, legitimacy and salience together. These concepts of 'credibility,' 'legitimacy' and 'salience' (including their trade-offs), which are largely compatible with our analysis, have been introduced and explained by the seminal Harvard GEA project[7] (e.g., Mitchell et al., 2006; Farrell and Jäger, 2006) in terms of widely accepted criteria for GEA influence. However, more specific recommendations for different contemporary GEAs are required that consider the evolving governance landscape and the trade-offs between the three criteria. In this sense, our synthesis of promising options for solution-oriented GEAs to address the challenges identified contributes to the further development of the basic Harvard idea for GEA design into more specific recommendations for contemporary, solution-oriented GEAs.

Beyond Mitchell et al., (2006) and related publications, different strands of the existing theoretical literature regard the first challenge as highly important: (1) literature on the complexity of wicked policy issues (e.g., Rittel and Webber, 1973; Carley and Christie, 2000: 156; Head, 2008); (2) literature on the challenge of true interdisciplinarity and on the integration of scientific results into a common framework (e.g. Victor 2015); as well as (3) literature on the rapid growth of literature and the lacking knowledge aggregation particularly in the peer-reviewed social-science literature (e.g. Elsevier, 2016; Minx et al., 2017).

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[5] While GEAs might be better suited to address wicked problems than other science-policy-society platforms (see main text at the beginning), the wicked problems also imply severe challenges and limitations for GEA processes, including the impossibility to provide a consensus on policy options and pathways.

[6] http://www.mcc-berlin.net/en/research/cooperation/unep.html

[7] http://www.hks.harvard.edu/gea/

The second challenge is about integrating diverse and divergent viewpoints. While this can and has resulted in very practical challenges for GEA processes (for example, as highlighted in the main text with regards to the IAASTD), it also relates to broader debates over the politics of knowledge exchange and integration (Scoones, 2009), and to GEAs providing deliberative learning platforms at the international science-policy-society interface (Miller and Erickson, 2006; Kowarsch et al., 2016). The politics inherent in the exchange of knowledge is a central feature of any GEA process, which brings together a diversity of actors to assemble and synthesize available scientific and other knowledge (Scoones, 2009; Kowarsch et al., 2016).

These diverse actors come from different disciplinary backgrounds but also hail from different parts of the world, hold different institutional affiliations, and operate at different scales. Such a diverse group also implies a diversity of worldviews inter alia with regards to problem framing, judging the impacts of these problems, and assessing and prioritizing potential solutions pathways as well as more precise policy instruments. Bringing together these actors and integrating their often-divergent viewpoints through deliberation and reasoning together over the course of an assessment process is thus one of the major opportunities as well as a central challenge of GEAs (Miller and Erickson, 2006).

As these enterprises become increasingly inclusive (as can be observed, for example, in the ambitious plans to engage with stakeholders in the IPBES process, Díaz et al., 2015) addressing this challenge will become increasingly important. Politics of knowledge may in fact often inhibit accommodating divergent normative viewpoints. Even if diverse stakeholders are brought together, that does not mean they participate in knowledge production on equal terms: there are important knowledge and power imbalances.

This is particularly evident between state and non-state actors, or scientific knowledge vs indigenous knowledge (Obermeister, 2017), or natural sciences vs. social sciences. In fact, intergovernmental settings typically limit non-state stakeholders' agency because governments are often not willing to share power and authority. This is the case for the IPCC and has been observed for the IPBES too (Esguerra et al., 2017). Also, several authors have discussed the difficulties of engaging non-scientific stakeholders in scientific knowledge production and related tensions (van der Hel, 2016; Klenk et al., 2015).

The third challenge, i.e. the issue of increasing the influence of GEAs in the evolving governance landscape, is highlighted in more generic terms inter alia by Shulock (1999), Schreurs et al., (2001), Victor (2015), Posner et al., (2016) and Riousset et al., (2017). Since GEAs are usually intended to play a significant role in public policy processes, and since policy influence is generally hard to measure and dependent on various factors (many of which are beyond the control of GEA processes), facilitating outcomes and impact is a relatively natural challenge for GEAs. Riousset et al., (2017) highlight that the Social Learning Group (2001) and the Harvard GEA project pioneered research into the role played by scientific assessments produced by international institutions in attention cycles on global environmental risks, while some later publications have criticized their seminal findings for not adequately capturing the "*dynamic, continuous and multi-directional interactions between science, policy and society*" (Sarkki et al., 2015) in science-policy-society interfaces. The evolving governance landscape with its diversity of actors and lacking consensus (as characterized in the main text) increases this challenge.

4.11.2 Who is a stakeholder

The term 'stakeholder' can be broadly understood to refer to any individual affected by problems covered in a GEA, their impacts, or the solutions explored (for example through reference to the 'all affected' principle discussed by Goodin, 2008, and many others). Theoretically, this could include every person on the planet and even future generations. However, in such a large-scale process as a GEA, it is functionally impossible to engage with everyone who could potentially be considered a stakeholder given this broad definition. As with any large-scale policy advisory process, a certain degree of representation is required to render deliberation and organization practically feasible given the transaction costs of communication. Considering the need to somehow reduce the number of stakeholders, the concept of relevant stakes becomes important in determining criteria to identify who are the most relevant stakeholders to engage. Criteria can be based on the objectives for engagement (Garard and Kowarsch, 2017), and the selection of stakeholders can in theory follow logically which groups or individuals are most crucial to achieving the objectives. Major stakeholder groups in solution-oriented GEA processes include, besides policy-makers, business and industry, NGOs and civil society more broadly, GEA authors and users, etc.

4.11.3 Objectives for engaging with stakeholders

There is a huge diversity of potential objectives for engaging with stakeholders in a GEA process, which can include everything from the official objectives for engagement in the entire process distributed by the convening institution to the objectives held by individual participants for specific meetings. Drawing from the work of Garard and Kowarsch (2017), we briefly describe four prominent objectives for stakeholder engagement in GEAs from the literature.

1. Stakeholders can provide diverse sources of information to a GEA process, contributing inter alia to the design and content development of a GEA. This can include input from a variety of scientific disciplines (Norgaard, 2008; Díaz et al., 2015), from decision makers (Reed, 2008), as well as from representatives of a broader diversity of viewpoints and knowledge systems (Berkes et al., 2006).
2. Engaging with stakeholders can increase the efficacy of communication and outreach of a GEA by ensuring the outputs and both relevant and comprehensible to target audiences (Mitchell et al., 2006; Field and Barros, 2015).
3. Stakeholder engagement can encourage a dialogue between diverse actors (including a fair dialogue between developed and developing countries), which can in turn build trust, enable learning, and ensure that outputs are based on rational argumentation and a plurality of viewpoints (Berkes et al., 2006; Stirling, 2008).
4. Engagement with stakeholders can increase their sense of ownership or buy-in to the assessment process and report, which in turn can increase the likelihood that they will use GEA outputs (Mitchell et al., 2006; Field and Barros, 2015).

Stakeholders can and should contribute to the content but also the objectives and design of GEA processes (as observed, for example, in the extensive stakeholder consultations which contributed to decisions on the IPBES conceptual framework, Díaz et al., 2015); appropriate protocols and institutions can facilitate the integration of a broader diversity of viewpoints into decisions taken on the objectives and design of GEA processes in their earliest stages.

4.12 References

Ostrom, E., 1990. *Governing the Commons: he Evolution of Institutions for Collective Action.* Cambridge University Press.

Petersen, A., Blackstock, J. and Morisetti, N., 2015. New leadership for a user-friendly IPCC. *Nature Climate Change*, *5*(10), pp.909-911.

Berkes, F., Reid, W.V., Wilbanks, T.J. and Capistrano, D., 2006. Conclusion: Bridging Scales and Knowledge Systems. *In:* W.V. Reid et al. *(eds.).* Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment. World Resources Institute. Washington D.C. pp. 315–331.

Carley, M. and Christie, I., 2000. Managing Sustainable Development. London: Earthscan.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. (2015). The IPBES conceptual framework – connecting nature and people. *Current Opinion in Environmental Sustainability* 14, 1–16.

Elsevier, 2016. Sustainability Science in a Global Landscape. A Report conducted by Elsevier and SciDev.Net. www.elsevier.com/research-intelligence/research-initiatives/sustainability-2015

Esguerra, A., Beck, S. and Lidskog, R., 2017. Stakeholder Engagement in the Making: IPBES Legitimization Politics. *Global Environmental Politics,* 17(1): 59–76.

Farrell, A.E. and Jäger, J., 2006. *Assessments of Regional and Global Environmental Risks. Designing Processes for the Effective Use of Science in Decisionmaking*. Danvers, MA: RFF Press Book.

Field, C.B. and Barros, V.R., 2015. Added value from IPCC approval sessions. *Science* 350(6256), 36.

Garard, J. and Kowarsch, M., 2017. If at first you don't succeed: Evaluating stakeholder engagement in global environmental assessments. *Environmental Science and Policy* 77, 235-243.

Goodin, R.E., 2008. *Innovating Democracy: Democratic Theory and Practice After the Deliberative Turn*. Oxford: Oxford University Press.

Grieneseisen, M. and Zhang, M., 2011. The current status of climate change research. *Nature Climate Change* 1(2): 72–73.

Head, B.W., 2008. Wicked problems in public policy. *Public Policy* 3(2), 101–118.

Jabbour, J. and Flachsland, C., 2017. 40 years of global environmental assessments: a retrospective analysis. *Environmental Science and Policy 77,* 193-202.

Klenk, N.L., Meehan, K., Pinel, S.L., Mendez, F., Lima, P.T. and Kammen, D.M., 2015. Stakeholders in Climate Science: Beyond Lip Service? *Science* 350(6262), 743–44.

Kowarsch, M. and Jabbour, J., 2017. Solution-oriented global environmental assessments: Opportunities and challenges. *Environmental Science and Policy 77,* 187-192.

Kowarsch, M., Garard, J., Riousset, P., Lenzi, D., Dorsch, M., Knopf, B., Harrs, J.-A. and Edenhofer, O., 2016. Scientific assessments to facilitate deliberative policy learning. *Palgrave Communications* 2: 16092.

Miller, C. and Erickson, P., 2006. The politics of bridging scales and epistemologies: Science and democracy in global environmental governance. In: W.V. Reid et al. (eds.). *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment.* Washington, D.C.: World Resources Institute, pp. 297–314.

Minx, J.C, Callaghan, M., Lamb, W.F., Garard, J. and Edenhofer, O., 2017. Learning about climate change solutions in the IPCC and beyond. *Environmental Science and Policy 77,* 252-259.

Mitchell, R. B., Clark, W.C., Cash, D.W. and Dickson, N.M. (eds.), 2006. *Global Environmental Assessments: Information and Influence*. Cambridge, MA: MIT Press.

Norgaard, R., 2008. Finding hope in the Millennium Ecosystem Assessment. *Conservation Biology* 22, 862–869.

Obermeister, N., 2017. From Dichotomy to Duality: Addressing Interdisciplinary Epistemological Barriers to Inclusive Knowledge Governance in Global Environmental Assessments. *Environmental Science and Policy* 68, 80–86.

Posner, S.M., McKenzie, E. and Ricketts, T.H., 2016. Policy impacts of ecosystem services knowledge. *Proceedings of the National Academy of Sciences*, *113*(7), 1760-1765.

Reed, M.S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141(10), 2417–2431.

Riousset, P., Flachsland, C and Kowarsch, M., 2017. Global Environmental Assessments: impact mechanisms. *Environmental Science and Policy 77,* 260-267. doi:10.1016/j.envsci.2017.02.006

Rittel, H. and Webber, M., 1973. Dilemmas in a general theory of planning. *Policy Sciences* 4(2), 155–169.

Sarkki, S., Tinch, R., Niemelä, J., Heink, U., Waylen, K., Timaeus, J., Young, J., Watt, A., Neßhöver, C. and van den Hove, S., 2015. Adding 'iterativity' to the credibility, relevance, legitimacy: A novel scheme to highlight dynamic aspects of science–policy interfaces. *Environmental Science and Policy* 54, 1–10.

Schreurs, M.A., Clark, W.C., Dickson, N.M. and Jäger, J., 2001. Issue attention, framing, and actors: an analysis of patterns across arenas. *In:* The Social Learning Group (ed.). *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain*. Cambridge, MA: MIT Press, pp. 349–364.

Scoones, I., 2009. The politics of global assessments: The case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *The Journal of Peasant Studies* 36(3): 547–571.

Shulock, N., 1999. The paradox of policy analysis: If it is not used, why do we produce so much of it? *Journal of Policy Analysis and Management* 18(2), 226–244.

The Social Learning Group (ed.), 2001. *Learning to Manage Global Environmental Risks: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain*. Cambridge, MA: MIT Press.

Stirling, A., 2008. "Opening up" and "closing down": Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values* 33(2), 262–294.

Strauss, A. and Corbin, J., 1998. *The Basics of Qualitative Research.* Thousand Oaks: Sage Publications. van der Hel, S. (2016). New Science for Global Sustainability? The Institutionalisation of Knowledge Co-Production in Future Earth. *Environmental Science and Policy* 61, 165–175.

Victor, D., 2015. Climate change: Embed the social sciences in climate policy. *Nature* 520(7545), 27–29.

5. The treatment of divergent viewpoints in global environmental assessments[1]

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Abstract

Global environmental assessment (GEA) processes routinely deal with a wide range of divergent viewpoints. The entanglement of disputed facts and values within these viewpoints raises challenges for their legitimate treatment, particularly in solution-oriented GEAs. We offer a conceptualization of 'divergent viewpoints' in GEA processes covering both scientific and the political (normative) dimensions, focusing on actors' framing of environmental policy problems or on the suitability of particular response options. Based on extensive empirical research on three selected GEAs and a literature review, we distill nine general approaches which have been employed to respond to divergent viewpoints, and present these in terms of simplified, ideal-type strategies. We furthermore generate hypotheses about the advantages and drawbacks of each approach as well as conditions for success. Our analysis suggests that for policy-relevant divergent viewpoints highly disputed both on normative and scientific grounds, collaboratively exploring the practical implications of policy alternatives through GEAs is a particularly promising approach, although practical challenges remain. More broadly, this article contributes to a better understanding and more explicit discussion of existing, often implicit approaches within GEA processes for responding to divergent viewpoints. This article is part of a special issue on solution-oriented GEAs.

Keywords: divergent viewpoint; environmental assessment; co-production; science-policy interface; conflict; value judgement

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5.1 Introduction

The existence of multiple viewpoints and the need to generate common understandings that are coherent across divergent viewpoints is a core rationale for initiating global environmental assessments (GEAs) in the first place; and arguably, their original *raison d'être*. If scientific consensus

[1]Published as Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J. and Riousset, P., 2017. The treatment of divergent viewpoints in global environmental assessments. *Environmental Science and Policy 77,* 225-234.

and certainty as well as universal political acceptance (or agreement) existed on environmental problems or the formulation of policy options, GEAs would hardly be needed. GEAs are large-scale, multi-stakeholder and often intergovernmental processes that review, assemble and synthesize relevant knowledge on a topic in order to inform decision-making processes (Kowarsch et al., 2016; see also the Introduction to the special issue). In many cases, GEAs serve as effective platforms to reconcile divergent viewpoints through consultative science-based deliberation. They have also helped to reconcile disagreements and stimulate new research to overcome knowledge gaps and uncertainty. One notable example is the scientific assessments by the Intergovernmental Panel on Climate Change (IPCC), which have over time contributed significantly to substantiating hypotheses of the human-induced climate change.

Despite important progress, the adequate representation and legitimate treatment of divergent viewpoints remains a fundamental challenge for GEA processes (e.g., Beck et al., 2014; Cash et al., 2003; Edenhofer and Minx, 2014; Kowarsch, 2016; Norgaard, 2008; Pascual et al., 2017; Sarewitz, 2004; Sluijs et al., 2010). As illustrated by many publications in science and technology studies (STS), opposition to assessment results and processes often occurs if the diverse stakeholders do not agree with, for instance, the scope, priorities or underlying assumptions of the GEA; ultimately, the inappropriate treatment of divergent viewpoints can exacerbate environmental controversies rather than resolving them (Cash et al., 2003; Jasanoff, 1990; Pielke, 2007; Sarewitz, 2004).

The increasing solution-orientation of GEAs further intensifies the challenge of divergent viewpoints. Jabbour and Flachsland (2017) describe changing contexts for GEAs in terms of recent shifts in demand for greater emphasis on, and engagement with, the solution space, including policy options (see also Carraro et al., 2015). In this sense, 'solution-oriented' GEAs focus primarily on assessing different possible solutions to complex, environmental problems. This does not necessarily imply that solution-oriented GEAs are *per se* more contentious than problem-oriented GEAs. However, the increasing diversity and number of stakes and stakeholders engaged in GEAs that exhibit a solutions focus has resulted in a proliferation of divergent viewpoints.[2] In particular, and more explicitly than problem-oriented assessments, solution-oriented GEAs face a broad range of divergent political stakes, interests, and ethical values, as well as different forms of disputed knowledge claims (e.g., traditional knowledge) in the assessment of specific policy options.

Moreover, the international environmental governance context in which GEAs are embedded exacerbates the potential for divergence and conflict given the interdependences with other policy fields and interactions between multiple layers of jurisdiction (Stechow et al., 2016; Victor, 2014). However, avoiding disputed policy assessment in GEAs altogether to reduce the risk of legitimacy problems comes at the expense of weakening policy-relevance (Cash et al., 2003). Thus, achieving a careful balance between deeper, more meaningful engagement with relevant policy options and the heightened risk of bias (i.e. one-sided policy statements) versus avoiding (or watering down) heated issues in GEAs and significantly reducing policy-relevance and salience remains an enormous challenge (Siebenhüner, 2003). The adequacy and conditions of success (or failure) of different GEA responses to divergent viewpoints are poorly understood thus far, making GEAs vulnerable to legitimacy debates.

[2] This is argued, e.g., by Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T.J., Watson, R., Haas, P.M. et al., 2017. Global environmental assessments and the path to solutions. *Nature Climate Change, 7(6): 379-382.*

Our guiding research question explores what existing approaches are applied in selected GEA processes to respond to divergent viewpoints regarding environmental policy problems or possible response options (framework explained in Section 5.2; results presented in Section 3). We furthermore briefly evaluate the major strengths and weaknesses and potential conditions of success for each of these approaches (Section 5.2). Our research aims to support and frame future discussions about the design of GEA processes, and particularly, the solution-oriented, regarding the treatment of divergent viewpoints to ensure the legitimacy and ultimately the effectiveness of these GEAs.

Although many relevant case studies in the fields of STS, political science and environmental governance research exist (see below), the literature does not thus far sufficiently support GEAs regarding this challenge. The Harvard GEA project[3] yielded seminal studies inter alia on legitimacy issues in GEAs (e.g., Cash et al., 2003), but this project was initiated more than two decades ago and some of the most interesting contemporary GEAs (see Section 5.2) have been produced later. Different scholars have provided empirical and theoretical research on the politics of knowledge, the concepts of 'consensus', 'diversity' and 'disagreement', and the concept of 'co-production' of natural and social orders regarding various cases of scientific policy advice and selected GEAs (e.g., Jasanoff 1990; 2004; 2013; Jasanoff and Wynne, 1998; Reid et al., 2006; Scoones, 2009; Sluijs et al., 2010), and have analyzed different strategies for, and contexts of, knowledge brokerage on disputed issues of environmental governance (e.g., Michaels, 2009; Saarela et al., 2015). Appendix A provides a short literature review.

Although these analyses provide a useful starting point for this study (see Sect. 2), they do not provide the integrated analysis and overview of different approaches for responding to divergent viewpoints in GEAs aspired to here. This article aims to address this research gap, building on the valuable existing studies in this regard.

5.2 Analytical framework, materials and methods

5.2.1 The Meaning of 'divergent viewpoints'

We employ the term 'divergent viewpoints' here in the ordinary sense of the term, as done, for instance, by UN Environment (UNEP 2014, Sect. IV.G) regarding their GEA processes.

Viewpoints include, for instance, specific opinions and interpretations, judgments, knowledge and truth claims, or assumptions. We assume that different specific views are closely related to and largely determined by the more fundamental, underlying viewpoints held by different actors, for example their general positions, attitudes, perspectives or ways of thinking – be they substantiated, well-justified or not. These viewpoints are made up of a complex combination of cognitive and moral principles, beliefs, values, knowledge, experience, social context, and other factors.

Given the diversity of actors involved in GEA processes (Garard and Kowarsch, 2017), it is not surprising that many different viewpoints are present and will at times be at odds with one another. Divergent viewpoints can include explicit disagreements and even conflicts, where the latter is understood as a situation 'in which interdependent people express (manifest or latent) differences in

[3] See https://sites.hks.harvard.edu/gea/index.html (accessed 28 January 2018).

satisfying their individual needs and interests, and they experience interference from each other in accomplishing these goals' (Donohue and Kolt, 1992, p. 4). Divergent viewpoints can also include situations where a perceived dissent is simply a matter of suboptimal communication rather than real disagreement, dispute or even conflict.

For our analysis, we are mainly concerned with the divergent viewpoints held by actors involved in GEA processes, related to (1) the appropriate characterization of environmental policy problems and the risks at stake (including uncertainties, interdependence and multi-dimensionality), and/or (2) the suitability of possible response options (such as technologies, behavioral options, public policies). These GEA actors include very different kinds of stakeholders (see Garard and Kowarsch, 2017): authors and experts; GEA coordinators and producers; GEA-related institutions; governments and other policy-makers; decision-makers from business, industry, and NGOs; target audiences; etc. Their policy-relevant divergent viewpoints can occur at any phase during the GEA process, including, for example, when developing the mandate and scope, the content development and shaping phase, the review process, and negotiating the Summary for Policy Makers (SPM), where applicable. An overview of prominent divergent viewpoints that feature in the environmental governance arena is provided by Urhammer and Røpke (2013); Hulme (2009) and Robert and Zeckhauser (2011) discuss those more specific to climate change.

A closer inspection of divergent viewpoints reveals important and far-reaching fact-value entanglements inherent in most disagreements. Consequently, in contrast to other publications in this field (e.g., Robert and Zeckhauser, 2011), we assume that facts and (epistemic, ethical and other types of) values are always highly intermingled in general and GEAs (Dietz, 2013; Douglas, 2009; Hulme, 2009; Kowarsch, 2016, Chap. 5). Divergent viewpoints cannot be categorized as either purely 'scientific' or purely 'political' (normative, etc.), but rather there are only gradual differences between these frequently employed categories which can rarely be disentangled in empirical examples. For instance, controversial truth claims regarding scientific issues can imply conflicting individual or group interests as well, and divergent institutional interests – e.g. those of UN Environment (UNEP) in positioning itself as the leading body on international environmental policy in line with its formal mandate (Dodds et al., 2014) – can be strongly dependent on disputed scientific claims regarding the degradation of the environment and its implications for human well-being.

Conceptualizing the term 'divergent viewpoints' in a very broad sense, i.e. in a manner that includes both factual and value judgment issues to varying degrees, is done deliberately in this article as responding to divergent viewpoints in GEAs requires dealing simultaneously with dimensions of truth and power (Jasanoff, 1990; Kowarsch, 2016). Though we emphasize the scientific and political dimensions of divergent viewpoints in our analysis, we acknowledge that there is no clear dichotomy between the two in practice, and that the differences are gradual and not stark.

Despite the broad and integrated understanding of 'divergent viewpoints', the following sections (see Section 5.4) will specify the characteristics of the divergent viewpoints analyzed, in particular to what extent they are scientifically complex, ethically value-laden, and actually disputed. While the other two terms are relatively straightforward, we characterize divergent viewpoints as highly 'scientifically complex' if scientific expertise and methodologies – compared with other possible types of knowledge and judgments – can potentially contribute significantly to better understanding the complicated and often uncertain underlying issues (e.g., in the case of disputes over the causes of climate change).

5.2.2 Analyzing 'treatments' of divergent viewpoints

Responding to divergent viewpoints, inter alia by negotiating boundaries between scientific expertise and policy, is a fundamental preoccupation of environmental assessment-making (Kloprogge and Sluijs, 2006). Our analytical framework aims at incorporating a wide range of varieties and contexts for the 'treatment' of divergent viewpoints, i.e. different approaches for responding to divergent viewpoints in selected GEA processes. While some analysis of specific, concrete practices – in terms of specific GEA modalities, institutional settings, actor constellations, or specific actions regarding specific cases of divergent viewpoints – is unavoidable for a full-fledged analysis and evaluation of the approaches, this article is not primarily intended to provide a thorough examination of these things. Rather, this article focuses on overarching approaches at any phase during the GEA process, in terms of *general* strategies to respond to divergent viewpoints.

We understand these general approaches as social processes and practices – formal and informal – for responding to divergent viewpoints, including institutional mechanisms and rules but also informal techniques and communication strategies employed by GEA producers and coordinators, experts and other stakeholders, etc. (Keller, 2009; Michaels, 2009). Our research is situated between, and draws from, (1) on the one hand, macro-perspectives as given, for instance, in general models for the role of scientific expertise in policy (e.g., technocratic versus decisionist versus democratic models, as discussed in Kowarsch, 2016, Chap. 4), and (2) micro-level, specific analyses of concrete processes and institutions in GEAs, and their specific contexts and challenges (for which we provide several examples in Sect. 3 and Appendix B). The decision to focus on the intermediate level of analysis in terms of the general approaches (e.g., Beck et al., 2014; Siebenhüner, 2003; and Vries and Petersen, 2009), rather than specific institutions or processes, was motivated by the assertion that improving concrete practices in GEA processes is hardly possible without establishing a baseline understanding of the general approaches that guide the concrete practices.

Possible approaches to respond to divergent viewpoints (Sect. 3) include, for instance, revealing and clarifying different viewpoints, or circumventing the discussion of particular divergent viewpoints in GEAs altogether. In any case, GEAs must *somehow* respond to the existence of these divergent viewpoints in one way or the other, implicitly or explicitly. Considering the fact/value entanglement, it is misleading – as is often done in both the literature and in GEA processes – to separate science-internal methods, strategies and successes regarding the resolution of 'scientific' divergent viewpoints and uncertainties from political or ethical conflict resolution approaches. Instead, integrated approaches, and integrated analyses thereof, are required. This makes the appropriate treatment of divergent viewpoints in GEAs so challenging. While all decision-making processes necessitate a pragmatic need to provisionally thwart debates (i.e., take decisions), we are not suggesting that GEAs should always aim to resolve divergent viewpoints. Divergent viewpoints in and of themselves are not problematic, but are an inherent and valuable attribute of knowledge production and pluralist democracies (Douglas, 2009). For instance, Beck et al. (2014), Reid et al. (2006), Edenhofer and Kowarsch (2015), Kloprogge and Sluijs (2006), Norgaard (2008), Sluijs et al. (2010), and Vries and Petersen (2009) all propose a more inclusive and open treatment of divergent viewpoints (including normative aspects) in GEA processes, going beyond consensus and reconciliation.

The widely accepted criteria of legitimacy, credibility and salience for the effectiveness of GEAs (e.g., Cash et al., 2003) – in terms of the adapted version developed by Kowarsch et al. (2016) – can provide

a normative conceptual framework for determining the 'appropriateness' or 'success' of different approaches. Building on these criteria, our focus is on the actual effects of approaches applied in GEA processes primarily in terms of legitimacy, as perceived by the diverse relevant actors. More specifically, we also evaluate the extent to which a particular approach helped facilitate an inclusive and fair deliberative learning process related to the divergent viewpoints at stake (Kowarsch et al., 2016).

There is, however, no one-size-fits-all approach to dealing with divergent viewpoints because certain approaches perform differently in different contexts and situations. As Michaels (2009, p. 997) describes, 'there is no single, ideal form of knowledge brokering for developing environmental policy'. This emphasizes the need for critical reflection on the conditions that determine the appropriateness of a particular approach within different GEA contexts. The literature on environmental knowledge brokerage sheds light on specific context factors affecting the success of different kinds of knowledge brokering, including the treatment of divergent viewpoints. 'Knowledge brokers' are boundary spanning individuals who communicate, mediate and translate in various ways as intermediaries between researchers and policy-makers (Michaels, 2009). Relevant context factors include, for instance, "the complexity of the policy problem, type of policy area, organisational norms, actor constellations and continuance and openness of information sharing" (Saarela et al., 2015, p. 325). Building on the conceptual framework and results provided by these studies relating to context factors, we discuss potential conditions of success of the approaches in Section 5.4.

5.2.3 GEAs selected for the analysis

We selected three GEA processes for our analysis: The Global Environment Outlook series (GEO), the IPCC assessments, and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). The GEO assessment (and particularly GEO-5) which is UNEP's flagship assessment was included because it is comparatively very comprehensive both in terms of geographic scope and thematic coverage. The IPCC (with a focus on the Working Group (WG) III contribution to the Fifth Assessment Report [AR5]) was selected because it is, on one hand, widely considered to be a role model for other GEAs and, on the other hand, it is arguably one of the most publicly contested (and perhaps most influential) GEAs (e.g., IAC, 2010) and widely discussed in the literature. The IAASTD was chosen because it struggled a lot with divergent viewpoints. Here, major disagreements over the appropriate role of genetically modified organisms in agriculture resulted in some private sector authors and members of the Bureau resigning (Feldman and Biggs, 2012).

We furthermore reviewed some literature on the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). The relatively young IPBES provides an interesting case given that stakeholder engagement and the legitimate treatment of divergent viewpoints are particularly emphasized here (e.g., Beck et al., 2014; Díaz et al., 2015; Pascual et al., 2017).

5.2.4 Sources of information and analytical methods

Information on existing approaches within GEA processes – as well as on their strengths, weaknesses, preconditions and consequences – was taken from an analysis of expert interviews with GEA participants, from an analysis of GEA documents and documentation, as well as from a review of the existing academic literature. We conducted 99 semi-structured interviews – the clear majority (89 interviews) with GEA practitioners, including authors, producers and other experts or governmental

officials involved in GEO-5 and IPCC WGIII AR5, as well as a smaller number (10 interviews) with non-involved intended target audiences of the three GEAs. The interviews lasted 55min on average and were conducted via Skype or telephone mainly between August 2013 and February 2015. Following the guidance of Strauss and Corbin (1998), we analyzed the interviews using Grounded Theory Analysis methodology in Max QDA software. We employed iterative coding to organize the vast amount of information and examples collected into nine types of approaches and their advantages or drawbacks.

In addition, the available GEA documents and documentation, publications about GEAs and the context factors of knowledge brokerage, as well as our personal involvement in recent IPCC and GEO assessment processes and different multi-stakeholder workshops on GEAs, provided multiple opportunities to collect further information on how governments, scientific experts and other stakeholders describe and evaluate different approaches for responding to divergent viewpoints within GEA processes. Given the interview methodology based on carefully drafted interview guidelines, as well as the possibility for extensively discussing our material with multiple audiences, we believe that our involvement in recent assessment processes does not considerably bias the results.

The general approaches for responding to divergent viewpoints were often only implicitly described by interviewees as well as in official documents relating to the three GEA processes analyzed. Therefore, to support the coding exercise for our Grounded Theory Analysis, we also drew on the existing literature on science-policy models in general (on the nature of such models, see Kowarsch, 2016, Sect. 4.1) and on GEA design for conceptually capturing and coding the different approaches indicated by the interviewees (see the references in Section 5.3 and Appendix B). As a final step, we cross-checked (triangulated) the interview statements coded into different categories of approaches with information from available GEA documents and documentation (GEA guidelines, scoping documents, process reports, GEA outputs, etc.).

The various approaches in practice rarely, if ever, occur *precisely* in the explicit and consistent manner suggested by the descriptions in Section 5.3. Rather, the suggested approaches are to be understood as 'ideal types' that can be valuable analytical tools to facilitate analysis. In an essay on objectivity in social science, Max Weber defines ideal types as conceptual tools which can facilitate social science analysis and which are hypothetical ideas or idealized models distilling key characteristics from social realities in a clear, descriptive, simplified manner (Weber, 1988, pp. 146–214).

Regarding the discussion of major strengths and weaknesses of the approaches in specific GEA contexts (Section 5.4), a major challenge and limitation involved assembling all the empirical data required for capturing the full scope of the implications of the approaches. This significantly limits the possibility of conducting a full-fledged evaluation of the approaches discussed here. The brief evaluation of the approaches presented in Sect. 4 is therefore rather hypothetical and preliminary, particularly regarding our more general claims, and is by no means comprehensive. However, some preliminary lessons can still be drawn. We rely on the interview statements as well as the existing literature to tell us whether certain approaches have had specific positive or negative implications in particular contexts. Based on this, we develop more general hypotheses on potential advantages and drawbacks of these approaches, and subsequently hypothesize about general conditions of success for different approaches.

5.3 Results: Different approaches for responding to divergent viewpoints

Nine different approaches for responding to divergent viewpoints can be identified within the selected GEA processes. These nine approaches correspond to the major coding categories resulting from the Grounded Theory Analysis.

Given the space constraints, the following paragraphs only highlight some major characteristics of each of the nine approaches. Annex B provides more detail and examples regarding the nine approaches. The examples given from interviews and documents for the approaches in the following sections as well as in Annex B are only intended to be illustrative. These examples are not necessarily describing cases where the given approach was used and implemented in a *successful* manner (Section 5.2.2) and under ideal conditions.

5.3.1. Approach 1: Clarify meaning

This approach aims to resolve an existing disagreement in a relatively straightforward way by clarifying the precise meaning and background of a disputed statement or assumption in a GEA. The underlying assumption of this approach is that several divergent viewpoints arise from simple misunderstandings, for example, due to the brevity of formulations, differing terminologies across scientific disciplines or other societal domains, insufficient individual knowledge, etc. Thus, these are pseudo divergent viewpoints that can be easily overcome by enhanced communication and explanation. This approach can be useful for all actors involved in a GEA process and can be used to mitigate disagreements between different actor categories (e.g., between scientists and policymakers) or within the same category (e.g., between authors). This approach can thus help to overcome the limitations of the traditional linear and one-way models of science communication (e.g., as described by Jasanoff, 1990 and 2004) with their lack of dialogue.

An example of how clarification could in fact work is provided by Hinkel (2011) regarding the confusion around vulnerability indicators.

5.3.2. Approach 2: Knowledge

This approach aims to resolve, or significantly reduce, divergent viewpoints by pointing to reliable and credible scientific knowledge that is widely accepted in the scientific community. This is typically done by relying on facts, evidence and objectivity, which are, in this approach, placed in sharp contrast to subjective judgments or politics, for example. At a minimum, this approach aims to clarify and validate the confidence level in the scientific community regarding a disputed issue in a GEA (e.g., through quantifying uncertainties and probabilities of future scenarios, see Sluijs et al., 2010). This approach is usually employed by GEA practitioners with the underlying assumption that certain divergent viewpoints can be resolved through better acknowledgment and integration of the existing scientific knowledge or at least through scientific progress in the future because scientific knowledge is associated with authority and credibility in society. The huge body of STS literature, for example on the 'technocratic' and 'linear model' of scientific expertise in policy (see above), thoroughly explains and critically discusses central ideas and mechanisms of this approach.

An example of this approach is the attempt to resolve the issue of anthropogenic climate change through an increased scientific consensus on climate physics, potentially ignoring, however, the many

underlying legitimate political dimensions of the climate change issue (Hulme, 2009; Pielke, 2007; Sarewitz, 2004).

5.3.3. Approach 3: Expert judgment

The third approach, called 'expert judgment', is like the knowledge approach, but in this case the divergent viewpoints are exclusively handled within a GEA writing team. In contrast to the knowledge approach, thus, it does not necessarily include the entire scientific community, nor a larger consensus-seeking process, but rather, a relatively narrow pool of authors and experts attempting to resolve the controversial issue through their own means. The underlying assumption of this approach is that during a GEA process, hundreds of decisions must be made by author teams, GEA experts, and producers; therefore, expert judgments are a more efficient (time-saving) and largely reliable way of dealing with the sheer volume of potential instances where scientific consensus cannot be reached (or in cases where policymakers do not want to make clear political decisions yet). In contrast to the knowledge approach, expert judgment builds on the scientific authority, hierarchy, and credibility of those who resolve the divergent viewpoints (be it individuals or teams), mainly because no scientific consensus exists.

An example is the GEO-5 Science and Policy Advisory Board composed of reputable scientific and policy experts. It was mandated to 'make the final determination on any science related contentious issue as raised by CLAs, the Secretariat or expert reviewers' (UNEP, 2012, p. 2). This Board was specifically tasked with supporting the GEO-5 process by providing scientific quality assurance to chapter authors and, in 'cases of uncertainty and/or contentious science related issues, the board will provide […] the final determination' (UNEP, 2012, p. 3).

5.3.4. Approach 4: Negotiated compromise

This approach tries to build a bridge between GEA authors and experts on the one hand, and a group of policymakers and other stakeholders that are involved in the GEA process on the other hand. The basic idea is to bridge scientific expertise and policy through a direct exchange of arguments within the GEA process, which may, ideally, lead to a compromise that is acceptable for all the parties involved (e.g., the 'honest broker' model, Pielke, 2007). A decisive underlying assumption is that such a direct dialogue and negotiation is necessary at the science-policy interface to overcome barriers and bridge the different priorities and perspectives that exist between groups of scientists and policymakers (e.g., Vries and Petersen, 2009).

Examples of this approach can be found in some of the formal SPM (or Summary for Decision Makers in the case of IAASTD) approval procedures of GEAs where experts and governments sometimes attempt to find compromises (see, e.g., IISD, 2012, for the GEO-5 SPM approval meeting). Another example is informal negotiation between leading assessment authors and governments. One leading author, for instance, reported that after some informal negotiation during the review phase of GEO-5, the government of Brazil 'finally agreed to text on deforestation' (see Appendix B).

5.3.5. Approach 5: Political decision

The previous approach outsourced the resolution of the divergent viewpoints to committees, plenaries or informal settings where authors, GEA producers, and policymakers were all included in the negotiations and discussions of the formulations. The fifth approach, 'political decision' (this is

similar to the decisionist model described by Habermas, 1971), delegates completely the resolution of controversial issues to the political realm, in some cases because writing teams regard it as appropriate to delegate certain divergent viewpoints to policymakers. In other cases, governments may simply exert their (legitimate or disputable) power as a major stakeholder group in the GEA process. In this approach, governments, policymakers, parliaments, and other political decision-making bodies make decisions regarding disputed viewpoints, and then GEAs build on that decision in their analyses of environmental problems and solutions.

'Large-scale' examples include the Aichi Biodiversity Targets, the Sustainable Development Goals, and the Paris climate agreement. In the case of the IPCC, for instance, author teams do no longer need to think of climate policy goals themselves, but can resort to given global and national goals now for structuring future IPCC assessments, such as the envisaged IPCC Special Report on the 1.5°C goal resulting from the Paris Agreement.

5.3.6. Approach 6: Public discussion

The 'public discussion' approach differs from the previous approaches in that there is not necessarily a resolution to the divergent viewpoints, at least not in the short term. It is a long-term, extensive approach envisaging a constructive and broad public discourse on the divergent viewpoints prior to, during, and/or after the GEA process. Even more than the 'political decision" approach, this approach constitutes a (long-term) project largely going beyond the boundaries of a traditional GEA process. The sciences can play a role in such public discussions by providing background information and inputs in an iterative process; but its role remains limited. The key assumption is that it is possible to resolve divergent viewpoints, sooner or later, through a constructive and fair democratic discourse where the sciences are not expected to contribute very much to the resolutions, which are usually assumed to be highly normative and value-laden. This approach can be linked to the literature refining or elaborating on Habermas' (1971) pragmatic ('democratic') model of scientific expertise in public policy (e.g., Maasen and Weingart, 2005; Goodin, 2008).

One example may be the old debate about how to conceptualize and measure the value of nature (e.g., Pascual et al., 2017) – a controversy that affects all GEAs. The German debate over nuclear phase-out can serve as another example. This heated debate lasted several decades, was intense and societally divisive at times, but eventually resulted in the broadly supported decision to abandon nuclear power (Strunz, 2014). Future GEAs can refer to this decision when discussing or comparing climate and energy policies.

5.3.7. Approach 7: Map implications

In the 'map implications' approach, scientific experts involved in GEAs play an active role in informing public deliberation processes, but do not directly resolve the major divergent viewpoints. Rather, the divergent viewpoints are explicitly scientifically analyzed considering their practical implications. These analyses can be conducted jointly with stakeholders and the public in a highly collaborative and iterative manner (Edenhofer and Kowarsch, 2015). The main assumption behind this approach is that stakeholders and the public can make more informed decisions if they have a better understanding of the implications of alternative policy pathways (Kowarsch, 2016). This approach requires, to some degree, cartography of the policy 'solution space', for instance in terms of a multi-scenario analysis.

A prominent example is the strategy that was used for the IPCC WG III AR5 where alternative climate policy pathways and their implications have been discussed (Edenhofer and Kowarsch, 2015).

5.3.8. Approach 8: Revealed controversy

The next approach, 'revealed controversy', differs from the previous approach in that GEAs do not explore the implications but, rather, attempt to make transparent and delineate the divergent viewpoints. In this case, it is assumed (e.g., Beck et al., 2014) that the divergent viewpoints can hardly be – or should not be – resolved, but also that the exercise of revealing (mapping) the divergent standpoints or conflict may help structure future public debate, particularly when scientific uncertainty is high.

An indicative example is found in a UNEP guidance document on GEA strategies that emphasizes this approach, inter alia stating that 'the assessment report may include in a footnote the differing views expressed' (UNEP, 2014, p. 19).

5.3.9. Approach 9: Avoid

Finally, the 'avoid' approach is used by GEA experts and producers, as well as authors and author teams, to avoid, circumvent or at least strongly water down the divergent viewpoints in GEAs, particularly the most heated and politicized ones. Policymakers also sometimes insist on avoiding certain issues in GEAs. The idea behind this approach is that, in some cases, it is wise to avoid the most heated issues to come to a consensus or at least an agreement on other important messages and results.

The IPCC WG III AR5 SPM negotiations provide an interesting example in this regard (Edenhofer and Minx, 2014). Governments insisted on deleting any country classifications regarding the ex-post assessment of progress in climate change mitigation because this issue was too heated.

5.3.10 Further results

The approach that was most often mentioned in the interviews is the 'expert judgment' approach, followed by the 'negotiated compromise' approach. In practice, there are often combinations and overlaps between these different approaches, and several of them may be employed simultaneously. Despite overlaps, these approaches can still conceptually guide a reflection process regarding the appropriate treatment of divergent viewpoints in specific cases and contexts.

The nine approaches may also be subsumed and further refined into four broader categories, which help to further understanding of the similarities and differences of the nine approaches:

- **The 'resolution by experts' category** (see white boxes in Table 5.1): The 'clarify meaning' approach is routinely and successfully used by GEA experts and employs communication to overcome small misunderstandings underlying divergent viewpoints. In the 'knowledge' and 'expert judgment' approaches, substantial divergent viewpoints are resolved by scientific experts. This typically occurs within broader academic processes, such as peer review, and aims to establish a robust and credible consensus (knowledge), or it occurs within GEAs; these approaches are often used to overcome a lack of a broader scientific consensus and high uncertainty.

- **The 'delegation to policy' category** (light blue boxes): In the 'negotiated compromise' and 'political decision' approaches, scientific experts at least partly delegate the resolution of some controversial issues to particular decision-makers and use the results to produce the GEA. In the 'negotiated compromise' approach, scientific experts can still play a relatively strong role in resolving the issue, while in the 'political decision' approach, experts completely delegate certain questions to decision-makers.
- **The 'public deliberation' category** (medium blue boxes): This category refers to more long-term and extensive approaches where GEA processes do not necessarily (and certainly not in the short-term) resolve the divergent viewpoints at stake. Rather, GEAs envisage a constructive and broader public discourse on these viewpoints (prior to, during, and/or after GEAs) to which GEAs then contribute either relatively little ('public discussion') or a great deal ('mapping implications', i.e., a scientific cartography of a broad range of implications of standpoints).
- **The 'heated conflict' category** (dark blue boxes): This category comprises approaches where divergent viewpoints are not resolved at all, but rather, where scientific experts either provide an overview of the controversial standpoints and contexts ('revealed controversy'), or avoid or water down the issues altogether ('avoid').

The order of the categories is based on the (decreasing) extent to which the categories, under ideal conditions, allow the scientific experts (on their own) to resolve (i.e., take a clear stand and settle controversial issues) divergent viewpoints in GEAs. However, it would be wrong to interpret the order of approaches or categories here as a normative ranking. Rather, the different categories of approaches are, under ideal conditions, particularly adequate for *different kinds* of divergent viewpoints that are varyingly difficult to resolve, *per se*.

5.4 Discussion

Employing the analytical framework and methods described in Section 5.2, the following hypotheses – summarized in Table 5.1 – can be developed around the pros and cons, and conditions of success, of each of the nine approaches.

5.4.1. Approach 1 (clarify meaning')

For viewpoints that have substantial and more complex origins or foundations, this approach becomes more difficult to apply because it assumes that the misunderstanding, errors, or individual lack of knowledge are relatively simple to resolve. This approach has very limited potential to bring about beneficial results in case of heated, value-laden debates that are also scientifically complex (as defined in Sect. 5.2.1).

5.4.2. Approach 2 ('knowledge')

Despite its merits in cases that presuppose a relatively well-functioning, fair, credible, and transparent scientific peer-review system, the risks associated with the knowledge approach are particularly high when there is a strong, implied conflict over the ethical issues or interests that underlie the divergent viewpoints (see Gupta et al., 2012, and the 'stealth issue advocate' described by Pielke, 2007). In these cases, the scientific community has little chance of reconciling divergent viewpoints using the standard

tools that are at the core of the knowledge approach. The knowledge approach seems comparatively effective if there are scientifically complex divergent viewpoints with limited ethical disputes or conflicts of interests, and limited uncertainty that can at least be partly overcome.

5.4.3. Approach 3 ('expert judgment')

The optimal conditions for the expert judgment approach seem to be those where divergent viewpoints are not highly disputed, not overly complex, and not directly (or normatively) about the evaluation of policy options, and where there is no scientific consensus. If one of these criteria is not fulfilled, this approach could lack legitimacy and credibility. Moreover, this approach seems to presuppose the existence of good leadership of coordinating lead authors (CLAs) and other actors in the GEA writing and production teams, as well as the willingness and capacity of scientific experts to have a fair and rational discussion within their teams, which in practical terms is exceptionally difficult to guarantee.

5.4.4. Approach 4 ('negotiated compromise')

This approach could be used by governments to pressure authors or, conversely, by scientific experts to strongly influence policymakers. Although negotiating a compromise can also lead to learning about environmental policy options and the underlying problems for those involved, these effects are naturally limited (compared with other approaches). This is because the approach emphasizes negotiation and compromise rather than a thorough and extensive scientific exploration of the issues at stake or an open deliberation about divergent viewpoints. Moreover, the legitimacy of this approach is weak from the perspective of those who are not involved. This approach may work particularly well if the issues at stake are less scientifically complex but relatively value-laden. Only in rare cases might this approach lead to a sustainable resolution of policy-related divergent viewpoints if there is no fair dialogue between the authors and policymakers.

5.4.5. Approach 5 ('political decision')

Besides being relatively time-efficient and well-aligned with the interests of governments, this approach is particularly useful for (1) creating the ownership and 'buy-in' of governments and (2) delegating the resolution of highly normative political issues to policymakers as the bearers of political legitimacy, which they derive from political representation or other means. One negative implication of this approach is that it does not contribute to a better understanding of the specific pros and cons of alternative environmental policy options or problem definitions. It runs the risk of assuming incorrectly that the sciences cannot contribute much to discussions about policy objectives and other highly normative issues in environmental policy.

5.4.6. Approach 6 ('public discussion')

The public discussion approach has considerable advantages, despite the obvious drawback of being time consuming, costly, and unpredictable in its outcomes for all parties. The most important positive effect is the high level of legitimacy if fair and democratic participation can be ensured. Over time, public discussion can foster a far-reaching learning process in society, as well as a steady adjustment of preferences. However, the assumption that the sciences plays only a very weak role, this approach tends to underappreciate the potential role of scientific expertise in contributing to the resolution of complex problems or even heated political debates (see the 'map implications' approach). For

example, gaps in knowledge about the future implications of adopting a certain viewpoint might impede the resolution of a conflict, but these gaps could reveal themselves once the contending parties become better informed. However, such public discussions might be relatively unstructured and, therefore, lack efficiency.

5.4.7. Approach 7 ('map implications')

While some policymakers might resist the open and time-consuming exploration of alternative pathways and their implications (Appendix C), this approach seems promising particularly for the highly complex, value-laden, and disputed cases of divergent viewpoints (such as, e.g., disputes over broader, longer-term policy pathways), i.e. considering the hybrid character of many divergent viewpoints as described in Section 5.2.

5.4.8. Approach 8 ('revealed controversy')

The use of GEAs as tools to inform the public about specific controversies and the different arguments put forward may be valuable for handling stagnant public debates. This would open-up debates instead of closing them down prematurely (Stirling, 2008), which can provide a meta-narrative for discussing divergent viewpoints more constructively. However, the lack of a scientific exploration of the implications for policy options reduces the learning potential for the issues at stake.

5.4.9. Approach 9 ('avoid')

Both the positive and negative aspects of the avoid approach are relatively obvious. Not addressing an issue at all, or watering it down, clearly does not have the potential to inform and foster public debate; this approach may in fact result in a lack of policy-relevance of GEAs. On the other hand, it can be the 'lesser of two evils' if such an approach at least allows for a constructive discussion and acceptance of other, less heated issues in GEAs (Siebenhüner, 2003).

The brief discussion of the conditions of success for each of the approaches shows that it matters a lot to what extent divergent viewpoints are:

(1) complex, such that the sciences can reasonably employ their sophisticated methods, rigor, and systematic long-term inquiries;
(2) value-laden, meaning they are usually about normative policy issues based on different interests, policy objectives, or ethical values, as well as their roles in evaluating policy options, and so on;
(3) disputed (publicly), which can furthermore be an indicator for the perceived importance of divergent viewpoints for policy-making processes.

This is not a comprehensive list of characteristics to be considered when selecting the appropriate approach, nor is it a comprehensive list of relevant context factors (see Section 5.2.2). However, these three context factors emerged as crucial in our analysis and can help future GEAs to evaluate and improve their choices regarding the various approaches for responding to divergent viewpoints.

Table 5.1. Preliminary evaluation of different approaches for responding to divergent viewpoints in GEAs

The first column represents the coding results from our Grounded Theory Analysis in terms of the nine approaches identified. The different shades in the first column indicate the different categories (Section 5.3) of approaches along the decreasing role of experts in resolving the issues at stake (i.e., darker blue represents a weaker role). The second column highlights key examples of specific means of implementing these general approaches (see also Appendix B). The third and fourth columns represent preliminary hypotheses on positive and negative practical implications of the approaches. The final column presents preliminary hypotheses on ideal conditions of success of the approaches.

GEA approach to divergent viewpoints	Different concrete GEA practices to realize the approach	Positive implications (hypotheses)	Negative implications (hypotheses)	Conditions of high appropriateness / success (hypotheses)
(1) Clarify meaning Communication and better explanation	Informal dialogues, formalized procedures, e.g., plenary sessions, responses to review	Low-hanging fruit for effective resolution; often facilitates learning	Limited potential if there is substantial disagreement	Lack of substantial disagreement, just misunderstandings, errors or individual lack of knowledge
(2) Knowledge Refer to credible scientific knowledge, or confidence level	Knowledge synthesis, peer review and consensus, initiate research if needed	Strong, credible, and widely accepted resolution, e.g., through consensus	Risk of "stealth issue advocate" through implied value judgments and uncertainty	Complex issues with only few disputed (implied) values and uncertainty
(3) Expert judgment Hierarchy and authority	Informal or formal, discussion and argumentation, or decision by individual	Effectiveness and efficiency based on expert knowledge	Limited legitimacy and credibility if there are stronger disagreements	Less value-laden, disputed issues if there is no consensus, good CLA leadership
(4) Negotiated compromise Between experts and policymakers	Informal or formal discussions during SPM negotiations, GEA review process	Accepted both by governments and scientists, time-efficient	Limited learning for the public and little legitimacy for the non-involved	If less publicly disputed and less complex, normative issues; fair dialogue
(5) Political decision Let policymakers decide (or majority vote); use results in GEAs	Decision either prior to or during (e.g., intergovernmental meeting) a GEA process, formalized and informal variants	Political buy-in and legitimacy through representation, time-efficient process	Conflicting issues are often difficult to separate from scientific knowledge	Not too many fundamental disputed issues, trust in governments, the sciences at best deliver contextual information
(6) Public discussion Resolution, if at all, through political debate; limited role of the sciences	Formalized meeting or platform, informal long-term public debate (media, etc.), limited role of scientific experts	Much learning possible (though limited), highest legitimacy (if democratic and fair participation)	Knowledge gaps about viewpoint implications might impede potential resolutions, often unstructured	Fundamental, disputed issues; the sciences can at best deliver contextual information, fair participation
(7) Map implications Cartography of alternative policy paths, iteratively with stakeholders	Strong or weak stakeholder engagement, multi-scenario analyses or deep interdisciplinary "cartography"	Deep public learning exercise about political solution space without being policy-prescriptive	Significant effort, possible opposition, no clear recommendations, challenge of interdisciplinarity	Complex, disputed, fundamental issues, at least some scientific knowledge on implications, interdisciplinarity
(8) Revealed controversy Capture different arguments and standpoints	Mapping conflicts in GEA report, other input to public debates by GEA experts, mapping ranges of results or probabilities	Opens up the debate, provides a conceptual framework and a "meta-narrative" to structure the policy debate	Not much learning regarding the potential solution to the conflict	If there is high scientific uncertainty and high policy-relevance and strongly disputed, if there has been no constructive political discussion yet
(9) Avoid Avoid heated issues, water down conflict	Postpone, water down the message, do not mention the topic, deletion during SPM negotiations	Allows for acceptance of at least of some insights	No contribution to society's heated debate, lack of policy relevance	Use if there is no chance for deliberation and the issue is too heated

Table 5.1 can be regarded both as a list of predominant actual approaches and as a list of major options for responding to divergent viewpoints in future GEA processes. As a rule, the more scientifically complex, ethically value-laden, and disputed the issues and related viewpoints are – i.e. the more 'wicked' they are –, the more appropriate it will likely be to choose an approach that is further down the list of approaches presented in Table 5.1. For example, the resolution by experts' category of approaches is more appropriate for cases that are not extensively disputed or overly value-laden, whereas the delegation to policy category is more likely to be appropriate for issues that are more value-laden and disputed. The public deliberation category of approaches could also be adopted for relatively complex, value-laden, and disputed issues, while the heated conflict category seems to be the most appropriate in extremely heated and value-laden cases with significant scientific complexity. In Appendix C, we provide an example of a case – the role of genetically modified organisms in agriculture – where some approaches, particularly the 'map implications' approach, are more appropriate than others when it comes to viewpoints that are highly disputed on both scientific and normative grounds.

Distilling insights from the interviews as well as the literature on knowledge brokerage and context factors, we further identify several specific measures which can be taken that may significantly affect the success of GEAs regarding the treatment of divergent viewpoints, including:

(1) Providing sufficient resources (i.e., time, funds, and expertise), employing prerequisite for the employment of the more resource-intensive approaches to divergent viewpoints;
(2) Offering training to increase authors' leadership and skills regarding the identification and treatment of divergent viewpoints;
(3) Facilitating an intensive dialogue between scientists, policymakers, and the public to enable mutual learning processes;
(4) Ensuring more transparency over divergent viewpoints and their treatment in GEAs, as a very basic but effective measure to improve the treatment of divergent viewpoints in GEA processes;
(5) Discussing and analyzing divergent viewpoints prior to the GEA process to reduce the analytic burden on GEA processes (e.g., regarding the 'map implications' approach).

Finally, future GEAs should discuss possible approaches for responding to divergent viewpoints as early as possible (i.e., mandating or scoping phase). The IPBES discussions in the past few years about the appropriate treatment of divergent viewpoints can possibly serve as a role model in this regard. A clear GEA mandate is required if, for instance, the 'map implications' approach is envisaged, to coordinate the expectations of all the participating stakeholders regarding the treatment of the divergent viewpoints.

5.5 Conclusions

This article has identified nine strategic approaches for responding to divergent viewpoints in contemporary GEA processes. The results empirically confirm the existence of some approaches already discussed or indicated in the literature, but also reveal actual approaches, or particular characteristics thereof, that go beyond what is discussed in the literature. Based on the decreasing extent to which scientific experts in GEAs employing such approaches can provide clear guidance on policy-related divergent viewpoints, the approaches range from little or medium-level complexity (i.e.,

the resolution by experts category and the delegation to policy category) to the more complex, long-term, and extensive approaches included in the public deliberation category of approaches. All of the approaches have particular strengths and weaknesses and promise to be more or less successful under specific circumstances.

To our knowledge, this article provides the first systematic overview of general approaches for responding to divergent viewpoints in contemporary GEA processes, which may promote more systematic reflections on how to design GEA processes in order to foster more rational, open public discussions about such divergent viewpoints. Our research is only one step towards more explicitly and constructively discussing and evaluating different approaches within GEA processes. Our exploratory research provides a valuable set of hypotheses that may help better frame future discussions about the appropriate treatment of divergent viewpoints in GEAs, and may help reduce confusion in some of the existing debates about this issue.

Given the increase of this challenge of divergent viewpoints in *solution-oriented* GEAs, these GEA processes in particular should be subject of further scrutiny. With this research and the analytical framework employed, we intend to open up and structure the field for a more rational inquiry that is often only subject to informal dinner conversations or individual case studies. Furthermore, the need for "ad hoc" approaches to respond to divergent viewpoints in GEAs could be reduced, and if there were more explicit deliberation, the conditions under which a particular approach is appropriate (or not) would be better understood. Most importantly, however, is making sure that the different approaches for responding to divergent viewpoints are discussed openly to begin with. The research presented here may encourage solution-oriented GEAs – despite the related risks and challenges – to address very complex, disputed, value-laden, and highly politicized divergent viewpoints more explicitly by increasing awareness that promising coping strategies do exist.

5.6 References

Beck, S., Borie, M., Chilvers, J., Esguerra, A., Heubach, K., Hulme, M. et al. (2014). Towards a Reflexive Turn in the Governance of Global Environmental Expertise. The Cases of the IPCC and the IPBES. *GAIA* 23(2), 80-87.

Carraro, C., Edenhofer, O., Flachsland, C., Kolstad, C., Stavins, R., Stowe, R. (2015). The IPCC at a crossroads: Opportunities for reform. *Science* 350, 34f.

Cash, D.W., Clark, W.C., Alcock, F., Nickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B. (2003). Knowledge systems for sustainable development. *PNAS* 100(14), 8086–8091.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. (2015). The IPBES Conceptual Framework: Connecting nature and people. *Current Opinion in Environmental Sustainability* 14, 1–16.

Dietz, T. (2013). Bringing values and deliberation to science communication. *PNAS* 110(3), 14081–14087.

Dodds, F., Laguna-Celis, J., Thompson, L. (2014). From Rio+20 to a New Development Agenda: Building a bridge to a sustainable future. London: Routledge.

Donohue, W., Kolt, R. (1992). *Managing interpersonal conflict*. Newbury Park: Sage Publications.

Douglas, H.E. (2009). *Science, Policy, and the Value-Free Ideal*. Pittsburgh: University of Pittsburgh Press.

Edenhofer, O., Minx, J. (2014). Mapmakers and navigators, facts and values. *Science* 345 (6192), 37f.

Edenhofer, O., Kowarsch, M. (2015). Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy 51, 56–64.*

Feldman, S., Biggs, S. (2012). The politics of international assessments: The IAASTD process, reception and significance. *Journal of Agrarian Change* 12(1), 144–169.

Garard, J. Kowarsch, M. (2017). If at first you don't succeed: Evaluating stakeholder engagement in global environmental assessments. *Environmental Science & Policy* (available online), doi: 10.1016/j.envsci.2017.02.007.

Goodin, R.E. (2008). *Innovating democracy: Democratic theory and practice after the deliberative turn*. Oxford: Oxf Univ Press.

Gupta, A., Andresen, S., Siebenhüner, B., Biermann, F. (2012). Science Networks. In *Global Environmental Governance Reconsidered*, eds. Biermann, F., Pattberg, P., 69–93. Cambridge MA: MIT Press.

Habermas, J. (1971). *Toward a Rational Society*. Boston Mass.: Beacon Press.

Hinkel, J. (2011). Indicators of vulnerability and adaptive capacity: Towards a clarification of the science–policy interface. *Global Environmental Change* 21(1), 198–208.

Hulme, M. (2009). *Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity*. Cambridge: Cambridge Univ Pr.

IAC (InterAcademy Council) (2010). Climate change assessments: Review of the processes and procedures of the IPCC.

IISD (2012). A Summary Report of the Intergovernmental Meeting on the Fifth Global Environmental Outlook Summary for Policy Makers. *Earth Negotiation Bulletin* 182(4).

Jabbour, J., Flachsland, C. (under review – expected to be forthcoming soon). The future of global environmental assessments: Occupying the solutions space. *Environmental Science & Policy* (special issue on solution-oriented GEAs, 2017).

Jasanoff, S. (1990). *The Fifth Branch: Science Advisers as Policymakers*. Cambridge, MA: Harvard Univ Pr.

Jasanoff, S. (ed.) (2004). *States of Knowledge: The Co-production of Science and the Social Order*. London: Routledge.

Jasanoff, S. (2013). A World of Experts: Science and Global Environmental Constitutionalism. *Environmental Affairs Law Review* 40(2), 439-452.

Jasanoff, S., Wynne, B. (1998). Science and decisionmaking. In *Human choice and climate change. Volume 1: The societal framework*, eds. Steve Raynor and Elizabeth Malone, 1–87. Colombus, OH: Battelle Press.

Keller, A. (2009). *Science in Environmental Policy: The Politics of Objective Advice*. Cambridge, MA: MIT Press.

Kloprogge, P., Sluijs, J.P. van der (2006). The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. *Climatic Change* 75(3), 359–389.

Kowarsch, M. (2016). *A Pragmatist Orientation for the Social Sciences in Climate Policy. How to Make Integrated Economic Assessments Serve Society*. Boston Studies in the Philosophy and History of Science 323. Switzerland: Springer.

Kowarsch, M., Garard, J., Riousset, P., Lenzi, D., Dorsch, M., Knopf, B., Harrs, J.-A., Edenhofer, O. (2016). Scientific assessments to facilitate deliberative policy learning. *Palgrave Communications* 2, 16092.

Maasen, S., Weingart, P. (2005). What's new in scientific advice to policy? In *Democratization of Expertise? Exploring Novel Forms of Scientific Advice in Political Decision-Making*, eds. Maasen, S., Weingart, P., 1–19. Dordrecht: Springer.

Michaels, S. (2009). Matching knowledge brokering strategies to environmental policy problems and settings. *Environmental Science & Policy* 12(7), 994–1011.

Norgaard, R. (2008). Finding hope in the Millennium Ecosystem Assessment. *Conservation Biology* 22, 862–869.

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M. et al. (2017). Valuing nature's contributions to people: the IPBES approach. *Current Opinion in Environmental Sustainability* 26, 7–16.

Pielke, R.A. Jr. (2007). *The Honest Broker: Making Sense of Science in Policy and Politics*. Cambridge: Cambridge Univ Pr.

Reid, W.V., Berkes, F., Wilbanks, T.J., Capistrano, D., eds. (2006). *Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment*. Washington, D.C.: World Resources Institute.

Robert, C., Zeckhauser, R. (2011). The methodology of normative policy analysis. *Journal of Policy Analysis and Management* 30(3), 613–643.

Saarela, S-R., Söderman, T., Lyytimäki, J. (2015). Knowledge brokerage context factors: What matters in knowledge exchange in impact assessment? *Environmental Science & Policy* 51, 325–337.

Sarewitz, D. (2004). How science makes environmental controversies worse. *Environmental Science & Policy* 7(5), 385–403.

Scoones, I. (2009). The politics of global assessments: The case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *The Journal of Peasant Studies* 36(3), 547–571.

Siebenhüner, B. (2003). The changing role of nation states in international environmental assessments: the case of the IPCC. *Global Environmental Change* 13(2), 113–123.

Sluijs, J.P. van der, Est, R. van, Riphagen, M. (2010). Beyond consensus: reflections from a democratic perspective on the interaction between climate politics and science. *Current Opinion in Environmental Sustainability* 2, 409–415.

Stechow, von C., Minx, J.C., Riahi, K., Jewell, J., McCollum, D.L., Callaghan, M.W., et al. (2016). 2°C and SDGs: United they stand, divided they fall? *Environmental Research Letters* 11, 034022.

Stirling, A. (2008). “Opening up” and “closing down”: Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values* 33(2), 262–294.

Strauss, A., Corbin, J. (1998). *The Basics of Qualitative Research*. Thousand Oaks: Sage Publications.

Strunz, S. (2014). The German energy transition as a regime shift. *Ecol. Econ. 100*, 150–158.

UNEP (2012). *Guidelines for Ensuring Scientific Credibility and Policy Relevance of the GEO-5 Assessment*.

UNEP (2014). *Proposed procedures for enhancing future assessment processes*. UNEP/EA.1/INF/14.

Urhammer, E., Røpke, I. (2013). Macroeconomic narratives in a world of crises: An analysis of stories about solving the system crisis. *Ecological Economics* 96, 62–70.

Victor, D.G. (2014). Copenhagen II or something new. *Nature Climate Change* 4, 853–855.

Vries, B.J. de, Petersen, A.C. (2009). Conceptualizing sustainable development: An assessment methodology connecting values, knowledge, worldviews and scenarios. Ecological Economics 68(4), 1006–1019.

Weber, M. (1988). *Gesammelte Aufsätze zur Wissenschaftslehre*. 7th edition. Ed. Johannes Winkelmann. Tübingen: Mohr.

5.7 Annex A: Literature review related to our analytical framework, and further research questions

In our article, we consider assessments as social processes, which facilitate the production and dissemination of scientific discourses as well as their transformation into institutionalized policy discourses (Riousset et al., 2017). Knowledge, politics and power are closely intertwined in all assessments of environmental and other policy issues (Hertin et al., 2009; Partidario and Sheate, 2013). The available knowledge is often incomplete, uncertain, or based on tentative assumptions, preliminary models, or educated guesses (Sluijs et al., 2008) and requires contextualized interpretation. Interpretation of, for instance, knowledge gaps, scientific results, uncertainties and action to take, may differ from one person or group to the other depending on their respective value orientation and beliefs on the (sustainability) issue at stake (Kloprogge and Sluijs, 2006; Sluijs et al., 2008). Values that guide the behavior of individuals or groups affect the interpretation of sustainability issues (Vries and Petersen, 2009) and may lead to divergent viewpoints which might even result in conflicts or disputes within assessment processes (Kloprogge and Sluijs, 2006; Sluijs et al., 2008). Thus, "in the policy realm the nature of knowledge is inherently conflictual" (Michaels, 2009). Beliefs and values may be more or less amenable to change (Sabatier and Jenkins-Smith, 1993).

This discussion also relates to the concept of 'politics of knowledge' that is inherent in the exchange and integration (e.g., Scoones, 2009), as a central feature of all GEA processes. The increasingly inclusive GEAs (see, e.g., Díaz et al., 2015) bring together a higher diversity of actors with diverse viewpoints as well as different disciplinary, geographic, cultural and other backgrounds. This implies a huge diversity of worldviews – as both a challenge and opportunity for GEAs (Reid et al., 2006). Simply binging together, a diversity of stakeholders is, however, not sufficient to ensure equal participation in GEA processes, given knowledge and power imbalances particularly between state and non-state actors and between standard scientific knowledge and indigenous & local knowledge (ILK; see Obermeister, 2017). Intergovernmental settings particularly limit the agency of non-state stakeholders, as discussed both in the case of the IPCC and in the case of the IPBES (Esguerra et al., 2017). More broadly, there are many challenges for engaging non-scientific stakeholders in GEA processes (Hel, 2016; Klenk et al., 2015; Garard and Kowarsch, 2017).

More specifically, regarding the treatment of divergent viewpoints about environmental governance issues, the literature particularly focuses on (to mention just a few examples): uncertainties (Slujis et al., 2010); the degree of diversity of viewpoints (Stirling, 2008); wicked problems (Head, 2008); divergent understandings of climate change (Hulme, 2009); broader policy narratives (IISD, 2013; Shanahan et al., 2011; Urhammer and Røpke, 2013); strategies for and contexts of knowledge brokerage (Michaels, 2009; Saarela et al., 2015); and specific stakeholder engagement approaches to respond to divergent viewpoints (Reed, 2008; Garard and Kowarsch, 2017). Different aspects of the treatment of divergent viewpoints in GEAs have been discussed in various strands of the existing literature. It has been widely acknowledged that GEAs need to engage with multiple rationalities and the inherent, often conflicting values in a transparent and efficient manner (Richardson, 2005; Sluijs et al., 2008). However, as said, there is still a lack of understanding the different GEA approaches to respond to divergent viewpoints.

More research is needed to better understand the approaches for responding to divergent viewpoints. Acquiring more robust, evidence-based insights on all the variations and implications of these

approaches would require a series of specific case studies and comparative analyses across various GEAs. Moreover, it would be interesting to learn more about the reasons why GEA producers took certain approaches, and did not take others. Essential questions for future deliberations on GEAs and divergent viewpoints based on the present research may furthermore include: how to improve the means, such as institutions and processes, to implement these approaches in GEAs; which viewpoints are, or should be, included or excluded in specific contexts, given a particular approach; how we can better understand and monitor the transitions (e.g., tipping points) of the characteristics and contexts of divergent viewpoints, which indicate whether or not there is a need for changing the approach; how the risk of failure for particular approaches in specific GEA contexts can be better estimated, particularly in terms of legitimacy and if it is possible to create an early warning system.

5.8 Annex B: More detailed description and examples of the nine approaches

The following paragraphs are to be regarded as amendments to what has already been said in the main text about the nine approaches for responding to divergent viewpoints.

5.8.1. Approach 1: clarify meaning

Several more precise methods, processes, and institutions have been used to achieve improved communication, which can help overcome disagreements in GEA processes. These include informal dialogues between authors and policymakers during the SPM negotiations, responses by authors to review comments on their chapters, and formalized communication during GEA plenary sessions. While this approach emphasizes the existence of misunderstandings, there is a thin line between this approach and, for instance, the fourth approach discussed below (negotiated compromise), which emphasizes slightly altering standpoints, negotiation, and two-way learning. There is also a thin line between the knowledge, expert judgment, and public discussion approaches.

This first approach seems to be commonly employed in GEA processes, particularly for less disputed issues. Examples of this approach include:

(1) Our interviews suggest that misunderstandings between different scientific disciplines and communities (e.g., natural scientists versus policy analysts or scientists versus non-science stakeholders) have been overcome in GEA author teams through communication and explanation. Mutual learning about different perspectives was a commonly achieved outcome in the GEO-5 process, as illustrated by the following response from one of the GEO-5 authors who was responding to a question about whether there were divergent viewpoints and how they were dealt with: “I mean, certainly working with people from a variety from different backgrounds, disciplines and countries. I think we all learned something, we all gained some capacities through the process.”

(2) Conflicts between authors as simple as misunderstandings in terms of non-native vocabulary and colloquial language, as the following response from a GEO-5 author exemplifies: “There was a woman there and, I mean, I know that she means well, but she didn't understand the word robust so she wanted to supply the word rigorous. And she was saying no, no, no I don't understand, I don't understand, we should just put this word in; and all scientists were sitting there […] and say, well, they mean two completely different things.”

(3) According to interviews with participants, during the SPM negotiations for the IPCC WG III contribution to the AR5 (April 2014, Berlin), as well as during other GEA SPM negotiations (e.g., for GEO-5), the wording of the SPM draft was slightly altered in several cases as a response to government officials who had expressed concern about unclear and possibly misleading statements, or to minor careless mistakes. According to a GEO-5 author, misunderstanding between scientific experts and policymakers occurred during the review process as follows: "I mean, certainly some of the comments that we got from governments and from reviewers in my mind just showed that they didn't understand what we were trying to say, and […] we had to be clear so we revised things."

The clarify-meaning approach is low-hanging fruit for GEA processes, in that it can effectively resolve strongly policy-related divergent viewpoints with minimal effort or risk. In many cases, it also seems to imply a learning process for those involved about the issues at stake. This approach presupposes that there are many opportunities for exchange between different actors and actor groups within a GEA, which also involves high transaction costs.

There is plenty of literature in the field of STS that explains the conditions that lead to successful communication between different actors at the science-policy interface.

5.8.2. Approach 2: Knowledge

The second approach, knowledge, is one of the most important notions at the science-policy interface and is precisely what many people typically expect from science-policy institutions, such as intergovernmental assessments.

Depending on their philosophy of science, people have different opinions on the adequate implementation mechanisms for this knowledge strategy in GEAs because different opinions exist on what constitutes 'reliable scientific knowledge'. Consequently, alternative means to realize this approach include:

a) A version that assumes that the science can make reliable, virtually undisputable recommendations for policy goals or means without making any disputable ethical value judgments if the appropriate method is employed (either by scientific publications that feed into GEA reports or, more rarely, by GEA writing teams themselves). Therefore, divergent viewpoints on policy options or underlying problems can best be solved by scientific experts alone and through their well-defined set of proven methods. For GEAs, this usually means synthesizing the most credible literature.

b) Another variant is the more moderate version, which acknowledges the relevance of ethical value judgments, as well as inevitable uncertainty of many scientific recommendations for public policy, but indicates that the knowledge approach can, nonetheless, work in situations where a widely accepted 'consensus' on relevant ethical norms and uncertain scientific issues can be assumed (see Sluijs et al., 2010; Edenhofer and Kowarsch, 2015). This consensus can be identified, for instance, by reviewing and synthesizing the literature.

If there is no full resolution, both variants can be used to establish scientific confidence. Moreover, both alternatives typically emphasize the scientific peer review process as an important instrument to achieve scientific confidence. Scientific peer review is certainly among the most important and successful means for achieving new and widely accepted scientific knowledge. GEA reports are

typically built on peer-reviewed literature, but they also use review processes to ensure the scientific quality of their own statements. This double emphasis on the scientific peer review process is a key instrument for implementing the knowledge approach in GEA practices.

If there is remaining disagreement in the scientific community, one option is to initiate future research to fill the knowledge gaps and overcome uncertainty. GEAs can do this by indicating research gaps in the GEA chapters (as explicitly demonstrated in the GEO-5 and IPCC WG III AR5 chapters) and by providing incentives for research communities to address the research gaps.

The knowledge approach is a widely used approach in GEAs that responds to divergent viewpoints labeled as 'scientific', i.e., those that are not regarded as overly value laden. Numerous examples exist in GEAs:

- One of the key messages of the IPCC WG III AR4 report was that the long-term global economic costs of ambitious global climate change mitigation targets were relatively moderate under ideal conditions. This message built on the knowledge approach. Moreover, many model numeric analyses that employed integrated economic-technological-climatic assessment models were generated to underpin this finding. This effort aimed to resolve the key climate political dispute regarding whether ambitious global climate policies were economically costly or not.

Several responses from different GEA authors further illustrate the knowledge approach:

- "Now, do we just make recommendations based on what the governments wants to hear or on what we think is best in terms of, based on evidence, what we think the best approach is in terms of improving environmental sustainability. I think that the GEO process has to go with that option, has to recognize that sometimes the options will be difficult, choices will be difficult but we have to, as a knowledge organization or as a knowledge process, be able to make recommendations."
- "Well I think the intention to really get objective information, so the intention to get an objective document which just summarizes our situation. Summarizes the situation of a different part of the environment, about their state, about their trends, and about possible solutions to deal with them."
- "So, I think first of all, try to separate politics from research…think it should be important that GEO-5 should not be a political document…. That it should not be a political document, but it should be a statistic, a description of what is that we have, what are possible solutions and then politicians can use these documents to put priorities and the priorities and to make decisions to say, ok these are for us the most important urgent issues."

The following response from an interview with a GEO-5 author highlights the idea of identifying the scientific confidence level: 'Yes, I think you should definitely…try to give it balance as well, because if 90% of scientists say A and 10% of scientists say B, then you might reflect both of the points of view, but indicated clearly that 80% or 90% of the scientists' support option A.'

The knowledge approach is crucial for tackling divergent viewpoints at the science-policy interface. Throughout history, scientific progress has helped to resolve a plethora of divergent viewpoints. The knowledge approach is an effective tool because it has enough scientific rigor to resolve complex,

open questions. However, it can be an onerous and time-consuming process that is dependent on scientific progress and wide acceptance of specific evidence across the entire scientific community. More importantly, this approach can be misused or misrepresented as a 'legitimation model' or a 'stealth issue advocate' model (Pielke, 2007), as the STS literature has highlighted in recent years with plenty of concrete examples. Under the guise of accepted (legitimate) scientific authority – a crucial precondition for the effectiveness of the knowledge approach – and alleged scientific consensus and certainty, scientists and policymakers can promote their own interests and specific points of view in an opaque and sometimes questionable manner (Edenhofer and Kowarsch, 2015; Funtowicz and Ravetz, 1990; Habermas, 1971; Jasanoff, 1990; Jasanoff and Wynne, 1998; Pielke, 2007). This is achieved using opaque uncertainty or implied value judgments that are not made transparent, but frequently occur in policy-relevant science.

As a hypothetical example, integrated assessment models (IAMs) used to calculate global and regional economic cost estimates for ambitious climate policy pathways, which inevitably implied several normative assumptions (Ackerman et al., 2009; Beckerman, 2011; DeCanio, 2003; Kowarsch, 2016, Chap. 8; Schneider, 1997; Tavoni and Tol, 2010), such as fair distribution of wealth and goods. If such disputed assumptions underlying the IAM results had not been made transparent in the studies or GEAs, one could have easily misinterpreted the results with implications for climate policy and other political standpoints. The knowledge approach can even intensify political controversies instead of resolving them, as many studies have sown (see especially Sarewitz, 2004).

A misguided use of the knowledge approach also works the other way around: it can be used by policymakers as a strategy to delay political action in cases that are complex and uncertain, because it may take a very long time to achieve scientific consensus (if at all). Without such a consensus, policymakers can argue that there is no need to act.

5.8.3. Approach 3: Expert judgment

The expert judgment approach is mostly employed in an informal manner during the writing process, but can also occur through more explicit and structured modalities, such as special committees or official production meetings for coordinating lead authors (CLAs). Variations of this modality include (1) cases where CLAs, assessment chairs, coordinators, or other stakeholders with leadership functions in the GEA process take authoritative decisions as individuals (or as committees) and (2) more frequently, cases where GEA writing and production teams jointly discuss disputed issues in meetings (face-to-face or virtually), and then come to a deliberated agreement or compromise within the group. Some STS literature describes (usually in non-GEA contexts) how expert teams arrive at their decisions and key messages through such approaches (e.g., Noble, 2004).

Expert judgment is often used to resolve divergent viewpoints in the GEA process. In our interviews with GEA authors, several of them reported cases that clearly belonged to this category. In most cases, the divergent viewpoints concerned priorities (i.e., which topics or sub-aspects to include or not). Since this implies judgments about whether a certain issue is to be regarded as an urgent problem, this type of divergent viewpoint is clearly normative). Statements from the interviews that highlight the expert judgment approach include:

- "I didn't think consensus was necessarily to be the ultimate aim…. I think it is the ultimate aim, do you want kind of consensus somehow with the group, that people agreed to what they were writing, and I think we did achieved that."

- "Everybody wanted what they thought was important whether it was energy or soil or land or whatever and so I remember there just being this argument about the table but I mean, again it was a relatively constructive argument and I know some things that I wanted to put in there were not put in but I accept that and, as I said, it was quite constructive."
- "I think that in our case, it was resolved reasonably well. We…had a good coordinating lead author that tried to get a balance within this different types of…information, and…the final chapter you can see that all views are reflected in the chapter."
- The expert judgment approach is highly efficient and can be credible given that the decision-makers in this case are experts. However, it can also lack credibility and legitimacy if the viewpoints are more severely disputed and value laden, for example, in complex environmental policy assessment situations of strong trade-offs between valued objectives, such as economic growth and environmental quality. Since these policy issues affect almost all people on earth, a GEA that relies strongly on this approach might be perceived as less than credible, either by policymakers or other stakeholders (Sarewitz, 2004). These challenges were evident in many interview statements:
- "I think there is a balance, you know, that because consensus within the group is not necessarily the kind of the final [um] perfect outcome necessarily, because it's a broader experience to draw on, kind of other aspects in sort of deciding what important issues are and being able to have that in context."
- "So I was able to go over some of the stuff that other people felt it just didn't read right…. So I did that a bit…and then when GEO-5 came along, I actually got messages from people…saying that they really wished I was around because there wasn't a lot of that critical thinking, there was just a lot of, you know, team cheerleading going on."
- "The whole process…of selecting who will be, I think to me that's actually the most key, because a lot of what you see with this report is very much a function of one or two people that were on those chapters that, so which makes sense, but many times those one or two people aren't necessarily the people with the best intentions or the most interest in seeing the best product come out."
- "I had written up a couple of pages that I was hoping they would include, which they didn't. And so, I don't know. Different priorities, I guess."
- "The issue of invasive species and especially of aquatic invasive species was not important to any particular individuals on that chapter, then that was what falls through the cracks."

5.8.4 Approach 4: negotiated compromise

The fourth strategy, negotiated compromise, is the first one belonging to the "delegation to policy" category of approaches. This approach is somewhat like the expert judgment approach in that it relies on internal GEA negotiations and decision-making approaches. This approach is frequently used in GEAs to respond to divergent viewpoints. Obvious examples include the formal SPM (or "SDM") approval procedure that is part of many GEAs, informal discussions during these approval meetings, or government reviews of GEA report drafts (such as with the IPCC).

This approach is frequently employed informally (e.g., through talks during breaks at GEA meetings, or simply through phone calls), but also often occurs within specific, formalized GEA procedures (e.g., the SPM approval procedure) and committees in which a small number of selected GEA authors, experts, policymakers, and other stakeholders negotiate. One could also think about engaging a mediator for such an approach. There is significant potential overlap with the first approach (clarify meaning) and the ninth approach (avoid, as described below), and is mildly like the expert judgment approach.

Fortunately, some GEA SPM processes are well documented. These documents provide examples of this negotiated compromise approach (see IISD, 2014, and Edenhofer and Minx, 2014, for the IPCC WG III AR5 SPM, and IISD, 2012, for the GEO-5 SPM approval meeting). Examples from the interviews supporting this approach include:

- "We had one from China but it was so small, it was just fine, we'll just change it, it wasn't a big deal…they didn't like the way we portrayed something…. There were some comments that were kind of annoying, but for the most part, we were able to either make a change that would resolve it or write a response that we felt like addresses things."
- "There is also a resolution acknowledging the GEO-4 exists, and that was negotiated in Monaco, but there the United State didn't want any reference to the main body of GEO-4 because they said that has not been negotiated, that's independent by researchers we don't accept all outcomes; we only want to refer to the summary for policy makers that we even negotiated and agreed to."
- "I had had with my chapter, with the two rounds of governmental review, huge battles with Brazil about how we represent the case…and they had sent this text, but it wasn't backed up by literature that my colleagues thought was appropriate. We finally agreed to texts on deforestation, there was no way on this planet that I would now change that text again so it would be published with something that I had not agreed to with the Brazilian colleagues."

The negotiated compromise approach, as "boundary work" at the science-policy interface, is strong regarding the involvement of policymakers and stakeholders. This approach could lead to enhanced communication between scientific expertise and policy and possibly stronger acceptance of GEA results by governments. The communication between these groups can be beneficial in several ways, and there is ample literature concerning the characteristics of and the need for such boundary work at the science-policy interface (e.g., Cash et al., 2003). Not only is it efficient, but the negotiated compromises may be acceptable for both the scientific and political realms.

An interview with a GEO-5 author showed how problematic this approach can be, particularly if institutional interests come into play: "We already just talked about it in terms of, like, resolving differences of opinions with authors, but then there is this whole other layer of basically governments fund UNEP, and UNEP commissions and coordinates GEO, and then GEO is supposed to give advice to governments. But it must be an advice that governments are at least slightly receptive to hearing or else it threatens the future of the whole loop. And so, then there were conflicts that in later with governments' review process first and outside of the review process with governments contesting or challenging or wanting to de-emphasize some points that were in the report points."

5.8.5. Approach 5: Political decision

Once a political decision has been made, a GEA can (and often does) refer to it as a given starting point for analysis in the GEA report (e.g., the international climate policy decisions and declarations that are referred to by the IPCC assessment reports). The major underlying assumption is that, for democratic reasons, highly normative, value-laden divergent viewpoints in GEAs can only be resolved by policymakers and not by scientists. Policymakers can make decisions, for instance, through (1) general political processes prior to a GEA process, (2) within a GEA process in a formalized setting (e.g., an intergovernmental meeting on GEAs) and (3) in informal ways. There is a thin line between this approach and the sixth one (public discussion); and there is a close relationship with the negotiated compromise and avoid approaches.

The most illustrative example of this approach usually occurs during the scoping stage of the GEA when policymakers ask scientists to analyze certain questions and to omit others. Without such decisions, the writing teams themselves would need to resolve which themes and topics should be included and excluded in the GEAs.

Another example is the High-Level Intergovernmental Advisory Panel for GEO-5 that had the task of specifying the policy goals and priorities to be analyzed in certain parts of the GEO-5 (though there was still some leeway for the writing teams): "Establish a High-Level Intergovernmental Advisory Panel with adequate representation from all regions to identify relevant internationally agreed goals for Part 1 and provide guidance to chapter authors in Parts 1, 2 and 3 in their consideration of goals and policies. Furthermore, the Panel will consult with lead authors and advise on the Summary for Policy Makers (SPM). The Panel will be comprised of high-level policy experts from government" (UNEP, 2012). An interviewee commented on this panel: "There wasn't even one single instance that the authors did not agree with the recommendations set forward by the advisory panel and no, no divergence…. All the solutions fit for the areas and for the regions, of course, because the high level advisory panels were geographically distributed, being more informed and more in-depth about the priorities of their own region."

The debate over the 2°C goal in global climate policy (or in setting national climate mitigation objectives) offers an illustration. Arguing that decisions about what level of climate policy to adopt should ultimately rest with policymakers (not with scientists) will usually garner much support. However, without reliable scientific information about the implications of alternative decisions, policymakers cannot make independent decisions. By contrast, science might inform policymakers and the public about the expected implications of alternative mitigation pathways with respect to multiple societal objectives. Finally, in extreme cases, resorting to this approach might theoretically lead to questionable domination of others by more powerful actors.

The interviews revealed some of the pitfalls and risks of the political decision approach:

- One interviewee talked about powerful governments: "They wanted control of the…overall outcome."
- Another interviewee stated that a governmental representative "had an extraordinary impact on the GEO report, you know, he went to all the advisory meetings and it just shouldn't be done that way, so there's got to be some way to neutralize personalities so that, you know, scientific process is not driven by, you know, who shows up in the room."

The ideal conditions for the political decision approach are that scientists do no contribute much (at best: some context information) to resolving the issue, and the divergent viewpoints are highly normative and disputed, but not so fundamental that they cannot be resolved at all. Trust in political decision-makers will also increase the acceptability and legitimacy of this approach.

5.8.6. Approach 6: public discussion

This approach can be implemented via public debates using various formats that range from informal conversations, to organized meetings, to platforms, to dialogue forums (i.e., public consultations), to the mass media, and so on. Moreover, if the sciences play a stronger role in such public debates, there may be overlaps with the negotiated compromise approach, the political decision approach, the map implications approach, and the revealed controversy approach.

This approach largely operates outside of the GEA process and the GEA writing and production teams. However, besides informing these debates, GEAs can deliberately draw on the results and agreements from earlier public discussions, as well as actively initiate new public discussions by proposing to delegate the disputed issues to public discussion.

Examples include the regional consultations organized by GEO-5. Other examples include the IPBES practice of having several multi-stakeholder consultations where divergent viewpoints on content-related issues (priorities, evaluative criteria, etc.) were openly discussed. Other examples for this approach also required broader societal debates that took years or even decades to resolve, often involving heated public debate.

This approach is not used intentionally very often because it requires that facilitation of large-scale public debates. However, there is some literature on science-policy models that recommend this approach for responding to divergent viewpoints (Habermas, 1971; Hulme, 2009; etc.).

Ideal conditions for this approach seem to be given if the issues at stake are highly value-laden and fundamental to policy processes, disputed and if the science cannot deliver much due to high uncertainty, etc.

5.8.7. Approach 7: map implications

Multi-scenario analyses and interdisciplinary impact assessments, which have already been employed in GEAs for a long time, come closest to this approach. Full realization would include exploration of the quantitative and qualitative implications of the disputed policy options (or problem descriptions). There can be overlap with the public discussion and revealed controversy approaches. 'Implications' include (1) direct effects, (2) secondary effects, (3) unwanted side effects, and (4) co-benefits of policy options or business-as-usual paths.

Although the basic underlying idea of this approach is quite old (multi-scenario analyses, tracing implications of policy options; see, e.g., Lempert, 2003), it is relatively novel because it has rarely been employed in GEAs. A prominent example is the map implications strategy that was used in the IPCC WG III to some extent (Edenhofer and Kowarsch, 2015; Edenhofer and Minx, 2014; IPCC, 2014, Preface). In a special report (SRREN, see IPCC, 2011, p. 59, Fig. TS.2.9), the IPCC provided an overview of alternative, disputed narratives regarding future bioenergy use. Some of the implications of each pathway were explored. Moreover, instead of recommending a specific climate mitigation goal or avoiding disputed political issues, the recent IPCC WG III report (IPCC, 2014) explored the implications

of alternative ambition levels for climate mitigation, adopting a multi-metric perspective (see Edenhofer and Minx, 2014). For this purpose, sophisticated multi-scenario analyses were conducted that explore the implications of alternative policies, timings, delays, and metrics, as well as technological and other assumptions for climate policy in general and specific sectors. Some of the potential co-benefits of ambitious climate policies were analyzed in detail (IPCC, 2014, Chap. 6) to better understand the political solution space.

One interviewee offered a view that is like the map implications approach:

> "I think that for the big challenges that we face there are no easy, quick solutions and so what's most important is, discovering effective mechanisms that can unite diverse groups, you know, lasting, you know, sustained manner that can succeed at uncovering pathways, you know, towards effective solutions that have this joint ability to take into account, you know, the facts, the science, as well as to, to be politically viable. And so, you know, I think, one of the examples where that has worked effectively is the, the European transboundary air pollution case, whereas, you know, today it's just almost routine and so people don't even think about it too much but, you know, the 80s and 90s it was very politicized and, you know, people either because they were very smart or very lucky or a little of each, you know, they, they figured out assessment processes that, that had all those characteristics that I am talking about. They, they were viable over the long run, they permitted political compromise to take place in a way that was grounded in the science but it was politicized enough that it actually worked, you know, it was, wasn't just scientists screaming at people to do the right thing. It was scientists, you know, working in a long-term basis to understand the constraints that politicians have and helping them steer in a new direction. You know for the big, you know, for biodiversity, water, climate, energy, I don't think we figured out yet, mechanisms that have those characteristics, so that, that transboundary air pollution case is one that fits. I think in the health arena you can find others, you know, like the community that's mobilizing to eradicate polio or control malaria, you know, you have similar kinds of fusions of these, these different kinds of perspectives and interests that have proven capable of sustaining themselves on, you know, a multi-decade timeframe."

This approach emphasizes the need for a broad, open, participatory debate about these value-laden and disputed issues, but also gives science a strong role as cartographers (not navigators) of the political solution space. Though mapping implications is not policy-prescriptive (because alternatives are explored), it can strongly support and inform public debates about controversial issues by explaining the conditions, trade-offs, overlaps, synergies, winners, and losers of and between policy pathways. Sometimes (in less complex and uncertain cases), this transparent and trans-disciplinary exercise can indirectly reveal that certain paths are preferable over others.

Edenhofer and Minx (2014) suggest another challenge. They argue that this approach came under attack by governments through the ex-post policy evaluations of past emissions trends, as well as international cooperation issues during the IPCC AR5 WGIII SPM negotiations due to their adverse political implications for some governments. In a similar vein one interviewee stated: "Countries don't like to be ranked, particularly when they negatively ranked them…. Countries don't like to have failures identified and in some other, the best lesson to come out of policy analysis come out of failed policies."

Another main challenge associated with this approach is that it is highly resource-intensive because significant inter- and trans-disciplinary cooperation is required, and the policy issues at stake tend to be large-scale and complex. Moreover, this approach does not necessarily result in clear-cut policy

recommendations. However, whether this is regarded as a vice or a virtue depends on the preferred science-policy model.

If interdisciplinary cooperation can be fostered, stakeholders are successfully engaged, and if at least some scientific knowledge is available on the implications of policy options, this might be a promising approach to be adopted by future GEAs.

5.8.8. Approach 8: Revealed controversy

This approach can be realized through a direct mapping of the conflict in the GEA report (or by explaining the ranges of the results and probabilities; or via footnotes in the SPM where unresolvable disagreements between governments are mentioned), as well as through input (oral, media, or presentations) by GEA researchers to public debates. Moreover, this approach can differ depending on whether external stakeholders are strongly included. Although there can be a very strong overlap with the map implications approach, this approach is a strategy on its own because the idea of evaluating and possibly revising the policy options (including policy objectives) based on their implications is quite different from merely mapping the existing controversy. The literature that describes the revealed controversy strategy includes Hulme (2009), Robert and Zeckhauser (2010) on the case of climate policy, Campbell (2002), Urhammer and Røpke (2013), and IISD (2013). The latter publication analyzes the divergent policy narratives of various environmental policies.

There are an increasing number of examples of this approach in contemporary GEAs, perhaps because the focus on consensus in GEAs has decreased (Sluijs et al., 2010). An interesting case is a UNEP document on GEA strategy that emphasizes this approach more than any other (UNEP, 2014):

"Inclusion of divergent viewpoints:

1. Identifying science and policy-related contentious issues, where different viewpoints exist, will be the responsibility of the Coordinating Lead Authors, as well as the Reviewer Editors.
2. Assessments should describe different, possibly controversial, scientific, technical, and socio-economic views on a given subject, particularly if they are relevant to the policy debate.
3. Coordinating Lead Authors and Lead Authors should explicitly document in the assessment where a range of viewpoints around data, science and policies have been considered, and Coordinating Lead Authors and Review Editors should satisfy themselves that due consideration was given to properly document alternative views.
4. In preparing the first draft of an assessment report and at subsequent stages of revision after review, authors should clearly identify disparate views for which there is significant scientific, technical or socio economic support, together with the relevant arguments. Sources of uncertainty should be clearly identified, listed and quantified where possible. The implications for decision-making of the findings, including knowledge gaps, contrasting evidence and minority opinions, should be explicitly discussed.
5. Coordinating Lead Authors are required to record views that cannot be reconciled with a consensus view but that are, nonetheless, scientifically, technically or socio-economically

valid. Consensus does not imply a single view, but can incorporate a range of views based on the evidence.

6. If necessary, with guidance from the Scientific Advisory Panel, the assessment report may include in a footnote the differing views expressed in comments submitted by Governments during their final review of the document if these are not otherwise adequately reflected in the paper."

(a) The revealed controversy approach makes particular sense if the issues at stake are highly uncertain (i.e., science cannot deliver a map of the solution space) and disputed, or if there is very limited political will to constructively discuss the divergent viewpoints.

5.8.9. Approach 9: avoid

This approach can be realized in different ways, including formal and informal ones. During the mandating process and SPM negotiations, avoidance of certain statements or topics is sometimes negotiated between authors, experts, and policymakers, for instance, by deleting certain topics or statements from the SPM drafts. Avoidance can also happen on a smaller scale, i.e., within a GEA chapter or author team if there is no agreement among the authors themselves. Avoiding heated issues can mean being silent about an issue or watering down the most heated aspects of it. It can also mean simply postponing the discussion until a later stage (e.g., the next GEA cycle in the case of recurring GEAs) when more scientific knowledge is available or when the political debate is less heated. There can be strong overlap with the negotiated compromise and political decision approaches.

This approach is used often (see Pielke, 2007; Siebenhüner, 2003) in different ways. An obvious example is the IPCC WG III AR5 SPM negotiations (see Edenhofer and Minx, 2014, and Stavins, 2014) where the governments insisted on deleting certain paragraphs and figures from the SPM draft because the underlying divergent viewpoints could not be resolved. For instance, as Edenhofer and Minx (2014) explain, the country classifications for the AR5 ex-post assessment of progress in climate change mitigation had immediate relevance for political negotiations, resulting in the fact that governments objected and the figures and associated text were removed from the SPM.

Governments' concerns over the grouping of countries arose despite efforts to provide a balanced assessment of how emissions have grown as countries developed and how these patterns have shifted over time. The fear of some governments was that approval of any country classification other than the one currently used in the negotiations could be disadvantageous in upcoming negotiations for a new international climate regime. Another example for governments' concerns with ex-post evaluation of their policies was the fact that some governments felt uncomfortable with certain AR5 sections on the performance of the European ETS.

In this sense, the SPM negotiations can be regarded as an example of the negotiated compromise approach, but other approaches also come into play within these negotiations.

The ideal condition for this approach is when there is no chance for constructive deliberation (at that point in time) because the issues, and possibly the circumstances surrounding the issues, are simply too heated.

5.9 Annex C: Challenges of evaluating the approaches

Here we briefly discuss a hypothetical example to better illustrate our hypotheses. In one of the interviews, a GEO-5 author said

> "Well I guess on the GMO issue I think, I think the biodiversity chapter's position was important because we couldn't say something completely different from what they said without acknowledging that, and I guess I don't know if that was the best way to resolve it, but I guess we resolve it by discussing in maybe a smaller core group…how we should treat what we said on that…. So I think it ended up sort of aiming for a kind of compromise and acknowledge authors' viewpoints and also make clear the link to, to what the biodiversity chapter talked about it."

This means that a GEA writing team used the expert judgment approach to deal with the controversial issue of how genetically modified organisms (GMOs) are used in agriculture and what the related public policies should look like. This interview shows us that the expert judgment approach was applied successfully, or at least there was agreement between the GEA authors in the end. The authors may not have had a chance to choose another strategy due to the severe time restrictions in the GEO-5 process; however, other assessments such as the IAASTD, have struggled with the heated and complex topic of GMOs, which has plenty of policy implications. It is also worth noting that the IAASTD has been attacked for representing divergent viewpoints inadequately (Feldman and Biggs, 2012). So, given the interview statement above, how should future GEAs in similar situations respond to disputed and complex issues with direct policy implications?

A robust answer to this question requires a differentiated analysis of the divergent viewpoints at stake, as well as the GEA context (including, not least of all, the time resources available). If the divergent viewpoints regarding GMOs are mainly technical in nature (i.e., scientifically complex issues that are not highly value-laden and not overly disputed), then the knowledge approach might be adequate; otherwise, the expert judgment approach could work. Yet, divergent viewpoints that seem to be harmless cases at the beginning can later turn out to have strong and highly disputed political and ethical implications. This transition in the character of divergent viewpoints can be due to either the negligence of the writing team or a change in the political context, which can lead to an increased politicization of the issue. In any case, it may be appropriate to consider a change in the approach of the GEA to avoid an escalation of the conflict.

It seems that, in the long run, a disputed, complex, and value-laden question, such as the GMO issue, cannot successfully be addressed using the resolution-by-experts or the-delegation-to-policy categories of approaches. Rather, it requires the public deliberation category and perhaps the map implications approach as well. Multiple policy objectives (food security, sustainable water management, economic growth, biodiversity, climate change adaptation and mitigation, social justice, health, etc.) and values are at stake with complex interdependencies and manifold trade-offs. Obviously, not all the divergent viewpoints concerning GMOs could be made explicit and explored using the onerous map implications approach – but the most fundamental and disputed issues could be. Additionally, exploring the pros and cons of concrete policy options could help reveal the real divergent viewpoints (e.g., political interests instead of scientific uncertainties) that often underlie heated debates (Sarewitz, 2004). Moreover, this approach is dependent on the will of governments

and their commitments to such ambitious social learning exercises. However, both scientific experts and governments often seem unwilling to promote open and systematic learning about the political solution space. Both the theoretical literature, as well as the GEA expert interviews, revealed a couple of instances where powerful governments intervened in the GEA process, forcing scientists to delete certain politically undesirable viewpoints (e.g., Edenhofer and Minx, 2014). In order for the process to be successful, governments must take a stand during the inception phase of the GEA process on whether a policy assessment should allow for explicit divergent viewpoints or not. At the same time, the map implications approach is dependent on the researchers' willingness to explore a wide range of effects for alternative policy options. This presupposes inter- and trans-disciplinary cooperation. However, once again, the expert interviews partly revealed how difficult and challenging real interdisciplinary work is for many researchers.

5.10 Supplemental References

Ackerman, F., DeCanio, S.J., Howarth, R.B., Sheeran, K. (2009). Limitations of integrated assessment models of climate change. *Climatic Change* 95(3–4), 297–315.

Beckerman, W. (2011). Economics as applied ethics. Value judgements in welfare economics. Houndmills, Basingstoke: Palgrave Macmillan.

Campbell, L.M. (2002). Conservation Narratives in Costa Rica: Conflict and Co-existence. *Development and Change* 33(1), 29–56.

Cash, D.W., Clark, W.C., Alcock, F., Nickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B. (2003). Knowledge systems for sustainable development. *PNAS* 100(14), 8086–8091.

DeCanio, S.J. (2003). Economic Models of Climate Change. A Critique. New York: Palgrave Macmillan.

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. (2015). The IPBES Conceptual Framework: Connecting nature and people. *Current Opinion in Environmental Sustainability* 14, 1–16.

Edenhofer, O., Minx, J. (2014). Mapmakers and navigators, facts and values. Science 345 (6192), 37f.

Edenhofer, O., Kowarsch, M. (2015). Cartography of pathways: A new model for environmental policy assessments. *Environmental Science & Policy* 51, 56–64.

Esguerra, A., Beck, S., Lidskog, R. (2017). Stakeholder Engagement in the Making: IPBES Legitimization Politics. *Global Environmental Politics,* 17(1), 59–76.

Feldman, S., Biggs, S. (2012). The politics of international assessments: The IAASTD process, reception and significance. *Journal of Agrarian Change* 12(1), 144-169.

Funtowicz, S.O., Ravetz, J.R. (1990). Uncertainty and Quality in Science for Policy. Dordrecht: Kluwer.

Garard, J. Kowarsch, M. (2017). If at first you don't succeed: Evaluating stakeholder engagement in global environmental assessments. Environmental Science & Policy

Grieneisen, M., Zhang, M. (2011). The current status of climate change research. *Nature Climate Change* 1, 72–73.

Habermas, J. (1971). Toward a Rational Society. Boston Mass: Beacon Press.

Head, B.W. (2008). Wicked problems in public policy. *Public Policy* 3(2), 101–118.

Hel, S. van der (2016). New Science for Global Sustainability? The Institutionalisation of Knowledge Co-Production in Future Earth. *Environmental Science & Policy* 61, 165–175.

Hertin, J., Jacob, K., Pesch, U., Pacchi, C. (2009). The production and use of knowledge in regulatory impact assessment: An empirical analysis. *Forest Policy and Economics* 11(5–6), 413–421.

Hulme, M. (2009). Why We Disagree About Climate Change: Understanding Controversy, Inaction and Opportunity. Cambridge: Cambridge Univ Pr.

IISD (2012). A Summary Report of the Intergovernmental Meeting on the Fifth Global Environmental Outlook Summary for Policy Makers. Earth Negotiation Bulletin 182(4).

IISD (2013). The Future of Sustainable Development: Rethinking sustainable development after Rio+20 and implications for UNEP.

IISD (2014): Summary of the 12th session of Working Group III of the Intergovernmental Panel on Climate Change (IPCC) and the 39th session of the IPCC: 7-12 April 2014. *Earth Negotiation Bulletin* 12 (597).

IPCC (2007). In Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. Metz, B., Davidson, O., Bosch, P., Dave, R., Meyer, L. Cambridge: Cambridge Univ Pr.

IPCC (2011). Edenhofer, O., Madruga, R.P., Sokona, Y., Seyboth, K., Matschoss, P., Kadner, S., et al. (Eds.), Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge Univ Pr.

IPCC (2014). Edenhofer, O., Pichs-Madruga, R.P., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K. et al. (Eds.), Climate Change 2014—Mitigation of Climate Change: Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge Univ Pr.

Jasanoff, S. (1990). The Fifth Branch: Science Advisers as Policymakers. Cambridge, MA: Harvard Univ Pr.

Jasanoff, S., Wynne, B. (1998). Science and decisionmaking. In Human choice and climate change. Volume 1: The societal framework, eds. Steve Raynor and Elizabeth Malone, 1–87. Colombus, OH: Battelle Press.

Klenk, N.L., Meehan, K., Pinel, S.L., Mendez, F., Lima, P.T., Kammen, D.M. (2015). Stakeholders in Climate Science: Beyond Lip Service? *Science* 350(6262), 743f.

Kloprogge, P., Sluijs, J.P. van der (2006). The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. *Climatic Change* 75(3), 359–389.

Kowarsch, M. (2016). A Pragmatist Orientation for the Social Sciences in Climate Policy. How to Make Integrated Economic Assessments Serve Society. *Boston Studies in the Philosophy and History of Science* 323. Switzerland: Springer.

Lempert, R.J. (2003). Shaping the next one hundred years: new methods for quantitative, long-term policy analysis. Rand Corporation.

Michaels, S. (2009). Matching knowledge brokering strategies to environmental policy problems and settings. *Environmental Science & Policy* 12(7), 994–1011.

Noble, B.F. (2004). Strategic environmental assessment quality assurance: evaluating and improving the consistency of judgments in assessment panels. *Environmental Impact Assessment Review* 24, 3–25.

Obermeister, N. (2017). From Dichotomy to Duality: Addressing Interdisciplinary Epistemological Barriers to Inclusive Knowledge Governance in Global Environmental Assessments. *Environmental Science & Policy* 68, 80–86.

Partidario, M.R., Sheate, W.R. (2013). Knowledge brokerage: Potential for increased capacities and shared power in impact assessment. *Environmental Impact Assessment Review* 39, 26–36.

Pielke, R.A. Jr. (2007). The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge. Cambridge University Press.

Reed, M.S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141(10), 2417–2431.

Reid, W.V., Berkes, F., Wilbanks, T.J., Capistrano, D., eds. (2006). Bridging Scales and Knowledge Systems: Concepts and Applications in Ecosystem Assessment. Washington, D.C.: World Resources Institute.

Richardson, T. (2005). Environmental assessment and planning theory: Four short stories about power, multiple rationality, and ethics. *Environmental impact assessment review* 25(4), 341–365.

Riousset, P., Flachsland, C., Kowarsch, M. (2017). Global Environmental Assessments: impact mechanisms. *Environmental Science & Policy,* 77, 221-203

Robert, C., Zeckhauser, R. (2011). The methodology of normative policy analysis. *Journal of Policy Analysis and Management* 30(3), 613–643.

Saarela, S-R., Söderman, T., Lyytimäki, J. (2015). Knowledge brokerage context factors: What matters in knowledge exchange in impact assessment? *Environmental Science & Policy* 51, 325–337.

Sabatier, P.A., Jenkins-Smith, H. (1993). Policy change and learning: An advocacy coalition framework. Boulder, CO: Westview.

Sarewitz, D. (2004). How science makes environmental controversies worse. *Environmental Science & Policy* 7(5), 385–403.

Schneider, S.H. (1997). Integrated assessment modeling of global climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions? *Environmental Modeling and Assessment* 2(4), 229–249.

Scoones, I. (2009). The politics of global assessments: The case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *The Journal of Peasant Studies* 36(3), 547–571.

Shanahan, E.A., Jones, M.D., McBeth, M.K. (2011). Policy Narratives and Policy Processes. *The Policy Studies Journal* 39(3), 535–561.

Siebenhüner, B. (2003). The changing role of nation states in international environmental assessments: The case of the IPCC. *Global Environmental Change* 13(2), 113–123.

Sluijs, J.P. van der, Petersen, A.C., Janssen, P.H., Risbey, J.S., Ravetz, J.R. (2008). Exploring the quality of evidence for complex and contested policy decisions. *Environmental Research Letters* 3(2), 024008.

Sluijs, J.P. van der, Est, R. van, Riphagen, M. (2010). Beyond consensus: reflections from a democratic perspective on the interaction between climate politics and science. *Current Opinion in Environmental Sustainability* 2, 409–415.

Stavins, R. (2014), April 25. Is the IPCC government approval process broken? Web comment retrieved from http://www.robertstavinsblog.org/2014/04/25/is-the-ipcc-government-approval-process-broken-2/ (accessed 16 Feb 2017).

Stern, N. (2007). The economics of climate change. The Stern review. Cambridge: Cambridge Univ Press.

Stirling, A. (2008). “Opening up” and “closing down”: Power, participation, and pluralism in the social appraisal of technology. *Science, Technology, & Human Values* 33(2), 262–294.

Tavoni, M., Tol, R.S.J. (2010). Counting only the hits? The risk of underestimating the costs of stringent climate policy. A letter. *Climatic Change* 100(3–4), 769–778.

UNEP (2012). Guidelines for Ensuring Scientific Credibility and Policy Relevance of the GEO-5 Assessment.

UNEP (2014). Proposed procedures for enhancing future assessment processes. UNEP/EA.1/INF/14. Online: http://uneplive.unep.org/community/file/download/5557 (accessed 16 Febr 2017).

Urhammer, E., Røpke, I. (2013). Macroeconomic narratives in a world of crises: An analysis of stories about solving the system crisis. *Ecological Economics* 96, 62–70.

Vries, B.J. de, Petersen, A.C. (2009). Conceptualizing sustainable development: An assessment methodology connecting values, knowledge, worldviews and scenarios. *Ecological Economics* 68(4), 1006–1019.

6. Visualizing Relationships between Drivers of Environmental Change and Pressures on Land-Based Ecosystems[1]

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Carol Hunsberger

Abstract

The pursuit of human needs and demands is placing more pressure on land resources than ever before. The challenge of feeding 7 billion people is increasingly competing with rising demands for materials and biofuels. Deforestation and land degradation are among the pressing outcomes of these trends. Drivers of environmental change—including population growth, economic activity, consumption, urbanization, trade, conflict, and governance—clearly play a role in aggravating or mitigating these pressures on land. Despite advances in understanding causality in complex systems, navigating the interactions between these drivers remains a major challenge. This article analyzes and visualizes the relationships between multiple, interacting drivers of environmental change and specific pressures on land-based ecosystems. Drawing on experience from the development of the Drivers and Land chapters of the UN Environment Programme's (UNEP), Fifth Global Environment Outlook report (GEO-5), we use a series of Kiviat diagrams to illustrate the relative influence of key drivers on selected pressures on land. When individual diagrams are overlaid, patterns of influence emerge that can provide insight into where policy responses might best be targeted. We propose that, subject to some limitations, the Kiviat exercise can provide an accessible and potentially valuable "knowledge-intermediary" tool to help link science-based information to policy action.

Keywords: Drivers; Environmental Pressure; Land Use Change; Integrated Assessment; Science-Policy

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6.1. Introduction

Human activities are intensifying stresses on the Earth System—and producing biophysical surprises. Recently, planetary-scale transitions to a disturbance-dominated regime have become a major focus of research (Scheffer et al., 2009; Rockström et al., 2009; Barnosky et al., 2012). The Amazon basin

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provides emerging evidence of a terrestrial ecosystem experiencing such a biophysical transition, due largely to human influence. Loss of carbon storage and altered energy and water cycles, beyond the magnitude of natural variability, are among the most pressing potential consequences of repeated, prolonged disturbances in the Amazon basin (Davidson et al., 2012). Near-surface permafrost represents another system potentially undergoing a major shift: permafrost temperatures across the Arctic have increased by about 2˚C over the past 20 - 30 years (AMAP, 2011), and climate projections indicate a substantial and irreversible loss of up to 85% to 90% of near-surface permafrost by 2100 (Schaefer et al., 2012; Lawrence et al., 2008). Such rapid thawing would increase atmospheric CO2 concentrations, amplify surface warming and initiate a positive carbon feedback that could lead to a directional change in the carbon balance for the Arctic (from a sink to a source) as early as the mid-2020s; nullifying up to 88% of the total global land sink (Schaefer et al., 2011). Such critical transformations highlight the need to manage competition between current demands and future scenarios for biophysical systems, as well as to improve knowledge of the implications associated with altering the prevailing pressures on the environment (Barnosky et al., 2012; Davidson et al., 2012; Herrero and Thornton, 2012).

Pressures on land-based natural resources are increasing; despite internationally agreed goals intended to improve their management (UNEP, 2012; Jabbour et al., 2012). Recent studies, including large-scale integrated assessments, have modeled interrelated factors affecting land competition and suggest that future policy decisions across the agriculture, forestry, energy and conservation sectors will profoundly affect the intensification of both environmental stresses and future demand (Smith et al., 2010).

Demand is rising simultaneously for food, livestock feed, biofuels, and materials such as timber, alongside other competing demands (e.g. for carbon stocks, biodiversity conservation and subsistence livelihoods). Deforestation and land degradation are among the pressures on the environment that are intensified by these trends. For example, recent research finds that 40% of terrestrial ecosystems have now been transformed to agricultural land (Foley et al., 2011). The area harvested for soybean crops alone has doubled in the last 30 years, while oil palm production has expanded rapidly—from 4.2 million ha in 2000 to 7.1 million ha in 2009 in Indonesia alone (FAO, 2012). Coastal wetlands continue to be lost at the rate of about 100,000 ha per year, while dry land plant productivity is in persistent decline (Foley et al., 2011). Global forest loss, while slightly slower than in the 1990s, remained at 13 million ha per year from 2000-2010 (FAO, 2011). These changes reflect a particularly acute convergence of rising human demands for a finite resource base.

Anticipating the outcomes of these environmental changes—and acting to mitigate or avoid them—requires an improved ability to identify root causes of human-driven global change. Better understanding the interactions between drivers of environmental change and their influence on specific pressures on land could help inform policy decisions to more effectively alleviate these pressures. However, an improved understanding of causality and complex interactions by itself is not enough to motivate such decisions. Enhancing communication among scholars, practitioners and decision makers, and fostering an accessible and deeper mutual understanding of this improved knowledge, is also crucially important.

The twin goals of understanding complex interactions and effectively conveying them to policy makers, educators and the public can be facilitated by the strategic use of visualization techniques.

Moreover, we argue that such techniques could help address some of the challenges facing sustainability scientists and the integrated environmental assessment community (*i.e.*, linking scientific analysis with policy narratives). This paper employs a series of conceptual diagrams—building on the Kiviat or "spider chart" technique—to display and analyze relationships between multiple drivers and pressures on land. The analysis presented here grew out of the process of developing the Land and Drivers chapters of UNEP's fifth Global Environment Outlook (GEO-5) assessment.

This article takes on three tasks. First, by adapting and applying the Kiviat diagramming method to the problem of drivers and pressures, it contributes to the development of techniques for effectively visualizing, investigating and communicating complex human-environment interactions. Second, by analyzing specific sets of interactions between drivers and pressures in terrestrial systems and overlaying them to identify patterns, it produces insights that could help to inform improved policy strategies for sustainable natural resource and land management.

Finally, developing this work through the GEO-5 process creates an opportunity to reflect on the possibilities of leveraging a collaborative, integrated environmental assessment process to advance research beyond the specific mandate for which it was convened. The analysis presented here adds to a growing body of research that suggests that mechanisms that enhance communication, mutual understanding, integration and engagement on both ends of the producer-user knowledge spectrum have a crucial role to play in improving the interface between science and policy with respect to global environmental change.

6.2. Environmental Drivers, Pressures and Global Environmental Change

A range of large-scale integrated environmental assessments (IEAs) have studied the current state of ecosystems and their future capacity to deliver key services for humans while maintaining natural functions in the context of global environmental change e.g., (MA, 2005; IPCC, 2007; UNEP, 2007; IAASTD, 2009). Each of these assessments and the analytical frameworks behind them assert that understanding the driving forces (or "drivers") of change is a precondition for managing human influence on the environment. Moreover, the effectiveness of interventions to mitigate adverse impacts, they argue, depends not merely on identifying correlations but also on understanding the causal mechanisms linking specific actions to environmental outcomes.

The challenge is that the impacts of human activities do not occur in a simple, linear manner. Altered ecosystems—the result of interactions between humans and their environs—are almost always caused by multiple, interacting drivers (Smith et al., 2010; Nelson et al., 2006; Liu et al. 2007).

Drivers are important to understanding and managing natural resources and environmental problems for many reasons. First, they *exert influence on environmental conditions*. Drivers are defined as underlying factors or forces that—together with actors' decisions—lead to pressures, seen as proximate influences on environmental change (UNEP, 2012; Hersperger et al., 2010). For example, if conversion of land to agriculture is a pressure, then demand for agricultural products can be considered a driver. The Millennium Ecosystem Assessment describes two analogous categories of global driving forces along a spectrum of influence. "Direct" or proximate drivers are seen to yield an unequivocal effect on environmental processes or an ecosystem, while "indirect" or underlying drivers

operate more diffusely by influencing one or more direct drivers (MA, 2005; Nelson et al., 2006; Carpenter et al., 2006; 2009; Giest and Lambin, 2002). Most drivers operate synergistically.

In the case of land cover change resulting from agricultural conversion, population growth, economic development, and globalization could all be considered relevant drivers that exert varying degrees of influence on both the processes and outcomes of land cover change. Similarly, technological advances can stimulate the rate of economic development, and vise-versa.

Second, drivers do more than account for known pressures. They can combine in time and space in novel ways to *create new pressures and influences*. For example, the combined forces of technological advancements and new consumption patterns resulted in the explosive growth of the mobile phone industry and other compact electronic devices in the 1990s, leading to a surge in demand and sudden price boom for the mineral ore "coltan" (columbite-tantalite). This in turn led to dramatic excavation activity in the eastern Democratic Republic of the Congo where large concentrations of coltan were found (Hayes, 2002). Lucrative revenue streams from rebel-controlled mining enclaves were in turn used to finance the long-standing violent conflict and perpetuate (at least indirectly) ongoing insecurity in the region (Sutherland, 2011; Smith and Mantz, 2006; Jackson, 2003). This has resulted in environmental consequences that go beyond the direct impacts of the mining operations (Smith, 2011).

Third, drivers can combine to create dynamic patterns of pressures that in turn *give rise to systemic interactions*—across spatial, temporal, and institutional scales. For example, concerns about climate change impacts, including increased crop vulnerability and food insecurity, gave rise to climate policies which included mandates for increasing the use of biofuels such as ethanol and biodiesel. The resulting demand for agricultural goods as fuel feed stocks generated a cascading set of pressures, including crop diversion, which drove up food prices and in turn increased food insecurity (UNEP, 2012; Pimentel et al., 2009). In this respect, the high inertia and path dependencies typically associated with drivers can give rise to different obstacles to effective action. The complex evolution of US farm policy, for example, has produced a system that favors the production of both ethanol and unhealthy foods—through its history of subsidies for 'overproducing' corn and other 'low-cost' commodity crops—and has thereby amplified existing policy challenges in changing long-term health trajectories including the childhood obesity epidemic (Wallinga, 2010; Adger and Jordan, 2009).

Finally, drivers are important *targets of policy innovation*. GEO-5 asserts that policy interventions that look beyond sectoral issues, and are instead designed and framed to target drivers, could conceivably reduce pressure across a range of environmental problems simultaneously and achieve co-benefits. As such, the study of drivers is attracting greater interest.

Environmental drivers are influenced by variable policies. For some drivers, the dominant existing policy mechanisms actively encourage outcomes that increase pressure on the environment. Examples include economic growth and trade. Success of mainstream policies regarding these drivers generally leads to higher resource and energy use. For other drivers, the dominant policy mechanisms encourage outcomes that reduce environmental pressure. Examples include conflict and weak governance. Success of mainstream policies about these drivers can ease competition over resources and create conditions that favor the development and implementation of long-term environmental management plans. For still other drivers, there are no significant policy mechanisms at work, one way or the other.

Understanding the interactions between drivers, and their influence on pressures, remains a major challenge. Research has typically focused on the emergent consequences of drivers and pressures on ecosystems, not on the effects of changed ecosystems on drivers and pressures—thus addressing only one part of a feedback loop.

Meanwhile, policy interventions tend to focus on pressures—through responsive courses of action—even though transformational change and the transition to a more sustainable world is more likely to be achieved by influencing underlying drivers of (UNEP, 2012; Adger and Jordan, 2009; Marshall et al. 2012). Stirling (2013) contends that for a more *reflexive* or anticipatory style of decision-making and intervention to succeed, drivers (and pressures) must be framed in *tractable* ways such that they offer specific moments, modes and loci for action. Engaging this notion, however, creates both the predicament and the challenge of differentiating between drivers and pressures—which are inherently conditional—and partitioning their properties and characteristics in relation to real-world instances.

Perhaps unsurprisingly, the integrated environmental assessment (IEA) research community has struggled to define such discrete, clear delineations between where a driver ends and a pressure begins (UNEP, 2012; Nelson et al., 2006; Carpenter et al., 2006). Hence, GEO-5 conceptualizes drivers and pressures as parts of a continuum rather than as mutually exclusive or collectively complete domains. The process by which the set of drivers and pressures used in this analysis was derived is explained in Section 4.2 (Procedure: step 1).

Various conceptual frameworks exist for organizing drivers and pressures and these have been applied in different assessments. In the global environmental change community, the DPSIR framework—Driving forces, Pressures, State, Impacts, and Responses—has been widely accepted and commonly used in IEA (Figure 6.1).

Devised in the mid-1990s, initially as a visual model to help decision makers see the impacts of political choices (EEA, 1995), DPSIR has evolved into an analytical tool to facilitate investigations of the causal interplay between determinants of change and proposed responses; it has subsequently been applied to several disciplinary areas including sustainable development (Carr et al., 2007). While the DPSIR framework has been praised for its simplicity, it has also been criticized for being too linearly constrained. With insufficient capabilities to account for the dynamics of the systems it models, it has been described as both poorly suited for representing complex interactions and overstretched in its empirical application (Svarstad et al., 2008; Rekolainen et al., 2003; Berger and Hodge, 1998; Gabrielson and Bosch, 2003). Svarstad *et al*. (2008) identify a series of 'discursive biases' of the framework, concluding that it lends itself to a limited range of perspectives and 'discourse-selective' understanding of complex issues. Others have raised questions about DPSIR's lack of methodological structure, or rigor, which they suggest has led to multiple interpretations and an inconsistent attribution of indicators across the framework's five components (Giupponi, 2002).

Ultimately, such organizing frameworks are useful to help nurture differentiated understandings and to foster better communication, but by themselves, are insufficient to perform hypothesis testing or to systematically and comprehensively examine a wider range of drivers. These challenges compel a broadening of tools and techniques that can at once help address systematic analysis of drivers (and pressures) and serve to bridge complex information across different actors and disciplinary groups. Applying such 'knowledge-intermediary' tools (as we will call them in this article), through

collaborative processes such as GEO—where different actors come together to understand environmental problems and contending pathways for decision-making—we argue, could offer possibilities to address certain tensions and communication challenges at the science-policy interface.

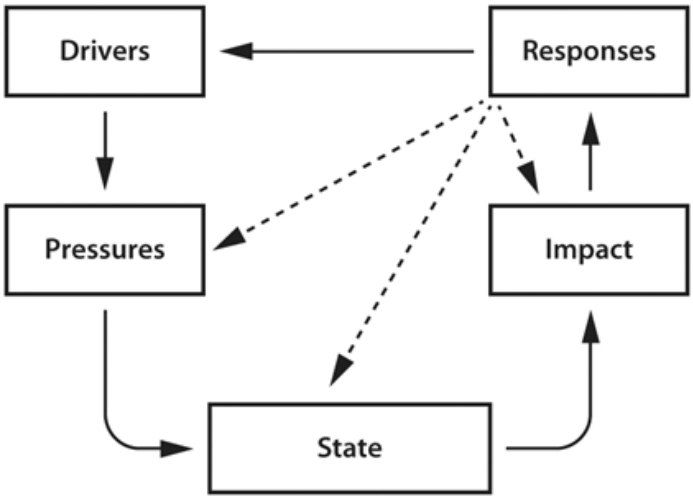

Figure 6.1. Simple Drivers-Pressures-State-Impact-Response (DPSIR) framework in the IEA context

6.3. GEO and the Integrated Environmental Assessment Process

In line with its mandate of keeping the global environment under review, UNEP coordinates integrated environmental assessments—consultative and participatory processes—that inform environmental decision-making and aim to facilitate interaction between science and policy. Five Global Environment Outlook (GEO) assessment reports have been produced by UNEP, in 1997, 1999, 2002, 2007 and 2012. Each has analyzed environmental state and trends at the global and regional scales, described plausible outlooks and formulated policy options. The fifth and latest iteration, *GEO*-5: *Environment for the future we want* was launched in June 2012 alongside the second Earth Summit in Rio de Janeiro. Building on previous assessments, GEO-5 suggests a shift in the analysis and framing of problems and responses, emphasizing interventions that employ a more reflexive approach and strategies that are less circumscribed in their ambitions to engage with underlying driver.

The goal of the GEO process is to ensure that environmental problems and emerging issues of international significance receive adequate and timely consideration by researchers, governments and other stakeholders. Given the complexity of global environmental issues and their interactions with society, a structured approach that includes political processes and the economic system is crucial. In its most basic form, the Integrated Environmental Assessment (IEA) process brings together knowledge from a wide range of scientific disciplines and stakeholders, so that integrated insights are made available to decision-makers. The IEA process provides a participatory, structured approach to linking knowledge and action. The framework for the IEA recognizes two key domains of the Earth System: human society and the environment. Over time, GEO has developed an increasingly integrated approach to environmental assessment, using indicators and reporting (Pintér et al., 2007).

The character and environmental policy orientation of IEAs have shifted dramatically in recent years. The makers of IEAs are now expected to address more complex problems, diverse audiences and varied time horizons than ever before. Even as researchers increasingly appreciate the complexity and interconnectedness of environmental problems, the number of separate international environmental agreements has proliferated and the institutions responsible for administering them have become increasingly fragmented, thus complicating even further the task of IEAs to provide a clear link between science and policy in the environmental domain (Jabbour et al., 2012).

Although the messages are becoming more complex, IEAs must still find accessible ways to communicate them if they are to fulfill their goal of informing policy makers. Hence there is much to be gained from adopting visualization tools that can distill and help interpret dynamic patterns. The *Kiviat* or "spider chart" technique presented here represents one such visualization tool. Its potential contributions and caveats are discussed in the following sections.

6.4. Methods

6.4.1. Kiviat Diagraming

We propose a methodological approach inspired by the Kiviat diagramming technique to illustrate and analyze the relative influence of key drivers on selected pressures on land. Kiviat diagrams, also known as spider charts or spider-webs, display multivariate data in the form of two-dimensional line graphs consisting of a sequence of axes, or spokes of equi-angular position, where each spoke represents one factor of the analysis (Friendly and Denis, 2001). The length of each spoke (defined by a data point) is proportional to the influence or magnitude of the relevant variable or factor relative to the maximum possible influence of the variable across all data points plotted.

For example, if we consider eight separate factors—in this case, drivers of environmental change—the resulting diagram would have eight distinct spokes or axes (Figure 6.2). The relative value assigned for each distinct factor (i.e., the eight drivers) for each entity of interest—in this case, a selected pressure on land—is plotted on the appropriate axis. Data points are then connected to form patterns that represent the entity under investigation (i.e., the pressure on land). The resulting multi-vector diagram thus turns a complex, multivariate entity or problem into a simple presentation; where a user can visualize critical dependencies, and analyze how multiple variables could interrelate.

Originally conceived in the 1970s as a classification tool to support performance evaluation in the field of computer engineering (Kolence and Kiviat, 1973), the Kiviat method has since been extended and applied to a variety of research problems oriented towards multivariate, pattern-analysis. In recent years, common uses of the technique have facilitated investigations including: performance metrics of competitive athletes; quality management improvements in organizations; evaluating design attributes in integrated supply chains; and testing large high performance computing systems e.g., (Bamford, 2005; Shepherd and Günter, 2006; Horatiu, 2008; Stewart et al.l 2010).

Here we present an empirical application of the Kiviat method with the goal of understanding and navigating the dynamic interactions between drivers of global environmental change and pressures on terrestrial ecosystems. Building on the method described above, we map multiple entities—land pressures—and superimpose them on the same diagram. Finally, we interpret the rendered Kiviat

shapes, reflecting on possible interdependencies that could suggest where targeted responses might meet, exceed or fail expectations for co-benefits in relation to the given land pressures.

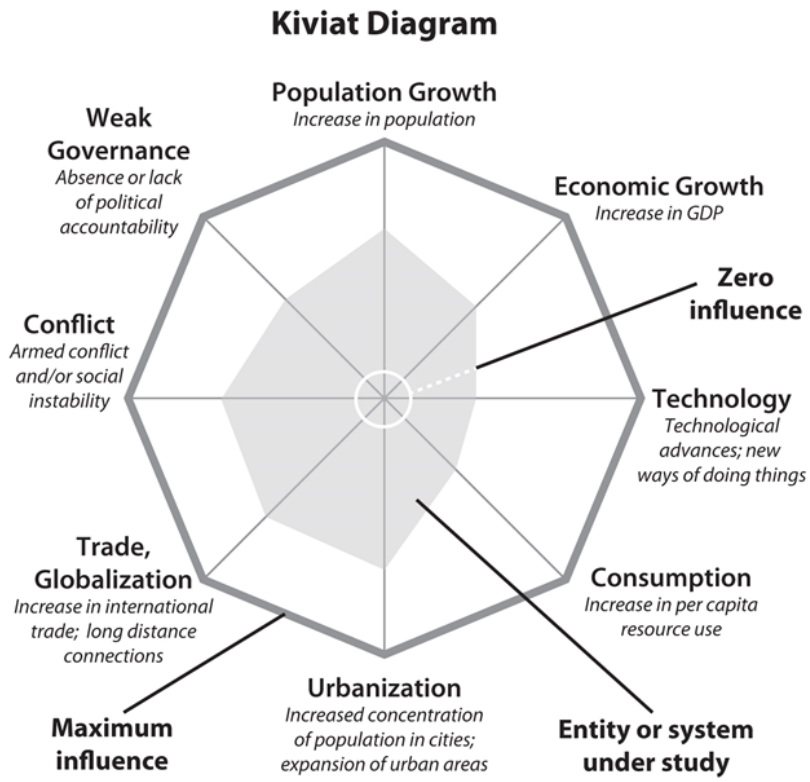

Figure 6.2. Hypothetical Kiviat diagram depicting eight distinct factors of influence

We draw on narratives developed in the GEO-5 Land chapter to help choose which combinations of pressures to analyze, and to guide the interpretation of critical interdependencies. The limitations, advantages and possibilities of our modified Kiviat approach are discussed in Sections 6.5 and 6.6.

6.4.2. Procedure

In the following sections, we outline the process we used to produce our Kiviat diagrams. This can be summarized in four steps:

1) Selecting the drivers and pressures
2) Standardize performance definitions
3) Rate each performance category/assign values
4) Plot, overlay and interpret the results

Define categories: selecting drivers and pressures

The first step was to create the analytical categories– in other words, to select the variables (underlying drivers) and entities (pressures on land) under investigation. The specific categories of drivers and pressures were generated inductively from preliminary discussions among GEO-5 expert working groups and emerging storylines of priority pressures on land. Authors of the Drivers chapter derived an initial list of priority, high-level drivers of change, informed by previous assessments (including past GEO reports) and modified to fit current thinking. Through an iterative process, expert

working groups of each thematic chapter (Atmosphere, Land, Water, Biodiversity, and Chemicals and Waste) debated and compiled a list of environmental pressures of greatest concern to their respective themes. Provisional lists were then shared between working groups prior to the first production and lead authors meeting to stimulate cross-pollination of ideas, insights and synergies. In the end, we arrived at eight underlying drivers and 21 priority pressures for the Land chapter, of which six were extracted for this analysis.

Table 6.1. Characteristics of selected drivers of environmental change[1]

Driver	Definition	Major effects	Key interactions	Dominant policy tendency
Population growth	Increase in human population	Increases demand for food, energy, materials	Effects mediated by levels of consumption, resource efficiency,	Direct policies relatively rare; can be either direction (one-child policy vs. child bonus payments)
Economic growth	Increase in GDP	Usually increases resource and energy use	Stimulated by population growth, consumption,	Encourage further growth
Technology	Technological advances; new ways of doing things become possible	Can increase resource efficiency (e.g. LED lights) or intensify environmental damage (e.g. mechanical forest harvesters)	Affects economic growth, consumption, trade and their impacts	Incentives for advancing particular kinds of technology depend on policy priorities
Consumption	Increase in per capita resource use (food, water, energy, materials)	Increases resource extraction, agricultural production, industrial processing, energy use	Generally increases with higher GDP per capita	Most encourage further consumption; some efficiency measures
Urbanization	Increased concentration of human population in cities and towns; expansion of urban areas	Can increase consumption through diet and lifestyle shifts; can also encourage resource efficiency (e.g. mass transit)	Affects patterns of consumption and interaction with technology	Economic and social policies incentivize living in urban or rural areas; zoning and urban planning affect land use
Trade/ globalization	Increased international trade; long distances between places where resources originate and their products are consumed	Increases transportation of goods; can obscure signals of environmental degradation; impacts of production occur far from where demand originates	Interacts with economic growth, consumption, technology; presents governance challenges	Trade rules encourage particular forms of trade
Conflict	Increase in armed conflict and/ or social instability	Can intensify competition and resource extraction; interferes with implementation of rules; reduces security of land tenure	Can be influenced by inequality, climate stress, weak governance	Seek to reduce conflict
Weak Governance	Absence of political accountability, due process, legal institutions	Difficult to enforce resource access rules or implement long-term management plans	May co-occur with conflict	Seek to reduce failure

[1]*GEO-5 identifies population and economic development as two major drivers with particularly strong influence on systemic interactions. Other drivers include technology, urbanization, globalization and trade, values, conflict and governance. The pressures that these drivers exert can include resource extraction, land use change, land degradation, and modification and movement of organisms.*

Standardize performance definitions

The degree to which a given driver influences a selected pressure on land is displayed as a point along the appropriate axis. Deriving these measurement scores (from 0 to 5) required that we normalize the factors (i.e., the selected drivers) to a standard performance definition. Table 1 presents the drivers considered in this analysis and their basic characteristics, including possible effects, key interactions and the direction of dominant policy tendencies. While these are summarized in aggregate, there are important regional and other variations in both the policy tendencies and the effects of these drivers that we kept in mind during the scoring exercise as well as the interpretation and analysis of the results. Once performance definitions were established, we scaled the ranking intervals—testing a few options—to arrive at levels that could show an appropriate range of influence.

Rate each performance category/ assign values

Given the findings of GEO-5, particularly those emerging from the Land Chapter, we reflected on the relative influence of each driver on each pressure, assigning a qualitative value from 0 (virtually no influence) to 5 (very strong influence). For each variable, the relative influence was assessed independently by individual authors of the Land Chapter. Responses were then brought together, discussed and negotiated, again through an iterative process of reflective dialogue and shared learning.

Connecting the dots: Plotting, overlaying and interpreting the results

In constructing the Kiviat diagrams, rankings (from the table) are plotted along the relevant axes. Lines are then drawn to connect the points on the adjacent spokes, and the resulting polygon shape—which in our analysis signifies a specific pressure on land—is then shaded. Superimposing multiple entities (pressure-scenarios) by plotting them on the same graph revealed patters that allowed us to identify possible interdependencies and derive preliminary insights into where policy responses might best be targeted to alleviate environmental pressures. The interpretation of results is discussed in detail below.

6.5 Results and discussion

This section presents the results of our analysis and discusses the insights it contributes to the three tasks identified in Section 6.1: identifying patterns of interaction between drivers and pressures for specific forms of environmental change related to land; assessing the strengths and limitations of the Kiviat technique for this type of analysis; and commenting on the role that this tool can play in supporting integrated environmental assessments.

6.5.1. On drivers and pressures

The world's forests have long been under serious duress. In recent decades, tropical forest landscapes, in particular, have faced disproportionate pressures due to various competing demands for productive land for agricultural commodities, meat consumption, palm oil production, and rising global demand for wood products. In the first Kiviat diagram (Figure 6.3) we consider three land pressure results related to forests that are featured in the GEO-5 Land chapter: the expansion of large-scale oil palm plantations; commercial timber extraction—both regulated and unregulated—for wood

and pulpwood products; and the production of traditional biomass (fuelwood and charcoal). While all three results produce similar outcomes – deforestation and forest degradation – they are driven by markedly different combinations of processes that operate and interact at multiple scales.

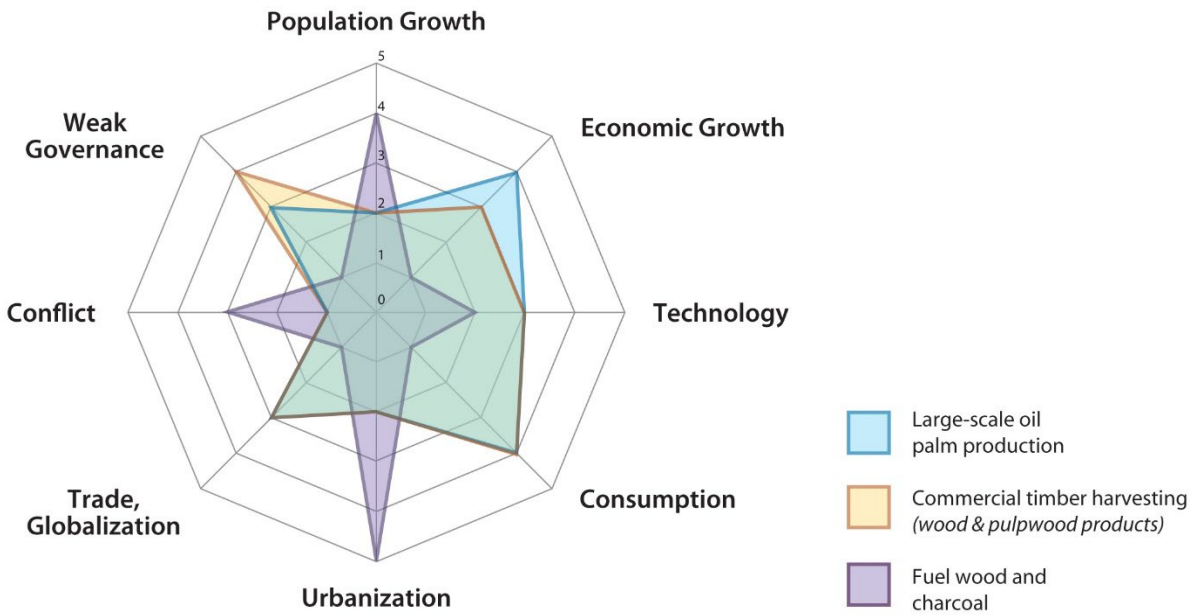

Figure 6.3. Pressure-scenarios for large-scale plantations, commercial timber extraction and traditional biomass

The *traditional biomass* pressure scenario is conditioned by fewer factors (or underlying drivers) that exert stronger relative influences – namely, population growth, urbanization trends, conflict or insecurity, and to a lesser extent technology. Rapid urbanization in developing countries coupled with high price elasticity and inadequate access to modern fuels has strongly influenced household energy demand, with a pronounced shift from fuelwood to charcoal; by some estimates a one per cent increase in urbanization leads to as much as a 14 per cent increase in charcoal consumption (World Bank, 2009). Given that charcoal, unlike fuelwood, is typically produced from intact natural forests, from a deforestation perspective this substitution trend is disconcerting; especially when many urban and peri-urban forested areas lack adequate forest management systems (Girard, 2004; Kuser, 2007). This situation raises important questions regarding mainstream energy policies that place an over-emphasis on household income to explain fuel choices (i.e., the 'ladder model') and whether such postulations, as some researchers suggest, misleadingly imply that a socio-economic move up to a new 'superior' fuel is simultaneously a move away from traditional biomass fuels (Heltberg, 2005; Nyembe, 2011).

The aggregate pressure results for *commercial timber extraction* and *oil palm plantations* on the other hand, are affected by a wider variety of factors with moderate degrees of relative influence, resulting in more diffuse Kiviat patterns. While enabling conditions and country circumstances vary, a growing body of evidence suggests that key barriers impeding the effective implementation of policies and interventions designed to address large-scale forest loss are symptoms of deeper deficiencies in global markets, trade structures and governance (Agrawal, 2008; Turner et al., 2008; Nelleman et al., 2012; UNEP, 2012). Thus, it is not surprising that the latter two pressure results (which are characterized by

a dominance of commercial versus subsistence incentives) are similarly conditioned by several common critical drivers: weak governance, economic growth, and globalization and trade. In this sense, a convergence of interests between dominant actors—foreign and domestic—who stand to benefit from market distortions and 'problematic' governance tendencies could be understood as a critical dependency and partial explanation for some of the complex and context-specific factors that are often unmitigated by policy interventions. This analysis resonates strongly with a key narrative in GEO-5 which suggests that distorted incentives and financial pressures (encouraged by a global economic system based on the pursuit of perpetual growth) have exaggerated the short-term returns from deforestation at the expense of natural capital (UNEP, 2012).

Contrasting the current policy discourse on REDD+ (Reducing Emissions from Deforestation and Forest Degradation[2]) against these results also reveals interesting signals about enabling factors consistent with the literature (e.g. Angelsen et al., 2009; Larson and Petkova, 2011; Corbera and Schroeder, 2011; Kissinger et al., 2012), particularly that the efficacy, equitability and viability of REDD+ requires a stronger emphasis on safeguards against forest *governance failures*, *conflict and instability* in forest dependent-communities (stemming largely from restricted access to land), as well as preventing perverse incentives from the market and trade.

In the second Kiviat diagram (Figure 6.4) we consider three pressure-scenarios based on simultaneous increases in demand for food, feed and biofuels. While these act to intensify competition for arable land, there are important differences in the processes at work.

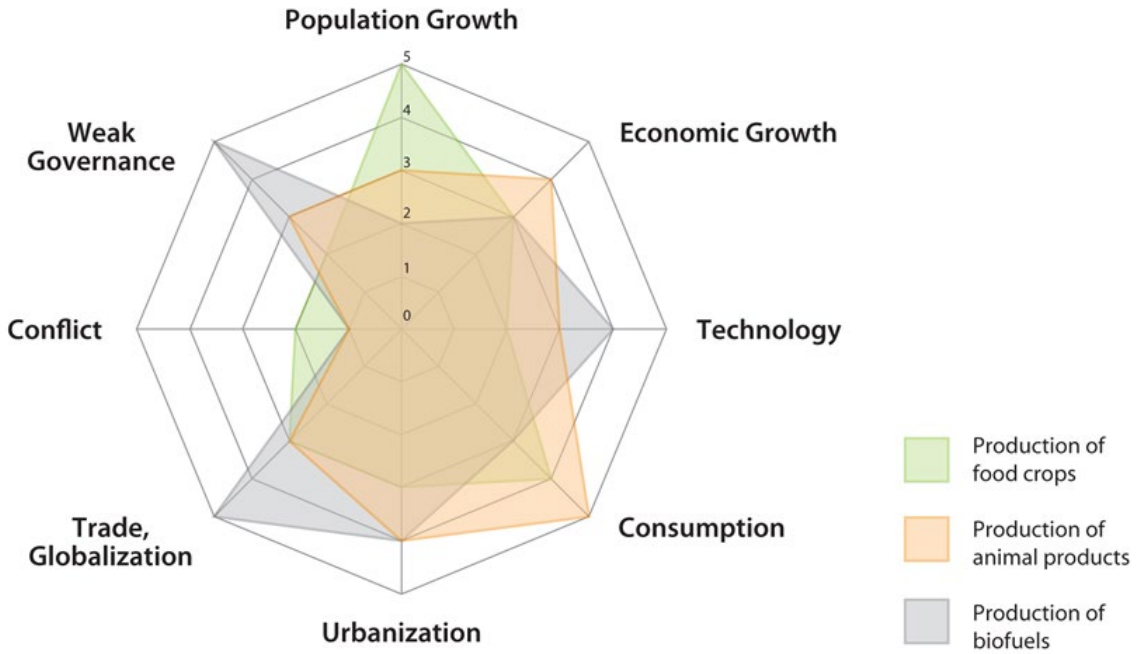

Figure 6.4. Pressure-scenarios for production of food crops, animal products and biofuels.

This analysis finds that the production of food crops is more strongly affected by population growth than by any other driver. Demand for staple foods is generally less elastic than that for animal products and biofuels, meaning the total consumption of food crops remains closely linked to population. However, processed foods represent one way to increase the per capita consumption of some crops, particularly corn and sugar (Vos et al., 2008; Monteiro et al., 2010).

Demand for animal products – meat, dairy and eggs – varies more as a function of income, expressed here as stronger influence from the economic growth and consumption drivers. Livestock production creates pressure on land resources in (and downstream from) places where ranching and intensive livestock raising occur, as well as where crops are produced for feed. For example, the total area harvested for soy, an important feed crop, roughly quadrupled over the 30-year period up to 2009 (FAO, 2012).

Governance and trade are the most influential processes driving the increased production of biofuels. This reflects the crucial role that quantity-based biofuel mandates have played in creating markets and incentives for expanded biofuel production (Mitchell et al., 2011). It also reflects the challenges that subsequent policy measures such as 'sustainability criteria' and voluntary certification have faced in attenuating the environmental impacts of widespread production of feedstocks such as sugarcane, corn, oil palm and soy (Bailis and Baka, 2011). Biofuel production has also been driven by technological advances that enable new ways of deriving biofuels and the ability to use them in a wider range of engines. Urbanization and consequently higher liquid fuel consumption also plays a role.

Does this set of results suggest a strategy for intervention that could reduce pressure on land from food, feed and biofuel production simultaneously? This analysis resonates with Smith et al.'s (2010) assertion that further policies addressing the primary drivers of competition for land (population growth, dietary preference, protected areas, forest policy) could significantly contribute to reducing competition for land. Population, economic growth and consumption have broad influence on food, feed and biofuel production, making them potentially attractive areas for intervention. However, these drivers are attached to deep-seated normative values and addressing them directly can be very difficult. In such cases indirect leverage points can be used to approach underlying drivers. For example, initiatives to improve education and technological capacity can reduce impacts linked to population growth, while resource efficiency strategies can help to curb some impacts of increased consumption and economic activity.

6.5.2. On the use of the Kiviat technique

The preceding diagrams explore the interactions between drivers and pressures of environmental change at a global level. How well suited is the Kiviat technique for this task? The 'spider webs,' through the patterns they revealed, opened-up a way of thinking about potentially synergistic policy interventions and trade-offs that did not otherwise find their way into the GEO-5 discussion. Moreover, generating the 'spider webs' through an iterative process of reflective dialogue and mutual learning, as we have done, enabled an integration of different vantage points and illuminated, for example, new insights into less-obvious systemic interactions and possible feedbacks. However, the illustrative and analytical contributions of this exercise should not be confused with predictive power or nuanced explanation. Working at such a high level of aggregation and abstraction inevitably masks important differences in the political and institutional context in different locations and across scales. The Kiviat diagrams as applied here also cannot account for crucial place-specific social factors. While the global analysis presented here should not be generalized to local circumstances, we believe the same technique could be applied – with similar caveats – to analyze interactions at other scales.

Many drivers and pressures interact in unpredictable ways. While it may be impossible to completely avoid unintended consequences within complex systems, visualization techniques such as this one may help to better understand patterns of interaction and anticipate possible synergies and frictions.

Of course, applying this method—on any complex system with high uncertainty—comes with limitations and warrants further study. One risk of Kiviat diagrams is that users may interpret the area of a graph as an indicator of the magnitude of impact associated with a given pressure scenario. However, this is not accurate. If a localized pressure is strongly influenced by several drivers, it may generate a diagram with a greater area than a pressure with aggregate impact of continental proportions, if the latter is strongly influenced by fewer drivers.

6.5.3 On this exercise as a knowledge-intermediary tool for IEAs

Based on the work presented here, we argue that the Kiviat exercise offers a unique conceptual tool for depicting and communicating complex relationships. Both a strength and limitation of the Kiviat diagramming exercise is this power to represent complex interactions at a glance. While the ability to recognize patterns through shapes could help non-specialist audiences or decision makers to rapidly take in the results of a collaborative assessment process, the Kiviat exercise (and resulting diagrams) should serve as an entry point for dialogue and mutual learning, rather than be interpreted as a prescription for desirable courses of action.

To this end, using this technique, as we try to show in this paper, can facilitate visualization of information in a way that supports intuitive interaction; stimulates and assists the analysis of causality in complex systems; and enables a way of communicating patterns that allows users to appreciate unpredictable interactions. Moreover, the Kiviat technique can evoke a productive interaction between actors—by collectively capturing, interpreting and visualizing multiple layers of analysis—that inadvertently exposes important assumptions and biases linked to people's values, beliefs, policy orientations, cultural practice, and experience and expertise.

Taking these assertions, a step further, we propose that the Kiviat exercise could provide an accessible and potentially valuable 'knowledge-intermediary[3]' tool at the science-policy interface addressing critical contemporary issues that require productive interactions among science, society and policy (i.e., making science-based information more effective components of societal discourse and public policy action). If strategically applied, for example during the framing and problem analysis stages of future Integrated Environmental Assessment processes, such an exercise could enable new opportunities to address certain barriers and broken bridges at the science-policy interface, not least the need for improved communication and engagement. Bridging science and policy (or practice), in virtually any context, involves a variety of actors and institutions, possible pathways, a complex web of interactions, and thus, by necessity, mutual responsibility towards a convergence of interests (Vogel et al., 2007). In the IEA context, 'boundary' organizations that engage with more than one major community of knowledge and practice (e.g., UNEP) have faced formidable challenges in reconciling the inherent tensions and diverging motivations at the science-policy interface. These are often amplified during the later phases of the knowledge production process. Jones et al. (2008) suggest that a key friction exists between the need to encourage specialized expertise versus efforts to "democratize" knowledge, to deepen the engagement of certain actors. Thus agreement is emerging from a growing literature (e.g., Komiyama and Takeuchi, 2006; Vogel et al., 2007; Weichselgartner and Kasperson, 2010; Solinís and Bayá Laffite, 201; Jones et al., 2012; Salas-Zapata et al., 2012; McCollum et al., 2013) that suggests that improving productive interactions among science, society and policy in the 21st century will require a new generation of integrated tools and approaches that emphasize 'two-way' communication and that facilitate improved dialogue and better engagement on both ends of the producer-user spectrum in co-generating actionable, evidence-based policy responses.

This paper has argued that the Kiviat diagram technique can help in understanding and communicating multivariate relationships, and arrived at this conclusion through a process that was set up to produce an integrated environmental assessment – GEO-5. It is worth reflecting on parallels between the content and the process of such an undertaking. Integrated environmental assessments are expected to address profoundly complex, multi-faceted problems and – crucially – to do so through a process of collaborative knowledge production involving large teams with diverse geographical, cultural and disciplinary backgrounds. Complex interactions are thus a feature of the process of conducting an integrated environmental assessment as well as its subject material. While this paper has discussed the contribution of the Kiviat technique in terms of visualizing, understanding and communicating causality in complex systems (drawing on discussions that had already occurred in the context of GEO-5), it is also worth considering the possibility that this technique could be used to help guide and focus problem analysis during the course future IEA processes.

6.6. Conclusions

This work has presented a conceptual tool to stimulate and support the analysis of causality in complex systems in general, and land systems in particular. It has identified clusters of drivers with relatively strong influence on combinations of pressures, acknowledging both the importance and difficulty of addressing multiple drivers in an integrated way.

We argue that this technique is well suited for stimulating collective thinking, discussion and deliberation about causality in complex systems and the links between science and policy. While it can help identify areas where policies targeting particular drivers or combinations of drivers might produce synergistic benefits, it does not help answer the difficult question of what kinds of policy measures would be feasible or acceptable in specific contexts.

Finally, we have shown how applying this exercise as a knowledge-intermediary tool could contribute to integrated environmental assessments, and (relatedly) enable improved communication and inclusive dialogue between the science and policy communities – keeping in mind caveats related to nuance, unanticipated outcomes, political-institutional context and scale.

6.7 References

Adger, W.N. and Jordan, A. (2009). *Governing Sustainability*, Cambridge University Press.

Agrawal, A., Chhatre, A. and Hardin, R. (2008). Changing Governance of the World's Forests, *Science* 320:1460-1462.

AMAP (2011). *Snow, Water, Ice, Permafrost in the Arctic (SWIPA): Executive Summary*. Arctic Monitoring and Assessment Secretariat, Oslo.

Angelsen, A., Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W. D. and Wertz-Kanounnikoff, S. (eds) (2009). Realising REDD+: National strategy and policy options. CIFOR, Bogor, Indonesia.

Bailis, R. and Baka, J. (2011). Constructing Sustainable Biofuels: Governance of the Emerging Biofuel Economy. *Annals of the Association of American Geographers* 101(4): 827-838

Bamford, J. (2005). Implementing quality: A practical guide to tools and techniques. *International Journal of Operations & Production Management* 25(10): 1034.

Barnosky, A.D., Hadly, E.A., Bascompte, J., Berlow, E.L., Brown, J.H., Fortelius, M., Getz, W.M., Harte, J., Hastings, A., Marquet, P.A., Martinez, N.D., Mooers, A., Roopnarine, P., Vermeij, G., Williams, J.W., Gillespie, R., Kitzes, J., Marshall, C., Matzke, N., Mindell, D.P., Revilla, E. and Smith, A.B. (2012). Approaching a state shift in Earth's biosphere. *Nature* 486, 52–58 (07 June 2012) doi:10.1038/nature11018.

Berger, A.R. and Hodge, R.A. (1998). Natural change in the environment: a challenge to the pressure-state-response concept. *Social Indicators Research* 44:255-265.

Carpenter, S.R., E.M. Bennett, and G.D. Peterson. (2006a). Editorial: Special Feature on Scenarios for Ecosystem Services. *Ecology and Society* 11(2): 32.

Carpenter, S.R., DeFries, R., Dietz, T., Mooney, H.A., Polasky, S. and Reid, W.V. (2006b). Millennium ecosystem assessment: research needs. *Science* (314): 257–258.

Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., Defries, R.S., Diaz, S. (2009). Science for managing ecosystem services: beyond the millennium ecosystem assessment. *Proc. Natl Acad. Sci. USA,* (106): 1305–1312.

Carr, E.R., Wingard, P.M., Yorty, S.C., Thompson, M.C., Jensen, N.K. and Robertson, J. (2007). Applying DPSIR to sustainable development. *International Journal of Sustainable Development and World Ecology,* 14(6): 543-555.

Corbera, E. and Schroeder, H. (2011). Governing and implementing REDD+. *Environmental Science and Policy*, 14: 89-99.

Davidson, E.A. de Araújo, A.C., Artaxo, P., Balch, J.K., Brown, I.F., Bustamante, M.M.C, Coe, M.T., DeFries, R.S., Keller, M., Longo, M., Munger, J.W., Schroeder, W., Soares-Filho, B.S., Souza, C.M., and Wofsy, S.C. (2012). The Amazon basin in transition. *Nature* 481: 321–328 doi:10.1038/nature10717.

EEA (1995) Europe's Environment: the Dobris Assessment. European Environment Agency. Copenhagen.

FAO (2012). *FAO Statistics*. Food and Agriculture Organisation of the United Nations, Rome.

FAO (2011). *2011: State of the World's Forests.* Food and Agriculture Organization of the United Nations, Rome.

Foley, J.A., Ramankutty, N., Brauman, K.A., Cassidy, E.S., Gerber, J.S., Johnston, M., Mueller, N.D., O'Connell, C., Ray, D.K., West, P.C., Balzer, C., Bennett, E.M., Carpenter, S.R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. and Zaks, D.P.M. (2011). Solutions for a cultivated planet. *Nature* 478, 337–342.

Friendly, M. and Denis, D. J. 2001. Milestones in the history of thematic cartography, statistical graphics, and data visualization. York University, Toronto.

Gabrielson, P. and Bosch, P., 2003. Environmental Indicators: Typology and Use in Reporting. EEA Internal Working Paper. Copenhagen.

Giest H. and Lambin, E., 2002. Proximate causes and underlying driving forces of tropical deforestation. *Bioscience* 15: 143-150.

Giupponi C., 2002. From the DPSIR reporting framework to a system for a dynamic and integrated decision-making process. Venice.

Hayes, K., 2002. Update on coltan mining in the Democratic Republic of Congo. *Oryx* 36, 12-13

Heltberg, R., 2005. Factors Determining Household Fuel Choice in Guatemala. *Environmental and development economics* 10: 337-61.

Hersperger, A.M., Gennaio, M., Verburg, P.H., and Bürgi, M., 2010. Linking Land Change with Driving Forces and Actors: Four Conceptual Models. *Ecology and Society* 15(4): 1.

Herrero, M. and Thornton, P.K., 2012. Production systems for the future: balancing trade-offs between food production, efficiency, livelihoods and the environment. CGIAR, Nairobi, Kenya

Horatiu, C., 2008. Performance Metrics in Downstream Supply Chain. Doctoral dissertation. University of Padova, Italy.

IAASTD, 2009. The International Assessment of Agricultural Science and Technology for Development. Island Press, Washington DC.

Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Levy, M.A., Patel, N., Singh, A. and S. Schwarzer., 2012. Internationally agreed environmental goals: a critical evaluation of progress. *Environmental Development* 3:5-24.

Jackson, R.J., Minjares, R., Naumoff, K.S., Shrimali, B.P. and Martin, L.K., 2009. Agriculture policy is health policy. *Journal of Hunger and Environmental Nutrition* 4(3–4): 393–408.

Jones, N., Jones, H. and Walsh, C., 2008. Political science? Strengthening science–policy dialogue in developing countries. ODI Working Paper 294. London.

Jones, H., Jones, N., Walker, D. and Walsh, C., 2009a. Strengthening science–policy dialogue in developing countries: a priority for climate change adaptation. ODI Background Note. London

Jones, N., Datta, A., Jones, H., Akhmadi, N., Boa, E., Correa, N., Hang, N., Sharma Paudel, N., Schumacher, L. and Telleria, R., 2009b. Knowledge, policy and power: Six dimensions of the knowledge–development policy interface. ODI Working Paper 294. London.

Jones H., Jones N., Shaxson L., Walker, D., 2012. Knowledge, policy and power in international development: a practical guide. Bristol: The Policy Press.

Kissinger, G., Herold, M. and De Sy, V., 2012. Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers. Lexeme Consulting, Vancouver Canada, August 2012

Kolence, K.W. and Kiviat, P. J., 1973. Software Unit Profiles and Kiviat Figures. ACM Sigmetrics. *Performance Evaluation Review*, 2(3): 34-39.

Komiyama, H. and Takeuchi, K., 2006. Sustainability science: building a new discipline. *Sustainability Science*, 1(1): 1-6.

Kumar, P. (ed.), 2010. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, Washington, D.C.

Kuser, J.E. (ed.), 2007. Urban and community forest in the Northeast, 2nd edition. Springer.

Larson, A.M. and Petkova, E., 2011. An Introduction to Forest Governance, People and REDD+ in Latin America: Obstacles and Opportunities. *Forests* 2(1): 86-111.

Lawrence, D.M., Slater, A.G., Tomas, R.A., Holland, M.M. and Deser, C. (2008). Accelerated Arctic land warming and permafrost degradation during rapid sea ice loss. *Geophysical Research Letters* 35, L11356

Liu, J., Dietz, T., Carpenter, S.R., Folke, C., Alberti, M., Redman, C.L., Schneider, S.H., Ostrom, E., Pell, A.N., Lubchenco, J., Taylor, W.W., Ouyang, Z., Deadman, P., Kratz, T. and Provencher, W. (2007). Coupled Human and Natural Systems. *AMBIO: A Journal of the Human Environment* 36(8): 639-649.

MA, 2005. Millennium Ecosystem Assessment: Ecosystems and human well-being. Volume 1. Current state and trends. Island Press, Washington, D.C., USA.

Marshall, N.A., Park, S.E., Adger, W.N., Brown, K., and Howden, S.M., 2012. Transformational capacity and the influence of place and identity. *Environmental Research Letters,* 7(3): p.034022.

McCollum, D.L., Krey, V. and Riahi, K., 2011. An integrated approach to energy sustainability. *Nature Climate Change* 1(9):428-429

Mitchell, C., Sawin, J.L., Pokharel, G.R., Kammen, D., Wang, Z., Fifita, S., Jaccard, M., Langniss, O., Lucas, H., Nadai, A., Trujillo Blanco, R., Usher, E., Verbruggen, A., Wüstenhagen, R., and Yamaguchi, K., 2011. Policy, Financing and Implementation, in: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. Von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Monteiro, C.A., Levy, R.B., Claro, R.M. de Castro, R.R.I. and Cannon, G., 2010. Increasing consumption of ultra-processed foods and likely impact on human health: evidence from Brazil. *Public Health Nutrition* 14(1): 5–13.

Nellemann, C., INTERPOL Environmental Crime Programme (eds)., 2012. Green Carbon, Black Trade: Illegal Logging, Tax Fraud and Laundering in the Worlds. Tropical Forests. A Rapid Response Assessment. United Nations Environment Programme, GRIDArendal.

Nelson, G.C., E., Bennett, A.A., Berhe, K., Cassman, R., DeFries, T., Dietz, A., Dobermann, A., Dobson, A., Janetos, M., Levy, D., Marco, N., Nakicenovic, B., O'Neill, R., Norgaard, G., Petschel-Held, D., Ojima, P., Pingali, R., Watson and M. Zurek., 2006. Anthropogenic drivers of ecosystem change: an overview. *Ecology and Society* 11(2): 29.

Nyembe, M., 2011. An econometric analysis of factors determining charcoal consumption by urban households: The case of Zambia. Master's Thesis. Swedish University of Agricultural Sciences.

Ostrom, E., T. Dietz, N. Dolsak, P. C. Stern, S. Stonich, and E. Weber, editors. (2002). The drama of the commons. National Academy Press, Washington, D.C., USA.

Pimentel, D., Marklein, A., Toth, M.A., Karpoff, M.N., Paul, G.S., McCormack, R., Kyriazis, J. and Krueger, T., 2009. Food versus biofuels: environmental and economic costs. *Human Ecology,* 37(1): 1–12.

Pintér, L., Swanson, D. and Chenje, J. (eds.), 2007. GEO Resource Book: A training manual on integrated environmental assessment and reporting (module overviews). United Nations Environment Programme, International Institute for Sustainable Development. http://www.unep.org/geo or http://www.iisd.org/measure

Rekolainen, S., Kämäri, J. Hiltunen, M., 2003. A conceptual framework for identifying the need and role of models in the implementation of the water framework directive. *International Journal of River Basin Management* 1(4): 34-43

Rockström, J., Steffen, W. Noone,K, Å. Persson, F.S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V. J. Fabry, J. Hansen,

B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley., 2009. Planetary Boundaries: Exploring the Safe Operating Space for Humanity. *Ecology and Society*, 14(2): pp.32.

Salas-Zapata, W.A., Rios-Osorio, L.A. and Trouchon-Osorio, A.L., 2012. Typology of scientific reflections needed for sustainability science development. *Sustainability Science,* 7(1): 25-43.

Schaefer, K., Zhang, T., Bruhwiler, L., and Barrett, A.P., 2011. Amount and timing of permafrost carbon release in response to climate warming, *Tellus Series B: Chem. Phys. Met.*, DOI: 10.1111/j.1600-0889.2011.00527.x.

Scheffer, M. Bascompte, J., Brock, W.A., Brovkin, V., Carpenter, S.R., Dakos, V.,

Held, H., van Nes, E.H., Rietkerk, M. and Sugihara, G. (2009). Early-warning signals for critical transitions. *Nature* 461: 53–59.

Shepherd, C. and Günter, H., 2006. Measuring supply chain performance: Current research and future directions. *International Journal of Productivity and Performance Management,* 55 (3-4): 242-258

Smith, P., Gregory, P.J., van Vuuren, D., Obersteiner, M., Havlík, P., Rounsevell, M., Woods, J., Stehfest, E. and Bellarby, J., 2010. Competition for land. *Phil. Trans. R. Soc. B*, 365, 2941–2957 doi:10.1098/rstb.2010.0127.

Smith, J.H. and Mantz, J.W., 2006. Do Cellular Phones Dream of Civil War? The Mystification of Production and the Consequences of Technology Fetishism in the Eastern Congo. *In* Inclusion and Exclusion in the Global Arena. Max Kirsch and June Nash, (eds.) Pp. 71–93. New York, Routledge

Smith, J.H., 2011. Tantalus in the Digital Age: Coltan ore, temporal dispossession, and "movement" in the Eastern Democratic Republic of the Congo. *American Enthologist*, 38(1): 17–35

Solinís, G. and Bayá-Laffite, N. (*eds*.), 2011. Mapping out the research-policy matrix: a report on the outputs from the first International Forum on the Social Science-Policy Nexus. UNESCO, Paris, p.245

Stewart, C.A., Link, M., McCaulay, D.S., Rodgers, G., Turner, G., Hancock, D., Wang, P., Saied, F., Pierce, M., Aiken, R., Mueller, M.S., Jurenz, M., Lieber, M., Tillotson, J. and Plale, B.A., 2010. Implementation, performance, and science results from a 30.7 TFLOPS IBM BladeCenter cluster. *Concurrency and Computation: Practice and Experience*, 22(2): 157–174.

Stirling, A. 2013. From Sustainability, through Diversity to Transformation: towards more reflexive governance of technological vulnerability. In: Hommels, A.M.J. and W.E. Bijker. (eds.). (2013). Vulnerability in Technological Cultures: New Directions in Research and Governance. Cambridge, MA: MIT Press.

Sutherland, E., 2011. Coltan, the Congo and your cell phone: The connection between your mobile phone and human rights abuses in Africa. LINK Centre, University of the Witwatersrand, South Africa.

Svarstad, H., Petersen, L.K., Rothman, D., Siepel, H. and Wätzold, F., 2008. Discursive biases of the environmental research framework DPSIR. *Land Use Policy,* 25: 116-125.

Turner, A., Buongiorno, J., Katz, A., Zhu, S. and Li, R., 2008. Economic Incentives Exist to Support Measures to Reduce Illegal Logging. *International Forestry Review,* 10(1):74-80. 2008.

UNEP, 2012. Fifth Global Environment Outlook Report: Environment for the future we want. United Nations Environment Programme. Earthprint, Nairobi.

UNEP, 2012b. Schaefer, K., Lantuit, H., Wegener, A., Romanovsky, V.E., Schuur, E.A.G. and I. Gärtner-Roer. Policy Implications of Warming Permafrost. United Nations Environment Programme. Nairobi, Kenya.

Vogel, C., Moser, S.C., Kasperson, R.E. and Dabelko, G.D. (2007). Linking vulnerability, adaptation and resilience science to practice: Players, pathways and partnerships. *Global Environmental Change,* 17: 349–364.

Vos, M.B, Kimmons, J.E., Gillespie, C., Welsh, J. and Blanck, H.M., 2008. Dietary Fructose Consumption Among US Children and Adults: The Third National Health and Nutrition Examination Survey. *Medscape Journal of Medicine,* 10(7): 160-

Wallinga, D., 2010. Agricultural Policy and Childhood Obesity: A Food Systems and Public Health Commentary. *Health Affairs* 29(3): 405-10, doi: 10.1377/hlthaff.2010.0102.

Weichselgartner, J. and Kasperson, R.E., 2010. Barriers in the science-policy-practice interface: Toward a knowledge-action-system in global environmental change research. *Global Environmental Change,* 20(2): 266-277.

World Bank, 2009. Environmental crises or sustainable development opportunity? Transforming the charcoal sector in Tanzania. The World Bank, Washington, D.C.

7. Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia [1]

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Abstract

Urban and peri-urban agriculture (UPA) is increasingly being promoted as a multi-focal strategy for enhancing urban food security and advancing climate change adaptation and mitigation efforts in cities. The extent to which this potential can be realized is circumscribed by access to adequate land and water resources, the degree of recognition of UPA within the urban policy domain, and the ability of producers to effectively navigate the myriad risks associated with food production in urban and peri-urban environments. This paper argues that UPA faces significant interlocking stresses stemming from marginalization of land and water resources, increasing exposure to climate risks, and ineffective policies and poor governance that undermine its long-term potential to address urban food security and climate change adaptation concerns. This article examines key environmental and governance dimensions of UPA in the context of rapidly growing cities in Africa and Asia, and advances understanding of how increasing urban pressures on land and water resources, and intensifying climate risks, are undermining the resilience of UPA in the face of rapid change. The paper's findings are drawn from a series of assessments on UPA that were recently conducted in nine cities spanning West and East Africa, and South Asia.

Keywords: Urban and peri-urban agriculture; Climate change; Adaptation; Africa; South Asia; Science-Policy interface.

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7.1. Introduction

Rapid urbanization together with the extraordinary growth of cities is proceeding on a scale and at a rate that is unprecedented. Today, more than half the world's population resides in urban centers (UNDESA, 2013), and over the next several decades the pace of urbanization will accelerate. Much of this growth is expected to occur in urban centers of Africa and Asia (Montgomery, 2008; Revi et al.,

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2014; Taylor and Peter, 2014). These low and middle-income regions face significant adjustment pressures, as poverty becomes increasingly urbanized, demand for urban services swells, and cities exert greater influence on peri-urban and rural livelihoods and environments (Forster and Escudero, 2014). For the poorer segments of society, the convergence of pressures brought about by the urban transition is exacerbating existing patterns of uneven development, informality, and deeply entrenched inequality. Thus, achieving international ambitions for sustainable development (eradicating poverty and hunger) will depend to a large extent on how developing-country cities are planned, managed and governed (Jabareen, 2013; Cohen, 2006; Allen, 2003).

The multiplicity of challenges and uncertainties associated with the growing urban footprint are accentuated by emerging risks from climate change. In developing countries, urban centers are particularly vulnerable to climatic extremes due to their strongly interlocking social and environmental stresses associated with rapid growth, systemic poverty, environmental degradation, and poor governance (Revi et al., 2014; Lwasa et al., 2014; Lwasa, 2014; World Bank, 2011 a,b,c,d; De Bon et al., 2010; Zhao et al., 2010).

The concept of 'resilient cities', which is becoming increasingly prominent within the discourse on climate change adaptation, provides an important entry point for addressing urgent urban development needs while also considering longer-term implications of changes in the amplitude of risks that cities will face in the coming decades. Strategies for building urban resilience are most effective where they include a wide range of shocks and stresses, not just those attributed to climate change, and where they consider how resilience-building efforts can influence important equity issues associated with urban development (Kithiia, 2010; Leichenko, 2011; Moench et al., 2011; Satterthwaite and Dodman, 2013; Jabareen, 2013; Bahadur et al., 2013).

Concerns over urban food security are beginning to gain traction within the resilient cities and urban adaptation framework in large part because of the food price crisis that began in 2007 (Frayne et al., 2012; Revi et al., 2014). The consequences of the food price crisis continue to reverberate for the urban poor who typically devote more than half of their income to basic food purchases, and thus are highly sensitive to food price fluctuations (Cohen and Garrett, 2010; Crush and Frayne, 2010, 2011). In a number of developing-country cities, discrete episodes of social unrest, including violent protests and riots in 2008 and 2011 throughout Africa and the Middle East, coincided with large peaks in global food prices (Lagi et al., 2011; Holt Giménez and Shattuck, 2011).

Urban and peri-urban agriculture (UPA) resides within the current urban food security discourse, where it is viewed by some scholars as an important entry point for addressing both urban food security challenges as well as urban resiliency and adaptation goals (De Zeeuw et al., 2011; Dubbeling and De Zeeuw, 2011; FAO, 2012; Gerster-Bentaya, 2013; Lwasa et al., 2014). However, a central role for UPA in addressing urban food security is disputed by others who contend that UPA's importance to urban food security, especially that of the urban poor is overestimated (Battersby, 2013; Crush et al., 2010; Frayne et al., 2014; Mkwambisi et al., 2011; Webb, 2011). Recent, empirical studies on UPA's contribution to food security are few and therefore provide only a partial picture. One such study, of food security in 11 Southern African cities (Crush et al., 2012; Frayne et al., 2014), indicated that UPA had limited importance as a contributor to food security amongst poor households in these cities. Conversely, meta-analyses of UPA studies from across the developing world by Zezza and Tasciotti, 2008, 2010 described an equivocal link of UPA to urban food security whereby engagement in urban food production contributed significantly to household income and dietary diversity of the poorest

quintile in some countries yet contributed very little in others. Both sets of studies warn against looking for universal success from UPA in helping the urban poor, but both also acknowledge to varying degrees the reality and potential for UPA, embedded in a wider urban-development strategy, to contribute to more resilient urban food systems.

While the effectiveness of UPA as a means of reducing urban food insecurity remains an open question, recent empirical evidence suggests that the sector does play an important role in diversifying urban diets in cities where UPA is vibrant. This diversification is primarily achieved through the production of leafy green vegetables and other fresh produce, milk, poultry, eggs, and small livestock (Cofie et al., 2003; De Zeeuw and Dubbeling, 2009; Dossa et al., 2011; FAO, 2012; Lee-Smith, 2010; Simatele and Binns, 2008). In addition to its food provisioning attributes, UPA can potentially provide important ecosystem services related to use of urban organic waste as an input for food production, dampening of storm water runoff, biodiversity conservation, and aesthetic enhancement. Moreover, UPA has potential to shorten value chains that result in lower food costs in the informal economy and source diversity of nutrient rich foods, as well as reduced greenhouse gas emissions associated with food transport (De Bon et al., 2010; Orsini et al., 2013; Lwasa et al., 2014).

This suite of urban ecosystem services attributed to UPA has been used to advance the position that UPA can play a critical role in helping cities achieve climate change adaptation and mitigation goals as well as achieve greater overall resilience in the face of rapid social and physical changes (Dubbeling and de Zeeuw, 2011; Lwasa et al., 2014; Moglia, 2014; UN-Habitat, 2011). While UPA may indeed offer potential to strengthen urban resilience and advance adaptation efforts, the knowledge base to support this position is quite tenuous, and the sector itself faces serious threats to its sustainability that could undermine this potential.

The nature of these threats revolves around interacting drivers of population growth and rapid urbanization with the associated effects on land-use change, water resource management, environmental pollution, and climate change. Given the difficult choices and uncertainties facing long-term urban planning, promoting UPA as a resilience-building, adaptation strategy requires conclusive evidence of how UPA is faring under these intensified drivers of change and the degree to which the policy community is responding to these threats. In the developing world, and particularly Africa, UPA has been largely ignored or actively discouraged by municipal and national policy bodies (Simatele and Binns, 2008; Mkwambisi et al., 2011; Halloran and Magid, 2013). However, the historically antagonistic relationship between the urban policy community and urban agriculture is gradually shifting toward greater acceptance of UPA (Redwood, 2009 a,b; Lwasa et al., 2014).

The knowledge base pertaining to the environmental dimensions of UPA is fragmented and largely outdated, particularly in considering the rapid changes underway in urban areas. This paper provides critical insights into these environmental change dimensions through synthesizing findings from a recent assessment of UPA undertaken in nine cities across Africa and South Asia, thus helping to address this important knowledge gap. The assessments aimed to better understand critical interactions at the land–water–climate nexus that influence resilience of UPA systems in the context of rapidly growing cities of the global south that are facing a changing climate. This paper highlights important points of intersection and convergence across the nine cities, describes critical knowledge gaps, and offers potential responses that could serve to enhance the resilience of UPA.

7.2 Description of the assessment

In 2011–12, integrated knowledge assessments[2] were undertaken in nine cities to examine the state of UPA through the lens of intensifying urban pressures and increasing climate risks. A key objective of these assessments was to better understand critical issues at the land–water–climate nexus that influence the productivity and viability of UPA systems in the context of rapidly growing developing-country cities. Assessments were carried in Addis Ababa (Ethiopia); Chennai (India) Dakar (Senegal); Dar es Salaam (Tanzania); Dhaka (Bangladesh); Ibadan (Nigeria); Kampala (Uganda); Kathmandu (Nepal); and Tamale (Ghana).

A diversity of climates (humid to semi-arid) and locations (coastal to inland) were considered in selecting the cities. Additionally, consideration was given to cities where past work on UPA had been done and thus where expertise was available within the cities to carry out the assessments. The nine selected cities range from large to mega-city status except for Tamale, in northern Ghana. This size bias may require some measure of caution in considering the applicability of findings from these assessments to small and medium-size urban areas. Also, the selection of cities where past work on UPA had been done implies an importance of the UPA sector that may not be applicable to cities where the UPA sector is less vibrant.

7.2.1. Methodological approach

The assessments examined the current state of knowledge and identified knowledge gaps, as well as critical entry points for devising responses intended to strengthen UPA. Specifically, the assessments explored: (1) the historical evolution and context of UPA in each city; (2) the predominant production systems; (3) the major stresses facing UPA related to urban encroachment, water allocation, and pollution; (4) climate stresses that potentially intersect with the non-climate stresses; (5) key policy, institutional, and governance factors that influence the viability and utility of UPA; and, (6) the development of recommendations for actions that could be taken at the city level to address sustainability concerns identified and described in the assessment reports.

This paper builds on the information captured and aggregated from the nine assessments, which provides a basis upon which to consider the resilience of UPA systems, as described in Section 7.5 of this article.

The composition of the nine assessment teams varied, with some of the teams being comprised predominately of researchers from universities and research institutes, and other teams comprised of a mix of researchers, city officials and NGO practitioners (Table 7.1). The researchers on these teams had ample experience interacting with policy and practice communities so even those teams comprised of only researchers had a strong orientation toward stakeholder engagement. There was diverse disciplinary expertise across the assessment teams that included geography, agriculture (including livestock), urban planning, water resource management, environmental science, development practice, and economics.

Information gathered for the assessments came from a variety of secondary data sources, including government reports and statistical bulletins, project reports, and academic articles, that were augmented with meteorological data, spatial mapping, focus group discussions, and expert interviews.

[2] We define knowledge assessments as highly collaborative and deliberative processes for synthesizing, interpreting and organizing existing empirical information, knowledge and experience on complex issues in an integrated manner with a view toward informing policy and decision-making processes, and advancing the knowledge base (Jabbour et al., 2012).

The focus group discussions were held with farmers, and the interviews with a variety of sectoral experts and city officials with direct relevance to the assessment topic.

The development of the assessment topic and subsequent actions in carrying out the work, were consultative and highly participatory throughout. The process began with a scoping meeting at UNEP headquarters in Nairobi, Kenya in January 2011, which involved researchers working on various aspects of urban agriculture and food systems, and included representatives from the RUAF Foundation (Resource Center on Urban Agriculture), and the African Food Systems Urban Network. The Nairobi meeting resulted in further refinement of the assessment topic in preparation for regional consultative meetings held later in 2011 in West Africa, East Africa and South Asia.

The regional consultations engaged researchers, policy makers, urban planners and NGO representatives from the nine cities targeted for the assessment. The wide-ranging expertise and disciplinary perspectives of the participants was used to critically examine the assessment topic and sub-themes in the context of their respective cities. Each assessment team continued the consultative process by convening city inception meetings at the outset of their respective assessments to garner input from diverse stakeholder groups regarding relevant decision-making priorities and knowledge deficits and to identify potential sources of information for the assessment. Several of the assessment teams convened subsequent meetings with city officials and others over the course of the assessment to update them on findings and to garner additional inputs.

The consultative process that the teams undertook in engaging city-based stakeholders produced reports that differed somewhat in their emphasis and direction, depending on decision making needs and priorities of relevant city-based stakeholder groups as well as on the availability of adequate information upon which to base the assessment. For example, while the overall assessment topic dealt with both urban and peri-urban agricultural systems the city teams emphasized these systems differently; some cities gave considerable weight to both urban and peri-urban systems (e.g. Addis Ababa, Kampala, Dar es Salaam, Ibadan and Dhaka) while other cities primarily or exclusively emphasized peri-urban systems (i.e. Dakar, Tamale, Chennai and Kathmandu). The reports also emphasized different components of UPA, reflecting the relative importance of systems across the various cities. For example, urban livestock keeping featured prominently in the Kampala assessment, paddy rice and fisheries in Chennai, aquaculture in Dhaka, and irrigated vegetables in Dakar.

Table 7.1. Composition of the nine city assessment teams

City	Team composition
Addis Ababa	Researchers, city officials, NGOs
Kampala	Researchers, city officials
Dar es Salaam	Researchers
Ibadan	Researchers, city officials, NGOs
Dakar	Researchers, city officials, NGOs
Tamale	Researchers, NGOs
Dhaka	Researchers
Chennai	Researchers
Kathmandu	Researchers

7.3. Key attributes of urban and peri-urban agriculture in the nine cities

7.3.1. Urban and peri-urban agriculture: Arriving at a common definition

In the context of today's demographic transition and the acceleration toward a predominantly 'urbanized' world, researchers continue to grapple with persistent definitional difficulties between urban, peri-urban and rural environments; not least, how these systems interact. The obvious challenge is that of temporal and spatial heterogeneity: where jurisdictional boundaries vary enormously across countries and over time (Montgomery, 2008). Moreover, a deeply-entrenched dichotomy between what in actuality, is better conceived as a continuum (rather than detached zones) has given rise to mischaracterization of urban areas and a trivialization of the peri-urban transition space. As metropolitan areas continue to sprawl, there is an increasing perception that a deeper understanding of the peri-urban interface is critical for mitigating the multiplicity of stressors and uncertainties of the growing urban footprint (Simon, 2008).

Similar challenges are manifested in the agricultural context. Here, arriving at a meaningful and uniformly agreed distinction between urban and peri-urban spaces—which in large part determine the constraints and opportunities for agricultural production systems—has resulted in multiple characterizations of 'urban and peri-urban agriculture' (UPA). In the developing-country context, where informality, density, and types and patterns of land uses vary tremendously between and within metropolitan areas – the nature of peri-urban spaces are highly dynamic, both geographically and conceptually. As such, the concept of UPA has not been amenable to a single definition.

Despite inherent and persistent definitional ambiguities, at a basic level, the notion of UPA is generally acknowledged in the literature, as the production of crops, livestock agriculture, and cultivation of fish within and around metropolitan areas, for local sale and consumption (Hodgson et al., 2011). For the purposes of our analysis, the common characteristics of urban and peri-urban agriculture (UPA) include an emphasis on the production of fresh, nutrient-dense foods (leafy green vegetables, dairy, poultry, eggs, etc.) that is typically carried out on a small scale and is often opportunistic about accessing land, water, and other inputs. The UPA systems described in the nine city-level knowledge assessments fall well within this definition.

7.3.2. UPA's contribution to the urban food system

Table 7.2 describes important attributes of UPA production systems in the nine cities. These details were primarily obtained through peer-reviewed publications and city statistical reports and other secondary literature. In the case of vegetables, dairy, and eggs, the UPA contribution in most of the African cities was quite high, confirming findings of previous reports on the extent to which UPA provides nutritionally important components to urban diets (e.g. De Zeeuw and Dubbeling, 2009; Lee-Smith, 2010; Simatele and Binns, 2008.) By contrast, evidence of UPA's contribution in the South Asian cities was considerably less. However, three cities are a small sample size, thus no broader inferences about UPA's contribution to the food supply in South Asian cities can be drawn from these findings. With a few exceptions, empirical examination and quantitative information on UPA's contribution to urban food systems is outdated and fragmented, indicating the need for robustly designed, quantitative studies to update the state of knowledge with respect to UPA's contribution.

One important finding across many of the cities concerned the highly dynamic nature of the urban livestock sector. Livestock rearing including poultry, dairy, cattle, and other ruminants, provides readily available market opportunities with quick returns and income stability from relatively little

land area that can meet an increase in demand from the urban population (Guendel and Richards, 2002). Poultry production, in particular, is an important component of UPA in these cities, ranging from large-scale commercial operations to small-scale household production. Vertical chicken houses are an important response to space constraints. In two of the cities, Ibadan and Dakar, peri-urban poultry production serves as an important supply hub for their respective countries (Adelekan et al., 2014; Sy et al., 2014). In Ibadan production of chicks and eggs are traded throughout Nigeria and neighboring countries.

Table 7.2. Description of UPA systems in the nine cities.

City	Main production systems	Contribution to urban food supplies
Addis Ababa	*Urban:* Vegetables, poultry, eggs, honey, dairy, livestock. *Peri-urban:* Cereals, oil crops, vegetables, dairy, livestock	Based on 2007 estimate, 30% of vegetables (60–70% of leafy greens); 60–70% of milk; 40–60% of eggs
Kampala	*Urban:* Vegetables, cereals, dairy, livestock, poultry, eggs. *Peri-urban:* Root crops, cereals, banana, vegetables, livestock	Precise estimates lacking. Large increase in urban livestock keeping over the past decade, especially poultry
Dar es Salaam	*Urban:* Vegetables, root crops & fruits, livestock, dairy. *Peri-urban:* Fruits, cashew nuts, livestock, increasingly intensive farming practices	Based on estimates from 1997 and 2000, 90% of leafy vegetables and 60% of milk
Dakar	*Urban and peri-urban*: Intensive, commercial vegetable and fruit production, livestock	Dakar's peri-urban vegetable production provides 60% of total demand in Senegal. Based on 2000 estimate, 65% of national poultry demand supplied by peri-urban areas
Ibadan	*Urban*: Backyard vegetable and fruit production, livestock, aquaculture. *Peri-urban:* Root crops and cereal plantations, livestock, vegetable plots, aquaculture	Estimates from 2001 indicate 54% of food crops to the city supplied by peri-urban areas. Based on 2012 estimates, urban horticulture accounts for 80% of the city's vegetable supply
Tamale	*Urban:* Vegetables, ornamental horticulture, livestock. *Peri-urban:* Cereals, legumes, ornamental	No data available on UPA's contribution to the city's food supply
Chennai	Peri-urban: Paddy rice, marine-coastal fisheries, eggs, dairy cattle	No data available on UPA contribution. Most of UPA occurs in peri-urban areas where there has been a recent decline in cereal, vegetable & milk production
Dhaka	Urban: Backyard and garden cereal and vegetable crops, fruits, flowers, fish. Peri-urban: Rice, cereals, sugarcane, vegetables, tobacco, oil seeds, fruits, flowers, fish	In 2010–2011, Dhaka metropolitan area produce 9.5% of the total rice demand for the city. Estimates from 2004 indicate 7–10% of fresh fish sold in Dhaka are from peri-urban areas
Kathmandu	Peri-urban: Cereals, vegetables, oilseeds, livestock	The Kathmandu Valley produces 8% of the highly perishable vegetables consumed in the city, according to a 2012 survey

Table references: Addis Ababa – Gebremichael et al. (2014), Kampala – Sabiiti et al. (2014), Dar es Salaam – Mlozi et al. (2014), Dakar – Sy et al. (2014), Tamale – Adelekan et al. (2014), Tamale – Gyasi et al. (2014), Chennai – Nambi et al. (2014), Dhaka – Rahman et al. (2014), Kathmandu – Dixit et al. (2014).

In many of the cities, dairy and other livestock producers are facing significant pressures from the escalating cost of animal feed, the increasing constriction of available grazing land, and the absence

of government support for livestock keeping. In response to diminished and fragmented grazing lands and space constraints, dairy farmers, for example in Kampala and Dar es Salaam, have transitioned toward zero grazing, supported by 'cut-and-carry' fodder supplied from distant sources and sorted urban organic waste as a food source (Mlozi et al., 2014; Sabiiti et al., 2014). These trends are similar to what has been reported elsewhere for peri-urban livestock keepers facing diminished grazing areas (Duku et al., 2010). In three of the cities (Addis Ababa, Dar es Salaam, and Kampala), micro-credit schemes and other support from NGOs and government programs targeted to female-headed households, widows, and the elderly help mitigate some of the stresses facing urban livestock keepers, although these efforts have limited impact relative to the scope of the challenges (Gebremichael et al., 2014; Mlozi et al., 2014; Sabiiti et al., 2014).

7.3.3. UPA's contribution to livelihoods

The socio-economic status of UPA producers varies across the nine cities. High-income producers appear to be increasing in peri-urban areas of Dar es Salaam, Ibadan, and Kampala, likely in response to growing business opportunities, particularly for livestock keeping and fish rearing (Adelekan et al., 2014; Mlozi et al., 2014; Sabiiti et al., 2014). Vegetable producers generally tended to be of low- or middle-income status though there were exceptions; for example, Dakar's market-oriented vegetable production is an important economic activity for farmers across the income spectrum. In several of the cities, UPA farmers represent a broad spectrum of income classes, and a significant portion of the farmers are long-term residents who have obtained sufficient resources, networks, and other forms of social and physical capital to engage in UPA, and are not the poorest of the poor. This finding is consistent with previous studies by Dossa et al. (2011), Lee-Smith (2010), and Frayne et al. (2014). In Kampala, a series of economic and political crises in the 1970s and 1980s were an important precursor to the revitalization of UPA and it remains strongly embedded in the urban landscape today, with participation that spans income classes. This observation is consistent with other studies that have shown how urban agriculture exists partly in response to political and economic crises that spawn increased informalization of the economy (Babo, 2010; Gómez-Baggethun and Barton, 2013; Kutiwa et al., 2010; Maconachie et al., 2012).

7.4. Land and water resources for UPA

7.4.1. Policy and governance dimensions

Our analysis of the assessments reveals that diminishing access to land and water is a significant concern across all nine cities. The peri-urban dimension of UPA is under intensive pressure from urban encroachment and from increasing urban demand for water from peri-urban sources. High population growth rates in these cities are an important driver of encroachment onto peri-urban agricultural land. Additional factors exacerbating urban encroachment pressures identified across the nine assessments include the emergence of informal land markets that favor development in peri-urban areas, the erosion of traditional tenural arrangements that have safeguarded agricultural lands from development, the lack of policy frameworks for urban development and the promotion of urban renewal policies that relocate residents outward from core areas of the city (Table 3). Similar dynamics

of urban pressures on peri-urban farmlands have been described by Lynch et al. (2001), Maconachie et al. (2012), Redwood (2009 a,b), and Thuo (2013).

Urban encroachment is also exerting pressures on agriculture in the core urban areas of the nine cities. Within urban boundaries, vegetable producers and livestock keepers face increasing pressure to adopt space saving approaches to cope with increasingly crowded conditions. The assessments note that urban growth pressures on UPA also manifest in terms of waste hazards, as urban waste dumping concentrates in low lying areas and utility and transport corridors—lands considered marginal for development but that are used opportunistically by urban farmers to produce vegetable crops. Population growth in the nine cities is projected to increase sharply over the next few decades, which will exert further pressures on the land and water base.

Attempts to develop proactive policy responses have begun to emerge in some of the nine cities. For example, policy frameworks that explicitly support UPA have recently been developed in Kampala, Dar es Salaam, and Tamale; a UPA policy framework is being developed in Addis Ababa, and existing environmental preservation policies in Dakar have direct potential to be supportive of UPA. Also, urban agriculture offices within city government have been established in Addis Ababa and Kampala.

While the creation of policies favorable to UPA in some of these cities represents progress, the existence of significant gaps between policy promulgation and actual implementation calls into question the effectiveness of current policy responses. For example, in Kampala, farmers are unaware of licensing requirements for UPA and view enforcement of new rules regulating UPA as arbitrary and punitive; moreover, policies in Kampala that are ostensibly favorable for UPA are weakened when set against city efforts to crack down on informal food markets that are served by UPA (Sabiiti et al., 2014).

As noted in Table 3, our analysis of the nine assessments reveals that the lack of a coordinated response across different layers of authority is undermining efforts to protect lands used for UPA. For example, in Dar es Salaam, the assessment findings show that municipalities are not enforcing state laws meant to protect UPA and are reluctant to configure UPA into land-use planning, such as setting aside land for urban farming (Mlozi et al., 2014). In Dakar, vagueness in jurisdictional responsibilities between state level and municipal governments is hampering efforts to implement programs designed to preserve encroachment of urban settlements into environmentally sensitive areas where UPA is practiced (Sy et al., 2014); similarly, in Tamale a lack of coherency between different policy bodies and government units with respect to land-use planning in peri-urban areas has led to diminished land security for farmers (Gyasi et al., 2014). In other cities, including Kathmandu, Chennai and Dhaka, the assessments found that there are no protections for agriculture in urban and peri-urban land use planning and existing land and water-use policies directly undermine peri-urban agriculture (Dixit et al., 2014; Nambi et al., 2014; Rahman et al., 2014).

These findings underscore the degree to which ambiguities in jurisdictions, policies, and legal codes in urban and, particularly, peri-urban areas exacerbate pressures on UPA. Other studies have shown how tensions associated with these governance failures lead to increased opposition between empowered and marginalized groups over productive resources, and fragmented landscapes with negative consequences for food production, water supply, waste regulation and flood risk management (Eakin et al., 2010; Garschagen et al., 2011; Makita et al., 2011; Mbiba and Huchzermeyer, 2002; UN Habitat, 2011).

Table 7.3. Characteristics of land pressure on peri-urban agriculture in the nine cities.

City	Characteristics of peri-urban land	Policy and governance dimensions
Addis Ababa	Informal and formal settlements outpacing infrastructure development. Buffer zones along rivers being developed counter to master plan. Peri-urban farmers displaced to marginal agricultural lands	Urban renewal policies resulting in relocation of farmers to increasingly marginal lands. Lack of harmonization between relevant land administration agencies. Corruption of political processes
Dar es Salaam	Liberalization of the transportation sector and housing subsidies for civil servants encourage settlement in peri-urban areas. Emergence of an informal land market; exponential increase in peri-urban land prices driven by housing needs	Mismatch of strong policy support for UPA at the state level with a lack of action on and antagonism of UPA at the municipal level (i.e. no official demarcation of land for UPA; eviction of farmers by municipal officials)
Kampala	High housing prices in the urban core driving a quest for affordable housing in peri-urban areas. Wetland areas converted for informal settlements and providing brick making materials. Emergence of informal land market as response to inefficient formal land market	Lack of an urban planning policy, and weakly enforced laws. Lack of qualified urban planners
Dakar	Peri-urban wetland areas and forests are under heavy encroachment pressures. Flood-prone areas traditionally used for agriculture are being developed for settlements. Exponential increase in peri-urban land prices driven by housing needs	Lack of clear delineation of roles and responsibilities between state and local authorities resulting in lack of enforcement of policy framework for protecting against development in the environmentally sensitive Niayes area
Ibadan	Loss of forest reserves and prime agri-cultural land including land adjacent to wetlands. High rate of illegal settlements along river corridors that exacerbate flooding. Industrial pollution. Increasing uncertainty over whether 'idle' land will remain so or be developed contributes to residents foregoing cultivation	Traditional communal land tenure system giving way to individual titles to land, which increases farmer uncertainties over land access. Deterioration of previously dependable infrastructure, including dams. Lack of urban land-use policy frameworks
Tamale	Changes in housing arrangements from traditional compound housing to self-contained dwellings, which require more land per capita. Selling of land to developers through informal land market. Prime agri-cultural land in valley bottoms under pressure for settlements	Traditional communal land tenure system giving way to arrangements whereby chiefs able to sell land to developers. High potential for corruption by traditional authorities
Chennai	Soil and water degradation, reduced profit-ability of farming, and industrial develop-ment and housing pressures driving land-use conversion. Farmers selling water to urban consumers rather than using on crops	Tripartite Agreement of 2000 created a lucrative market for selling water rights to industrial and urban users. Farmers not holding water rights are being marginalized
Dhaka	Infilling of water bodies through unplanned urban development has diminished natural drainage systems that are in turn negatively impacting on aquaculture	Weak enforcement of existing regulations, Lack of coordination between government agencies responsible for monitoring unplanned expansion/ encroachment
Kathmandu	Prime agricultural land being lost to industrial development, brickmaking and housing in periurban areas. Haphazard and unregulated development increasing the riskiness of agriculture as access to water resources becomes less dependable	Lack of urban policy frameworks and enforcement mechanisms for construction in peri-urban areas. The Kathmandu Valley Town Development Committee deemphasizes agriculture in its recent 5-year plans

Table references: Addis Ababa – Gebremichael et al. (2014), Kampala – Sabiiti et al. (2014), Dar es Salaam – Mlozi et al. (2014), Dakar – Sy et al. (2014), Tamale – Adelekan et al. (2014), Tamale – Gyasi et al. (2014), Chennai – Nambi et al. (2014), Dhaka -- Rahman et al. (2014), Kathmandu – Dixit et al. (2014).

7.4.2. Urban pressures and climate risks

The opportunistic use of marginal lands for urban farming, which is one of UPA's important characteristics, will likely become more difficult to the extent that urban growth pressures and climate change impacts converge. Examples of such convergence in the UPA context include insecure land tenure situations that prevent investments in irrigation to cope with moisture deficit periods, and the likelihood of more extreme rainfall, associated with climate change, superimposed upon more concretized land surfaces and haphazard urban growth patterns that create flood-conducive conditions (Kenyon et al., 2008; Wheater and Evans, 2009). The following examples from cities where the UPA assessment took place illustrate how urban development pressures are increasing farmer exposure to flooding and other climate risks.

- **Dar es Salaam:** Vegetable farmers report that flooding in river valleys has increased, attributable to development, which leaves fewer channels for water to disperse. Flooding interrupts production for months at a time; farmers cope by finding other income sources or temporarily migrating back to home villages or to other cities to grow vegetables for income while waiting for flood waters to abate. Vegetable farmers who lack land tenure security do not have the incentive, nor the means, to cap wells during floods to prevent contamination of wells and groundwater from urban wastes (McLees, 2011).
- **Addis Ababa:** Farmers report that flooding has intensified, which they attribute to increased siltation caused by upstream erosion and solid waste dumping from upstream urban areas (Gebremichael et al., 2014).
- **Ibadan:** Poultry and fish producers recently experienced high losses from flooding exacerbated by illegal building in stream setback corridors, blockage of the storm water drainage system by municipal solid waste dumping, and siltation of natural drainage waterways that reduces the rate of runoff discharge (Adelekan et al., 2014).
- **Dakar:** Urban development in the dunes surrounding the Niayes ecosystem has increased runoff volumes and flooding in lowland areas where intensive vegetable production takes place. Irrigation infrastructure is in poor condition (Sy et al., 2014).
- **Kampala:** Vegetable farming adjacent to wetlands, and mostly carried out by low-income households, faces consistent threat of washout by heavy rains and flooding. Projections of high settlements rates in these marginal land areas over the next few decades indicate potential that settlement patterns will amplify future flood risks (Sabiiti et al., 2014).
- **Kathmandu:** Quarrying, brick making, and extraction of sand and gravel from riverbeds, combined with poor planning, increase hazards of flooding, landslides, and debris flow that adversely affect agricultural lands. Deterioration of irrigation delivery systems is increasing peri-urban farmers' vulnerability to extended dry periods and drought (Dixit et al., 2014).
- **Tamale:** River valley bottoms that provide good land for agriculture and that drain the city of storm water runoff are experiencing increasing urban encroachment pressures (Gyasi et al., 2014).
- **Chennai**: Sale of water rights allocated for peri-urban rice production to urban consumption reduces irrigation water availability to those farmers who do not have water rights. Deterioration of irrigation delivery systems exacerbates the impact of diminished water rights during drought periods (Nambi et al., 2014).

The impacts of flooding in these cities are likely to intensify in the coming decades to the extent that extreme rainfall events become more prevalent with climate change. Analysis of long-term temperature trends indicated a decadal warming trend in most of the nine cities, and decadal analysis of extreme rainfall events indicated a slight increase in heavy rainfall events in two of the African cities, Addis Ababa and Dakar (Gebremichael et al., 2014; Sy et al., 2014).

Groundwater salinization was identified as a critical threat in the three coastal cities where high urban demand for groundwater is contributing to saltwater intrusion into freshwater aquifers. In Dakar, irrigation water used for intensive vegetable production is becoming increasingly saline, and the surrounding Cap Vert peninsula is highly vulnerable to sea level rise (Sy et al., 2014). In Dar es Salaam, vegetable farmers reported having to curtail production during periods when irrigation water salinity is high (Mlozi et al., 2014). In Chennai, the transfer of water rights from farmer to urban consumer has accelerated groundwater extraction thus increasing the potential for saltwater intrusion, a situation that will be increasingly aggravated by sea level rise (Nambi et al., 2014).

Several of the nine city assessments explored, through surveys and focus group discussions, how urban farmers observe and perceive climate change. These perceptions included increased temperatures, especially at night, more intense and unseasonable rainfall events, stronger winds, and increased cloud cover (Table 7.4). Farmers attributed hazards such as flooding to changes in both climatic and non-climatic stresses, the latter of which including blocked storm drainage systems, unregulated settlements in environmentally sensitive areas, and land degradation. The extent to which vulnerabilities are increasing due to climate change as opposed to changes in covariate stresses that increase vulnerability to climate is not clear.

A consistent finding from across the nine cities is that climate impacts are intensifying underlying vulnerabilities that UPA systems and related livelihoods are experiencing due to urban development pressures. Two recent studies describe situations comparable to our findings presented in this article. Simatele et al. (2012) reported that UPA farmers in Lusaka, Zambia contend with significant flooding risks that are exacerbated by land degradation linked to illegal quarrying, and Aubry et al. (2012) described how rice cultivation in peri-urban Antananarivo, Madagascar has become increasingly risky once embankments were constructed in the floodplain to protect the city.

In the Lusaka study, Simatele et al. found evidence that farmers are responding by making changes to their farming systems—switching to drought tolerant crops in some areas and cultivating rice in other areas where flooding episodes are becoming more common. Similar findings of changing production practices emerged from a number of the nine cities included in our analysis. Notable examples include Addis Ababa farmers in flood prone areas switching from leafy greens to more inundation-tolerant root crops in response to increased flooding risks, peri-urban farmers in Tamale and Dar es Salaam favoring more drought tolerant crops and varieties, and farmers in peri-urban Ibadan switching from maize to cassava because of heat and water stress (Adelekan et al., 2014; Gebremichael et al., 2014; Gyasi et al., 2014; Mlozi et al., 2014). Conversely, Chennai farmers are facing difficulties in switching from rice to finger millet, as a drought mitigation strategy, because of labor shortages, lack of appropriate processing facilities and other institutional barriers to agricultural diversification (Nambi et al., 2014). Grothmann and Patt (2005) report a similar situation in Zimbabwe where high institutional barriers obstructed farmers who were trying to shift from maize to millet during low rainfall periods.

Table 7.4. Observations of climate change by UPA farmers.[a]

City	Characteristics of peri-urban land	Policy and governance dimensions
Addis Ababa	Increase in heavy and unseasonable rainfall; intensified flooding; increase in rust (fungal) diseases and insects; increase in livestock diseases during warm periods	Flooding losses and crop storage losses from heavy and unpredictable rains; flooding takes land out of production for prolonged periods
Dar es Salaam	Unseasonably high temperatures; unseasonable rains; intensified flooding; salinization of irrigation water; stronger winds; increased cloudiness, which farmers linked to increased fungal diseases	Vegetable producing season shortened due to higher temperatures, stronger winds, and increased salinity of irrigation water; flooding takes land out of production for prolonged periods
Kampala	Changes in the timing and distribution of rainfall; increase in unseasonable and heavy rainfall events; warmer temperatures, particularly at night; stronger winds; changes in cloud cover and increased hail	Soil erosion is increasing and soil water holding capacity is decreasing; heat stress of livestock is increasing, as is livestock disease prevalence; livestock shelters and crops damaged by heavy rains and hail
Dakar	Increasing salinity of irrigation water; increase in heavy rainfall; intensified flooding; unseasonably high temperatures	Floods, poor quality irrigation water, and high temperature stress results in increasingly risky vegetable production
Ibadan	Changing rainfall patterns including delayed onset of the rainy season and/or early cessation of rains; increase in heavy rainfall events and flooding; high temperatures	Two harvests of maize no longer possible, switching to cassava; reduced flowering of vegetable and pulse crops; crops and agricultural processing equipment washed away by floods; high livestock and aquaculture losses; food spoilage
Tamale	Rainfall increasingly erratic, unseasonably high temperatures, changing pattern of the Harmattan winds, increased windstorms	Drier conditions and shortened rainy season; high temperature stress at critical crop development stages
Kathmandu	Rainfall becoming increasingly erratic	Delays in the monsoon rains, which shift planting times and reduce maturation periods; weed management during low rainfall periods

Table references: *Addis Ababa – Gebremichael et al. 2014; Kampala – Sabiiti et al. 2014; Dar es Salaam – Mlozi et al. 2014; Dakar – Sy et al. 2014; Tamale – Adelekan et al. 2014; Tamale – Gyasi et al. 2014; Kathmandu – Dixit et al. 2014;* [a] No surveys of farmer observations of climate change were obtained from Dhaka or Chennai.

The strong interactions between climatic and non-climatic stresses, and the high likelihood that these stresses will intensify in the future, call into question UPA's suitability as an effective adaptation response in rapidly growing urban environments, as has been suggested by others (e.g. Dubbeling and de Zeeuw, 2011; FAO, 2012; Gerster-Bentaya, 2013; Lwasa et al., 2014). Though UPA could play a role in bolstering adaptive capacity and urban resilience, in its current form UPA's potential as an adaptation response is seriously constrained and will become increasingly so in the absence of significant policy interventions and investments to enhance its sustainability. Lwasa et al. (2014) identify several nascent initiatives toward integrating UPA and urban forestry into urban land use planning that could provide a way forward for UPA. However, it will be critical to identify and address knowledge and governance barriers to their full implementation. Moreover, significant uncertainties exist concerning interactions between land cover change and climate change in urban environments that will need to be captured in land-use planning. Section 5 explores responses that could advance such efforts.

7.4.3. Pollution and wastewater

In most of the nine cities assessed in this study, farmers rely on urban wastewater and on heavily polluted surface waters to irrigate vegetables. Increased industrialization and unregulated dumping of industrial and household wastes into urban surface waters was noted as an important threat to the safety of UPA products in Addis Ababa, Dar es Salaam, Ibadan, Dhaka, Kathmandu, and Tamale,

particularly where industry is moving rapidly into the largely unregulated peri-urban territory (Adelekan et al., 2014; Dixit et al., 2014; Gebremichael et al., 2014; Gyasi et al., 2014; Mlozi et al., 2014; Rahman et al., 2014). Risks identified from the assessments include industrial pollution of surface waters in peri-urban Ibadan that is increasing health risks associated with food production; contaminated runoff behind micro-dams increasing pollutant levels in irrigation water used for urban agriculture in Tamale; and a pilot investment in wastewater treatment for irrigated vegetable production in Dakar that has not led to a meaningful reduction in farmer reliance on untreated wastewater for irrigation.

These findings are consistent with those from other developing-country cities, where use of contaminated waters for irrigation of urban crops is a widespread practice by urban farmers. The practice entails benefits derived from providing nutrient-rich irrigation water at no or little monetary cost (e.g. Allen, 2003; Eaton and Hilhorst, 2003; Parkinson and Tayler, 2003; Qadir et al., 2010; Raschid-Sally, 2013), as well as hazards, related to biological and chemical contamination for both producers and consumers of UPA products (Birley and Lock, 1998; Qadir et al., 2010; Hanjra et al., 2012; Hofmann, 2013). The conveyance and use of wastewater is another critical concern for accountability and property rights governance (Raschid-Sally and Jayakody, 2013). To achieve more sustainable wastewater use, Hanjra et al. (2012) stress the need to create adaptive co-management processes that emphasize inclusiveness, dialogue, and conflict resolution, as well as improved inter-sectoral policy coordination.

The challenge of managing urban water resources risks will increase with the intensification of both urban development pressures and climate change. While the general contours of the health hazards associated with untreated wastewater use in UPA are well understood, understanding is still weak about how such hazards could change under a warmer and more variable climate. Farmers are expected to increase their reliance on irrigation to cope with greater evaporative losses from crops under warmer conditions; thus, there is a strong need for new information about potential shifts in risk thresholds. Increased reliance on irrigation, in the absence of measures to pre-treat wastewater and/or reduce unregulated industrial discharge into rivers, could result in heavier loading rates of heavy metals and other pollutants in soil (Rattan et al., 2005; Li et al., 2009; Hanjra et al., 2012) leading to greater potential exposure of producers and consumers to contaminated food.

7.5. Resilience of UPA, and responses that promote an urban resilience transition

7.5.1. Analysis of resilience

Drawn from the theory of ecological resilience –the ability of systems to resist, endure and recover from disturbances and perturbations–the application of urban resilience requires approaches that can harness the innovation potential of cities and that recognize inter-dependencies between ecosystem health, livelihoods and multi-functional landscapes (Leichenko, 2011; Bahadur et al., 2013; Forster and Escudero, 2014). The forces shaping UPA's resilience are largely circumscribed by the accessibility and quality of the land and water resource base that underpins UPA's productivity, as well as by several economic and sociopolitical factors that interact with the resource base. These factors include the degree of policy recognition of, or antagonism toward, UPA; the timeliness and adequacy of inputs and information that can be productively used by farmers; and, the availability of other livelihood

options that allow flexibility in responding to risks and opportunities associated with farming in urban and peri-urban environments.

The factors that shape the multi-stressor context of UPA, as described in the preceding sections, provide a basis for identifying key attributes of UPA's resilience in rapidly growing developing-country cities and for identifying critical entry points for bolstering its resilience. In Table 5, we evaluate the state of resilience of UPA across the nine cities assessed, adapting a framework developed by Tyler and Moench (2012) as a basis for considering components of systems, agents, and institutions that shape UPA. The Tyler and Moench framework views resilience in terms of the interplay among the three components: systems that contain human and environmental elements; agents that carry out actions responding to and recovering from shocks and stresses; and institutions that shape the ability and capacity of agents to act effectively.

For the purposes of this analysis, the systems are agricultural activities intermixed with residential and industrial settlements in urban and peri-urban settings, the agents are primarily though not exclusively farmers and the institutions primarily encompass those related to city-level governments and the policy frameworks in which they act. These do not represent the full sweep of systems, agents and actors that influence UPA but they are the principal ones examined in this nine-city assessment. The information contained in Table 5 demonstrates diminishing resilience of UPA in the face of significant urban development pressures, with the potential of climate change to act as a stress multiplier.

In the 'systems' category, development pressures are impinging on the flexibility and robustness of UPA, and the ability for safe failure is undermined by climate risks interacting with other non-climatic changes, such as rapid land-use conversion in urban areas. Flexibility and robustness in turn link directly to impoverished rights and entitlements and decision making for UPA, as described in the 'institutions' category. Attributes of UPA in these nine cities that have potential to support greater resilience include redundancy and diversity in the 'systems' category, and responsiveness and reorganization in the 'agents' category, though these are relatively minor contributions to resilience when set against the factors that undermine resilience of UPA.

The findings of this analysis are specific to UPA in the nine assessed cities and thus cannot be extended to other cities without careful consideration of city-specific dynamics that influence the vitality of UPA systems. However, the consistency with which urban pressures, governance failures and policy shortcoming were manifested across the nine cities suggests that this analysis could have broad applicability to other urban areas in the developing world. Sections 7.5.2–7.5.4 describe potential responses that could enhance resilience though improved risk management, more comprehensive knowledge generation, and stronger policy measures that would seek to optimize ecosystem services provided by UPA. Such efforts have the potential to also advance resilience transition in the cities themselves.

7.5.2. Enhance risk management and effective policy outcomes

City-specific recommendations from the nine knowledge assessments addressed a range of risk management priorities relating to UPA. These include improved access to productive inputs and credit, stronger links to markets and other opportunities for value-added agriculture, enhanced support from extension services, and better access to information, especially regarding weather forecasts and flood early-warning systems (Adelekan et al., 2014; Gebremichael et al., 2014; Gyasi et al., 2014; Sabiiti et

al., 2014; Sy et al., 2014). Such investments largely conform with near-term needs identified to enhance climate risk management for current, and near-term future, climate change and development challenges in rural areas (Niang et al., 2014). Achieving progress toward enhanced risk management requires a flexible and varied response. Across the nine cities, there were several recommendations to give greater agency to farmers through creating opportunities to form farmer associations, convening multi-stakeholder task forces to explore ways of addressing threats to UPA sustainability, and integrating UPA into existing policy frameworks for both food security and poverty reduction.

Table 7.5. Characteristics of UPA resilience in the nine cities examined in the UPA assessment, framework adapted from Tyler and Moench (2012).

Criteria	State of play in the nine cities
1. Systems category	
Flexibility	UPA is spatially and temporally opportunistic and innovative but that flexibility is increasingly constrained by urban growth pressures. An example of where flexibility remains strong is in some urban livestock systems (e.g. Kampala) that are transitioning to zero grazing and able to productively use urban organic wastes as a feed substitute for traditional fodder that is becoming increasingly scarce, and in the use of elevated platforms for floriculture production that reduces exposure to flooding.
Robustness	UPA is becoming less robust as competition for land and water interact with more intensive flooding, higher temperatures that limit cropping cycles, heightened pest and disease pressures, and greater difficulties in accessing adequate irrigation water. Robustness will be further diminished by future climate change; the extent this could be offset by adaptation is unclear. Robustness of UPA is likely to be further undermined by sea-level rise in coastal cities.
Redundancy, modularity and diversity	Redundancy and diversity remain sources of strength for UPA in most of the 9 cities, as evident by short value chains and high source diversity that contribute milk, eggs, poultry, vegetables, etc. to informal markets. Modularity is diminishing to the extent that agriculture on high value lands in peri-urban areas, such as those with good soils and not flood prone, is being displaced to lower quality lands.
Safe failure	At the production systems level, safe failure for UPA may be diminished where slow-onset disaster risks are punctuated by extreme events, as in the case of saline intrusion into aquifers added to increased risk of storm surges that affect freshwater sources for agriculture, or where haphazard urban planning interacts with extreme rainfall events to increase the frequency of failure in production systems, thus increasing the recovery burden. At the individual or household level, potential for safe failure is variable. For low-income producers the loss of vegetable crops to flooding diminishes safe failure whereas for middle- and high-income farmers safe failure is presumably greater to the extent that this income class has greater capital resources for diversification and recovery.
2. Agents category	
Responsiveness and Reorganization	UPA systems, given the right conditions, can be responsive to market signals that create new opportunities. Responsiveness is evident through new market opportunities that have emerged, particularly for high-income producers (e.g. in aquaculture and livestock).
Resourcefulness	Resourcefulness is circumscribed by external forces that shape robustness and flexibility (described above), and where farmers lack access to credit, timely inputs and formal information streams, as in the case of weather forecasts and early warning systems.
Capacity to learn	A capacity to learn that spans formal and informal spheres, and institutional and jurisdiction levels, is constrained by lack of farmer voice within the urban policy and planning process, poor interagency and inter-ministerial communication, an outdated and fragmented knowledge base regarding UPA's contribution to urban food systems and food security, as well as by poor understanding of how the amplitude of risks and impacts on UPA may increase with climate change. Recent efforts to formalize UPA within policy frameworks could enhance learning capacities, particularly where such policies contain strong outreach and enforcement mechanisms.

Criteria	State of play in the nine cities
3. Institutions category	
Rights and entitlements	Erosion of rights and entitlements for UPA farmer is evident through policy gaps and governance failures, lack of formal land tenure, escalating land prices and the emergence of informal land markets. Diminishing access to quality land and water, poor access to formal credit and markets, and information streams contribute to low entitlements.
Decision making	UPA is gradually gaining visibility in urban policy and planning frameworks though in many cities it is still largely ignored or actively discouraged in the policy-making realm. The lack of coherent and enforceable urban planning frameworks, and political corruption in peri-urban land allocation decisions, contribute to the invisibility of UPA in urban land use decisions.
Information	The flow of information between farmers and urban policy and sectoral planning is generally quite weak though in some of the assessed cities it is improving. Lack of access to flood early warning systems and to actionable weather forecasts was noted as an important information bottleneck. The hindrances noted in the Capacity to Learn entry above also play into poor information flow.

Our analysis suggests that more robust and responsive policy outcomes for UPA could be achieved by embedding UPA within urban resilience-building and adaptation-planning efforts, which emphasize just and accountable governance and effective coordination. For example, there are several potential links between efforts to bring UPA into a more supportive policy environment and efforts to promote community-based adaptation (CBA). The CBA approach operates at the local level in communities that are particularly vulnerable to the impacts of climate change. It focuses on empowering and strengthening the capacity of local people by implementing community-based development activities, in a highly participatory manner, building on existing cultural norms and addressing local development concerns that underlie vulnerability (Ayers and Forsyth, 2009; Dodman and Mitlin, 2013); such characteristics complement the need for greater support of UPA in the policy process.

Recognition of the need for greater inclusion of NGO and civil society coalitions in strategic planning processes for adaptive urban governance (Brinkmann et al., 2012) and for robust stakeholder platforms to empower local communities and inform policy development (Dodman and Mitlin, 2013; Prain and Lee-Smith, 2010) provide opportune entry points for UPA. However, it is important to bear in mind that the ''right'' policies are only one part of an enabling environment. Other critical enabling factors include capacity building mechanisms and financial support for relevant institutions, and a clear understanding of local-level impediments and trade-offs associated with new policies and of the solutions to such impediments (Halloran and Magid, 2013; Kithiia, 2010; Roberts et al., 2012).

7.5.3. Optimize UPA's ecosystem services

Better understanding and optimizing the multi-functionality of UPA, and quantifiably estimating ecosystem services associated with its use, are key to strengthening the sector in the face of urban encroachment and the rapidly increasing demand for non-agricultural uses of urban land and water resources (Lwasa et al., 2014; Moglia, 2014). Notable examples of ecosystem service provision from UPA that emerged through the knowledge assessments include the productive reuse of urban organic wastes for food production, and the use of wetland fringe areas and other flood-buffering lands for agriculture. The concept of urban ecosystem services has taken on greater importance as cities grapple with building resilience to a wide range of shocks and stresses in increasingly hazard-prone urban landscapes (Cilliers et al., 2014; Gómez-Baggethun and Barton, 2013; Lwasa et al., 2014; Roberts et al., 2012). Urban and peri-urban agriculture can be an important component of urban ecosystem

services, beyond food provisioning, offering opportunities to regulate water flow and moderate runoff, mitigate urban temperature extremes, and recycle wastes (Gómez-Baggethun and Barton, 2013). Such 'multi-functionality' has developed as an approach to optimize the range of positive externalities generated from agriculture that ultimately contributes to society beyond the market-based valuation of agriculture (Renting et al., 2009).

On the reverse side of these positive externalities, ecosystem disservices are recognized as an important part of the urban resilience equation, given the interlocking nature of food, water, health, energy and commerce systems within urban areas (Cilliers et al., 2014; Gómez-Baggethun and Barton, 2013). In the context of UPA, our analysis suggests that these disservices include biological and chemical contamination of food and the environment, as well as nuisances associated with livestock keeping in confined areas and zoonotic diseases. While the ecosystem services associated with UPA outweigh its disservices, the latter category deserves attention because of the potentially significant health risks associated with unregulated use of dangerous pesticides, reliance on untreated wastewater and heavily polluted surface waters for irrigation, air pollution particulates and heavy metals deposits in soils and crops, and potential for emergence of zoonotic disease outbreaks in confined areas (Agrawal et al., 2003; Binns et al., 2003; Birley and Lock, 1998; Carvalho, 2006; Galt, 2008; Lynch et al., 2001; Prajapati and Tripathi, 2008). As noted in Section 5.3 below, there is a need to better understand how health and environmental risks associated with UPA may change under warmer and more variable climate regimes.

As with other urban ecosystem services, the capacity to optimize the multi-functionality of UPA requires greater understanding of trade-offs associated with its various functions in the context of other non-agricultural demands for urban land. The concept of 'territorial sustainability' (Aubry et al., 2012) may provide a useful way of unpacking the complex issue of multi-functionality. Aubry et al. argue that where UPA can be shown to contribute a critical function, such as flood protection that cannot easily be replaced by alternative land uses, then a high territorial sustainability value for UPA can serve as a counterforce against urban expansion pressures. To be appropriate to the reality of rapidly expanding urban areas, territorial sustainability should also consider the strong linkages between urbanization, agriculture, and deforestation in situations where displacement of urban and peri-urban agriculture by urban development pushes farming further out into forests, wetlands and other environmentally sensitive areas (Brinkmann et al., 2012; Forkuor and Cofie, 2011; Vermeiren et al., 2012; Seto et al., 2010). Moreover, where known limits to such expansion exist, for example in semi-arid urban areas where absolute water scarcity prevents UPA from expanding outwards, anticipatory measures and monitoring strategies will become increasingly important to preserve farmland (Brinkmann et al., 2012).

Inclusion of UPA's territorial sustainability in urban planning requires a robust foundation of knowledge on land-use change and hydrologic functions aligned with strong governance systems and political will. In this context, stronger capacities are needed for instituting spatial planning that considers locally relevant climate and land-use scenarios, and that evaluate the potential for increased frequency of damaging floods and other impacts from extreme events under different land-use scenarios. It is important to understand where UPA can be most strategically placed to enhance flood protection and where potential food production trade-offs exist. Significant research efforts are needed to inform decision making in this arena (Aubry et al., 2012).

As noted in Section 7.5.2, efforts to strengthen capacities for urban adaptation offer an opportunity to encompass flood suppression, urban waste stream reduction and other ecosystem services of UPA, provided that governance shortcomings and institutional weaknesses are sufficiently understood and addressed. Addressing these challenges requires multilevel institutional coordination, stronger horizontal interplay across sectors and policies, better cooperation across formal and informal spheres that engage key actors, advocates, and champions, and mechanisms for enforcement of legal codes (Bahadur and Tanner, 2014, 2013; Mimura et al., 2014). Experiences gained through resilience-building initiatives, such as the Asian Cities Climate Change Resilience Network, indicate potential modalities for achieving vertically integrated problem solving (Sharma et al., 2014). The lack of these elements in the nine cities involved in the UPA assessment contributed strongly to on-going loss of high quality agricultural lands to urban development pressures that in turn diminishes the potential of UPA to support resilient, adaptable cities. The situation in these nine cities reflects planning challenges in both developing and industrialized regions, though they are often more acutely experienced in rapidly growing developing-country cities.

7.5.4. Address critical knowledge gaps

Garnering greater support for actions that enhance UPA's sustainability requires a robust evidence base to inform and support policy and action. Information about UPA is fragmented and largely out of date, as was apparent across the nine cities examined in this assessment. The lack of reliable data on the contribution UPA to urban food systems, food security, and livelihoods in cities reflects the informal nature of the enterprise and its various non-income dimensions that do not conform to official information-gathering efforts that prioritize economic indicators within the formal economy. Bringing greater prominence to UPA and positioning it squarely within the urban adaptation realm requires new research to better quantify and analyze long-standing uncertainties around UPA related to food and livelihood security, its urban economic dimensions, and its ecosystems provisioning. Moreover, embedding UPA within broader challenges facing urban food systems and food security—where and how is food produced, transported, processed, stored, marketed and consumed—would be a more robust approach than would one that focuses solely on urban food production (Battersby, 2013).

Knowledge generation on emerging global change challenges for UPA is also required. Understanding climate change impacts on UPA, such as those manifested through abiotic and biotic stress of crops and livestock, lags far behind understanding of such impacts on staple crops and extensive livestock systems in rural agricultural systems. In considering UPA, the urban context brings a unique set of challenges with respect to food production. Climate surprises may reveal new thresholds for crop and livestock components of UPA and, for that matter, the infrastructure systems that deliver food, water and energy to cities. The IPCC's recent Special Report on Climate Extremes (IPCC, 2012) estimated a substantial reduction in the return period for a 1-in-20 year heat wave event by mid-century across much of Africa and Asia, raising significant challenges for managing urban services and producing food in urban environments.

There are also important knowledge deficits with respect to how expected increases in temperature and humidity and changes in rainfall patterns could influence existing or emerging pest and disease pressures on urban crops and livestock. Understanding of interactions between climate change and agricultural pests and diseases is increasing (Anderson et al., 2004; Garrett et al., 2006; Thomson et

al., 2010; Müller et al., 2011), though not for the kinds of widespread but small-scale vegetable and livestock production systems found in urban areas of developing countries. In such systems, research lags farmer observations and knowledge of local conditions and trends. Our analysis established that pest and disease management for crops and livestock were a significant concern in many of the assessed cities (e.g. Dar es Salaam, Dakar, Kampala, Addis Ababa, and Ibadan). Farmers succumb to advice and advertisements for highly toxic pesticides—many of them banned in northern regions—with little or no extension service-advice on the dangers involved with the use of these compounds, the suggested timing or rates for applications to have optimal effect, or measures to protect the user or surrounding areas from the toxic effects (Binns et al., 2003; Carvalho, 2006; Galt, 2008). While integrated pest management and organic vegetable production are being promoted on a project-by-project basis there is no sustained support for this effort.

Knowledge gaps also exist with respect to how a warming climate could affect waterborne pathogens and parasites. This particular concern is relevant to the widespread use of wastewater in UPA. Studies by Mas-Coma et al. (2008, 2009) and Karvonen et al. (2010) detected increased activity of common human parasites under elevated water temperatures, suggesting a potential for increased risk in a warming climate, though there have been no studies done to specifically understand the health hazards dimensions across the variety of UPA systems that rely on untreated or inadequately treated wastewater.

7.6. Conclusions

This is the first study that the authors are aware of in which UPA is examined through the dual lens of urban and climate pressures. The paper was able to draw from a large array of developing region cities to describe important governance dimensions of UPA that have relevance for urban adaptation and resilience.

Overall, UPA across these nine cities remains reasonably vibrant even though the sector faces significant interlocking stresses stemming from marginalization of land and water resources and climate risks that could diminish its resilience and undermine its long-term sustainability. Many of these stresses are slow onset in nature (i.e. changes in land and water access, increasing pollution loads, etc.) and the impacts of these stresses on UPA are largely invisible within the formal urban planning and policy milieu.

Urban pressures are currently a much larger driver of vulnerability in UPA systems than is climate change. However, climate stresses are likely to intensify as urban areas, and the UPA systems embedded within them, become increasingly vulnerable to impacts stemming from storm surges and sea level rise, heat stress, heavy rainfall, flooding, drought, and water scarcity associated with climate change. Farmers across the assessed cities consistently noted the degree to which the increasing urban footprint is reducing thresholds for damaging floods that impact their production systems. Such circumstances call into question UPA's potential to play a significant role in advancing urban adaptation and resilience-building efforts, absent significant policy interventions and investments to strengthen the sector, and indicate the need for proactive measures to help UPA itself adapt to increased risks from climate change and other pressures.

Urban policies are slowly beginning to recognize urban food production as a legitimate and desirable activity yet substantial hurdles remain in moving these nascent policy efforts toward formalized

actions that produce substantive benefits for UPA. Weak governance—manifested as vague and overlapping institutional mandates, lack of clear delineation of functions and responsibilities between national, state and local governments, lack of incentives for cross-sectoral coordination among relevant government ministries, and corruption in the allocation of land—presents significant impediments to progress on the policy front. Sharply rising land prices, the emergence of informal land markets, and erosion of traditional tenural arrangements compound these governance failures.

Responding effectively to the broad swath of sustainability challenges facing UPA, as well as the uncertainties associated with climate and other global change drivers, requires a comprehensive approach to risk management that encompasses resiliency. Strategies to enhance the resilience of UPA will not succeed based solely on the merit of its food producing function given the substantial demand for non-agricultural uses of land and water in rapidly expanding cities. The greatest opportunities for bolstering UPA instead lie in understanding and optimizing the multi-functionality of UPA in increasingly hazard prone urban landscapes. The ability to optimize multi-functionality requires greater understanding of the various tradeoffs associated with the environmental services to urban areas provided by UPA, notably flood dampening, set against other non-agricultural demands for land in urban areas. Such knowledge will become increasingly critical as urban areas contend with increasing flooding and other risks stemming from haphazard urban development interacting with climate change.

7.7 References

Adelekan, I., Olajide-Taiwo, L., Ayorinde, A., Ajayi, D., Babajide, S., 2014. Building urban resilience: assessing urban and periurban agriculture in Ibadan, Nigeria. *In:* Padgham, J., Jabbour, J. (Eds.), United Nations Environment Programme (UNEP) Nairobi, Kenya.

Agrawal, M., Singh, B., Rajput, M., Marshall, F., Bell, J.N.B., 2003. Effect of air pollution on peri-urban agriculture: a case study. *Environ. Pollut.* 126 (3), 323–329.

Allen, A., 2003. Environmental planning and management of the peri-urban interface: perspectives on an emerging field. *Environ. Urban.* 15 (1), 135–148.

Anderson, P.K., Cunningham, A.A., Patel, N.G., Morales, F.J., Epstein, P.R., Daszak, P., 2004. Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends Ecol. Evol*. 19 (10), 535–544.

Aubry, C., Ramamonjisoa, J., Dabat, M.H., Rakotoarisoa, J., Rakotondraibe, J., Rabeharisoa, L., 2012. Urban agriculture and land use in cities: an approach with the multi-functionality and sustainability concepts in the case of Antananarivo (Madagascar). *Land Use Policy* 29 (2), 429–439.

Ayers, J., Forsyth, T., 2009. Community-based adaptation to climate change. *Environ.: Sci. Policy Sustain. Dev.* 51 (4), 22–31.

Babo, A., 2010. Sociopolitical crisis and the reconstruction of sustainable periurban agriculture in Abidjan. Côte d'Ivoire. Afr. *Stud. Review.* 53 (3), 101–120.

Bahadur, A.V., Tanner, T., 2013. Policy climates and climate policies: analysing the politics of building urban climate change resilience. *Urban Clim.* 7, 20–32.

Bahadur, A., Tanner, T., 2014. Transformational resilience thinking: putting people, power and politics at the heart of urban climate resilience. *Environ. Urban.* 26 (1), 200–214.

Bahadur, A., Ibrahim, M., Tanner, T.M., 2013. Characterising resilience: unpacking the concept for tackling climate change and development. *Clim. Dev.* 5 (1), 55–65.

Battersby, J., 2013. Hungry cities: a critical review of urban food security research in sub-Saharan African cities. Geogr. *Compass* 7 (7), 452–463. Binns, J.A., Maconachie, R.A., Tanko, A.I., 2003. Water, land and health in urban and peri-urban food production: the case of Kano, Nigeria*. Land Degrad. Dev.* 14 (5), 431–444.

Birley, M.H., Lock, K., 1998. Health and peri-urban natural resource production. *Environ. Urban.* 10 (1), 89–106.

Brinkmann, K., Schumacher, J., Dittrich, A., Kadaore, I., Buerkert, A., 2012. Analysis of landscape transformation processes in and around four West African cities over the last 50 years. Landsc. *Urban Plan*. 105 (1), 94–105.

Carvalho, F.P., 2006. Agriculture, pesticides, food security and food safety. Environ. Sci. Policy 9 (7), 685–692.

Cilliers, S., du Toit, M., Cilliers, J., Drewes, E., Retief, F., 2014. Sustainable urban landscapes: South African perspectives on transdisciplinary possibilities. *Landsc. Urban Plan.* 125, 260–270.

Cofie, O.O., van Veenhuizen, R., Drechsel, P., 2003. Contribution of urban and peri-urban agriculture to food security in sub-Saharan Africa. Africa session of 3rd WWF, Kyoto, p. 17.

Cohen, B., 2006. Urbanization in developing countries: current trends, future projections, and key challenges for sustainability. *Technol. Soc*. 28 (1), 63–80.

Cohen, M.J., Garrett, J.L., 2010. The food price crisis and urban food (in) security. *Environ. Urban.* 22 (2), 467–482.

Crush, J., Frayne, B., 2010. The Invisible Crisis: Urban Food Security in Southern Africa. AFSUN, Cape Town.

Crush, J., Frayne, B., 2011. Supermarket expansion and the informal food economy in Southern African cities: implications for urban food security. *J. South. Afr. Stud.* 37 (4), 781–807.

Crush, J., Hovorka, A., Tevera, D., 2010. Urban food production and household food security in Southern African cities. Urban

Food Security Series. No. 4. African Food Security Urban Network. Cape Town, South Africa, p. 33.

Crush, J., Frayne, B., Pendleton, W., 2012. The crisis of food insecurity in African cities. J. Hunger *Environ. Nutr.* 7 (2–3), 271–292.

De Bon, H., Parrot, L., Moustier, P., 2010. Sustainable urban agriculture in developing countries. A review. Agron. *Sustain. Dev*. 30 (1), 21–32.

De Zeeuw, H., Dubbeling, M., 2009. Cities, Food and Agriculture: Challenges and the Way Forward. RUAF Working Paper No. 3.

De Zeeuw, H., Van Veenhuizen, R., Dubbeling, M., 2011. The role of urban agriculture in building resilient cities in developing countries. *J. Agric. Sci.* 1–11. doi.org/10.1017/S0021859610001279.

Dixit, A., Subedi, Y., Rai, R.D., Aryal, M., Chhetri, M.R., Wenju, R., 2014. Building Urban Resilience: Assessing Urban and Periurban Agriculture in Kathmandu, Nepal. In: Padgham, J., Jabbour, J. (Eds.), United Nations Environment Programme (UNEP), Nairobi, Kenya.

Dodman, D., Mitlin, D., 2013. Challenges for community-based adaptation: discovering the potential for transformation. *J. Int. Dev*. 25 (5), 640–659.

Dossa, L.H., Abdulkadir, A., Amadou, H., Sangare, S., Schlecht, E., 2011. Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. *Landsc. Urban Plan.* 102 (3), 197–206.

Dubbeling, M., de Zeeuw, H., 2011. Urban Agriculture and climate change adaptation: ensuring food security through adaptation. In: Resilient Cities. Springer, Netherlands, pp. 441–449.

Duku, S., van der Zijpp, A.J., Howard, P., 2010. Small ruminant feed systems: perceptions and practices in the transitional zone of Ghana. *J. Ethnobiol. Ethnomed*. 6, 1–11.

Eakin, H., Lerner, A.M., Murtinho, F., 2010. Adaptive capacity in evolving peri-urban spaces: responses to flood risk in the Upper Lerma River Valley, Mexico. *Glob. Environ. Change* 20 (1), 14–22.

Eaton, D., Hilhorst, T., 2003. Opportunities for managing solid waste flows in the periurban interface of Bamako and Ouagadougou. *Environ. Urban.* 15 (1), 53–64.

FAO, 2012. Growing Greener Cities in Africa: First Status Report on Urban and Peri-urban Horticulture in Africa. Food and Agriculture Organization of the United Nations, Rome, Italy, p. 116.

Forkuor, G., Cofie, O., 2011. Dynamics of land-use and land-cover change in Freetown, Sierra Leone and its effects on urban and peri-urban agriculture – a remote sensing approach. *Int. J. Remote Sens.* 32 (4), 1017–1037.

Forster, T., Escudero, A.G., 2014. City Regions as Landscapes for People, Food and Nature. EcoAgriculture Partners, on behalf of the Landscapes for People, Food and Nature Initiative, Washington, DC.

Frayne, B., McCordic, C., Shilomboleni, H., 2014. Growing out of poverty: does urban agriculture contribute to household food security in Southern African cities? In: Urban Forum. Springer, Netherlands, pp. 1–13.

Frayne, B., Moser, C., Ziervogel, G., 2012. Understanding the terrain: the climate change, assets and food security nexus in Southern African cities. In: Frayne, B., Moser, C., Ziervogel, G. (Eds.), Climate Change, Assets and Food Security in Southern African Cities. Earthscan, Oxford, UK, pp. 1–34.

Galt, R.E., 2008. Beyond the circle of poison: significant shifts in the global pesticide complex, 1976–2008. *Glob. Environ. Change* 18 (4), 786–799.

Garrett, K.A., Dendy, S.P., Frank, E.E., Rouse, M.N., Travers, S.E., 2006. Climate change effects on plant disease: genomes to ecosystems. *Annu. Rev. Phytopathol.* 44, 201–221.

Garschagen, M., Renaud, F.G., Birkmann, J., 2011. Dynamic resilience of peri-urban agriculturalists in the mekong delta under pressures of socio-economic transformation and climate change. In: Stewart, M.A., Coclanis, P.A. (Eds.), Environmental Change and Agricultural Sustainability in the Mekong Delta. Springer, Netherlands, Dordrecht, pp. 141–163.

Gebremichael, D., Gebremichael, A.T., Worku, A., Abshare, M.W., Habtemariam, Y.M., Balcha, G., Gebremichael, Dereje, 2014. Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Addis Ababa, Ethiopia. In: Padgham, J., Jabbour, J. (Eds.), United Nations Environment Programme (UNEP), Nairobi, Kenya. www.start.org/upa/addis_ababa.pdf.

Gerster-Bentaya, M., 2013. Nutrition-sensitive urban agriculture. *Food Sec.* 5 (5), 723–737.

Gómez-Baggethun, E., Barton, D.N., 2013. Classifying and valuing ecosystem services for urban planning. *Ecol. Econ.* 86, 235-245.

Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. *Glob. Environ. Change* 15 (3), 199–213.

Guendel, S., Richards, W., 2002. Peri-urban and Urban Livestock Keeping in East Africa – A Coping Strategy for the Poor. Scoping Study Commissioned by DFID. Natural Resources Institute, Aylesford.

Gyasi, E.A., Fosu, M., Kranjac-Berisavljevic, G., Mensah, A.M., Obeng, F., Yiran, G.A.B., Fuseini, I., 2014. Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Tamale, Ghana. In: Padgham, J., Jabbour, J. (Eds.), United Nations Environment Programme (UNEP), Nairobi, Kenya. www.start.org/upa/tamale.pdf.

Halloran, A., Magid, J., 2013. Planning the unplanned: incorporating agriculture as an urban land use into the Dar es Salaam master plan and beyond. *Environ. Urban.* 25 (2), 541–558.

Hanjra, M.A., Blackwell, J., Carr, G., Zhang, F., Jackson, T.M., 2012. Wastewater irrigation and environmental health: implications for water governance and public policy. *Int. J. Hyg. Environ. Health* 215 (3), 255–269.

Hofmann, P., 2013. Wasted waste—disappearing reuse at the peri-urban interface. *Environ. Sci. Policy* 31, 13–22.

Holt Giménez, E., Shattuck, A., 2011. Food crises, food regimes and food movements: rumblings of reform or tides of transformation? *J. Peas. Stud.* 38 (1), 109–144.

IPCC, 2012. Summary for policymakers. In: Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M., Midgley, P.M. (Eds.), Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1–19.

Jabareen, Y., 2013. Planning the resilient city: concepts and strategies for coping with climate change and environmental risk. *Cities* 31, 220–229.

Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Singh, A., Levy, M.A., Schwarzer, S. 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development* 3, 5-24. https://doi.org/10.1016/j.envdev.2012.05.002

Karvonen, A., Rintamäki, P., Jokela, J., Valtonen, E.T., 2010. Increasing water temperature and disease risks in aquatic systems: climate change increases the risk of some, but not all, diseases. *Int. J. Parasitol.* 40 (13), 1483–1488.

Kenyon, W., Hill, G., Shannon, P., 2008. Scoping the role of agriculture in sustainable flood management. *Land Use Policy* 25 (3), 351–360.

Kithiia, J., 2010. Climate change risk responses in East African cities: need, barriers and opportunities. *Curr. Opin. Environ. Sustain.* 3, 1–5.

Kutiwa, S., Boon, E., Devuyst, D., 2010. Urban agriculture in low income households of Harare: an adaptive response to economic crisis. *J. Hum. Ecol.* 32 (2), 85–96.

Lagi, M., Bertrand, K.Z., Bar-Yam, Y., 2011. The food crises and political instability in North Africa and the Middle *East. Soc. Sci. Res.* Netw. http://dx.doi.org/10.2139/ssrn.1910031.

Lee-Smith, D., 2010. Cities feeding people: an update on urban agriculture in equatorial Africa. *Environ. Urban.* 22 (2), 483–499.

Leichenko, R., 2011. Climate change and urban resilience. Curr. Opin. Environ. Sustain. 3 (3), 164–168.

Li, P., Wang, X., Allinson, G., Li, X., Xiong, X., 2009. Risk assessment of heavy metals in soil previously irrigated with industrial wastewater in Shenyang. *China. J. Hazard. Mater*. 161, 516–521.

Lwasa, S., 2014. Managing African urbanization in the context of environmental change. *INTERdisciplina* 2 (2), 263–280.

Lwasa, S., Mugagga, F., Wahab, B., Simon, D., Connors, J., Griffith, C., 2014. Urban and peri-urban agriculture and forestry: transcending poverty alleviation to climate change mitigation and adaptation. *Urban Clim.* http://dx.doi.org/10.1016/j.uclim.2013.10.007.

Lynch, K., Binns, T., Olofin, E., 2001. Urban agriculture under threat: the land security question in Kano, Nigeria. *Cities* 18 (3), 159–171.

Maconachie, R., Binns, T., Tengbe, P., 2012. Urban farming associations, youth and food security in post-war Freetown, Sierra Leone. Cities 29, 192–200.

Makita, K., Fèvre, E.M., Waiswa, C., Bronsvoort, M.D.C., Eisler, M.D.C., Welburn, S.C., 2011. Population-dynamics focused rapid rural mapping and characterisation of the peri-urban interface of Kampala, Uganda.

Mas-Coma, S., Valero, M.A., Bargues, M.D., 2008. Effects of climate change on animal and zoonotic helminthiases. *Rev. Sci. Tech.* 27 (2), 443–457.

Mas-Coma, S., Valero, M.A., Bargues, M.D., 2009. Climate change effects on trematodiases, with emphasis on zoonotic fascioliasis and schistosomiasis. *Vet. Parasitol.* 163 (4), 264–280.

Mbiba, B., Huchzermeyer, M., 2002. Contentious development: peri-urban studies in sub-Saharan *Africa. Prog. Dev. Stud.* 2 (2), 113–131.

McLees, L., 2011. Access to land for urban farming in Dar es Salaam, Tanzania: histories, benefits and insecure tenure. *J. Mod. Afr. Stud. 49* (4), 601–624.

Mimura, N., Pulwarty, R.S., Duc, D.M., Elshinnawy, I., Redsteer, M.H., Huang, H.Q., Nkem, J.N., Sanchez-Rodriguez, R.A., 2014. Adaptation planning and implementation. *In:* Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 869–898.

Mkwambisi, D.D., Fraser, E.D., Dougill, A.J., 2011. Urban agriculture and poverty reduction: evaluating how food production in cities contributes to food security, employment and income in Malawi. *J. Int. Dev.* 23 (2), 181–203.

Mlozi, M.R.S., Lupala, A., Chenyambuga, S.W., Liwenga, E., Msogoya, T., 2014. Building urban resilience: assessing urban and peri-urban agriculture in Dar es Salaam, Tanzania. In: Padgham, J., Jabbour, J. (Eds.), United Nations Environment Programme (UNEP), Nairobi, Kenya. <www.start.org/upa/dar_es_salaam.pdf>.

Moench, M., Tyler, S., Lage, J. (Eds.), 2011. Catalyzing Urban Climate Resilience: Applying Resilience Concepts to Planning Practice in the ACCCRN Program (2009–2011). Institute for Social and Environmental Transition, International.

Moglia, M., 2014. Urban agriculture and related water supply: explorations and discussion. *Habitat Int*. 42, 273–280.

Montgomery, M.R., 2008. The urban transformation of the developing world. *Science* 319 (5864), 761–764. http://dx.doi.org/10.1126/science.1153012.

Müller, C., Cramer, W., Hare, W.L., Lotze-Campen, H., 2011. Climate change risks for African agriculture. *Proc. Natl. Acad. Sci*. 108 (11), 4313–4315.

Nambi, A.A., Rengalakshmi, R., Madhavan, M., Venkatachalam, L., 2014. Building Urban Resilience: Assessing Urban and Periurban Agriculture in Chennai, India. In: Padgham, J., Jabbour, J. (Eds.). United Nations Environment Programme, Nairobi, Kenya. www.start.org/upa/chennai.pdf.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014. Africa. In: Barros, V.R., Field, C.B., Dokken, D.J., Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199–1265.

Orsini, F., Kahane, R., Nono-Womdim, R., Gianquinto, G., 2013. Urban agriculture in the developing world: a review. *Agron. Sustain. Dev*. 33 (4), 695–720.

Parkinson, J., Tayler, K., 2003. Decentralized wastewater management in peri-urban areas in low-income countries. *Environ. Urban.* 15 (1), 75–90.

Prain, G.L., Lee-Smith, D., 2010. Urban Agriculture in Africa: What Has Been Learned? Springer, New York, pp. 13–35.

Prajapati, S.K., Tripathi, B.D., 2008. Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution. *J. Environ. Qual.* 37 (3), 865–870.

Qadir, M., Wichelns, D., Raschid-Sally, L., McCornick, P.G., Drechsel, P., Bahri, A., Minhas, P.S., 2010. The challenges of wastewater irrigation in developing countries. *Agric. Water Manage.* 97 (4), 561–568.

Rahman, A., Nabi Nurun, A.K.M., Amin, S.A.M., Abu Syed, M., Rahman, S., Hossain, P.R., Rahman, M.H., Hossaine, S.M.M., Mirza, M., 2014. Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Dhaka, Bangladesh. In: Padgham, J., Jabbour, J. (Eds.). United Nations Environment Programme (UNEP), Nairobi, Kenya. www.start.org/upa/dhaka.pd.

Raschid-Sally, L., 2013. City waste for agriculture: Emerging priorities which influence agenda setting. *Aquat. Procedia* 1, 88–99.

Raschid-Sally, L., Jayakody, P., 2013. Drivers and characteristics of wastewater agriculture in developing countries. Results from a global assessment. IWMI

Rattan, R.K., Datta, S.P., Chhonkar, P.K., Suribabu, K., Singh, A.K., 2005. Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agric., Ecosyst. Environ.* 109 (3), 310–322.

Redwood, M., 2009a. Introduction. In: Redwood, M. (Ed.), Agriculture in Urban Planning. Generating Livelihoods and Food Security. Earthscan, London, pp. 1–20.

Redwood, M. (Ed.), 2009b. Agriculture in Urban Planning: Generating Livelihoods and Food Security. Earthscan.

Renting, H., Rossing, W.A.H., Groot, J.C.J., Van der Ploeg, J.D., Laurent, C., Perraud, D., Stobbelaar, D.J., Van Ittersum, M.K., 2009. Exploring multifunctional agriculture. A review of conceptual approaches and prospects for an integrative transitional framework. *J. Environ. Manage*. 90 (Suppl 2), S112–S123.

Revi, A., Satterthwaite, D., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R.B., Pelling, M., Robert, D., Solecki, W., Gajjar, S.P., Sverdlik, A., 2014. Towards transformative adaptation in cities: the IPCC's Fifth Assessment. *Environ. Urban*. 26 (1), 11–28.

Roberts, D., Boon, R., Diederichs, N., Douwes, E., Govender, N., McInnes, A., McLean, C., O'Donoghue, S., Spires, M., 2012. Exploring ecosystem-based adaptation in Durban, South Africa ''learning-by-doing'' at the local government coal face. *Environ. Urban*. 224, 167–195.

Sabiiti, E.N., Katongole, C.B., Katuromunda, S., Sengendo, H., Basalirwa, C.P.K., Atukunda, G., Nambuubi, S.K., 2014. Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Kampala, Uganda. In: Padgham, J., Jabbour, J. (Eds.). United Nations Environment Programme (UNEP), Nairobi, Kenya. www.start.org/upa/kampala.pdf.

Satterthwaite, D., Dodman, D., 2013. Towards resilience and transformation for cities within a finite planet. *Environ. Urban.* 25 (2), 291–298.

Seto, K.C., Sánchez-Rodríguez, R., Fragkias, M., 2010. The new geography of contemporary urbanization and the environment. *Annu. Rev. Environ. Resour.* 35, 167–194.

Sharma, D., Singh, R., Singh, R., 2014. Building urban climate resilience: learning from the ACCCRN experience in India. *Int. J. Urban Sustain. Dev.* 6 (2), 1–21.

Simatele, D.M., Binns, T., 2008. Motivation and marginalization in African urban agriculture: the case of Lusaka, Zambia. In: *Urban Forum,* 19(1). Springer, Netherlands, pp. 1–21.

Simatele, D., Binns, T., Simatele, M., 2012. Urban livelihoods under a changing climate: perspectives on urban agriculture and planning in Lusaka, Zambia. *J. Hum. Dev. Capabil.* 13 (2), 269–293.

Simon, D., 2008. Urban environments: issues on the peri-urban fringe. Annu. Rev. Environ. Resour. 33, 167–185.

Sy, M., Khouma, M., Diagne, M.O., Dial, M.L., Diop, O., Niang, I., Badiane, N.Y., Niang, Y., Ndong, M.S.G., 2014. Building Urban Resilience: Assessing Urban and Peri-urban Agriculture in Dakar, Senegal. In: Padgham, J., Jabbour, J. (Eds.). United Nations Environment Programme (UNEP), Nairobi, Kenya. <www.start.org/upa/dakar_en.pdf> and <www.start.org/upa/dakar_fr.pdf>.

Taylor, A., Peter, C., 2014. Strengthening Climate Resilience in African Cities: A Framework for Working with Informality. Draft Report. African Center for Cities.

Thomson, L.J., Macfadyen, S., Hoffmann, A.A., 2010. Predicting the effects of climate change on natural enemies of agricultural pests. *Biol. Control* 52 (3), 296–306.

Thuo, A.D.M., 2013. Exploring land development dynamics in rural–urban fringes: a reflection on why agriculture is being squeezed out by urban land uses in the Nairobi rural–urban fringe? *Int. J. Rural Manage.* 9 (2), 105–134.

Tyler, S., Moench, M., 2012. A framework for urban climate resilience. Clim. Dev. 4 (4), 311–326.

UNDESA, 2013. World Population Prospects: the 2013 Revision. United Nations Department of Economic and Social Affairs, Population Division. New York.

UN-Habitat, 2011. Cities and Climate Change: Global Report on Human Settlements. United Nations Human Settlements Programme. Earthscan, London, p. 279.

Vermeiren, K., Van Rompaey, A., Loopmans, M., Serwajja, E., Mukwaya, P., 2012. Urban growth of Kampala, Uganda: pattern analysis and scenario development. *Landsc. Urban Plan.* 106 (2), 199–206.

Webb, N., 2011. When is enough, enough? Advocacy, evidence and criticism in the field of urban agriculture in South Africa. *Dev. South. Afr.* 28 (2), 195–208.

Wheater, H., Evans, E., 2009. Land use, water management and future flood risk. *Land Use Policy* 26, S251–S264.

World Bank, 2011a. World Development Indicators. <http://data.worldbank.org/indicator/>.

World Bank, 2011b. Introduction: cities and the urgent challenges of climate change. In: Hoornweg, D., Freire, M., Lee, M.J., Bhada-Tata, P., Yuen, B. (Eds.), Cities and Climate Change: Responding to an Urgent Agenda. World Bank, Washington, DC.

World Bank, 2011c. World Development Indicators 2011: Part 2. World Bank, Washington, DC.

World Bank, 2011d. Guide to Climate Change Adaptation in Cities. The International Bank for Reconstruction and Development and the World Bank, Washington, DC.

Zezza, A., Tasciotti, L., 2008. Does urban agriculture enhance dietary diversity? Empirical evidence from a sample of developing countries. In: Paper Prepared for Presentation at the 12th EAAE Congress 'People, Food and Environments: Global Trends and European Strategies', Gent (Belgium), 26–29 August, p. 5.

Zezza, A., Tasciotti, L., 2010. Urban agriculture, poverty, and food security: empirical evidence from a sample of developing countries. *Food Policy* 35 (4), 265–273.

Zhao, J., Dai, D., Lin, T., Tang, L., 2010. Rapid urbanisation, ecological effects and sustainable city construction in Xiamen. Int. J. *Sustain. Dev. World Ecol.* 17 (4), 271–272.

8. Conclusions

8.1 Summary and discussion of findings

This thesis is motivated by the underlying assumption that achieving sustainability, globally, will require—among other things—fundamental and deliberate changes in our knowledge production systems, including a vastly improved orientation toward societal concerns and collective action, and crucially, new norms for meaningful engagement with the solution-space. To this end, the six core chapters of the thesis examine how past and existing contexts, configurations and limitations of the scientific assessment enterprise interact with international decision-making, including goal-setting efforts, and, ultimately, prospects for advancing future global sustainability governance.

The six core chapters of this dissertation explore this overarching theme from different perspectives, each addressing one or more of the following specific research questions.

1. How have integrated scientific assessments evolved over the past four decades? How do the current reform debates relate to their historic development?
2. How has the scientific assessment enterprise shifted towards a policy focus, and why?
3. What practical lessons can be drawn from developing and analyzing tools for knowledge aggregation on policy analysis, building on and required for use in scientific assessments?

The following subsections summarize the main findings of the six core chapters (8.1.1 – 8.1.3) and synthesize their contributions to the overarching theme (8.1.4). Emphasis is placed on the constraints and opportunities for advancing more explicit engagement with solution pathways and pragmatic reflections on rethinking the decision-support function of integrated assessments. Section 8.2 reflects on the theoretical underpinning and the concepts, methods and approaches employed in this thesis to guide the retrospective analyses and ensure its rigor. The outlook in Section 8.3 offers some final reflections, general conclusions and personal remarks on evolving the role and future direction of scientific assessment in a global sustainability governance perspective, and finally, it considers ideas for further research.

8.1.1 Expert knowledge and governance: The rise and stall of scientific assessments

In the five intervening decades since the UN Conference on the Human Environment in Stockholm, nation states have constructed an intricate web of international regimes, commitments and institutional arrangements that together form the basis of a global governance system for confronting and coping with the manifestations of environmental threats and planetary changes. As Chapter 2 shows by means of an ex post analysis of international goal-attainment over this period, sustained progress has only been realized in less than five per cent (i.e. of the 90 goals evaluated). Moreover, given current trajectories, most internationally-agreed goals are unlikely to be fulfilled and/or achieve a significant measure of success within their respective commitment periods.

Meanwhile, environmental conditions continue to degrade at an alarming pace, pressing on limits of subsistence and common-pool resources—and thereby exacerbating existing vulnerability, poverty, and food insecurity (Gupta and Ekins, 2019).

The analysis in Chapter 2 points to several institutional and operational obstacles that have hindered the achievement of internationally agreed environmental goals and that continue to interfere with the adoption of integrated approaches, long-term perspectives and transnational cooperation that are needed for goals to gain traction and become more successful (not less) with the passage of time. For example, many of these goals are built around non-legally binding instruments and voluntary participation, reinforcing a tendency to establish implementation arrangements that lack substance, codification and specificity in order to entice broad support (i.e. optimizing the number signatories). Moreover, the metrics for their associated targets are often aggregated to align with global narratives (e.g. enhanced sustainability), with little attention to practical modalities to downscale international ambitions into domestic and subnational policy pathways, or, response options to incentivize action.

Similarly, the goal-setting processes themselves—which are internationally negotiated and typically characterized by pluralistic and competitive approaches, at least initially, are flawed. They consistently lack coherent strategies to consider and effectively navigate cross-scale interactions. Environmental and socioeconomic problems (and solutions) in complex coupled systems, meanwhile, play out over different spatial, temporal and jurisdictional scales. Yet internationally-agreed goals are scarcely framed in a way that reflects the nuances of the interacting systems they seek to manage. The formulation of the SDGs and their Tier I and II indicators are a notable exception, insofar as the attempt to apply integrated policy analysis and systems thinking in their development. And still, the framework lacks the mechanisms to anticipate multiscale tradeoffs and integrate synergistic policies into national planning; or, a reliable means to measure domestic 'inputs' (pledged investments) against 'outputs' (national progress). These in-built deficiencies shed new light on the interaction between expert knowledge and intergovernmental processes, and the potential effectiveness of well-informed global governance arrangements for sustainability in the 21st century (see section 8.1.4).

Integrated scientific assessment, as it emerges from the chapters of this dissertation, have become deeply emmeshed in the institutional challenges and dynamics of the international decision-making apparatus for sustainability. At a general level, the present analysis suggests a widening incongruence and tension between scientific knowledge production systems and their ability to interact and cope with the growing complexity of international regime performance and governance arrangements.

As evidenced in Chapters 2, 3 and 4, the prevailing conditions and assumptions which gave rise to the need for consensual expert knowledge aggregation at the international level—vis-à-vis integrated scientific assessments—have changed significantly in the last four decades. One of the main findings that emerged from this research is the substantial increase in the epistemic and institutional/ process complexity that contemporary scientific assessments must contend with. The results in Chapter 4 show how over time, the formal objectives and negotiated scope (i.e. the agreed breadth and nature of ambition) for assessments has proliferated and become much more diffuse. In other words, assessments are being pulled in many different directions, and, are expected to address a widening set of functions. Furthermore, given that different objectives are developed and negotiated by different stakeholders, often in isolation, they tend to result in directives that are at odds with each other, or, incompatible. Meanwhile, the potential attainment of one objective frequently influences the development and effectiveness of other objectives, and, in return, is also influenced by its relationship to the overarching mandate and normative function (e.g., enhanced transnational policy leaning and methodological constraints on linking ex-ante and ex-post policy appraisal).

The results of the present analysis, however, show no evidence of any deliberate prioritization or ranking of such objectives for scientific assessments—against their respective primary mandates—thereby leaving the relative importance of each objective open for interpretation. Consequently, broadening the scope of attention with no clear alignment to both the function and prevailing narratives, has served to diminish the intensity of analyses, create confusion and friction among experts, and, perhaps most crucially, expose assessment processes to being diverted and arguably subsumed by peripheral issues.

The results in Chapters 4 and 5 also suggest that assessments have become far more preoccupied with the obligation to account for and demonstrate procedural legitimacy—with a notable increase in objectives that speak to a formularization of rules and social practices about the openness and 'quality' of production processes. Conversely, the results indicate that disproportionately fewer objectives pertain to the substance and scope of the content, or, how it is shaped. In recent years, for example, some of the largest assessments including the IPBES, GEO and IPCC continue to invest an increasing share of their resources on developing disclosure and transparency procedures (e.g. author selection, conduct procedures, review processes, information sharing protocols, creative commons and open source standards etc.). While these remain important, they have hugely increased administrative and operational costs and continue to detract the available resources and intellectual capital (i.e. experts' time) for advancing conceptual frameworks and analytical tools to respond to evolving knowledge needs.

The results of this research also find a notable diverge from first-generation assessments, including early iterations of the UNEP/NASA-led *Scientific Assessment of Ozone Depletion* (1985-1991) and the first three assessments reports of UNEP's flagship *GEO* process (1997-2002)—whose objectives and mandates where almost exclusively concerned with content development. Consequently, many contemporary assessment processes have inadvertently become complicit in their methodological inertia. This is consistent with recent scholarship on the urgent need to evolve a new generation of tools (e.g. bottom-up scenarios, big-data meta-analysis methods, recursive dynamic modelling) to enable improvements in the distillation and utility of assessment knowledge, particularly in the area of analyzing and structuring the much needed climate policy information (Pierre et al., 2019; Haas, 2017; Minx et al., 2017; Lemoiney and Rudikz, 2016).

The rapid and exponential growth in scientific literature and relevant data and source materials has also given assessment processes other immediate issues with which to contend. Advancements in environmental science and global change research, compounded by the increasingly multi-scalar and multidimensional nature of information, has served to complicate what was already an inherently demanding and complex task. As shown by the results, all assessments examined, without exception, have experienced a significant upsurge in peer-reviewed literature and data sources (e.g. 13-fold increase for IPCC and 10-fold for GEO) and, relatedly, markedly higher citation-to-content ratios. What has also emerged from this research, however, is an inverse relationship between the volume and velocity of available information versus the capacity of existing assessments and their knowledge-aggregation systems to cope. This is consistent with conclusions and bibliometric analysis of Minx et al., (2017) showing a rapid decline in the number of references in successive IPCC assessment reports in proportion to the available relevant literature on climate change.

The proliferation of assessment objectives and scope, against the vast and accelerated accumulation of peer-reviewed literature (and data) appears closely linked to the significant increase in assessment lengths over time, as shown in this research. Successive iterations of IPCC and GEO reports, for example, have seen nearly five and sevenfold increases in lengths respectively, since their inception. A similar trend can be seen in comparing most non-recurring or periodic assessment reports over time. The increasingly voluminous quality of integrated scientific assessments has long been the subject of criticism in the reform debates. Many observers argue that streamlining and simplifying assessment information will improve readability, utility, and potentially help circumvent the emergent crisis of coherence across the scientific assessment landscape (Hulme, 2010; Stocker and Plattner, 2014; Griggs, 2014). Meanwhile, the digital revolution is creating new challenges for assessments; reshaping how knowledge production interacts with issues of language, dissemination, social learning and power (Slaughter, 2017; Schwab, 2017; Jensen and Campbell, 2018; Luers et al., 2019).

Beyond the surge in available information, findings from Chapters 4 and 5 suggest that assessment narratives and framings continue to be designed with the belief that more information will change peoples' minds and that more granular data on risk exposure, for example, will alleviate political inertia—when empirical evidence suggests otherwise (e.g. Sturgis and Allum, 2004; Beck et al., 2014; Simis et al., 2016). In fact, recent anecdotal and observational evidence in scholarly research indicate that some of the most impactful and explicitly ingested or utilized assessments (and/or findings) are those characterized by concision, simplicity, and highly visualizable parameters that are both dynamic and directly connected to ongoing choices and actions (Beck et al., 2014; Rowe et al., 2014; Mach and Field, 2017; Alcamo, 2017; Pearce et al., 2018). For example, the annual UNEP *Emissions Gap Report*—a very succinct, solutions-oriented assessment that sets out principles and indicative measures to help policymakers design effective policies to drive innovation—is among the most frequently accessed and consistently government-cited assessments produced by UNEP (as of December 2019). The production of the *Emissions Gap Report,* incidentally, has benefited both from a consistent and restrained set of objectives, and, a longstanding propensity for experimenting with methodological approaches including, the use of more dynamic communication tools (e.g. see Hsu et al., 2019; Christensen and Olhoff, 2019; Höhne et al., 2019). These attributes however, including selectivity and reflexivity, as this research has found, are the exception not the rule, for contemporary assessments.

Based on these considerations, this thesis concludes that in the absence of explicit guidance or stricter measures on the development of objectives as well as concerted efforts to modernize knowledge aggregation systems, many scientific assessment processes could soon be besieged by their own mandates, unwieldy bulk and methodological deficiencies. Moreover, there is a pressing need to set-up parameters to revisit the decision-support function of integrated assessments, and critically assess whether current resources are aligned with existing and future demands (see Section 8.1.2).

8.1.2 Sink, swim or fly: A reorientation toward solutions

The second part of this dissertation explores whether and how the scientific assessment enterprise, over time, has shifted towards a stronger policy focus; and why. In the first instance, the main finding here points to a demonstratable reorientation occurring over the last decade towards the pursuit of policies and solutions. Moreover, this dissertation establishes clear lines of evidence for an emerging

reversal in the functional and conceptual practice of traditional scientific assessments; where the focus has shifted away from dissecting problems, and, progressively towards evaluating management pathways and tangible options to mitigate risks and address degradation. The analysis presented in Chapters 3 and 4 suggest that this trend is gaining momentum and that the dominant modalities, outputs and expectations of contemporary scientific assessments increasingly, and more explicitly, align with decision-support functions. This is reflected in both their design features (i.e. objectives and organizing frameworks) and their actual content and underlying findings—where text analysis was used to map linguistic repertoires and the proportions of narratives and source materials that are explicitly or implicitly connected to response options. The analysis presented Chapter 4 indicates that contemporary assessments place increasing emphasis on future outlooks, response strategies, action-oriented narratives, and to varying degrees, public policy analysis relative to analyzing the biophysical and ecological problems underlying global environmental challenges.

While some of these variants and attribute-shifts can be observed from analyzing the contents and structural framings of scientific assessments, others remain much harder to quantify empirically. Investigating and understanding the expectancy and attribution patterns (i.e. the underlying factors driving these changes), for example, are extremely challenging to test and/or measure. The analysis presented in this thesis, thus, triangulates both quantitative and qualitative findings from surveys, focus groups and retrospective metadata analysis to investigate the supply-driven versus demand-driven dynamics for solutions (see Section 8.2).

Contrary to what many scholars and practitioners have conjectured, the results of this thesis indicate a growing desire on the part of decisionmakers and political actors (not just independent experts) for policy analysis and integrative response options. As illustrated in Chapter 4, discernable changes have been both institutionalized (i.e. through authorizing mandates and formal objectives) but have also manifested informally through more subversive means. In the latter case, this was reflected in the analysis of government-negotiated scoping processes and informal guidance for UNEP assessments, as well as the analysis of reform deliberations on the Future of the IPCC— initiated by the Bureau in 2014—that explicate a clear desire by member states for a deeper and more substantive engagement with the solutions space; despite subsequent actions to the contrary (e.g. recommendations to revisit the Working Group structure facilitate greater policy relevance are not reflected in the AR6 Cycle). Implicit demand for reframing assessment processes and the shifting emphasis towards decision-support functions, also surfaced in the interviews where key respondents within the policymaking segment, expressed frustration that some of the world's leading thinkers and scientific resources are occupied with helping boundary organizations and society quantify exposure, rather than mitigate environmental threats.

At the same time, the results of this thesis shed light on the institutional context and complex political oscillation within the decision-making sphere between demand and tolerance. In other words, the prevailing disinclination to accept (or approve) certain outcomes of solutions-orientated analysis, and particularly the evaluation of policy performance, despite increasing instances where precisely that, is being requested. The analysis here finds that these tensions—which as other scholars note are evident in the intergovernmental processes for negotiating '*summaries for policymakers*'— (e.g. Stavins, 2014; Chan et al., 2016; Gerard et al., 2017; Riousset et al., 2017) are embedded in a highly dynamic, multifaceted context with inherent tradeoffs. The reconciliation of these tradeoffs, crucially, is subject to changing political settings (including policy cycles) that are neither anchored to a single

ideology, or, contrary to what others have argued (e.g. Cash et al., 2003; Gauchat, 2012; Mach and Fields, 2017), beholden to the pursuit of political neutrality and knowledge inclusivity.

Rather, this research suggests that more inclusive arrangements in contemporary assessments, while essential, have not necessarily led to greater credibility, salience or legitimacy of knowledge systems, or, a more robust science-policy interface. Given that societal issues are so politically polarized these days, there is a tendency to assume that every contentious issue that breaches the international collective consciousness and elicits the pursuit of alternative pathways must, at its root, be a fight between factual ("scientific") concepts and normative value-judgements. However, as the analysis in Chapter 5 illustrates, the assumption of this polarization oversimplifies the actual dynamic at work. For one thing, it falsely assumes that there is no way to systematically reconcile diverging viewpoints, or rationally deliberate the inherent entanglements of facts and values at the science-policy interface. Moreover, this polarization serves to perpetuate and entrench dissonance in the assessment world with respect to what constitutes suitable 'scientific advice', often conflating policy responses with political prescriptions, thereby inciting a false dichotomy between viable alternatives (e.g. energy policy in the United States). As Edenhofer and Minx (2014, p.38) describe, in negotiating the IPCC's *Summary for Policymakers*[1] a crucial opportunity for informed debate on rational mitigation responses was lost, because government parties failed to agree on a "reasonable way to analytically distinguish scientific analysis from potential political and legal interpretations".

These dynamic tensions and highly polarized debates at the science-policy interface obscure the ability of boundary organizations to appropriately restructure and advance institutional as well as conceptual processes and seize the full potential of scientific assessments: Informing and thereby influencing international governance and domestic decision-making (Section 8.1.4). On the other hand, they have also exposed the need to broaden the basis for dialogue. Important steps have already been taken, for instance, to normalize the conversation on reconciling the entanglement of facts and values in ex post policy evaluations. The findings of this thesis, however, underscore the need to evolve a new set of tools and frameworks to accelerate this learning, catalyze the convergence and divergence of knowledge (on solutions), and, provide a reliable and defensible means for integrating values in social scientific research. None of these challenges is insurmountable. But addressing them will require deliberate attention from decisionmakers and the scientific assessment community, and the collective resolve to deviate from the path that assessment-making is on today—resituating the enterprise toward solutions.

8.1.3 Analysis of tools and cases with practical application for future assessments

Building on the reflections and conclusions of the previous sections regarding the shifting orientation of scientific assessments, the final core chapters of this dissertation (i.e. Chapters 6 and 7) illustrate, among other things, how the way assessments are produced can affect the nature of knowledge and its utility. Here, the results and analysis offer practical insights and lessons from developing and analyzing tools for knowledge aggregation on policy analysis, building on and required for application in scientific assessment processes going forward.

[1] Summary for Policymakers for the Working Group III contribution to the IPCC's Fifth Assessment Report released in 2014.

The findings from Chapter 6 challenge the conclusions from Chapters 3 and 4 by showing as proposed by Moss (2016), that there is need to rethink the current knowledge deficit model and the prevailing assumption that decisionmakers require more comprehensive information with high confidence levels before they can act, and/or engage and thereby narrow the 'usability' gap.

Through a participatory application of an adapted technique called Kiviat diagramming presented in Chapter 6, the findings suggest that intuitive visualization tools can serve as a simple but effective means to engage non-specialist audiences, and communicate complex coupled human-environment interactions in assessment processes. Moreover, the analysis demonstrates how two-way exchanges among assessment experts and practitioners ('producers') and the wide spectrum of decisionmakers ('users') on tradeoffs and synergies can be enabled with simple bottom-up approaches. The strategic use of such basic techniques—as employed experimentally in the GEO-5 process—can also foster an accessible and deeper mutual understanding (between experts and non-experts) on policy assessment knowledge, and specifically, in linking scientific analysis with policy narratives. Crucially, the findings in Chapters 6 and 7 also suggest that the uptake of, and engagement with, policy information may be inhibited by a lack of decision support processes—basic as they may be. These processes can assist decisionmakers and assessment users in the interpretation and differentiation of uncertainty and risk and, at the same time, provide guidance to experts on how the communication of response pathways (and associated levels of confidence) can be better characterized to relate to local contexts and ongoing decisions. Given the impetus for solutions, the use of intuitive visualization techniques as a knowledge-intermediary tool, can serve to catalyze policy learning, explore futures and thereby inspire new ways to frame and inform choices.

The analysis presented in Chapter 6 adds to a growing body of research which suggest that improved mechanisms for bottom-up (i.e. participatory) interactive explorations of futures, can help produce assessment narratives in a more reflective or anticipatory manner so that policy interventions are framed in more tractable ways that offer specific moments, modes and loci for action (e.g. Mach and Field, 2017; Pereira et al., 2019). Building on these considerations, the findings in Chapter 7 further illustrate how contemporary scientific assessment processes (beyond the reports) can serve as an effective platform to facilitate (and incorporate) two-way interactions and cross-sectoral unity—at local, regional and international levels—through informal but systemic learning on the solutions for specific issues. The use of retrospective frameworks and ex-post analysis to evaluate key policies against a range of factors, as presented in Chapter 7, was perceived by local decisionmakers (e.g. municipal planners and city managers) as a practical tool to improve the formulation of assessment framings in a way that relates to local realities, and, to help anticipate unforeseen circumstances that can influence the viability and efficacy of potential interventions.

With respect to the overarching theme of this thesis, the findings suggest that despite challenges, effective policy analysis and aggregations of policy performance, particularly at the subnational level, can facilitate important mutual learning processes on solutions and viable policy pathways to help advance the prospects for a new political economy of sustainability. While the most pressing and complex environmental challenges are seemingly local in their impacts, they are often driven, if not ostensibly, by cross-scale interactions and transnational phenomena. Therefore, response options need to be rooted in the potential to optimize integration across boundaries (and the imperative to be synergistic). However, as the analysis in Chapter 7 illustrates, there is also a point at which integration has diminishing returns. In other words, too much complexity and too many variables can

result in interventions that are overdetermined, and/or, perceived as impractical and detached from the inherent local realities and constraints on decision-making. Helping decisionmakers navigate this difficult space and ingest the learnings of ex post policy evaluations (e.g. to inform future pathways), thus, require tools that are both intuitive and attuned to the increasingly decentralized and polycentric landscape of policy responses.

8.1.4 Can scientific assessments advance global sustainability governance?

The international sustainability governance debate, beyond the global climate discourse, has been a powerful equalizer to the perils of unchecked globalization. Scientific assessments of the past decades have no doubt played a crucial role in effectively exposing, among other things, environmental threats and the underlying drivers of change. Together with the multilateral apparatus for the environment, scientific assessments, it can be argued, have helped bring a measure of predictability, stability, and order to transnational issues—not least on climate change, stratospheric ozone depletion and loss of biodiversity. However, the production and transmission of this knowledge base alone has not been able to rise to challenge of redressing these urgent and complex problems. Moreover, as the analysis in this thesis illustrates, many of the structures, norms and institutional parameters currently in place for scientific assessments—that invariably govern their conduct—are limited in the extent to which they can enable and influence domestic policy development or guide specific actions needed to avert transnational crises (or planetary-scale changes).

The interaction between expert knowledge and multilateral processes has changed significantly since the first scientific assessments were produced in the mid-1970s when the concepts of environmental sustainability and international governance were in their infancy. At that time, expert inputs were drawn from a relatively narrow collection of isolated Western academic voices—often detached from policy processes—thus, reflecting only partially the plurality of perspectives, values and transnational dynamics now entwined in the process of globalization. Today, domestic conditions (i.e. economic, environmental and social wellbeing) are shaped, to an ever-greater degree, by occurrences abroad. Meanwhile, escalating geopolitical tensions in the 21st century, and the rising social tensions within countries—as citizens question their relationship with the ruling elite—further complicate a bifurcated and decentralized system of global governance and knowledge-governance interactions (Abbott, 2012; Biermann and Pattberg, 2012). To a certain extent, this is illustrated by the growing polarization at the international science-policy interface, as observed in Chapters 3 and 4, and the mismatch between the types of knowledge being demanded, and, that which is tolerated.

Calls for crucial changes to our knowledge production systems—some already underway—stress the need for new frameworks better equipped to address these emergent challenges (e.g. Van der Hel and Biermann, 2017; Van der Hel 2016; Wesselink et al., 2013). The ability of assessments to generate scientifically robust and defensible information that can inform decisions and difficult choices amidst increasingly contested and uncertain futures, as illustrated in Chapter 5, require new approaches for managing dissent, controversy and ambivalence. Furthermore, as proposed by Van der Molin (2018), enabling well-informed governance goes beyond managing the interface between knowledge and governance, but also cultivating the capacity and proclivity for more reflexive modes of governance—and the strategies by which these are achieved. These assertions are consistent with the analysis in Chapter 7 which suggest that assessment processes that facilitate interactive and deliberative learning

on reflexive governance arrangements are more likely to enable conditions to support the practical application (or willingness to engage) policy evaluations. Furthermore, this thesis finds that interactive bottom-up approaches that can bring together disparate actor groups to foster mutual understanding, and, that can ultimately promote integration and engagement on both ends of the producer-user-knowledge spectrum, have an important role to play in strengthening the interface between science and policy for global sustainability.

But can the shift towards explicit and contextualized engagement with policy performance and the solution-space benefit efforts to guide and advance global sustainability governance? Based on the findings of this thesis, there is a compelling case, that it can.

As our understanding of social and environmental crises deepens, it is increasingly clear that many pervasive issues cannot be analyzed, confronted or resolved in isolation (Haas et al., 2001). Similarly, no single actor group or nation state, acting alone, can be effective. The multidimensional nature of governance arrangements, political institutions and international networks in today's hyperconnected world have made international cooperation essential. As illustrated in this thesis, increased global connectivity and geopolitical interdependence has rendered nation states far more susceptible to policies and activities outside their jurisdiction that influence their relationship with the interacting systems they seek to navigate: economic globalization, migration, trade and capital flows, climate change, disaster risk etc. Moreover, as evidenced in the adoption and early implementation of the SDGs, a better understanding of the interactions, interdependencies and co-evolutionary pathways to achieve collective goals will, among other things, require enhanced policy integration (UNEP, 2019). This thesis finds that integrated scientific assessments that engage in multi-dimensional both ex ante and ex post policy evaluations can help decisionmakers anticipate indirect effects across different policy domains (e.g. fiscal, monetary, health policy etc.), and cope with inter and intra-jurisdictional interactions.

The increasingly intertwining roles of science, politics and technology have blurred the traditional boundaries between sectors—with a less direct governance role for nation states and a wider role for civil society, private enterprise and other non-state actors. Particularly within the environmental sustainability domain, as shown by Arts (2006), political power is becoming more diffused in the global system—as recently evidenced in the international climate debate. This is not to suggest that state sovereignty is incompatible with international progress for solving difficult environmental problems. But rather, as the analysis in this thesis suggest, there may be a compelling need to change the incentive structures for global governance to generate new coalitions and incentives for transnational cooperation and multi-actor responses. It is within this emerging narrative, as reflected in the 2030 Agenda for Sustainable Agenda, that the shift to solutions-oriented assessments—including the institutional and epistemic transformations that such a change would necessitate—could help advance knowledge foundations, improve the conditions for political compromise, and, ultimately create more durable and productive domestic policies for global sustainability.

These considerations, alongside the overarching findings that emerge from this thesis lead to three main conclusions. First, scientific assessments have not kept pace with the shifting institutional and political context in which they are embedded, and that gave rise to their historical function. Second, rigorous scientific assessments can be much more valuable in the role of evaluating response options and informing solution pathways than the context of an endless cycle of incremental problem analysis.

Specifically, the actualization of international regimes and multilateral agreements (vis-à-vis domestic interventions) can be informed by a robust and scientifically rigorous analysis of potential choices, for instance, cross-sectoral policy integration; an interdependent mix of financial resources; technology development and transfer; inclusive, distributive and equitable emissions trading systems including effective carbon pricing mechanisms; and the establishment of enabling institutional and national policy conditions. And lastly, demand-driven solutions-oriented scientific assessments can help the multilateral system converge to present a united front to achieve global sustainably, by reasserting the authority of science and expert advice in global governance.

8.2 Reflections on concepts and methods

This dissertation investigates the historical origins, role and coevolving orientation of integrated scientific assessments and the political context in which they are embedded. The research aims to provide original contribution by elucidating the limitations, constraints and prospects for these integrated systems to guide and advance global sustainability governance.

This research is theoretically informed by sustainability science, an emerging inter- and trans-disciplinary field of study that seeks to understand the fundamental character of relationships and interactions among and between social systems, the natural environment and global processes; and, crucially, how these dynamics affect the pursuit of sustainability (Kates et al., 2001; Clark and Dickson, 2003; Matson et al., 2016). The conceptual foundations of the nascent discipline of sustainability science are particularly relevant here: reasserting the influence and epistemic authority of science, which, as several scholars have argued, has become increasingly estranged from the international discourse and global agenda for sustainable development (Kates et al., 2001; Turner et al., 2003; Ziegler and Ott, 2011; Miller et al., 2014). Sustainability scientists place emphasis on advancing scholarship and practice simultaneously thereby creating a dynamic link between knowledge and action (Clark, 2007). This, together with the explicit attention given to social learning processes, real-world problem solving and working across boundaries—between institutions, disciplines, and socio-political realities (McGreavy et al., 2013)—makes *sustainability science* and its critical framework well suited to examining the interaction between integrated scientific assessments and emerging global political order.

8.2.1 Employing a mixed-methods research approach

The overall research design and specific methods and techniques employed for this dissertation include a triangulation of data, analyses and reflective observation, and, engage a deliberate combination of appropriate qualitative and quantitative methods across the various phases of the research process (i.e., conceptualization, data collection, analysis and inference stages).

Given the research interest of this dissertation—understanding complex interactions between coevolving social processes—and the interdisciplinary and retrospective nature of the questions under examination, a mixed-methods approach was seen to be most appropriate. The concept of mixed-methods research has emerged alongside quantitative and qualitative approaches as one of the three major research methodology paradigms. The approach is broadly characterized by the systematic integration, or mixing, of quantitative and qualitative data, and the use of suitable techniques from

multiple approaches, concurrently, within a single investigation (Tashakkori and Teddlie, 1998). The basic premise rests on the notion that such empirically-driven integration can yield more comprehensive and balanced (or more unbiased) data and insights about social phenomena than discrete quantitative and qualitative data collection and analysis (Maxwell and Loomis, 2003; Tashakkori and Teddlie, 1998; Mertens, 2003; Johnson and Onwuegbuzie, 2004; Creswell and Clark, 2011; Venkatesh et al., 2013).

Ultimately, the objective of mixed-methods research which acknowledges the unique advantages and limitations of both qualitative and quantitative methodological paradigms, is to draw from the strengths and minimize the weaknesses of each in pursuit of a single investigation. An expanding body of scholarship in the social and behavioral sciences, including the fields of sustainability science, political ecology and human geography—where research has become highly interdisciplinary and dynamic—has embraced the mixed-methods paradigm and demonstrated its value and legitimacy (e.g., Creswell et al. 2008; Koteyko et al., 2013; Lund et al., 2015; Timma et al., 2015; Cuevas, 2016). This has been precipitated, in part, by the realization that methodological pluralism can help facilitate multi-perspective explorations and help neutralize potential biases (Tashakkori and Teddlie, 2003; Leech and Onwuegbuzie, 2009).

Notably, a tendency towards the mixed-methods approach can be observed in research involving direct experiential observation where researchers' relationships (and/or interactions) with the phenomena being studied is of crucial significance (Onwuegbuzie and Leech, 2004). This same challenge was an important consideration in the overarching research design for this dissertation given that the analysis was heavily supported by observation and direct experience with (and access to) some of the assessment processes being studied. Creswell and Clark (2011) make a compelling argument that the adoption of mixed-methods research, when undertaken effectively, can facilitate more nuanced investigations of social phenomena, limit the biases of researchers and strengthen the validity of their findings. This seminal body of work, together with research on the philosophical theory and procedures of mixed-methods was the basis for selecting and applying the approach (Reichardt and Rallis, 1994; Tashakkori and Teddlie, 1998; Leech and Onwuegbuzie, 2009).

Throughout this dissertation, the use of multiple approaches, in parallel, was central in navigating the different lines of evidence used to triangulate data and corroborate findings with experience. In Chapter 2, a combination of quantitative and qualitative data was used to map various biophysical trends against an *ex post* evaluation of international environmental goal attainment, which then drew on qualitative techniques to conceptualize narratives and examine correlations between goal-setting approaches and implementation constraints. Moreover, adopting the mixed-methods approach for examining the phenomena of how integrated assessments and their political contexts coevolved, and why, helped elucidate important overlaps and key path dependencies between organizational design choices, objectives and shifts in assessment mandates over time. In Chapter 3, quantitative content analysis of the occurrence and proliferation of objectives over a four-decade period was augmented with a qualitative analysis of open-ended interview responses which among other things, focused on examining participants' perceptions and experiences on the role and influence of objectives.

Similarly, quantitative evaluations and comparative analysis of metadata on other assessment attributes, including source materials, key messages, the composition and distribution of participants, citations, and bibliometrics were paired with qualitative data—derived from document analysis and

interviews—and analyzed using practices of grounded theory and constant comparative techniques (Strauss and Corbin, 1998). The combination of both qualitative and quantitative data types helped provide validation for each other, and, in multiple instances, helped mitigate biases in the interpretation of results from the interviews (Chapters 3, 4 and 5). It also fostered a deeper understanding of certain inconsistencies within and between datasets. For example, interpreting seemingly contradictory findings for demand for greater (or lesser) emphasis on, and engagement with, the solution-space in scientific assessments (Chapters 2, 3 and 4).

8.2.2 Data sources and specific methods of analysis

The analysis and findings presented in the core chapters of this dissertation are based on multiple lines of evidence from different data types. A combination of primary and secondary data derived from a wide range of sources including 99 semi-structured interviews, a survey questionnaire, two focus groups, extensive literature and document review and metadata-analyses form the empirical backbone of this research.

An extensive dataset (or catalogue), bringing together comparable metadata for 20 scientific assessments—spanning the period of 1977 to 2015—was developed specifically for this thesis and together with the interviews, serve as the primary conduit through which insights were derived (particularly for chapter 3, 4 and 5). To the best of my knowledge, this is the first such effort to generate and assemble a dataset of this kind. Crucially, the analysis in this dissertation was also corroborated by observation and experiential data, from direct involvement with large-scale integrated scientific assessment processes (a more detailed elaboration of these specific methods can be found in Sections 3.6, 4.9 and 4.10 of this dissertation).

Two distinct data analysis methods were employed for studying the various qualitative data and metadata collected and synthesized for this dissertation. Grounded theory analysis was used to gather, organize and analyze the interview transcript data (Chapters 3, 4 and 5); while quantitative content analysis was used to transform and visualize observations from the survey questionnaire (Chapter 3 and 4), and contextualize and quantify the interpretations of documents and textual data that comprise much of the metadata catalogue (e.g., authorizing mandates, scope, objectives, source materials, operating budgets etc. *see Section 3.6*).

Grounded theory, developed by Strauss and Corbin (1967), is now one of the most widely used methodologies to collect and analyze qualitative data. The approach involves an iterative, constant comparison process, where each interpretation and finding is contrasted against existing findings as it emerges from the data analysis. As such, the process enables the researcher to inductively explore and develop latent social patterns and structures rooted or *grounded* in observation (Strauss and Corbin, 1998). Grounded theory draws on the principles of symbolic interactionism, a central tenet of which is that peoples' understanding and shared interpretations of social definitions, or meaning, occurs through interaction between individuals; the socialization process (Fendt and Sachs, 2008).

In addition to bringing structure and rigor to the analysis of the interview data for this thesis, grounded theory also informed the interview protocol and the refinement of a *conditional topic guide* which included a pre-developed set of generative questions, probes and prompts—organized around eight clustered areas of investigation (Table 8.1). The questions themselves were not intended to be either

static or confining, but rather helped guide the exploration of multiple conceptual relationships and theories, and, the eventual reflective coding matrix (see Sections 3.6 and 4.10).

Insights that emerged from the initial rounds of analysis and throughout the interview phase, were used to refine, test and modify the conditional questions in subsequent iterations. By the completion of the interview phase which took place over a 30-month period (between August 2013 and February 2015) a total of 37 revisions or iterations of the guide were logged. Interview data were tabulated under clustered themes to facilitate comparison and interpretation using Max-QDA software and the constant comparative technique (Strauss and Corbin, 1998; Ritchie and Spencer, 2002).

A defining characteristic of the grounded theory approach that lent itself to the inductive nature of this investigation, is that theories and multiple conceptual relationships evolve during the research process through a continuous interplay between analysis and data collection. This allowed for the discovery and elaboration of information—that was important to participants—but not previously thought of as pertinent during the initial research design. The iterative and inductive approach also helped facilitate the triangulation of important insights arising from the comparative metadata-analyses from the 20 large-scale assessments (which took place in parallel), as well as observations from the targeted focus groups. A belated refinement of two specific probing questions, for example, allowed new insights to emerge that helped explain and compliment findings and conclusions on the correlations between increasing complexity of contemporary assessment tasks, greater demands and rising expectations, and the uninhibited (unchecked) proliferation of objectives and scope overtime.

Table 8.1 – Conditional topic guide used to inform the semi-structured interviews

Clustered question areas/ lines of investigation	**No. of probing questions**
Background, scene-setting: general experience, motivation to engage	3
1. Impact, Objectives and Context: direct/indirect impact channels	6
2. Stakeholders engagement: methods, engagement processes, profiles	4
3. Means and Obstacles: institutional, personal challenges	3
4. Policy appraisal: engagement, approach, methods, challenges	4
5. Multi-scalar issues: decision-making support, organizing frameworks	4
6. Divergent Viewpoints: broad areas of disagreement, dynamics, conflicting interests	4
7. Reflecting: shifting orientation, political context, exogenous factors	3
8. Future role of assessments: key design, procedural aspects, motivation, ambition	3

Quantitative content analysis was the main methodological tool employed to systematically extract, categorize, evaluate and quantify textual information and data that comprised much of the metadata catalogue. The use of the method and its various applications and techniques was largely informed by the seminal works of Krippendorff (2004) and Schreier (2012). For the purpose of this dissertation, two distinct but related modes of content analysis were applied. In the first instances, a branch of content analysis called *conceptual analysis* was used as a measurement tool to essentially determine the presence and frequency of certain concepts, themes or words in sets of text or a given document. The second application, typically referred to as *relational analysis*, builds on conceptual analysis and supports deeper systemic examinations of the relationships among concepts in a text, in order to develop inferences about the messages and quantify the interpretations (Riff et al., 2014).

This technique was used to guide and facilitate a contextual analysis and interpretation of a subset of central or salient messages—as articulated in the *executive summaries* or stand-alone *'key messages'* from eight scientific assessments published between 1985 and 2012. Text sets (n=365) were extracted, categorized and evaluated to identify special characteristics of messages and the co-occurrence of phrases, implicit and explicit, and the presence of any ostensible shifts in discourses—structural or linguistic (Chapter 3). Relational content analysis was employed to systematically analyze the 2014 survey questionnaire responses (on the future of the IPCC) and helped contextualize qualitative inferences about the reform debate—linking results to the environment in which they were produced (Chapter 4). To increase the reliability and validity of the method, two researchers performed the text segmenting and clustering analysis separately, then discussed their results to obtain consensus on a final hierarchy of categories and a more differentiated interpretation of survey comments.

8.2.3 Limitations of the research and challenges

As discussed in the previous sections, the conceptual and methodological foundations of this thesis build on relevant theory and practice. Moreover, the core of this research is inductive, and the intended tone and analytical approach is both pragmatic and balanced. This is both consistent with, and a reflection of, my personal and professional experience with integrated scientific assessment processes. However, it's also a response to the perceived need for deeper critical reflection (historical and empirical) on the evolution, inner workings and future utility of assessments (Clark et al., 2001; Pinter, 2002; Mitchell et al., 2006; Hulme and Mahony, 2010; Shapiro et al., 2010; Ravindranath, 2010; Beck et al., 2014; Carraro et al., 2015; Kowarsch and Jabbour, 2017; De Pryck and Wanneau, 2017).

As with any qualitative inquiry in the social sciences, self-reflection is an essential part of the research process—irrespective of the chosen method and approach. Navigating the balance of harnessing this preconceived knowledge (understanding) of the subject area and its context, while minimizing the risk of this 'pre-understanding' introducing bias—of the researcher's own influence—is a crucial challenge for all research involving social phenomena (Golafshani, 2003). This same dynamic has challenged and even inhibited previous empirical research, largely published in the ecological economics and political science literature, on how scientific assessments operate and exert influence on the decisions shaping our future (e.g., Siebenhüner, 2002; Cash et al. 2003; Jasanoff and Martello, 2004; Clark et al., 2006; Farrell and Jäger, 2005; Beck, 2012).

Building on the lessons of these seminal bodies of work, and reflecting on my own research process, three closely related challenges and/or limitations that impact the study of assessments, including the research and results presented in this dissertation, need to be acknowledged.

First, assessments are the result of socially constructed processes. They are shaped by, and comprised of, people and their interactions and relationships. These processes and how they are facilitated, are, in part, the outcome of a series of decisions and choices that result from the internal conditions and imperatives that shape the relationships and connections that these systems invariably tend to form. The concept of *social constructivism*—which emphasizes the complexity of how knowledge is created in co-constructed social interactions (Kukla, 2013)—provides insight into the challenges of studying assessments processes, that are similarly co-constructed with large and diverse groups, negotiated, modified, and, crucially, neither stable or constant.

Second, approaching scientific assessments as inherently social enterprises, and examining how they interact between global processes, requires that they also be understood as coupled systems. The challenge in studying any complex coupled system—their dynamics and processes—involves, among other things, framing the study in a way that systematically reflects the nuances (political, economic or social factors) of the interacting systems it seeks to manage (Levy et al., 2001). While this dissertation does not claim to have followed a specific analytical framework for examining the political ecology or epistemic authority of assessment-making throughout the entire research, much of the analysis draws on the extensive work regarding this phenomenon (e.g. Peter Haas 1989, 1992, 2015, 2017). A more rigorous political discourse analysis on the intergovernmental negotiations that ultimately shape assessment mandates, might yield additional insights into the increasing polarization on, and the growing dominance of politicization regarding global environmental change issues and phenomena (Dunlap et al., 2016; Hart and Nisbet, 2012; McCright and Dunlap, 2011). And how in turn, those processes have influenced the evolution and uptake of scientific assessment knowledge.

Third, the production of integrated scientific assessments, and particularly those beholden to (and to some degree controlled by) intergovernmental bodies, are typically closed processes. As such, they are naturally difficult to study as a purely academic exercise. It is this assertion and disposition, observed over the last 17 years of engaging with scientific assessments—as a knowledge consumer, then practitioner (or knowledge-intermediary), and most recently, a researcher—that has motivated both my research approach and pursuit to build a deeper empirical understating of this constraint, to inform future processes.

The direct experience that was brought to bear in this research, has served as both an important mode of learning—challenging preconceptions and deepening understanding—while facilitating direct and unmediated access to process dynamics that are otherwise impossible to document. At the same time, access has its limitations, and care needs to be taken to control for subjective bias. The strategy to do so was to collect the empirical data, including from the interviews; regularly discuss findings and interpretations within the research teams of the different studies, as well as other scholars, experts, and practitioners; and to triangulate the results with the comprehensive and systematic review the scientific assessment literature (as detailed in Sections 3.6, 4.9 and described in sections 8.2.1 above).

Qualitative document and content analysis, naturally, have methodological limitations and caveats that must be acknowledged. As discussed in the previous section (8.2.2) all qualitative techniques, including *relational content analysis* deal with some interpretation. For this research, given the time and resource constraints, the 'linguistic repertoires' that were developed to categorize and gauge the extent or proportion and speed at which assessments are shifting (i.e. toward solutions-oriented content) may have benefited from more sophisticated quantitative language analysis techniques. That said, the varying degrees and/or depth of abstraction imposed on the findings is also function of rigor—the ability to distance one's self—and, not just the approach (Krippendorff, 2004; Kukla, 2013).

To the best of my knowledge, the research presented in this dissertation, represents the first attempt to generate a comprehensive retrospective analysis of comparable metadata for various attributes of large-scale integrated scientific assessments. Not surprisingly, several challenges were encountered in assembling the database, related to the diffusion (and volume) of relevant information and in some cases its limited availability or accessibility.

Issues of confidentiality and restricted disclosure—including intergovernmental deliberations and proceedings—also presented difficulties. In some instances, and particularly for the scientific assessments that predate the internet and the digitization of information, relevant documents (e.g. participant lists, mandate documents, budgets etc.) were poorly documented, if at all. As such, much of this information resides in the institutional memories of a limited number of individuals that were directly involved in the design and execution of these processes. Having access to these key individuals was an important element in populating the database and ensuing its accuracy.

Finally, harmonizing heterogeneous datasets across different assessment processes was also a challenge. These obstacles underscore the inherent difficulties of studying scientific assessment processes and cultivating the reflexivity and deliberative learning that assessment structures require to evolve (Rowe et al., 2014; Shapiro et al., 2010).

8.3 Outlook

8.3.1 Further research

The applied research and analysis presented in this thesis contribute to a small but growing body of empirical work and critical reflection which seeks to improve the future utility of scientific assessments and their potential to enable effective sustainability governance. Beyond exploring the distributional access (and impacts) of assessment knowledge, and the underlying mechanisms that influence their uptake, further research could take on one of three directions.

First, as the analysis in this thesis and previous research illustrate, the efficacy of scientific assessments cannot be separated from the legitimacy and credibility of the institutions that administer them. While an extensive body of scholarship has examined the authority and effectiveness of international regimes and boundary organizations (namely the United Nations and its and subsidiary bodies), few studies have examined the layers of institutional independence and potential autonomy of influence. For example, the evolution of the UN's role in shaping knowledge-governance interactions through formal and informal channels and normative pursuits—sperate from the will of its members—remains poorly understood and merits further research. This knowledge could provide important insights on new norms for engagement across the science-policy-society interface to help build more effective relationships and coalitions. Assessment outputs (e.g. reports) are often mistakenly understood and conceptualized as the focus of these interfaces, however, the processes themselves are just as critical to outcomes (Cashmore and Axelsson, 2013). Furthermore, globalization has blurred the traditional boundaries between sectors and rendered a more direct role for non-state actors in sustainability governance. Thus, further research needs to be directed to how new actors, including private sector and civil society, interact with scientific assessments processes and how their distinctive governance profiles (Nasiritousi et al., 2016) can be leveraged to influence other actors on implementing action.

Second, taking up the issue of methodological deficiencies discussed in section 8.1.2, further research is needed to advance both conceptual frameworks and analytical tools for assessing response options and mapping policy alternatives. For example, a new generation of integrated assessment modeling tools to better anticipate and convey collective impacts across multiple interacting policy domains can potentially support more coherent and effective decision-support systems. Understanding trade-offs and synergistic relations between different policy goals and targets is also crucial for monitoring the

required course corrections to realize global sustainability. This is especially true for analyzing and structuring the much-needed information on climate policies. Similarly, the design and application of methods for *ex post* and *ex ante* policy appraisal, including guidance to facilitate rational discussions on value judgments, normativity and multiple perspectives, and new tools and metrics for evaluating societal inclusivity are also needed. The recent work of Collins et al. (2017) on inclusive wealth-based frameworks and dynamic simulation modelling, for example, offer important insights for assessments on facilitating prospective and quantitative evaluations of policies against sustainability goals.

Third, digital transformations have radically reshaped the way information is created, mobilized and consumed. The scientific assessment enterprise, however, has not yet adapted to the digital age or fully leveraged the potential of technological advancements including machine learning and artificial intelligence tools, like semantic analysis and natural language processing. Investigations into how such tools can help embed knowledge more effectively in the digital systems that influence decisions; and empower equitable collective learning can shed new light on how assessment processes are designed.

8.3.2 Concluding remarks

Scientific assessments have become an established feature of the global knowledge landscape. They have played a critical role in supporting multilateral negotiations and have served to inform, influence and even shape international agendas. There is, however, mounting indication that in their current form, scientific assessments are at risk of becoming a detached enterprise—remote from the choices and decisions shaping the future. Over the years, the intricate institutional machinery that drives assessment processes has become removed from the forces that precipitated its creation: a need to harness an international consensus of scientific authority to transcend divergent national allegiances and inform decision-making about solving complex problems.

This thesis finds that contemporary scientific assessments and the interplay of power, politics and science have reached a critical inflection point. The evolution of the intended function of global scientific assessments, juxtaposed to the changing political and institutional contexts in which they are situated, now compels conceptual and pragmatic reconfigurations. Recent reform debates and systematic reflection on the future of knowledge production systems have stimulated the emergence of a new solutions-oriented paradigm that integrates scientific inquiry and social learning to maximize the capacity for linking knowledge with action for sustainability (Clark and Dickson 2003; Fang et al., 2018). Relatedly, issues of voice and representation must be brought to center stage, while maintaining scientific objectivity. This will require a new generation of tools and analytical capacities for policy assessment and for addressing increased complexity. Also needed are multiple reinforcing channels of influence, including cross-national learning, and a full exploitation of digital communication and collaboration. Researchers and practitioners have recently developed more dynamic, transdisciplinary and networked knowledge platforms to enable new forms of policy engagement and leverage collective intelligence (Malone and Klein, 2007; West et al., 2019). These developments offer new ways of thinking to help transform the intention and utility of scientific assessments. Reflecting on the results of this research and my own experience, it is my belief that future assessments—if reoriented as such—could be a powerful conduit to chart integrated solution pathways for mitigating immediate risks, and, to help foster a new political economy of global sustainability.

While nation states grapple with the utility and relevance of the international governance system in the 21st century, the Earth's biophysical limits and the accelerating decline of its natural resources and life-support systems have become a stark reality. The imperative for collective global action to resolve the most urgent and intractable crises has never been greater. At the same time, the current economic and socio-political systems continue to reward the willful exploitation of the environment in favor of short-term gains; in the same vein, subvert the empirical findings of scientific assessments that continue to provide unequivocal proof of the threats we face and the attribution of responsibility.

It would be naïve to suppose that future assessments alone can reveal simple solutions that transcend these systems or provide a singular pathway to transformative governance. Conversely, it is equally inappropriate to dismiss the shared innovation and potential that emerges from such collaboration that can inform a wider set of policy choices and new means and incentives for cooperation among nation states. Uniting around alternative framings, solutions and visions for a future society can be a powerful agent for constructing new networks and international coalitions. Thus, the methodological, conceptual and institutional choices made at this crucial junction will condition the future authority and narrative for scientific assessments and how they interact with global sustainability. To be most effective, future arrangements as Haas et al. (1993, p.24) propose, must simultaneously respect the "integrity of the nation-state and penetrate the state politically". Finally, without a concerted and deliberate effort to recalibrate the assessment enterprise towards deeper and more meaningful interactions with decision-making, the capacity for self-correction looks limited, or rather, the feedback loops and challenges that constrain assessments seems self-perpetuating.

8.4 References

Abbott, K.W., 2012. Engaging the public and the private in global sustainability governance. *International Affairs*, 88(3) pp.543-564.

Barkemeyer, R., Dessai, S., Monge-Sanz, B., Renzi, B.G. and Napolitano, G., 2016. Linguistic analysis of IPCC summaries for policymakers and associated coverage. *Nature Climate Change*, 6(3), p.311.

Beck, S., Borie, M., Chilvers, J., Esguerra, A., Heubach, K., Hulme, M., Lidskog, R., Lövbrand, E., Marquard, E., Miller, C. and Nadim, T., 2014. Towards a reflexive turn in the governance of global environmental expertise. The cases of the IPCC and the IPBES. *GAIA-Ecological Perspectives for Science and Society*, 23(2), pp.80-87.

Beck, S., 2012. Between Tribalism and Trust: The IPCC Under the" Public Microscope". *Nature and Culture,* 7(2), pp.151-173.

Berger, P. and Luckmann, T. 1966. The social construction of reality: a treatise in the sociology of knowledge. London: Penguin.

Biermann, F., Abbott, K., Andresen, S., Bäckstrand, K., Bernstein, S., Betsill, M.M., Bulkeley, H., Cashore, B., Clapp, J., Folke, C. and Gupta, A., 2012. Navigating the Anthropocene: improving earth system governance. *Science,* 335(6074), pp.1306-1307.

Biermann, F. and Pattberg, P.H. eds., 2012. *Global environmental governance reconsidered*. MIT Press.

Carraro, C., Edenhofer, O., Flachsland, C., Kolstad, C., Stavins, R., Stowe, R., 2015. The IPCC at a crossroads: opportunities for reform. *Science,* 350 (6256), 34–35.

Chan, G., Carraro, C., Edenhofer, O., Kolstad, C. and Stavins, R., 2016. Reforming the IPCC's assessment of climate change economics. *Climate Change Economics*, *7*(01), p.1640001.

Christensen, J. and Olhoff, A. (2019). Lessons from a decade of emissions gap assessments. United Nations Environment Programme, Nairobi.

Clark, W.C., Jaeger, J., von Eijndhoven, J. and Dickson, N.M., 2001. Social Learning Group. Learning to Manage Global Environmental Risks, Vols. 1 and 2: A Comparative History of Social Responses to Climate Change, Ozone Depletion and Acid Rain.

Clark, W.C. and N.M. Dickson. 2003. Sustainability Science: The Emerging Research Program. *Proceedings of the National Academy of Sciences* 100 (14): 8059–8061.

Clark, W.C., 2007. Sustainability Science: A room of its own. *Proceedings of the National Academy of Science* 104, 1737-1738; https://doi.org/10.1073/pnas.0611291104

Collins, R.D., Selin, N.E., De Weck, O.L. and Clark, W.C., 2017. Using inclusive wealth for policy evaluation: application to electricity infrastructure planning in oil-exporting countries. *Ecological Economics*, 133, pp.23-34.

Creswell, J.W. and Clark, V.L.P., 2017. Designing and conducting mixed methods research. 2nd Edition. Sage publications.

Creswell, J.W., Plano Clark, V.L. and Garrett, A.L. 2008. Methodological issues in conducting mixed methods research designs. In Bergman, M. M. (Ed.) Advances in mixed methods research: Theories and applications. Thousand Oaks, CA, Sage Publications.

Cuevas, S., 2016. Integrated mixed methods policy analysis for sustainable food systems: trends, challenges and future research. *Public health reviews,* 37(1), p.24.

Cundill, G., Cumming, G.S., Biggs, D., Fabricius, C., 2012. Soft Systems Thinking and Social Learning for Adaptive Management. *Conservation Biology* 26, 13–20.

De Pryck, K. and Wanneau, K., 2017. (Anti)-boundary work in global environmental change research and assessment. *Environmental Science & Policy*, 77, pp.203-210.

Dorsch, M.J., Flachsland, C., 2017. A Polycentric Approach to Global Climate Governance. *Glob. Environ. Polit*. 17, 45–64. https://doi.org/10.1162/GLEP_a_00400

Dunlap, R.E., McCright, A.M. and Yarosh, J.H., 2016. The political divide on climate change: Partisan polarization widens in the US. *Environment: Science and Policy for Sustainable Development,* 58(5), pp.4-23.

Edenhofer, O., Kowarsch, M., 2015. Cartography of pathways: A new model for environmental policy assessments. *Environ. Sci. Policy* 51, 56–64. https://doi.org/10.1016/j.envsci.2015.03.017

Edenhofer, O. and Minx, J., 2014. Mapmakers and navigators, facts and values. *Science,* 345(6192), pp.37-38.

Fang, X., B. Zhou, X. Tu, Q. Ma, and J. Wu., 2018. What Kind of a Science is Sustainability Science? An Evidence-Based Reexamination. Sustainability 10: 1478. doi: 10.3390/su10051478

Farrell, A.E. and Jäger, J. eds., 2006. Assessments of regional and global environmental risks: designing processes for the effective use of science in decisionmaking. Resources for the Future.

Fendt, J and W. Sachs. 2008. 'Grounded Theory Method in Management Research'. *Organisational Research Methods,* 11(3):430-455.

Garard, J., Koch, L. and Kowarsch, M., 2018. Multi-stakeholder deliberation platforms to foster social learning. *Palgrave Communications,* June 7, 2018.

Garard, J. and Kowarsch, M., 2017. If at first you don't succeed: Evaluating stakeholder engagement in global environmental assessments. *Environmental science & policy*, 77, pp.235-243.

Golafshani, N., 2003. Understanding reliability and validity in qualitative research. *The qualitative report,* 8(4), pp.597-606.

Haas, P.M., 1992. Introduction: epistemic communities and international policy coordination." *International organization* 46(1), pp.1-35.

Haas, P.M., Keohane, R.O., Levy, M.A. and Gasser, L. eds., 1993. Institutions for the earth: sources of effective international environmental protection. MIT Press.

Haas, P.M., 1989. Do regimes matter? Epistemic communities and Mediterranean pollution control. *International organization,* 43(3), pp.377-403.

Haas, P.M., 2015. Epistemic communities, constructivism, and international environmental politics. Routledge, 2015.

Haas, P.M., 2017. The epistemic authority of solution-oriented global environmental assessments. *Environmental Science & Policy,* 77, pp.221-224.

Hart, P.S. and Nisbet, E.C., 2012. Boomerang effects in science communication: How motivated reasoning and identity cues amplify opinion polarization about climate mitigation policies. *Communication Research,* 39(6), pp.701-723.

Herrick, C. and Sarewitz, D., 2000. Ex post evaluation: a more effective role for scientific assessments in environmental policy. *Science, Technology, & Human Values,* 25(3), pp.309-331.

Höhne, N., Fransen, T., Hans, F., Bhardwaj, A., Blanco, G., den Elzen, M., Hagemann, M., Henderson, C., Keesler, D., Kejun J., Kuriyama , A., Sha, F., Song, R., Tamura, K., Wills, W. (2019). Bridging the Gap: Enhancing Mitigation Ambition and Action at G20 Level and Globally. *An Advance Chapter of The Emissions Gap Report 2019*. United Nations Environment Programme. Nairobi.

Hulme, M., Mahony, M., 2010. Climate change: What do we know about the IPCC? *Progress in Physical Geography* 34(5): 705–718.

Hsu, A., Höhne, N., Kuramochi, T., Roelfsema, M., Weinfurter, A., Xie, Y., Lütkehermöller, K., Chan, S., Corfee-Morlot, J., Drost, P. and Faria, P., 2019. A research roadmap for quantifying non-state and subnational climate mitigation action. *Nature Climate Change*, *9*(1), pp.11-17.

Jensen, D, Campbell, J. 2019. The Case for a Digital Ecosystem for the Environment: Bringing together data, algorithms and insights for sustainable development. Technical report. March 2019. doi:10.13140/RG.2.2.10387.73764

Johnson, R.B. and Onwuegbuzie, A.J., 2004. Mixed methods research: A research paradigm whose time has come. *Educational researcher,* 33(7), pp.14-26.

Kates, R., Clark, W., Corell, R., Hall, J., Jaeger, C., et al. (2001). Sustainability science. *Science* 292, (5517): 641–642. doi:10.1126/science.1059386.

Kanie, N., 2014. Governance with multilateral environmental agreements: A healthy or ill-equipped fragmentation? *Green Planet Blues: Critical Perspectives on Global Environmental Politics*, p.137.
Koteyko, N., Jaspal, R. and Nerlich, B., 2013. Climate change and 'climategate' in online reader comments: A mixed methods study. *The Geographical Journal,* 179(1), pp.74-86.
Krippendorff, K., 2014. Content analysis: An introduction to its methodology. Sage publications.
Kowarsch, M. and Jabbour, J., 2017. Solution-oriented global environmental assessments: Opportunities and challenges. *Environmental Science & Policy,* 77: 187-192.
Kukla, A., 2013. Social constructivism and the philosophy of science. Routledge.
Landsverk, J., Brown, H., Chamberlain, P., Palinkas, L.A., and Horwitz, S.M. 2012. Design and analysis in dissemination and implementation research. In R. C. Brownson, G. A. Colditz, and E. K. Proctor (Eds.), Translating science to practice (pp. 225–260). New York: Oxford University Press.
Leech, N.L. and Onwuegbuzie, A.J. 2009. A typology of mixed methods research designs. *Quality & Quantity,* 43, 265—275. doi:10.1007/s11135-007-9105-3.
Levy, M.A., Keohane, R.O. and Haas, P.M., 1993. Improving the effectiveness of international environmental institutions. (*In) Institutions for the earth: Sources of effective international environmental protection*, pp.397-426. MIT Press.
Levy, M.A., Cavender-Bares, J., Clark, W.C., Dinkelman, G. and Nikitina, E., 2001. Goal and strategy formulation in the management of global environmental risks. See Ref, 55, pp.87-113.
Livingston 2018. From climates multiple to climate singular: Maintaining policy-relevance in the IPCC synthesis report. *Environmental Science & Policy,* 90:83-90
Lund, J.F., Burgess, N.D., Chamshama, S.A., Dons, K., Isango, J.A., Kajembe, G.C., Meilby, H., Moyo, F., Ngaga, Y.M., Ngowi, S.E. and Njana, M.A., 2015. Mixed method approaches to evaluate conservation impact: evidence from decentralized forest management in Tanzania. *Environmental Conservation,* 42(2), pp.162-170.
Malone, T.W. and Klein, M., 2007. Harnessing collective intelligence to address global climate change. *Innovations: Technology, Governance, Globalization,* 2(3), pp.15-26.
Matson, P., Clark, W.C. and Andersson, K., 2016. Pursuing sustainability: a guide to the science and practice. Princeton University Press.
Maxwell, J. A., and Loomis, D. M. (2003). Mixed methods design: An alternative approach. In *A. Tashakkori, and C. Teddlie (Eds.),* Handbook of mixed methods in social and behavioral research pp. 241–272). Thousand Oaks, CA: Sage.
McCright, A.M. and Dunlap, R.E., 2011. The politicization of climate change and polarization in the American public's views of global warming, 2001–2010. The Sociological Quarterly, 52(2), pp.155-194.
McGreavy, B., Hutchins, K., Smith, H., Lindenfeld, L. and Silka, L., 2013. Addressing the complexities of boundary work in sustainability science through *communication. Sustainability,* 5(10), pp.4195-4221.
Mertens, D. M., 2003. Mixed methods and the politics of human research: The transformative-emancipatory perspective. In A. Tashakkori & C. Teddlie (Eds.), Handbook of mixed methods in social and behavioral research (pp. 135–164). Thousand Oaks, CA: Sage.
Miller, T.R., Wiek, A., Sarewitz, D., Robinson, J., Olsson, L., Kriebel, D. and Loorbach, D., 2014. The future of sustainability science: a solutions-oriented research agenda. *Sustainability science,* 9(2), pp.239-246.
Minx, J.C., Callaghan, M., Lamb, W.F., Garard, J. and Edenhofer, O., 2017. Learning about climate change solutions in the IPCC and beyond. *Environmental Science & Policy,* 77, pp.252-259.
Moss R.H., 2016. Assessing decision support systems and levels of confidence to narrow the climate information "usability gap." *Clim. Change,* 135:143–55.
Nasiritousi, N., Hjerpe, M. and Linnér, B., 2016. The roles of non-state actors in climate change governance: understanding agency through governance profiles. *Int Environ Agreements* 16, 109–126.

Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. *Global Environmental Change* 19, 354–365.
Pereira, L., Asrar, G.R., Fisher, L.H., Hsu, A., Nel, J., Sitas, N., Ward, J., Vervoort, J., Selomane, O., Trisos, C. and Malone, T., 2019. Bottom-up Initiatives and Participatory Approaches for Outlooks-Global Environment Outlook (GEO-6): Healthy Planet, Healthy People Chapter 23. Cambridge University Press.
Pearce, W., Mahony, M. and Raman, S., 2018. Science advice for global challenges: Learning from trade-offs in the IPCC. *Environmental Science & Policy*, 80, pp.125-131.
Ostrom, E. 1990., Governing the Commons: The Evolution of Institutions for Collective Action Cambridge University Press.
Ravindranath, N.H., 2010. IPCC: accomplishments, controversies and challenges. *Current Science*, pp.26-35.
Reichardt, S.S., and Rallis, S.F. (1994). Qualitative and quantitative inquiries are not incompatible: A call for a new partnership. In C.S. Reichardt and S. F. Rallis (Eds.), The qualitative-quantitative debate: New perspectives (pp. 85–91). San Francisco, CA: Jossey-Bass.
Rickards, L., Ison, R., Fünfgeld, H. and Wiseman, J., 2014. Opening and closing the future: climate change, adaptation, and scenario planning. *Environment and Planning C: Government and Policy*, 32(4), pp.587-602.
Riff, D., Lacy, S. and Fico, F., 2014. Analyzing media messages: Using quantitative content analysis in research. Routledge.
Ritchie, J. and Spencer, L., 2002. Qualitative data analysis for applied policy research. *Qual. Res. Companion* 573 (2002), 305–329.
Riousset, P., Flachsland, C. and Kowarsch, M., 2017. Global environmental assessments: Impact mechanisms. *Environmental science & policy*, 77, pp.260-267.
Sarkki, S., Niemelä, J., Tinch, R., Van Den Hove, S., Watt, A. and Young, J., 2013. Balancing credibility, relevance and legitimacy: a critical assessment of trade-offs in science–policy interfaces. *Science and Public Policy,* 41(2), pp.194-206.
Schreier, M., 2012. Qualitative content analysis in practice. Sage Publications.
Schwab, K., 2017. The fourth industrial revolution. The World Economic Forum. Geneva, Switzerland.
Shapiro, H.T., Diab, R., de Brito Cruz, C.H., Cropper, M.L., Fang, J., Fresco, L.O., Manabe, S., Mehta, G., Molina, M., Williams, P. and Winacker, E.L., 2010. Climate change assessments: Review of the processes and procedures of the IPCC. InterAcademy Council, Amsterdam.
Siebenhüner, B., 2002. How do scientific assessments learn?: Part 1. Conceptual framework and case study of the IPCC. *Environmental Science & Policy,* 5(5), pp.411-420.
Simis, M.J., Madden, H., Cacciatore, M.A. and Yeo, S.K., 2016. The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science,* 25(4):400-414.
Slaughter, A.M., 2017. The Chessboard and the Web: Strategies of Connection in a Networked World. Yale University Press.
Stavins, R., 2014. Is the IPCC government approval process broken? Economic View of Environment. April 2014.
Stocker, T.F. and Plattner, G.K., 2014. Climate policy: Rethink IPCC reports. Nature News, 513(7517), p.163.
Sturgis, P., and Allum, N. 2004. Science in society: re-evaluating the deficit model of public attitudes. *Public understanding of science* 13(1): 55-74.
Tashakkori, A., and Teddlie, C. (1998). Mixed methodology: Combining qualitative and quantitative approaches. Applied Social Research Methods Series (Vol. 46). Thousand Oaks, CA: Sage.
Tashakkori, A., and Teddlie, C. (Eds.). (2003). Handbook of mixed methods in social and behavioral research. Thousand Oaks, CA: Sage.
Timma, L., Blumberga, A. and Blumberga, D., 2015. Combined and mixed methods research in environmental engineering: when two is better than one. *Energy Procedia*, 72, pp.300-306.

Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L. and Polsky, C., 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, *100*(14), pp.8074-8079.

van der Hel, S. and Biermann, F., 2017. The authority of science in sustainability governance: A structured comparison of six science institutions engaged with the Sustainable Development Goals. *Environmental Science & Policy*, 77, pp.211-220.

Venkatesh, V., Brown, S.A. and Bala, H., 2013. Bridging the qualitative-quantitative divide: Guidelines for conducting mixed methods research in information systems. *MIS quarterly*, pp.21-54.

Wesselink, A., Buchanan, K.S., Georgiadou, Y., Turnhout, E., 2013. Technical knowledge, discursive spaces and politics at the science–policy interface. *Environ. Sci. Policy,* 30: 1–9.

West, S., van Kerkhoff, L., Wagenaar, H., 2019. Beyond "linking knowledge and action": towards a practice-based approach to transdisciplinary sustainability interventions *Policy Studies*, 40:5, pp 534-555,

Ziegler, R. and Ott, K., 2011. The quality of sustainability science: a philosophical perspective. Sustainability: *Science, Practice and Policy,* 7(1), pp.31-44.

Statements of Contribution

The following paragraphs detail the contribution of the author to the six research papers (Chapters 2 to 6) that form the core of this dissertation and acknowledge major contributions of others.

Chapter 2[2]: The author of this thesis was responsible for the conceptual design, overall handling and writing of the article, with refinements from all authors. Together with substantial input from Carol Hunsberger and Roberto Sánchez-Rodríguez, he was responsible for the compilation and analysis of ex-post data presented in sections 2.3 and 2.4 on the goals and gaps of existing international environmental agreements, and the discussion on key obstacles. He also conducted the systematic literature and document review that support sections 2.1, 2.2, and 2.4. Stefan Schwarzer and Neeyati Patel contributed to developing and refining the figures for the article, and particularly Figures 2.1 and 2.2. Marc Levy, Fatoumata Keita-Ouane and Peter Gilruth provided advice and extensive discussions throughout the process. All authors contributed to editing and revising of the manuscript.

Chapter 3[3]: The author of this thesis was responsible for the conceptual design, the data collection, analysis and writing of the article. Christian Flachsland contributed in extensive discussions and by editing the manuscript.

Chapter 4[4]: The author of this thesis was a principal author for this manuscript and developed original text for various sections including the introduction, the 'Desirable shift to solutions', 'Enabling multi-dimensional policy assessment' and 'Reforms embedded in learning'. Together with Martin Kowarsch, the author of this thesis helped conceive the original idea, structure and framing of the paper and made substantial contributions to development of the paper and its critical revisions. He had a central role in the acquisition, analysis and interpretation of data related to Figure 1 -- the original data and analysis for which was derived from his extensive research related to Global Environmental Assessments.

Chapter 5[5]: The author of this thesis contributed to conceptual development of the paper through extensive discussions with the author team; in particular, he provided substantive inputs and feedback on the analytical framing (Section 5.2). He also contributed to the data collection and analysis processes and provided extensive editorial inputs during the development of manuscript and through subsequent revisions.

Chapter 6[6]: The author of this thesis was responsible for the conceptual design, overall handling and writing of the article. He also conducted the systematic literature and document review that support sections 6.2 and 6.3. Carol Hunsberger provided substantial inputs on the initial framing and

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[2] Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Singh, A., Levy, M.A., Schwarzer, S. 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development* 3, 5-24.

[3]Jabbour, J. and Flachsland, C., 2017. 40 years of global environmental assessments: A retrospective analysis. *Environmental Science and Policy*, 77, pp.193-202. doi.org/10.1016/j.envsci.2017.05.001

[4] Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T.J., Watson, Sir R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P., Pintér, L., Langford, C., Yamineva, Y., von Stechow, C., O'Reilly, J. and Edenhofer, O. (2017). A road map for global environmental assessments. *Nature Climate Change 7*(6), pp.379-382. doi:10.1038/nclimate3307

[5] Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J. and Riousset, P. (2017). The treatment of divergent viewpoints in global environmental assessments. Environmental Science & Policy, 77, pp.225-234. doi:10.1016/j.envsci.2017.04.001

[6] Jabbour, J. and Hunsberger, C., 2014. Visualizing Relationships between Drivers of Environmental Change and Pressures on Land-Based Ecosystems. Natural Resources, 5, 146-160.

methodological approach and contributed extensive discussions as well as text on the various pressure-scenarios analyzed in the results and discussion sections of the manuscript.

Chapter 7[7]: The author of this thesis was a principal author for this manuscript and developed original text for various sections including the Introduction, Sections 3.2. 'UPA's contribution to the urban food system'; 4.1. 'Policy and governance dimensions'; 5.2. 'Risk management and effective policy outcomes'; and 5.4 'Critical knowledge gaps.' Together with Jon Padgham, the author of this thesis helped conceive the original idea and framing of the paper and made substantial contributions to development of the paper and its critical revisions.

[7] Padgham, J., Jabbour, J. and Dietrich, K., 2015. Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. *Urban Climate,* 12: 183-204.

Tools and Resources

All texts were written with Microsoft Office Word 2016. The dissertation was assembled using Adobe Acrobat Pro DC 2015. Qualitative data collection in the form of interviews was done through Skype or telephone, and consent forms for all interviews conducted were prepared using Adobe Pro. In the empirical analyses for chapters 3, 4, and 5, coding was performed using Max QDA software. The metadata catalogue for chapter 3 uses a Microsoft Office Excel 2010 document. Figures were prepared using Microsoft Office Excel 2010 and 2016, Microsoft Office PowerPoint 2016 and Adobe Indesign 2015.

Publication List

Chapters 2 to 7 of this thesis consist of articles which have been accepted and published in peer-reviewed journals. They are listed below in order of their appearance in this thesis.

Chapter 2: This is the accepted manuscript of the Article published in *Environmental Development* as

Jabbour, J., Keita-Ouane, F., Hunsberger, C., Sánchez-Rodríguez, R., Gilruth, P., Patel, N., Singh, A., Levy, M.A., Schwarzer, S. 2012. Internationally agreed environmental goals: A critical evaluation of progress. *Environmental Development* 3, 5-24. https://doi.org/10.1016/j.envdev.2012.05.002

Chapter 3: This is the accepted manuscript of the Article published in *Environmental Science and Policy* as

Jabbour, J. and Flachsland, C., 2017. 40 years of global environmental assessments: a retrospective analysis. *Environmental Science and Policy* 77, 193-202.

Chapter 4: This is the accepted manuscript of the Article published in *Nature Climate Change* as

Kowarsch, M., Jabbour, J., Flachsland, C., Kok, M.T., Watson, R., Haas, P.M., Minx, J.C., Alcamo, J., Garard, J., Riousset, P., Pintér, L., Langford, C., Yamineva, Y., von Stechow, C., O'Reilly, J., and Edenhofer, O. 2017. A road map for global environmental assessments. *Nature Climate Change,* 7(6), pp.379-382.

Chapter 5: This is the accepted manuscript of the Article published in *Environmental Science and Policy* as

Kowarsch, M., Flachsland, C., Garard, J., Jabbour, J. and Riousset, P., 2017. The treatment of divergent viewpoints in global environmental assessments. Environmental Science and Policy 77, 225-234.

Chapter 6: This is the accepted manuscript of the Article published in *Natural Resources* as

Jabbour, J. and Hunsberger, C., 2014. Visualizing Relationships between Drivers of Environmental Change and Pressures on Land-Based Ecosystems. *Natural Resources,* 5, 146-160. This article is licensed under the Creative Commons Attribution International License (CC BY, http://creativecommons.org/licenses/by/4.0/)

Chapter 7: This is the accepted manuscript of the Article published in *Urban Climate* as

Padgham, J., Jabbour, J. and Dietrich, K., 2015. Managing change and building resilience: A multi-stressor analysis of urban and peri-urban agriculture in Africa and Asia. *Urban Climate,* 12: 183-204.