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Communicating Climate Change Information for Decision-Making

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Preface

As we embarked upon the preparation of this edited book, many events unfolded with implications for global climate change response. In particular, 2015 was considered a tipping year for humanity to tackle climate change. There were many initiatives converging to make the Paris Climate Agreement accepted. In the end, all the countries that signed the Agreement realized that if they were to go ahead and follow their individual modernization plans, this planet simply would not have been big enough. And then it came 2017, with spiraling international insurgence of conservative and protectionist aspirations. One could ask whether 2017 is the reverse tipping point year. Or is it a year that illustrates how climate change entangled itself in the period of Great Regression in which we live?

In his preface for the book entitled “The Great Regression”, Geiselberger[1] asks: “How have we ended up in this situation? Where will we be in five, ten or twenty years’ time? How can we stop the global regression and achieve a turnaround?” The reality is that despite the amount of information on climate change, there continues to be a denial of accepting it, and some now frame this denial not in terms of whether climate change is real, but in their ability to adjust economic development in the short term. For example, in one of his earlier tweets, President Trump said that “The concept of global warming was created by and for the Chinese in order to make U.S. manufacturing non-competitive.”[2] This statement raises doubts as to whether the origin of the current USA decision to withdraw from the Paris Agreement lies in the lack of conviction that climate change exists, and recasts the focus of policies on domestic as opposed to global benefits.

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[1] Geiselberger, H (2017) Preface. In *The Great Regression*, Ed. Geiselberger H, Wiley, pp. 7–15. http://www.thegreatregression.eu/preface-of-the-editor/.

[2] Trump, D [realDonaldTrump]. (11:15 AM—6 Nov 2012) The concept of global warming was created by and for the Chinese in order to make U.S. manufacturing non-competitive. [Tweet]. https://twitter.com/realDonaldTrump/status/265895292191248385.

It is a situation well illustrated by Latour[3] in the metaphor of the Titanic: "enlightened people can see the iceberg heading straight for the prow, know that shipwreck is inevitable, grab the lifeboats, and ask the orchestra to play enough lullabies so that they can make a clean getaway under the cover of night before the alarming list of the vessel alerts the other classes! (…) if they want to survive in comfort, they shouldn't seem to be pretending that they share their space with the rest of the world." Hence, efforts to develop and communicate climate change information to guide decisions and support proactive adaptation and mitigation strategies cannot ignore the concerns of parties which deny the information for their own short-term, self-interested benefits.

Deliberately declining to accept information about climate change clearly appears to be an expression of selfishness and self-centered interest for organizations, countries, sectors, and communities. It is a question of extracting oneself from the burden of solidarity in the face of a future that is frightening: not enough resources to maintain the resource-intensive lifestyles promoted by the developed world throughout the twentieth century for all in the twenty-first century and beyond. However, projections suggest that world population could peak by the middle of this century, reaching around 8.6 billion people and then declining to 6.9 billion by the end of the century.[4] Nonetheless, total world population size trajectories between now and the end of the twenty-first century depend on educational and health investments, especially for women—as explicitly highlighted by the solidarity sustainable development goal adopted by the United Nations in 2015.

As argued by Pottier[5] (2016), there are different reasons as to why mainstream economic discourse sets itself apart from reality and largely minimizes the severity of climate change impacts. Economists are well aware that models based on a conception of human being as *Homo economicus* and on a society that can be stabilized by markets are false, yet they continue to use them in the absence of a better economic paradigm. The cost-benefit analysis of climate change is proving to be a triple trap as it gives an innocuous image of climate change, masks uncertainties through the illusion of knowledge, and drives the assessment of climate change in endless controversies, in which the economist holds the upper hand.

While on June 1 2017, President Trump acknowledged that the USA was pulling out from the Paris Agreement, during the G20 Summit held in Hamburg on July 7–8 of the same year the other 19 parties (European Union plus 18 countries) reaffirmed their commitment to the Agreement. This reaffirmation was supported by a number of American States (despite the lack of commitment to the Agreement from their Federal Government) and major corporations, including oil companies. These latest developments do not make it useless to continue to produce and

[3]Latour, B (2017) L'Europe refuge in L'âge de la régression, dirigé par Heinrich Geiselberger, Ed. Premier Parallèle, Paris, pp. 115–126.

[4]KC S, Lutz W (2017) The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100. Global Environmental Change 42:181–192. https://doi.org/10.1016/j.gloenvcha.2014.06.004.

[5]Pottier A (2016) Comment les économistes réchauffent la planète. Anthropocène Seuil, France.

communicate climate change information. More than ever, these changes reinforce the need for credible information and examples of how such information can liberate us from the traps of economic and short-sited discourses and project us into a future of solidarity and respect for one another.

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Anne Coudrain is an Engineer in water sciences (Ph.D.—Paris School of Mines) and a Doctor of Sciences and Auditor of the "Institut des Hautes Etudes pour la Science et la Technologie." She is currently Honorary Research Director at the research unit ESPACE-DEV in the science societies field on climate change. Beginning her career in 1980 at the National Mining Industry Company in Mauritania, she researched the safety analysis of underground nuclear waste repositories, and the relationships between hydrosphere and climate, before becoming involved in managing research for development.

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Part I
Developing Climate Change Information

Chapter 1
Science and Knowledge Production for Climate Change Adaptation: Challenges and Opportunities

Silvia Serrao-Neumann and Anne Coudrain

After more than two decades of consistent messages emanating from the scientific community that the climate is changing, there is now recognized urgency for both climate change mitigation and adaptation. Addressing climate change is not a straightforward task with the International Panel on Climate Change calling for substantial and widespread transformational change (IPCC 2014). To enable such transformational change there needs to be significant advances in scientific, political, and social practice (Gillard et al. 2016). At the center of advancements lies the role of interdisciplinary research, including interactions between scientists and citizens or representatives of entities at risk (cities, ocean, biodiversity, climate).

One could argue that the climate change challenge offers one of the greatest opportunities for interdisciplinary research and inherent knowledge production to establish itself as an instrumental and fundamental form of research. Its role might not only apply to how it can generate new and more accurate science but also how it can contribute to the application of scientific, and other forms of, knowledge in providing much-needed responses to complex challenges such as climate change threats (Robertson et al. 2017; Obermeister 2017). In fact, embarking upon interdisciplinary research to address climate change threats is seen as researchers' responsibility to increase the usability and applicability of scientific knowledge outside the academic realm (Moser 2010).

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To maximize the applicability and usability of scientific knowledge for addressing climate change, partnerships need to be established between end users (policy makers, decision-makers, practitioners) and scientists (Mastrandrea et al. 2010; Dilling and Lemos 2011). It is a critical time for researchers to make their research and inherent scientific outputs more readily available to end users. Equally important, however, is how these outputs are communicated. Proactive action to deal with climate change cannot only be expected from decision-makers, it has also to start with climate change knowledge production and communication. Thus, researchers must also seek to transform how they produce and communicate climate change information.

This book explores many challenges and opportunities inherent in science and knowledge production and application for climate change adaptation and mitigation. In particular, it builds on the assumption that there is significant progress in knowledge generation about climate change, but such progress is largely represented by individual, or more aligned disciplines. Additionally, despite the availability of such knowledge, there has been relatively slow progress toward addressing climate change challenges at the political and policy implementation levels. Hence, the book offers a reflection and some insights as to how to increase the application of existing and new generated knowledge about climate change in practice.

To this end, the book compiles thirteen chapters to provide a snapshot of how climate change information is generated, communicated, and applied. Contributions come from different projects, continents, and countries, therefore providing a rich suite of both quantitative and qualitative perspectives.

1.1 Two Evolving Fields: Interdisciplinary Research and Climate Change Science

Addressing the challenges posed by climate change requires knowledge, but knowledge generation and applicability are not divested of power relations (Hagemeier-Klose et al. 2014; Klenk and Meehan 2015). There are power relations that assume some forms of climate knowledge are more relevant than others. For example, there are uneven grounds and acceptability concerning knowledge production involving natural, technological, and social sciences (Holm et al. 2013), and prioritization of scientific knowledge over other forms of knowledge such as indigenous knowledge (Obermeister 2017; Kagle and Baptiste 2017). There are power relations that influence the type and extent of scientific knowledge used in decision-making. In particular, proactive decision-making has been hindered by an assumption that available climate change knowledge is too uncertain to be taken into consideration (Quay 2010). There are also power relations in framing policy-relevant knowledge. For instance, while the International Panel on Climate Change (IPCC) consolidated the need for climate change-related research undertaken through interdisciplinary approaches, it placed substantial focus on earth system science research in the first assessment reports and is now shifting its focus to solutions to climate change impacts such as development pathways (Spencer and Lane 2017).

Discussions about the need for knowledge integration emerged in the early 1970s. Erich Jantsch's work is often identified to be a seminal piece in the field, calling for a systems approach to science, education, and innovation to understand the society—environment interface (Jantsch 1972). While more than forty years old, Jantsch's call is more contemporary than ever when climate change and the role of anthropogenic activity in it are at stake. Hence, there is a need for shared understanding to take place to enable the decoding of society–environment system complexity (Stock and Burton 2011).

The manner through which knowledge integration occurs ranges from being multidisciplinary, interdisciplinary, or transdisciplinary. Definitions and interpretations of those terms vary widely and continue to evolve as multidisciplinarity, interdisciplinarity, and transdisciplinarity are pursued and implemented in research, education, and practice (Stock and Burton 2011).

The top two forms of research seeking knowledge integration comprise interdisciplinarity and transdisciplinarity. The first focuses on addressing 'real problems' through bridging disciplinary viewpoints and collaboration from the outset of research problem framing, data collection and analysis. The second expands the collaborative effort to reach out to include nonacademic participants—that is, policy makers, practitioners, community members (Stock and Burton 2011).

However, as an evolving endeavor, knowledge integration through interdisciplinary and/or transdisciplinary research is confronted with several challenges. Perhaps, the most recurrent is the difficulty in breaking down discipline silos concerning disciplinary languages and terminologies and methodologies. Extrinsic to knowledge integration, epistemological challenges are barriers related to how it is supported, or not, within research institutions, academic peers, and funding opportunities (Milman et al. 2017). Hence, knowledge integration for the purpose of improving the understanding of complex problems to enable the generation of solutions is not straightforward (Stock and Burton 2011).

There has been a significant increase in climate change-related research across both natural and social sciences over the last decade, especially within natural sciences. Scholars point to the role of IPCC's assessment reports in influencing not only the amount but also the type of climate change-related research since its inception in the early 1990s (Vasileiadou et al. 2011). Notably, with time, this research has also become more interdisciplinary and transdisciplinary, requiring an application context for its broader evolution (Hellsten and Leydesdorff 2016). There is also reference to the IPCC's role in placing climate change at the center of policy agendas (Vasileiadou et al. 2011). In particular, more recent assessment reports highlighted the need for seeking adaptation in addition to mitigation and called for institutional and technological change as well as alternative adaptation pathways to enable system transition (Rothman et al. 2014).

Despite the amount of climate change information available, uptake by decision-makers has been patchy. Several reasons have been identified to explain the relative low usability and applicability of climate science in decision-making processes. These include institutional and organizational factors and intrinsic individual accounts of climate change such as beliefs and values. It also includes aspects relating to the knowledge generation process with calls for greater interaction between knowledge producers and knowledge users to shift from useful information to usable information (Lemos et al. 2012). To overcome this situation, new models of knowledge production underpinned by transdisciplinarity are being advocated such as the Mode 2 model and postnormal science. In particular, these models treat knowledge as complex in nature which in turn shapes how it is organized and coproduced as well as communicated, disseminated, and used. They also accept that science uncertainty is unavoidable hence the need to engage with stakeholders from the problem definition stage through to data collection and analyses and the development of usable information (Kirchhoff et al. 2013).

As the climate change science and interdisciplinary and transdisciplinary forms of research continue to evolve, there is no simple answer to address the pressing challenges being brought in by climate change. We have no alternative but to continue to 'learning-by-doing' and 'doing-by-learning' (Loorbach and Rotmans 2006). This entails making use of the best available information to address climate change, striving for knowledge integration as much as possible, and learning from successes and failures to guide transformational change. It also includes creating more opportunities for interdisciplinary and transdisciplinary climate change-related research now within institutional structures. Indeed, some call for radical inter- and transdisciplinary research environments to enable progress toward addressing climate change challenges (Holm et al. 2013). Others highlight the role of approaches which are in essence based on exploring current and future uncertainties in knowledge to anticipate future changes (Klenk and Meehan 2015). 'Learning-by-doing' and 'doing-by-learning' are critical to operationalize much-needed transformational change because society is still learning, and will continue for quite some time, how to do both developing and applying climate change information.

While some climate change impacts may already be unfolding, there is indication that impacts will become more intense and more frequent in the future. It is imperative thus that action is taken now to avoid future unwanted outcomes rather than waiting for the ideal suite of knowledge and solutions to emerge. Addressing climate change demands a degree of pro-action now to effectively manage future impacts. Many may argue that it is difficult to forecast future climate change impacts without uncertainty, but it is this uncertainty that places future, strategic, and long-term thinking at the forefront of climate change adaptation and mitigation. In particular, future thinking is a transdisciplinary field of enquiry that combines a variety of methods to explore plausible futures and, therefore, deals with situations underpinned by uncertainties and low levels of controllability such as climate change impacts (Bengston et al. 2012). It ranges from predictive/empirical approaches informed by natural and technological sciences through to participatory and holistic approaches supported by social sciences (Gidley 2013). It is therefore a strategy that can integrate multiple knowledge perspectives for devising multiple futures.

Preparing and planning for multiple plausible futures are perhaps the best, if not the only, alternative we have to deal with climate change impacts. Several approaches to develop pathways to navigate plausible futures are being developed in research and practice, including adaptive pathways and adaptation tipping points (Bishop et al. 2007; Haasnoot et al. 2013). Scholars point to the benefit in adopting future thinking to deliver holistic solutions and to encourage decision-makers to consider the big picture relating to multiple disciplinary perspectives, creative problem-solving, and account for longer temporal scales associated with the efficiency and robustness of decisions taken at present (Bengston et al. 2012).

In returning to the question of transformational change, it is important to stress the role of transdisciplinarity and future thinking in enabling climate change adaptation and mitigation. Transformational change however needs to be guided by a vision of the future (van der Helm 2009) or take the very long term into account. It is equally important to accept that we are dealing with dynamic changes that will continue to challenge how knowledge is developed and communicated (van der Leeuw et al. 2011). These challenges are here to stay, and the earlier we start to come to terms with them the better is the chance that we can learn from the past to anticipate the future.

1.2 Chapters Overview

This book is divided into three main parts of investigating aspects of how climate change information is being generated, communicated, and applied. *Part* I provides a snapshot on how climate change information is bridging natural/technological sciences and social sciences. It touches on aspects of evidence for policy implementation and participatory approaches to knowledge generation.

Morgan and *Di Giulio* investigate the relationship between science and policy to best guide research design to support decision-making and increase the usability of research outputs by end users. The authors draw on their research carried out in Queensland, Australia, and São Paulo, Brazil, to reflect on how more collaborative approaches can tackle the challenges put forward by uncertainty, complexity, and politics in decision-making involving climate change impacts.

Fargette, Loireau, Ben Khatra, Khiari, and *Libourel* explore the connection between geographical imprints and society–environmental relationships and global climate systemic functioning. They apply a conceptual systemic framework to investigate how scientific observatories enable the generation of sound information while enhancing arenas for democratic discussions and decision-making.

Devès, *Lang*, *Bourrelier,* and *Valérian* reflect on the IPCC's process of generating assessment reports in light of new demands placed on the types of expertise required by those reports. Using the example provided by the French Association for Disaster Risk Reduction, the authors discuss whether the IPCC needs to review its organization to ultimately provide support for effective implementation of climate change adaptation and mitigation programs that need to be integrated and operational across a range of spatial and temporal scales and stakeholder spectrum.

Gervet describes how computation constraint models can aid decision-making and design of holistic solutions. She focuses on techno-economic issues involved in the implementation of renewable energy parks in Egypt to describe how a computational model was used as a communication and simulation tool between involved parties to evaluate the impact and effectiveness of their energy management-related choices.

Part II offers examples of how climate change information can be communicated to inform decision-making with present and future implications. It covers aspects of stakeholder engagement to deal with uncertainty in climate change science, communication of climate change information within personal circles, and bridging research, practice, and decision-making.

Serrao-Neumann and *Low Choy* report on the suitability of scenario planning as a tool to inform decision-making and policy implementation in light of high uncertainty and low controllability. The authors use examples from Australia to discuss the intricacies of using scenario planning at multiple scales, including institutional and community scales.

Coulter notes on the difficulties of imagining and talking about a future that will be affected by climate change impacts. Focusing on Australian and Canadian examples, she highlights how challenges in communicating about climate change are not confined to circles of people who do not have access or lack of deep knowledge about climate change, but exceed knowledge to include emotional spheres of personal relationships.

Schuck-Zöller, Brinkamm, and *Rödder* analyze the role of interdisciplinary research in integrating research and practice. Drawing on the example of the Climate Services initiative, they argue for the integration between researchers and practitioners to solve real-world problems and propose a list of criteria to guide best practice in transdisciplinary dialogues.

Dubois, Stoverinck, and *Amelung* discuss how visualization can help users to understand complex and uncertain climate science. Based on the analyses of European examples, the authors offer important considerations to avoid confusion and improve understanding of uncertainty when using common visual tools to communicate climate change, including maps and their need for consistency and norms.

Howes outlines how policy-making processes to be effective need to enhance community empowerment. Analyzing three case studies from Australia, the USA, and the UK, he proposes a three-step approach to policy-making to inform, engage, and support democratic community-based adaptation.

Jacobson, Crevello, Chanseng, and *Chanthan* tackle the confronting issue of adaptation in information-poor situations. Using examples from rural Cambodia focused on using vulnerability and resilience assessments for policy dialogue, the authors offer much-needed engagement strategies to enable less resourced actors to also plan for their adaptation and transformation.

Part III provides a view on case studies which are applying climate change information. Selected cases offer examples of application and usability of complex climate change information through Web-based platforms, citizen science projects, and virtual laboratories.

Tellez-Arenas, Quique, Boulahya, Le Cozannet, Paris, Le Roy, Dupros, and *Robida* discuss the challenges in using large, complex, and heterogeneous datasets for informing climate change adaptation in coastal areas. The authors address the interoperability challenges of Web services that integrate multifaceted datasets and propose a flexible architecture to improve both analyses of complex scenarios by experts and their communication to the general public.

David and *Quod* propose an important innovation in monitoring programs for coral reef health by integrating ecological and social systems. The authors outline how financial and human resource barriers to carrying out monitoring activities can be overcome through engaging citizen scientists. They also discuss the dilemmas in choosing the focus of monitoring programs in terms of their applicability at large scales, their genericity, or local management application.

Gracie, Silva, Hacon, Matos, Barros, de Pina, and *Barcellos* report on the development of a virtual laboratory to inform climate adaptation in the human health sector. The authors focus on the Brazilian Climate and Health Observatory to investigate how a 'one-stop shop' for accessing information concerning health-related effects of environmental and climate change can facilitate its application by citizens, government agencies, and researchers.

Coulter and *Coudrain* conclude the book by providing an overall assessment on how climate change information is being developed, communicated, and applied in the context of developed and developing countries. Drawing on the various contributions gathered in this book, the authors discuss how climate change information is promoting informed action to manage climate change mitigation, adaptation, and management.

Overall, the contributions collated in this book offer a snapshot of contemporary developments in the generation, communication, and application of climate change information worldwide. They provide important insights for researchers and practitioners pursuing the implementation of transdisciplinarity and climate change adaptation and mitigation. The book targets researchers, practitioners, and citizens with an interest in climate change and cutting-edge forms of knowledge generation in many fields of enquiry, including natural sciences through to technologies and social sciences. Hence, it contributes to the continuous evolution of research and practice of both climate change science and transdisciplinarity.

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Chapter 2
Science and Evidence-Based Climate Change Policy: Collaborative Approaches to Improve the Science–Policy Interface

Edward A. Morgan and Gabriela Marques Di Giulio

Abstract Science has played a key role in the development of climate change policy. Although action has been slow to materialize, climate change is firmly on the policy agenda internationally and domestically in many countries across the world. Climate scientists have helped put the issue into policy agendas, and climate change science is expected to provide the basis for policy action on mitigation and adaptation. However, science and policy sometimes have an uneasy relationship, as highlighted by fraught political debates over climate change. Issues of uncertainty, complexity and politics all influence the interactions and result in a range of different roles for scientists. At the same time, it is not simply policy-makers wanting and using science: campaigners, industry, communities and a range of other stakeholders all want to use science to influence policy. The interactions are not one-way, but multifaceted, and the line between science, policy and politics can be increasingly blurred. As a result, collaborative, co-learning approaches are needed to improve the use of science in policy. Drawing on the authors' research, this chapter will discuss the challenges faced at the boundaries between science and policy and highlight how collaboration and collective action might be deployed to manage the interface. This can both help researchers better design their research to support decision-making and help decision-makers and other stakeholders improve their use of science for evidence-based policy-making.

Keywords Policy agenda · Stakeholders · Decision-making · Co-learning

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2.1 Introduction

Climate change is on the policy agenda in countries across the world in part thanks to the work of scientists. The issue of carbon dioxide and other greenhouse gases accumulating in the atmosphere and impacting the Earth's long-term climate patterns has long been recognized. Scientists have continued to improve understanding of the changes that are occurring, develop climate projections and highlight likely impacts. At the same time, science and research have been highlighting the challenges of, and providing options for, mitigating and adapting to climate change. The IPCC reports give a sense of the volume of research into the issue (IPCC 2014). This science has been used to inform policy at international, national and local levels. However, action on climate change has still been slow to materialize. The challenges of negotiating the interface between science and policy have been part of the reason for this limited action (Lemos et al. 2012; Lawrence et al. 2011).

Now that climate change is firmly on the agenda, concerted action on both mitigation and adaptation will continue to require science to inform and guide decision-making (Lemos et al. 2012; Lawrence et al. 2011). However, the challenges of the interface will still make the use of science in policy difficult. This chapter will discuss the role of science in policy and science policy interface, and highlight the challenges that can limit science contributing to effective policy-making. Then, this chapter will draw on empirical research to highlight strategies to address these challenges and better negotiate the interface.

This chapter argues that because climate change is characterized by complexity, uncertainty and politicization, using science to simply provide knowledge for policy is unlikely to be effective. Climate change science will be difficult to communicate, risks being questioned or ignored and can be used to support political positions. Further, as decision-making is likely to involve a wide range of stakeholders, science will be used in a wide array of interactions. To overcome these issues, we suggest that scientists need to become stakeholders in collaborative and participatory processes to help establish a shared understanding through co-learning. We use case studies from our research to show examples of how this has been done, and discuss the various barriers that are faced and strategies to overcome them. We show that these processes can prove effective when the science is uncertain and complex, and the issue is highly political. Although such processes are often difficult and resource-intensive, they have a range of benefits. We also suggest that scientists are well placed to support these processes.

2.2 Science and Evidence-Based Climate Change Policy

2.2.1 The Role of Science

The past few decades have seen the rise of evidence-based policy as a policy-making approach in many countries (Althaus et al. 2013; Head 2008; Marston 2003; Nutley et al. 2003). Clearly, evidence had been important to policy long before this, but evidence-based policy focuses on relying on scientific evidence to help understand the issue and guide decision-making. As Bell (2004, p. 23) notes, this evidence-based policy approach is based on 'the application of science-based, "objective" knowledge—the kind possessed by "experts"—to the solution of policy problems and the building of governing capacity'. The central challenge is, therefore, to gather enough evidence to make good decisions, or 'to close the "knowledge gap" in relevant policy domains'.

However, the evidence-based policy is in many ways a restatement of the rational model of policy (Bell 2004), which assumes that all society's values are known, weighted and can be compared, that policy outcomes and impacts can be effectively predicted and compared, and that the policy actors will make a rational choice based on this knowledge (Dye 2005). Uncertainty and complexity, especially around complex environmental and social issues, make such an assessment extremely difficult and complex, resulting in calls for more research to better understand the issue, which in turn often limits action (paralysis by analysis). Furthermore, it is clear that there is a range of different types of evidence present within policy-making, and that they are often treated differently (Head 2008; Marston 2003). Finally, there is the fact that policy is inherently value-based and political and evidence is likely to be harnessed to support existing political positions (Oreskes 2004; van Buuren and Edelenbos 2004), rather than being weighed and balanced in a rational way.

2.2.2 Expert Advice, Technocracy and Politicization of Science

This importance of, and apparent reliance on, scientific evidence in policy is indicative of an increasingly technocratic style of policy-making, in which decision-making is strongly based on the advice of experts (Fischer 2009). These moves towards more technocratic decision-making rely on a positivist view of scientific knowledge as value-free facts about the world (Fischer 1990). A more social constructivist view of science highlights that scientists (and also other experts) are not purely rational thinkers, and that science is not free of values, and hence, their advice cannot be value-free (Jasanoff 1990, 2003). If experts are not rational, value-free actors, a technocracy results in an undemocratic system where the views of experts override the values and knowledge of the other actors (Fischer 1990; Weingart 1999; Jasanoff 2003).

On the other hand, the difficulties of getting climate change on the policy agenda, despite its far-reaching and serious potential impacts, suggest that scientific evidence is not always the technocratic leader of policy, or at least not all experts are equal within the policy process. Policy processes are in reality highly political, and scientists and scientific evidence can easily become part of the political processes (Oreskes 2004; Weingart 1999). Scientists can become advocates for particular policies or policy positions, intentionally or otherwise (Lackey 2007; Pielke 2007). Hence, the role of science and scientists in policy is not straightforward (Morgan 2014b; Spruijt et al. 2014). Although scientific evidence has clearly been important to the establishing of climate change as an issue, it has also not been simply a case of presenting science to policy-makers.

2.2.3 The Science–Policy Interface

The traditional view of the science–policy interface is of a one-way knowledge transfer, where scientists (or potentially other 'experts') provide knowledge, or facts, to policy-makers or decision-makers. This comes with the assumption that better knowledge will result in better decisions. These traditional knowledge utilization theories (Landry et al. 2001; Weiss 1979) see science as providing knowledge for policy-makers to use and focus on how the scientific knowledge gets from the realm of science into the policy process. They imply a supply–demand relationship between science and policy (Sarewitz and Pielke 2007).

However, simply providing knowledge does not guarantee its use in policy (as highlighted by inaction on climate change despite the wealth of knowledge). Furthermore, these theories fail to take into account the messiness of policy by assuming the knowledge is disseminated neatly and intentionally (Landry et al. 2001; Slob et al. 2007). In response, the interaction or 'two-communities' model sees policy-making and science as two different communities that interact in a nonlinear way (Caplan 1979; Slob et al. 2007). As Landry states: 'It suggests that knowledge utilization depends on various disorderly interactions occurring between researchers and users rather than on linear sequences beginning with the needs of the researchers or the needs of the users'. (Landry et al. 2001, p. 335). In this model, more interaction (greater overlap between the communities) is likely to improve the interface (Bradshaw and Borchers 2000) and it is the differences between the communities that create barriers (Landry et al. 2001).

An important aspect that is sometimes missed is that in reality policy and science are rarely one community. A governance approach to policy highlights the importance of networks and the wide variety of different actors that are actually involved in policy-making in a range of different roles (Rhodes 2007). Complex issues, such as climate change, require governance approaches that involve interactions between governments, communities, industry and a wide range of other stakeholders (Rhodes

2007; Rijke et al. 2012). Hence, only considering the science–policy interface as a simple interaction between two communities risks missing a range of other, equally important, interactions. Recognizing this, Kasperson (2011) proposed a model of the science–policy interface in terms of a mediating network, or 'spider's web'. Rather than a simple interface between science and policy, he proposed a web of interactions. This implies that there is not one science–policy interface, but many; although there are likely to be similar challenges, a range of strategies might be needed to ensure science can be effective within governance. Strategies for successfully navigating the science–policy interface around complex and uncertain issues will need to be flexible and able to bring together a range of stakeholders, who may have a range of different knowledge, political views and values.

In summary, if science seeks to inform policy effectively, therefore, there is a range of challenges to consider. Head (2008) noted that evidence-based policy faced the challenges that: (a) policy is inherently value-based, (b) information is perceived and used in different ways, and (c) complex networks are difficult to harness to traditional forms of knowledge management, policy development and programme evaluation. In the context of climate change, these challenges are highlighted and exacerbated by the complexity, uncertainty and political nature of the issue.

2.3 Challenges for Climate Change Science and Policy

The role of scientific knowledge in policy is complex, and climate change exemplifies all the issues discussed above. Although there has been long-standing evidence for climate change and its impacts, action on mitigation and adaptation has been slow to materialize. Clearly, science has struggled to inform policy and result in effective action.

Recently, Lemos et al. (2012) reviewed a series of studies focused on how different factors influence climate information uptake in specific contexts. They highlighted several issues that are critical to the interface between climate change science and policy, including (1) credible and legitimate information, communication and dissemination; (2) participatory approaches that bring together producers and users of knowledge; (3) uncertainty; (4) the negative effect of the highly politicized context of climate policy-making; and (5) the public value of science.

Many of these issues are overlapping and interrelated, stem from the nature of the issue, and are not unique to climate change. In this chapter, we argue that the complexity of the issue, the uncertainty around the science and the politics of the significant change needed have combined to be major barriers to the use of science around climate change. Later, we draw on research into other, similarly complex issues, to highlight some approaches to overcome these barriers.

The complexity of climate change as an issue can mean it is a daunting task. The presence of both positive and negative feedbacks, as well as the possibility of tipping points, mean climatic changes and their impacts are nonlinear and difficult to predict and understand (Barnett 2001; Ruth and Coelho 2007). Significant resources have been put into gathering evidence and gaining a greater understanding to better support and inform policy-makers, as evidenced by the IPCC reports. This technocratic response suggests that there is a hope that more and better knowledge will result in clear solutions and decisions. However, this demand has grown as the issue becomes more complex—while earlier IPCC reports focused on the physical science surrounding the causes of climate change, later reports considered the social, economic and cultural elements of mitigation and adaptation. This realization of the need for social sciences and other knowledge has emphasized the complexity of the climate change challenge. Efforts to consider the socio-ecological system as a whole serve to highlight the complexity further.

At the same time, adding more science to the issue does not always point a way forward, but instead allows for a greater array of 'facts' from which policy-makers can choose from to support any particular choice of action or inaction (Sarewitz 2004). Ryan (2015), in his literature review on climate policy implementation at the city level, recognizes that problem framing is a relevant factor to the design and implementation of a climate policy. Climate-friendly policies are more likely to be developed and advanced if they can be framed in relation to local problems and generate social, economic and environmental benefits (Ryan 2015; Aylett 2014; Bulkeley 2010). Hence, greater complexity (and more science to explain that complexity) can encourage an array of different framings. Rather than helping to resolve a policy issue, the science can be used to justify any particular framing, which may avoid the broader climate change issue.

Uncertainty has also been a key challenge in the interactions between climate change science and policy (Ascher 2004; Barnett 2001; Dessai et al. 2007). Detailed and precise local and regional impacts of climate change are difficult to determine (Leitch and Robinson 2012), even though the fundamental physical nature of the greenhouse gases has been well understood for many decades. The impacts are long term, cross-scale, temporally and spatially complex and highly interconnected, the effectiveness of policy responses is also uncertain, and feedbacks and tipping points mean there are potential surprises. Barnett (2001, p. 982) summarizes the challenge:

> So, not only does policy have to plan for anticipated events whose specific form is uncertain (uncertainty of impact), and design strategies whose effectiveness will be uncertain (uncertainty of effective solution), it also has to have some capacity to minimize suffering and avert disaster from events whose very existence is impossible to predict.

Part of the challenge is communicating the uncertainty around climate change and finding strategies to deal with it (Bradshaw and Borchers 2000; Swart et al. 2008; Moss 2007). Policy-making is often uncertain, and the challenge is to ensure stakeholders understand the uncertainty. Ensuring stakeholders understand different types of uncertainty, as well as the role that consensus plays in the science process can help avoid a lack of action due to uncertainty.

Uncertainty can also be harnessed to politicize the issue. Even as the evidence of climate change grew and modelling became better, uncertainty was used as a reason not to take action (Heazle 2010). The IPCC reports were designed in part to address this concern by filling a knowledge gap. However, five reports describing increasing scientific certainty and consensus have all been met with much the same scepticism from some quarters. In many areas, perhaps most notably the USA and Australia, climate change policy rapidly became about 'knowledge fights' (van Buuren and Edelenbos 2004), with two sides (largely but not exactly defined by the left and right of politics) producing evidence to support their view (Pielke 2002; Sarewitz 2004). Vested interests are also mobilized to question the veracity and certainty of the scientific evidence (Oreskes and Conway 2011). Even though the scientific consensus was clearly very strong and growing (Cook et al. 2013), doubt was regularly cast on the certainty and agreement of the science, highlighting the fact that despite claims of evidence-based policy, the issue was fundamentally a political one. Scientists have inevitably been caught up in these political fights, being accused of bias and a lack of rationality.

Hence, despite claims of adherence to evidence-based policy by policy-makers, especially in Western developed countries, acceptance of climate change as a serious policy issue has been slow and patchy and has lagged behind the scientific consensus. This highlights that policy-making is rarely rational, and politics, emotions, values or other knowledge may challenge the apparent primacy of science within policy processes, even where issues appear to be highly technical and science-based. In reality, climate change is a political issue, with the choice of whether to take action or not, or when and what actions to take, value-based decisions based on perceptions and acceptance of risk.

Climate change impacts are examples of complex socio-environmental problems that characterize our contemporary societies, and have given rise to a growing discontent between the public's desire to see risks reduced and the visible action of risk management institutions (Renn 2008). These systemic risks (Bunting et al. 2007; Renn 2008) involve increased vulnerabilities and interconnections between the physical world, the economy, social relationships and political culture. Characterized by diverging scientific assessments, complexities, uncertainties and ambiguities (Renn 2008; Beck 1992, 2006), these risks are also seen as appropriate arenas for challenging traditional scientific approaches to knowledge creation and the production of new knowledge based on new perspectives and refined theories (Callon 1999; Funtowicz and Ravetz 1993; Avenier and Nourry 1999).

As a result, the importance of scientific evidence, and the role of scientists, is fundamentally decided by those with power, such as decision-makers, policy-makers, the public and other stakeholders. Certainly, partnerships, networks and alliances are of growing significance for climate policy and adaptation (Leck and Roberts 2015). Scientists can of course be members of these groups and have power and authority of their own that derives from the perception of science as rational knowledge. However, they must be aware that responses to climate change, particularly at the local level, are shaped to a suite of conflicting values and priorities, other environmental concerns and development pressures and goals (Romero-Lankao et al. 2015). As a result, consideration of the role of science has to go beyond considering how scientists interact with a small group of centralized policy- and decision-makers, to consider the role of science and scientists within the broader realm of decentralized governance networks (Kasperson 2011; Morgan 2014b). Scientists can become stakeholders within the process, not just rational knowledge suppliers providing expert advice, but knowledge brokers and translators, boundary workers and participatory co-learners (Guston 2001; Huitema and Turnhout 2009; Michaels 2009; Miller 2001; Turnhout et al. 2013). For climate change, this means there may even be a role for science (and scientists) in advocating for action (Grundmann 2002), despite the politicization of the science.

Understanding these disconnects and complexities at the intersection of scientific information and climate adaptation and mitigation responses and policies is still a big challenge for scientists. However, there are lessons from a range of other sectors that could help address these issues. Recently, Lemos and Kirchhoff (2016) identified critical disconnects in the interface between climate information and water management. They argue that to address these barriers, there is clearly a need to implement an intense process of interaction between producers of information and users through time. The authors argue that this would allow for both parts to understand better each other's needs, priorities and limitations, and ability to change them. Two-way communication and an ongoing relationship between producers and users can address barriers to understanding and use, as well as discussions of trade-offs and risks (Lemos and Kirchhoff 2016; Di Giulio et al. 2014).

The next section will draw on the authors' empirical research into the interactions between scientists and stakeholders to highlight strategies that can be used to better incorporate science into policy-making and combat some of the challenges faced at the many interfaces between science and policy.

2.4 Collaboration and Collective Action for Negotiating the Science–Policy Interface

2.4.1 Water Management in South East Queensland (SEQ): Co-learning and Collaboration

Just as with climate change, water management has relied heavily on science to both identify and address issues. Science is a key component of water management but, as with climate change, issues around water management can be highly complex, highly uncertain and highly political. Water recycling, for example, can be a very emotive issue that is about values despite often being treated as a technical, scientific issue over water purity (Morgan and Grant-Smith 2015). Similarly, issues over environmental water quality have proved to be highly complex and uncertain, since sources of pollution can be very diverse and diffuse and rivers often cross multiple political jurisdictions.

A recent research project has revealed the complex and political nature of the water management challenge, and the role that collaboration played in improving the science–policy interface (Morgan 2014a). The study looked at South East Queensland (SEQ): a rapidly growing and developing region on the east coast of Australia. In SEQ, there was general acceptance that environmental water quality was declining because of the increased population, increased development and limited water quality management. A national-level and state-level move towards more sustainable water planning and a focus on regional natural resource management provided an opportunity to focus on water quality (Cottingham et al. 2010; Morgan 2014a). Science was clearly needed to identify the issues and key measures that could be taken. However, there was deep uncertainty about causes of pollution, the issue was complex with water quality being affected by a wide range of both point and diffuse sources across several local governments (Cottingham et al. 2010). The issue was also political, with arguments between local governments over impact of sewage, disagreement over sources (with farmland often being highlighted as a major contributor) and the challenge of unclear and overlapping responsibilities for the many impacts on water quality (Morgan 2014a).

Through a collaborative approach under the banner Healthy Waterways, local and state governments collaborated with scientists, industry and community groups to address water quality. The Healthy Waterways Partnership was highly science-based, beginning with a scientific assessment and the development of a monitoring programme (Bunn et al. 2007). Close interactions with research scientists led to effective identification of key issues and the ability to communicate uncertainty and address complexity. Importantly, a decentralized governance process, in which scientists were important but not dominant stakeholders, avoided much politicization of the issue. Scientists were trusted and seen as independent, and a participatory and collaborative approach allowed all stakeholders, including scientists to be part of a learning process (Morgan 2014a). Science was used to resolve disputes between local governments over sewage sources and could be used to get stakeholder agreement on actions (Cottingham et al. 2010). Importantly, the approach allowed a shared understanding of the issue to be developed, both on a scientific level and policy level.

Hence, by allowing science to be used in a participatory co-learning process, the uncertainty, complexity and politicized nature of the issue could be more effectively dealt with. This approach required trust to be developed through long-term collaboration, substantial and consistent resourcing and champions to help build and maintain networks and momentum. Substantial resources were put into creating and maintaining effective networks and collaborations, and this effort was not always recognized by governments and research institutions.

2.4.2 Risks Associated with Extreme Events and Urban Expansion and Development on the North Coast of São Paulo: Improving Dialogue

Encouraging purposeful collective action and improving dialogue between producers and users of knowledge place at its heart questions of how we should deal with complex socio-environmental problems, such as climate change. This is supported by a second example: an empirical study undertaken on the North Coast of São Paulo, Brazil, which provides more details of the processes that proved effective. This region is under increased pressure from tourism, industrialization and oil extraction, further challenging its social and ecological integrity. The region is characterized by a rich and large environmental protected area, informal settlements, areas at risk of landslides and flooding, scarcity of drinking water and sanitation, and poor distribution of public services. Hence, the region is potentially threatened by climate issues, which will aggravate environmental and urban problems and will increase risks, especially for communities already living in vulnerable conditions (Ambrizzi et al. 2012; Di Giulio et al. 2014; Di Giulio and Ferreira 2013; Serrao-Neumann et al. 2013, 2016).

Through a collaborative approach, the São Paulo research study aimed to provide interactive arenas in which community stakeholders, policy practitioners and scientists were able to deliberate and reconstruct their understanding of risks associated with extreme events and development in the region, and the effects of the combination of these risks on their capacities to adapt and thrive within their communities (Di Giulio et al. 2016). The study was carried out in three coastal cities (São Sebastião, Caraguatatuba and Ubatuba—approximately 253,000 people) and involved eight focus group meetings, 20 interviews and two workshops. Analysis of this empirical material highlighted some critical points for comprehension of climate change perceptions and actions. Firstly, community stakeholders and policy practitioners made connections between a series of local potential threats related to climate change (e.g. floods, landslides, rising sea levels), and possible contributory causes of climate change (e.g. deforestation, vehicle pollution, greenhouse gas emissions) (Di Giulio et al. 2014, 2016; Di Giulio and Ferreira 2013). Secondly, there was a variety of reasons for having difficulties in confronting risks and threats locally: mainly controversies surrounding weather forecasting and scientific studies, the lack of dialogue between producers and users of knowledge, and social, economic and emotional conditions that limited the ability to deal with these threats and risks or enhance the capacity of communities to adapt to them. Thirdly, there were critical differences between how climate risks, needs and vulnerabilities were perceived from the perspectives of practitioners and affected communities. Finally, there was a strong feeling from the participants that public authorities and communities themselves are responsible for action on climate change at the local level, although other infrastructure development projects (oil and gas) in the region are of more immediate concern than climate change (Di Giulio et al. 2014, 2016; Di Giulio and Ferreira 2013).

From the perspective of the participatory approach, the focus group meetings were successful in bringing the opportunity to extract the perceptions and motivations of participants through an iterative process, which enabled them to address complex issues. The participants were comfortable to deconstruct and reconstruct their concepts about climate risks, urban problems and environmental issues. They brought their own personal experiences, information and possibilities of connections with other questions that naturally emerged during the meetings, in order to seek new responses to their concerns and anxieties. This approach allowed the iterative group process to be developed in a relaxing way that favoured stimulating changes and discoveries among the participants, as well as their compromised participation to the dynamic. On the other hand, the two workshops that aimed to exchange information on climate science between scientists, practitioners and policy-makers were less successful, when compared with focus group meetings. The research team expected an expressive number of practitioners and stakeholders, as both workshops had been organized to be participative and interactive. However, few of them (but a very qualified audience) accepted the invitation and attended, which highlighted some difficulties in engaging stakeholders in a participatory research process. Those difficulties are specifically linked to mobilization, engagement and participation aspects (Di Giulio et al. 2014; Di Giulio and Ferreira 2013). As Wilsdom et al. (2005) point out, public engagement will be really important in maintaining and renewing the social contract that supports science. As many more people are involved in the decision-making process, there is more chance to promote a debate of public values of science and encourage the dialogue between social groups, which can go beyond competitive propositions and reach a discussion of visions and goals.

2.5 Lessons for Researchers and Other Stakeholders

Scientists and researchers need to understand that the interactions between science and policy are complex, and getting involved in policy-making can be challenging. Simply trying to present facts may not always be effective, with uncertainty, complexity and politicization meaning that science can be ignored, questioned or used to justify a range of political agendas (intentionally or otherwise). In turn, the credibility and legitimacy of scientists themselves can be called into question, and scientists can find themselves deeply involved in political fights.

However, as the examples discussed here show, a different approach can mitigate many of these problems. Ensuring participatory and collaborative approaches to decision-making can help ensure different values and politics are explicitly recognized in the process, and that a shared understanding can be developed. This shared understanding can then provide a basis for a shared vision, and consensus around actions, avoiding knowledge becoming the focus of arguments. This can help ensure that complex information can be communicated, that uncertainty is understood by all those involved, and that political issues can be treated as value differences rather than as knowledge fights. All participants can bring their concerns and knowledge to the table, providing legitimacy to all viewpoints while ensuring complexity is understood and uncertainty effectively communicated.

Climate change as an issue is always likely to be complex, uncertain (especially in terms of local level impacts) and politically charged. While science is key to understanding climate change, getting on-ground action will require more than just scientific knowledge of physical systems. Values, emotions and politics are all important parts of the process, even if they are messy and create conflict.

Researchers need to be aware that they bring their values, emotions and politics to the table when they interact with others, whether they intend to or not. At the same time, other stakeholders need to be aware of the risk of 'cherry-picking' evidence. Stakeholders will always have a bias towards the knowledge that supports their values and politics. To avoid policy becoming knowledge fights that become proxy arguments and values, all stakeholders must be willing and able to bring knowledge, values and politics to the process explicitly and have it treated fairly.

Of course, such collaborative approaches are not always straightforward. Engaging with a wide range of stakeholders and bringing them together can be challenging, as the examples above highlighted. Running collaborative processes are time- and resource-intensive and do not always fit into traditional policy deadlines and processes. Efforts are needed to ensure participation is recognized. Power differentials are always a potential problem. There is a risk of participatory processes being hijacked by special interests or for some groups to be excluded. It is important to remember, for example, that scientists hold a level of power due to the perception that they can bring objective facts to the process. Hence, scientists must ensure they do not exclude or dismiss other knowledge, such as local or traditional knowledge, which may not be held in the same regard, but is still an important part of a genuinely collaborative process.

Despite these challenges, the possibilities for better and fairer outcomes that are more likely to be supported and implemented mean that the time and resources are likely to be worth it. Furthermore, there is a range of other benefits for those involved. In the context of the science–policy interface, researchers engaging with the public can maintain and renew the social contract that supports science. For other stakeholders, it both provides the opportunity to gain access to a range of knowledge and influence the future direction of research to help it address the issues of concern to them.

2.6 Conclusions

Issues around climate change are characterized by uncertainty, complexity and politicization. As a result, negotiating the science–policy interface around these issues requires careful consideration of the problems this can result in. We argued that within such a context, effective policy is best achieved through participatory and collaborative approaches.

Crucially, the aim of these processes must be to bring a range of knowledge, values and politics to the table and allow participants to express them. It benefits no one when science or knowledge becomes a political football, and each side attacks the others for being uncertain or politicized as a proxy for hiding their (conflicting) values. Instead, the processes must try to create a shared understanding, of which science is a key, but not the sole, part.

Such approaches are time- and resource-consuming, as well as unpredictable. At the same time, the need for these resources and the efforts of people involved are not always recognized by institutions. Nonetheless, these processes can ensure a shared understanding of the issue, leading to a shared vision and consensus on action.

We suggest that scientists and researchers can benefit from seeing themselves as one of many stakeholders in an issue and focus efforts on collaborating with other stakeholders to influence decision-making. In fact, their position as respected but perceived as independent can allow them to be important actors within participatory and collaborative processes, providing they are aware that their position comes with power, and explicitly recognize how their values and politics impact on a process.

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Chapter 3
Conceptual Analysis of Climate Change in the Light of Society-Environment Relationships: Observatories Closer to Both Systems and Societies

Mireille Fargette, Maud Loireau, Nabil Ben Khatra, Habiba Khiari and Thérèse Libourel

Abstract This chapter focuses on climate change, including the acuity of both scientific and social issues, which questions the future of humanity. We adopt a systemic reasoning that provides objectivity to the analysis. We represent society-environment relationships, and analyze climate global systemic functioning and its global scale connection to geographical imprints. In this conceptual systemic framework, we position an observatory, which observes, analyses, reports on facts, and enhances democratic processes by providing sound (scientific, accurate, unbiased) information to debate. We note the consistency of systemic and ethical approaches; thereby scientifically strengthening and justifying the latter if this was necessary. They converge on the proposal of a "System World" where humans as one whole would be conscious of the global systemics, responsible and fair players, and aware of the part they can play in climate regulation. The contribution of every single individual adds to the global effort, and acknowledging how they contribute to scaling climate regulation up and down would also promote greater equity and a better shared future.

Keywords Systemic regulation and adaptation · Geographical imprint
Social future and equity · Local-global circulation · 4 per 1000 initiative

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3.1 Introduction

Current climate change and the scenarios projected over the twenty-first century raise the question that the future of humanity as a whole is at stake. Given the risks encountered (IPCC 2014) and the challenges regarding the actions needed (i.e. COP21[1]), humanity faces a time of shared destiny and possibly a unique moment for truth with respect to choices for tomorrow's society. For the last twenty years, Conferences of Parties, in their advances as well as their difficulties and even failures, have shown how serious and complex the discrepancy is between local constraints and contradictory interests on one hand, and global systemic mechanisms on the other hand. Climate and the future of System Earth are parts of our common unshared heritage (Hulot 2015; Pope Francis 2015; Serres 2016; Tirole 2016).

With respect to climate change actions, there are conflicts of interest and worldwide powerful lobbies (e.g. energy lobbies); discrepancies between the richest and the poorest countries in their objectives, means and capacities (Haddad 2005; Thomas and Twyman 2005), which are not easy to overcome; and inertia (Claessens 2016), if not worse, is at work. However, side events to large international meetings such as yearly Conferences of Parties also show people's commitment, their needs and their will. One could ask whether this is part of utopia. Internet and social networks also reflect altogether current flows and opinions, people's power, will and expectations, the rationale of which requires interest and deserves consideration. S. Vauzelle,[2] a member of the United Nations Development Program (UNDP), summed up in one sentence the ambitions of the 17 Sustainable Development Goals[3] (SDGs) unanimously agreed at the United Nations General Assembly on 25 September 2015: "This is time to shift from the era of plunder to that of sharing." Decisions and actions regarding climate change should also be shared and joined.

In this complex context, which ranges from apparently very local critical situations to global challenges, the objective of this work is to adopt a systemic scientific approach to position actions and schemes for decision and action within a conceptual framework reflecting a global systemic understanding. To do so, concepts relevant to climate, climate change and society-environment relationships were analyzed, along with their links. The place for scientific observatories was explored, along with how this concept can both produce sound information and contribute to democratic processes. While systemics as a science provides objectivity to the process, we find that systemics and ethics converge to show the path to some utopia at hand.

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[1]COP21: Conference of Parties, 21st session, United Nations Convention on Climate Change, Paris, 2015.

[2]2016 IRD Summer school (Institut de Recherche pour le Développement).

[3]http://www.un.org/sustainabledevelopment/fr/objectifs-de-developpement-durable/

3.2 Methods

The Unified Modelling Language (UML formalism, Booch et al. 2005) was used to represent a series of conceptual schemes. Figures and text go hand in hand, and the text makes the conceptual scheme easier to decrypt in diagrams. Each figure includes a graphical legend detailing the type of relationship between concepts.

The analysis leaned against conceptual frames such as “society-environment relationships”, and “system, compartment and function”, both detailed in Fargette et al. (2018) and the “OSAGE observatory” presented in Loireau et al. (2015, 2017). The method elements presented below have been extracted from their publications:

- **Society-environment relationships**: were analyzed by following systemic reasoning (see below), with a particular interest in sustainability and systemic adaptation, and a focus on “Life” and “Organisation of society” functions.
- **The system, the compartment and the function**: a system (see Fig. 3.1) is characterized by its structure and functioning where consistency between the two latter provides viability to the system (sustainability). A system is also characterized by its dynamics where changes over time, in functioning regime or structure, lead to system evolution through adaptation, or to system breakdown if non-viable (i.e. when structure and functioning are not adapted to the system environment). The system is embedded within an environment. Driving forces as part of the environment force the system to fit environmental conditions (i.e. be adapted at any time), or recover fitness through adaptation (i.e. be adaptable over time). Otherwise, the system is at risk and may collapse. The system has no hold on the environment and does not impact on it in return. On the contrary, reciprocal interactions exist between neighboring systems; they communicate and exchange fluxes (material, energy, information), which induce regulation (or de-regulation, disturbance). To account for the diversity of systems, we consider that an abstract system is either elementary or complex, made up of components that can be systems themselves (see the composite pattern in Fig. 3.1).

When a system is complex, the compartment vision may be adopted; this is an interpretation[4] of reality, which only retains from the system the elements involved in the function identified by the “view”. This is how “Life” and “Organisation of society” functions were identified as taking part in society-environment relationships; it can be self-organized or induced by organizational pressures, the origin of which lies further away from the compartment.[5]

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[4]It relies on knowledge that is available, partial and sometimes even biased.

[5]This depends on the focus and level of precision adopted.

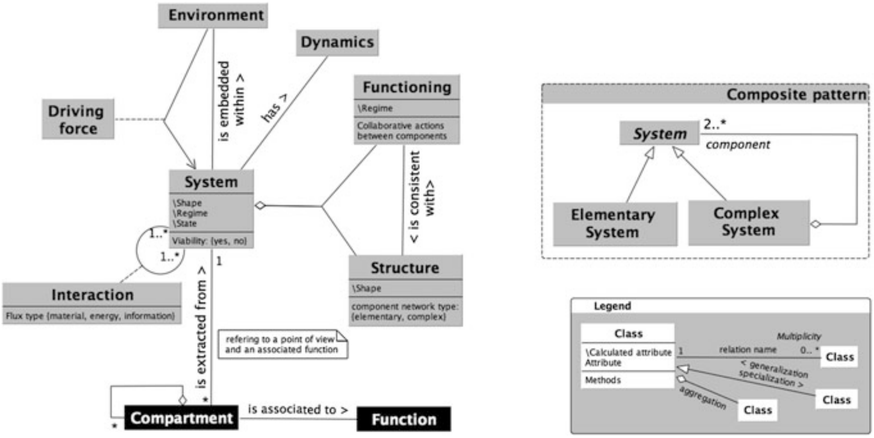

Fig. 3.1 System, compartment and function

- **Observatory**: In the case of one particular type of scientific observatory, identified as OSAGE (Observatoire Scientifique en Appui à la GEstion du territoire), the conceptual analysis is applied to scientific protocols and life cycle (collection, analysis, monitoring, reporting). Such devices and logics particularly focus on the relationships between local societies and their environment and on "Life" and "Organisation of society" functions. Observatories for Sahara and Sahel (OSS 2013, 2014) developed activities within related frames of action (Ben Khatra et al. 2012; Hirche 2015; Jauffret 2015).

3.3 Climate and Climate Change

We formulate the challenge of climate change issues (see Sect. 3.3.1 and Fig. 3.2) from System Earth to System World. In Sect. 3.3.3 we propose a systemic framework for System Earth functioning; to do so, we follow the track (Fig. 3.3 together with the detailed text in Sect. 3.3.2) from systemics to geography, and their link to climate. The issues raised in Sect. 3.3.1 are phrased in Sect. 3.3.3 within the systemic frame that is constructed.

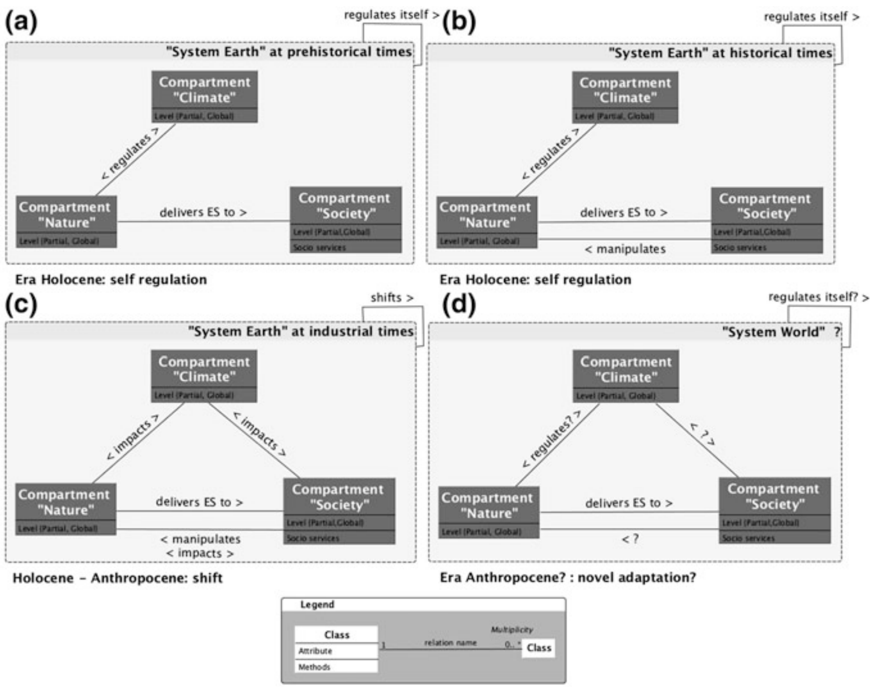

Fig. 3.2 Evolution of society-environment relationships and today's stake

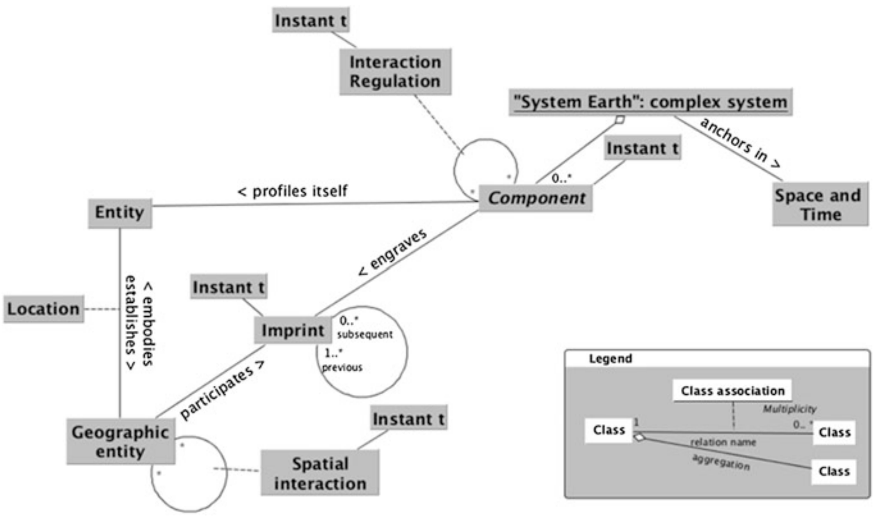

Fig. 3.3 System Earth, from regulation to imprint and vice versa (for further explanations, see Sect. 3.3.2.)

3.3.1 Evolution of Society-Environment Relationships and Today's Challenge

A specific view[6] (Fig. 3.2a) identifies Compartment[7] Society, separate, independent and (relatively) autonomous (Function Organization). Depending on the focus of the view, it can be a social group (at any level of precision, whatsoever) or the whole of humanity (global society). Compartment Nature delivers Function Life, i.e. a set of ecosystem services organized in types[8] (Millennium Ecosystem Assessment 2005), while Compartment Climate has an action upon delivery efficiency of services as a whole. However, from the beginning of historical times (Fig. 3.2b), as soon as agriculture and farm animal breeding have been adopted, Compartment Society has intruded into Compartment Nature through the manipulation of biological organisms, through work and transformation of inhabited places.

From the industrial era (Fig. 3.2c), impacts of human activity are obvious, not only on Compartment Nature but also more recently on Compartment Climate (IPCC 2014). In turn, Compartment Climate impacts on Compartment Nature and the delivery (quantity or quality) of some ecosystem services is even questioned. In return, this impacts on Compartment Society. Moreover, Compartment Climate directly affects Compartment Society because of apparently more frequent, more intense extreme climatic events and/or affecting places previously less prone to this type of phenomena.[9] It is therefore clear that humans have the ability to modify their own habitat; some authors mention the Anthropocene (Bonneuil and Fressoz 2016) in order to distinguish the present time, which may well reflect a transition period, a shift away from Holocene climatic conditions that have prevailed for 12,000 years. The challenge today (Fig. 3.2d) is to identify how (type of action, means and implementation mechanisms) to achieve the objective of moderating climate change.[10]

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[6]Western culture origin; a positioning which nowadays drives a globalized world. However, Descola's analyses (2010, 2011) discriminate other human positions relative to nature.

[7]As introduced in Sect. 3.2 and Fig. 3.1.

[8]Supply and provisioning, support and regulation, cultural services.

[9]We refer to events directly linked to climatic change; these may even be enhanced by an increase in society's vulnerability (when human settlements are at risk).

[10]E.g. constrain the increase in global temperature below 2 or 1.5 °C as discussed at COP21 in December 2015.

3.3.2 System Earth, from Regulation to Imprint and Vice Versa

Figure 3.3 summarizes a systemic and geographic frame of thinking and organizes concepts accordingly.

Spatial and geographical entity. System Earth, as a complex system example, consists of a set of components (these are systems complying with the composite pattern, see Fig. 3.1). The systemic rank of each of these reflects the degree of complexity, the position relative to neighboring systems and relationships with them. Every component inherits space and time dimensions from System Earth. With its own rank, each system:

- profiles itself at every moment in a figurative entity with characteristics such as structure (e.g. biomass organized in biomes, in food webs, in species, the United Nations organization, a nation or a territorial organization), or flows, which materialize functioning and exchanges with neighbors (e.g. ocean currents, trade or monetary flows) and maintain biological, physical, cultural processes;
- is established and located in one place of the global space and embodied as a geographical entity (e.g. a biogeographical region, a city) with structured body, physiognomy, positioning. Ongoing functioning gets stamped (instant footprint) into structural feature onto a geographical entity.

Instant footprint stamping and imprint engraving. An imprint is anchored in one place and is responsible for its appearance; it is a complex physiognomy engraved in this place as the result of past and present functioning and their successive stamps. Therefore, the imprint has a spatial and a temporal dimension and refers to both every successive instant (and relevant functioning) and to history (dynamics). Instant footprints are stamped on the historical substrate.

The imprint inherits from System Earth its engraved synthesis, a spatial and temporal memory. Its composite appearance summarizes System Earth dynamics (i.e. its geological history). Hence the organization of geographical entities and features attests both functioning and history: the imprint is complex and partly depends on the foregoing and on the present.

Functioning, regulation and spatial relationships

- Components profile themselves in entities (initially in biophysical entities and, more and more frequently, in entities that, at least in part, result from human activities) and get established into geographical entities. Hence, similarly, systemic interactions (between components of System Earth) correspond to interactions between geographical entities: spatial dimension is, by definition, ascertained in such interactions.
- Furthermore, on time lapses corresponding to geological eras regulatory capacity occurs, i.e. systemic retro-action between components. At the global rank, this ultimately corresponds to System Earth's self-regulation capacity; it is an emergent property originating from adjusted interactions (adaptation,

evolution), along long periods of time, between components of System Earth (Gaia Hypothesis).

- The link is then easy to follow between the functioning regime (characteristic of a time span, a geological era), and the spatial ordering acquired over time of geographic entities and their interactions. The system-imprint link is reciprocal. It is the result of systemic functioning, and also takes part in regulation, a result of historical cumulative adaptations. Alternatively, regulation (as soon as embodied) can also be seen as inertia, acting as regulator by slowing down shifts that might happen.

Thus, it is possible to superimpose maps: climate zones (i.e. instant footprints, stamps resulting from functioning), cartography of energy flows (i.e. thermodynamic and fluid dynamics functioning (Krinner 2016)): winds, sea currents, atmospheric rivers (Dettinger and Ingram 2013) and geographical distribution (i.e. imprint) of major biomes, which results in biogeographic zones (Lacoste and Salanon 1999). The latter inherit from the past their structure, extent and positioning, and operate in the present time.

By the embodied and historical connection between system and imprint, biogeographic zones arranged on the globe surface and interacting at the global systemic rank, both result and take part in climate function and regulation. In other words, the overall imprint physiognomy can be seen as a proxy of the climate regime.

3.3.3 System Earth

Based on Fig. 3.3 and the related reasoning on System Earth in Sect. 3.3.2, we can develop these ideas further and 'translate' Sect. 3.3.1 into a systemic framework:

Within System Earth (i.e. at the global systemic scale), internal energy fluxes occur that correspond to climate functioning (fluid dynamics, thermodynamics). They result from present interactions between entities; the body and geographic positioning of which (i.e. global structure[11]) result from geological history. These interactions, after successive adjustments (through feedback loops) across large time spans, participate to maintain the climate regime (i.e. regulation). Conversely, the climate shapes and regulates these entities (large structured masses such as oceans and biomes). Ultimately, there is reciprocity and dialectic between such entities, which correspond to the components of System Earth, with their specific geographical and historical roots. This reciprocity corresponds to systemic control loops and to System Earth self-regulation[12] at the global systemic rank. The climatic zones distributed over the globe communicate via thermodynamic exchanges.

[11]Spatialized: taking into account relative positions and metrics.

[12]This formulation meets the Gaia hypothesis (Lovelock 1979), revisited by subsequent works (Levin 1998; Karnani and Annila 2009; Dutreuil 2012; Volk 2002); not to forget also the pressures that come from beyond System Earth itself. They correspond to its systemic environment (e.g.

Solar energy received and processed, is overall redistributed via large marine and atmospheric fluxes as the result of System Earth climate functioning.

- Climate is a functional synthesis, the synthetic product of all these interactions, which regulate each other at the global systemic rank. There is a single Climate functioning at the global systemic rank which shuffles overall energy via systemic fluxes. In dynamic terms, any significant change involves the whole system.

Over time, System Earth has experienced a series of functional phases which, over long timespans (geological eras), have showed relatively stable conditions (functional stasis) followed by shifts, witnessed by fauna and flora remains. For 12,000 years,[13] since the end of the last Ice Age, the climate regime has described the Holocene era and has been relatively stable.[14]

- The Holocene climate regime not only incorporates the geological dimension of life settlement on earth but also the gradual historical dimension of the development of human groups and societies. Climate regime and regulation promoters are in question today.

This regime fits the distribution of the major biomes on the surface of the globe, i.e. biophysics and spatiotemporal arrangement of inherited large geographic entities (biogeographic zones). The imprint results from functioning and promotes exchanges (spatial interactions) via major tuned fluxes (i.e. acting as feedback loops); hence, it participates in functioning and regulating System Earth.

- There is a direct link between global imprint (complex evidence of systemic interactions between components) and Climate functioning (including control). Conversely, one can form the hypothesis that any significant change in the imprint will affect the functioning of System Earth; hence, changes in engraving may be seen as indicators of climate change.
- The global imprint seen 200 years ago corresponded to the Holocene functioning type.

Over the last two centuries, notable changes in the engraved result have occurred, due to human activity: changes in place occupancy, in resource use, such as massive deforestation, and uncontrolled urbanization (Reed and Stringer 2016). Their contribution to climatic changes noticed in modern times can be directly assumed. They reflect systemic changes (population growth, intensification of land

solar radiation and its possible fluctuations) and provide additional intervention on functioning regime and dynamics.

[13]And omitting the last two hundred years.

[14]At finer scales, fluctuations may occur, such as a warm period in the Middle Age, followed by the Little Ice Age in Europe and North America from the fourteenth to nineteenth centuries.

use, changes in ways of living), modifications in systemic interactions and possible/probable shift in the systemic functioning (climate regime transition?).

- Human activities are responsible for important systemic changes that affect System Earth's operating regulations and result in the ongoing climate change. Conversely, human activities should be able to get organized with the intent to minimize their deregulatory action.

3.4 Towards System World?

If human activities are responsible[15] for climate change conversely, they should also be able to regulate them and counterbalance their own effects on climate. Hence, what are the systemic principles that should be relied on and what are the action levers that should be used? What are the sorts of device and methodological solutions available? This is what is investigated in Sect. 3.4.

3.4.1 Global Social and Societal Issues—Global Society Adaptation

Ecosystems, even those with apparent localized positioning, depend on global climate functioning and climate regulation, whose formula is written at the global rank (see Sect. 3.3). Ecosystem services, identified as Life functions, derive from the overall functioning. Therefore, every Life function expected by society as a whole,[16] requires the entire System Earth (global ranking). The generic Function Habitat (derived from the Greek *oikos*) gathers a large set of more specialized, controlled and coordinated Life functions. Figure 3.4 points to a possible management approach that society could operate; it consists of socio-services, which originate from social regulation.

- As soon as the system deregulation is acknowledged by society (see Impact, Fig. 3.4), novel regulations (feedback interactions; cf. Ecosystem Services and Climate Change management under social regulation control in Fig. 3.4) should rely on global society's initiative (because global society is both a part and a stakeholder of System Earth) and result in society adaptation. Implemented efforts to take part in the regulation should not only involve novel management approaches; they should also imply deeper re-organization within society (through social re-organization). Global society shares its present and future on

[15]Even if these were only partially responsible for it.

[16]And, in the end, any individual of global society, and with respect of most (if not all) services.

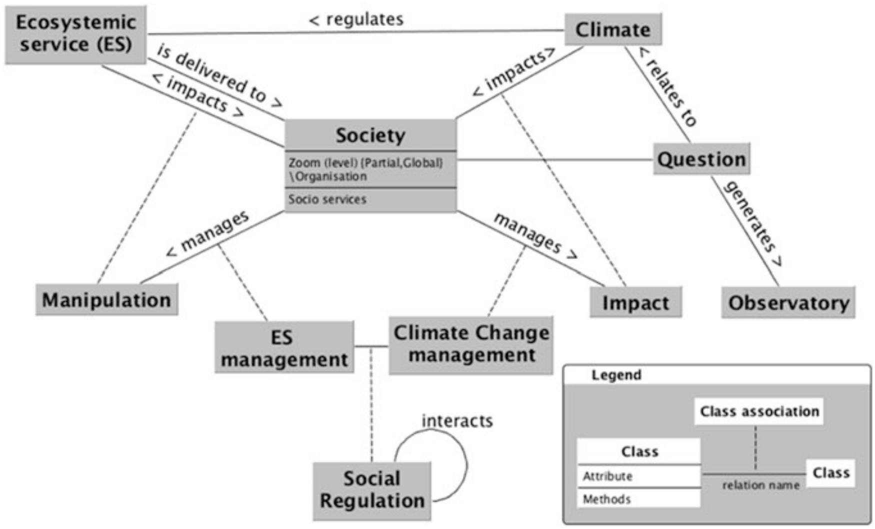

Fig. 3.4 Social issues—society adaptation

Earth and, hence, expected efforts for regulatory adaptive actions should also be based on a fair[17] share of effort and "constraint acceptance".

The imprint, biophysics materiality (which has also collected over recent centuries significant intrusive "spots" resulting from human settlements and activity) and climate represent structure and functioning of System Earth, respectively.

- Efforts for good management, whether they tackle the first one or the second one, represent different views on the same question; corresponding management intentions and actions converge[18] towards the same goal, "acting on" or "being part of"[19] a network of interactions at the global rank.

Ecosystem services manipulation should conform to management objectives (i.e. those which intend to recreate system viability[20]). Whether they aim at the management of ecosystem (Structure) services or at climate (Functioning) control, such technical processes converge in their results. Altogether they should be coordinated under the supervision of social regulation, which in turn should undergo its own adjustments. This should comply with the objective of sustainability, and there are two levels of adaptation relating to society-environment relationships (see Fig. 3.4;

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[17] See further down in the text.

[18] In this way, conventions on Climate, Desertification and Biodiversity represent views, and their objectives and expected results converge towards the same goal.

[19] Functional or structural interpretation, respectively.

[20] And not be limited to simple manipulations for the sake of speculative benefits to be extracted from ecosystems.

Fargette et al. 2018): one is the technical level (Ecosystem Service or Climate Change management) and the other is the social level (social organization), each level is driving its own share of changes in society.

- Society as a whole is concerned when it undergoes changes or when it actively participates in the adaptation effort.
- Society addresses the question collectively (at the time of joining a project or agreeing on an objective) and individually (at the time of taking part in the action).

Consequently, in a project of society in which choices for sustainability would unambiguously rely on systemic reasoning, one single global society would seek and be ready to act in the emergence of System World, where humans would be aware of the part they can play in, and accept to be a responsible player in the global systemic regulation. First, social interactions could progressively adjust (adapt) and eventually regulate technical management of society-environment relationships. Furthermore, society could undergo even more drastic changes (paradigm shift) through more profound questioning/discussing/inventing and subsequent adaptations. However, in order to be acceptable and be accepted by all and everyone (and not imposed), adaptive interactions can only comply with fairness and meet social equity.

One illustration of convergence of actions, whatever the view, is provided by considerations of soil properties and the 4 per 1000 initiative,[21] which is built on the following understanding:

General rule: Compartment Soil provides a bundle of services (multi-scale multi-functionality), e.g. local soil quality and spontaneous vegetation cover, which take part in global (temperature-humidity fluxes) climate regulation; e.g. local soil quality for local food supply. Society-soil interactions are numerous, diverse and inter-connected (complexity of situations, processes and scales) with the risk of contradiction in their effects (impact vs. management).

On the one hand, with respect to agriculture, soil is essential and organic matter in soils contributes to fertility (Life function: natural soil fertility). Agriculture can also be seen as a particular "Supply service" which necessarily involves labor (see also Fargette et al. 2018).

On the other hand, with respect to climate change, soils (through the organic matter they contain) naturally play a role in carbon sequestration (function: carbon sink) (Bernoux and Chevallier 2014).

However: Western intensive high-technology farming practices have contributed to reducing organic matter in the soil of large areas of arable lands, while chemical amendments, together with fast turnover of mineral elements, counterbalanced this depletion and even enhanced crop production. This practice contributed to the release of CO_2, one of the greenhouse gases playing a part in global warming.

[21] http://4p1000.org/understand

Conversely: Enhancing the carbon sink function of soils (especially in areas with carbon depleted soils) should contribute to climate change mitigation.

Hence: Increasing carbon content in soil (as organic matter) by agricultural practices[22] (direct seeding, no-till, burying crop residues, animal husbandry-cropping association, agroforestry, agroecology) should contribute to mitigating climate change by enhancing this carbon sinking function.

Therefore: Agricultural practices intending to increase organic matter in soil would not only improve local soil fertility (while reducing individual chemical inputs and increasing individual production and livelihood) but also participate in the joint action for attenuating climate change. The result should be particularly significant in places with carbon depleted soils (or prone to be).

Thus: Any farmer can take part in the 4 per 1000 initiative framework, wherever the location of the plot is and whatever the initial agricultural scheme practiced earlier.

Furthermore: In theory, there should be neither distinct nor omitted cases as long as farmers hold the means, knowhow and desire to contribute to the same objective and common cause. Here, the measurement of involvement and contribution could be estimated by the amount of labor dedicated to such practices, which are time consuming and "consistent with the objective".[23]

Indeed: This way of estimation would reshuffle relations between people and contribute to each other's recognition as taking part in a common effort.

- This is utopia but also some great opportunity for gathering people and linking it at the global rank, issues such as liability, mutual recognition, equity among humans and societies; everyone as an actor would be recognized, including the "smallest" (i.e. the fewest), the more isolated or peripheral, the less "significant" (or considered so, with respect to economical capacity): everyone has a part (duties and rights[24]) in the overall action and, once taken, this part should be acknowledged. This would be one step (organization and paradigm shift) towards System World.

Looking for a novel paradigm. In order to achieve effective systemic regulation, society self-organization should improve ways to scrutinize any initiative and innovation with open but critical mind: open because some new social paradigm is looked for; critical precisely because some new paradigm is looked for, and because so-called technical, political or economic innovations that merely re-edit pre-existing dominant patterns should be effectively analyzed with respect to them taking part, or not, in the novel paradigm.

Agriculture or forestry but also many industrial or touristic activities rely, by and large, on particular links with the environment. Society-environment relationships based on unrestrained profit for the sake of parts of society (lobbies) by exploiting

[22]"cf. the "Zaï technique" (Bernoux and Chevallier 2014).

[23]Environment-friendly.

[24]See further down in the text.

the environment, are likely to impact functioning regime or may even endanger the system itself; this is what can already be recorded with climate change. Such relationships are not systemics (while only systemic regulation is capable of ensuring system sustainability), and nothing new under the sun either (no paradigm shift).

In this respect, the organization of technical and financial resources that would, for example, pretend to contribute to the international 4 per 1000 initiative will not fall under systemic virtuous regulation (and will not ensure viability) unless returns of efforts are (re-) invested for the sake of soil, environment and those working at facilitating soil's ability to sequester carbon.

Conversely, acknowledging work and time devoted to this task, considering existing expertise and skills, facilitating training or technical input if necessary and under appropriate[25] conditions, would contribute to the acknowledgment of individual dignity and perhaps to a paradigm shift.

3.4.2 OSAGE Observatory: Closer to Systems and Societies

Interest for information collected

Life project and Living conditions, together with climate issues raise the question at stake (see Fig. 3.5), which will initiate the scientific approach for the "Observatory denominated OSAGE", described by Loireau et al. (2015, 2017). The issue of climate change is global-ranked; it interests the global society and any "local" society as part of the global one. Reciprocally, Life project and Living conditions in every place are important for every "local" society and a concern for global society as a whole. As a consequence, observation carried out, analyzed and reported from one place is of interest to the entire population of the world even if the observatory focuses its observation within one perimeter defined by sampling and observation protocols, and specifically refers to some processes and actors in the perimeter.

Observatories collect a variety of observation types; relevant acquisition protocols are adapted to societies, environment, and society-environment relationships. They focus on:

- Downstream: on the geographical imprint, with the objective either to report on a systemic transition or to track variation of footprint that would result from an effort of adaptation/ regulation intended by the society. This topic crosses Earth observation of different kinds, e.g. via satellites. In this respect, more applications will further emerge from in depth research on: (a) the link between instant

[25]Compatible with paradigm shift.

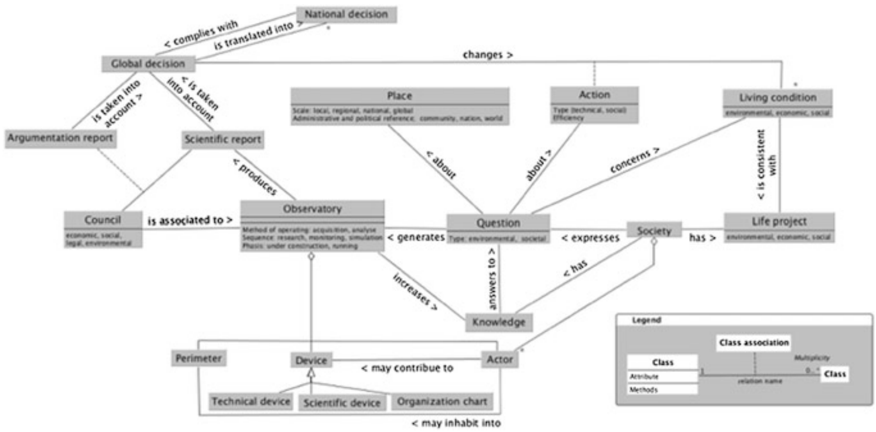

Fig. 3.5 Observatory, as close as possible to systems and societies

footprint and system functioning, and (b) imprint physiognomy decryption in satellite images.

- Upstream: on underlying mechanisms in bio-physical and sociological eco-systems, i.e. those mechanisms which generate changes in systemic regime and foot-printing.

Global decisions implemented through national or more local decisions modify ways and conditions of life (Fig. 3.5). Hence the question of society and derived activities of the observatory would relate to monitoring living conditions as much as the effectiveness of actions (technical or societal type of action) implemented for adaptation (to limit climate change). This corresponds to the two levels of adaptation mentioned in Sect. 3.4.1. Also, protocols adapted to societies and monitoring living conditions, could take account of active contribution to adaptation as well as unexpected impacts on living conditions.

The observatory, as a scientific and technical device, would produce reliable and objective information. Among other results, observatories would tell about the consistency or on the contrary, the gap between expected life project expressed by the society and adaptive constraint resulting from "decisions", and possibly imposed[26] on living conditions. Conversely, this would also convey and acknowledge the involvement of different parts of the society (participation through work) in overall effectiveness of the adaptive effort. On the longer run, this would initiate or reinforce acknowledgement and further strengthen equity in objectives, efforts and hence provide grounds for mutual respect and dignity, the prerequisites to increase democracy in a world to build.

[26]And possibly affecting legitimate rights.

Information analysis and local-global circulation

Scaling up and down is possible in two ways: (1) the focus chosen on the place (see Fig. 3.5: it ranges from local to regional, national or global with respect to the geographical scale; from community, to nation or world with respect to administrative or political references); (2) the concept of Human with references to philosophy, ethics, sciences, humanism applies to the whole of humankind; no human-being can be left aside from this frame. As a consequence, acknowledgment of each of them is expected, in their expectations as well as in their contribution or difficulties.

Accordingly, society choices and possible paradigm shift should be discussed in public circles and open to all.

Local democratic structures should be reinforced, or even invented, by organization capacity (and self-organization) of the society. In particular, a council, outside but leaned onto the observatory, could have its own economic, social, legal, environmental argumentation of the scientific report produced by the observatory; such analysis would be done in the light of the life project of the society. Council argumentation relies on both council representativeness and quality of observatory reporting. This would provide legitimacy to the debates and would strengthen testimony towards higher-level (national, international) deliberations. The same quality motives should help to establish the effectiveness of the dialogue and recognition between actors, by fair and democratic means.

As they are attentive and close to local conditions and societies under observation, observatories would report data, analysis and constructed information, in support for argumentation by local councils or other decision-making bodies. They would help create local—global gateways and would participate in the construction of System World, through the democratic processes they would feed with sound (scientific, accurate, unbiased) information.

3.5 Conclusion

The relationship “imprint↔climate functioning” investigated in this work, provides another approach to demonstrate the role of human activity in climate change. Indeed, this relationship could also trigger questions about the “ideal” imprint corresponding to sustainable System World. Complementary research approaches could confront and combine their respective knowledge to help the emergence of novel paradigms. Without doubt, this would call into question the systemic and geographic patterns induced by the globalization that is underway. Without doubt, observatories and relevant sciences can contribute by proposing concepts or methods to monitor climate change and society’s adaptation, and by producing knowledge and systemic rationale towards paradigm shift, if necessary.

The systemic approach showed that adaptation to climate change cannot be considered unless it is organized at the global scale, the scale of the question being addressed. Dedicated observatories would provide quality information on which to base and monitor adaptive approaches. Observatories would also be part of local-global gateways and would report towards different democratic discussion arenas and decision boards. In order to implement major conventions,[27] which provide a framework and overall objectives, technical proposals on their own will probably not be sufficient. Indeed, adaptation will also rely on societal paradigm shifts to move towards System World. In this respect, councils leaned onto observatories should play a particularly active role in participating in more global (between councils, national and international) debates. Data and information delivered by observatories would act as witness for local situations. As a result of information circulation, equity may be increased and democratic processes as a whole may be strengthened.

We find that conceptual and systemic reasoning on the climate change issue is consistent and compatible in its findings and proposals with ethical considerations. Furthermore, the large basis on which it lies also meets sound and deep intuitions as expressed by the nineteenth century poet Hölderlin[28] who wrote: “There are two ideals for our existence: a state of the highest simplicity, where our needs are in reciprocal accord with themselves, with our powers, and with all those in relation to us, through the mere organization of nature, and without our assistance; and a state of the highest culture, where the same condition is attained through infinitely more multiple and strengthened needs and powers, by means of the organization that we are in a position to bestow ourselves.” Utopia[29] has been at work for more than 2000 years in literature, philosophy, politics with Plato, Thomas More, Rabelais, Voltaire, Fourier.[30] It is certainly a trigger[31] for reflection and action. Ours would be “Let’s care about the people and our world/the planet will be safe”. Will twenty-first century motivations be strong enough to invent expected society paradigm shift towards what Hölderlin phrased so clearly?

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[27]E.g. on climate, desertification or biodiversity.

[28]Hölderlin F (1967) Œuvres, Paris, Gallimard, Pléiade, p 1150.

[29]Théodore Monod. 1999. “Utopia is not the unrealizable, but the unrealized”. Révérence à la vie, conversations avec Jean-Philippe de Tonnac, Grasset.

[30]Plato, The Republic; Thomas More (1516), Utopia; Rabelais, F. (1532), Gargantua; Voltaire (1759), Candide; Fourier (c.1830), le Phalanstère.

[31]Thomas More invented the literary genre of utopia; he had the ambition to widen the field of the possible and not the impossible.

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Chapter 4
Rethinking IPCC Expertise from a Multi-actor Perspective

Maud H. Devès, Michel Lang, Paul-Henri Bourrelier and François Valérian

Abstract Since the adoption of the United Nations Paris Agreement, scientists have been confronted with a difficult question. The needs for expertise have changed. The Paris Agreement is based on a bottom-up approach that, to be successful, requires extending and reinforcing the existing process for including expertise. Better understanding how the climate system works and its impact on societies remains a priority. However, the real challenge for effective implementation of programs that integrate mitigation and adaptation actions is to operationalize existing knowledge across temporal and spatial scales that take into consideration the realities of a range of actors, at the scale at which they operate. This raises the question of whether the Intergovernmental Panel on Climate Change can answer these new needs without rethinking part of its organization. That is the issue this chapter explores, based on the experience of the authors, who work together at the interface between science and policy in the framework of the French Association for Disaster Risk Reduction (UNISDR French platform), as a researcher, engineer or public officer in the French administration.

Keywords Climate change · Climate governance · Expertise · IPCC
Science and policy

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4.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) is a pioneer in the field of international expertise. Created in 1988 under the patronage of the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO), the Panel was charged with assessing the role of anthropogenic greenhouse gas (GHG) emissions on climate change, its potential effects on societies, and in formulating "realistic response strategies for the management of the climate change issue" (IPCC 1990, p. iii). So far, it has issued five assessment reports (ARs), eleven special reports and eleven methodology reports. On the impact of anthropogenic emissions on climate, the assessments have evolved from "not quantified" in the 1990 AR1; to "discernible" in the 1995 AR2; "a probability of 2/3" in the 2003 AR3; "9/10" in the 2007 AR4; and most recently "9.5/10" in the 2013 AR5 (Jones 2013). These reports have also explored the range and diversity of risks that could be associated with climate change. It would seem the overall results have long been worryingly enough to justify a rapid political response; however, the Panel has been unremittingly attacked on its methods and aims which has contributed to discredit its message (see Schrope 2001; Tol 2011 for snapshots of the controversies at two different times). After almost 30 years of negotiations, however, its message eventually had effect. In December 2015, in Paris, the decision was taken to hold "the increase in the global average temperature to well below 2 °C above pre-industrial levels" and to pursue "efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (Paris Agreement, UNFCCC 2015). The Paris Agreement states that each country is responsible for defining its own strategy, but every country is expected to make significant efforts to reach that ambitious common goal.[1] The Paris Agreement is based on a bottom-up approach that, to be successful, requires extending and reinforcing the existing process for including expertise.

Better understanding how the climate system works and its impact on societies remains a priority, but now the greater challenge is to: firstly, articulate global scaled predictions within smaller scale strategies, while considering the multiplicity of actors who operate at different scales and are subjected to different constraints; and secondly, to support effective implementation of programs that integrate mitigation and adaptation actions. At its 43rd Session in April 2016, the IPCC decided to accept the invitation from the United Nations Framework Convention on Climate Change (UNFCCC) to "provide a special report in 2018 on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways" (IPCC 2016). This request, however, does not address the issue

[1]The Paris Agreement entered into force on the 30th day after the date on which at least 55 Parties to the Convention (accounting in total for at least an estimated 55% of the total global greenhouse gas emissions) had deposited their instruments of ratification, acceptance, approval or accession with the Depositary. This was reached on 4 November 2016.

of the diversity of scales and actors. But can the IPCC actually tackle this diversity issue without rethinking part of its organization? The present chapter addresses this question in two steps. In Sect. 4.3, we briefly review the current organization of the IPCC. In Sect. 4.4, we explore whether the IPCC is well adapted to answer new needs for expertise and opens leads for strengthening and enlarging the existing expertise process. The reader should be alerted that the concept of “expertise” is sometimes used in a way that is classical in French but does not have an exact equivalent in English. When we talk about the methodology or deontology of the “expertise”, we refer to the methodology or deontology adopted during the process of translation of knowledge from research to decision support. Experts do not only summarize research results. There is a creative part in their work as they have to find ways to articulate pieces of knowledge established using sometimes very different epistemologies. In contrast to researchers who can work in relative isolation, centred on their specialty, experts have to develop interactions between their obligations and their end-users in order to provide relevant support in the process of decision-making. Experts thus do not do the same job as researchers and referencing expertise as a specific function is a useful way to make this clear (this is discussed in greater details in the third section of Devès 2015).

4.2 Methodology

Our methodology builds on an extensive review of existing peer-reviewed literature and credible but non-academic “grey” literature. Most actors who have a role to play in climate mitigation or adaptation are not engaged with the academic publication system. Their feedback is nonetheless crucial to understand the interplay of science and policy and how it could operate better. We also build on, and contribute to, an iterative thinking process undertaken within the framework of the scientific council of the French Association for Disaster Risk Reduction (AFPCN). Formerly, the French Committee for the International Decade for Natural Disaster Risk Reduction (UN-IDNDR), AFPCN, is a multidisciplinary platform that aims to strengthen the coherence of public policies on disaster risk reduction. On the release of the fifth IPCC report, members of its scientific committee started to re-examine the organization of IPCC expertise exploring how it could evolve in the future. Interviews were undertaken with former and current heads of the French IPCC Focal Point and with several French climate scientists, some of whom had contributed to the IPCC assessment as bureau member or chapter coordinator, in working groups I and II. On that basis, the group decided to adopt an iterative process in order to confront the views of different actors, public and private. This process is presented in Box A. A preliminary report was written, sent off to the public authorities and disseminated to the wider public on the occasion of a first public study day. Following the discussions, a synthesis report was issued, serving as a basis to design a second study day focusing on an issue raised by the participants during the first study day. Several study days were scheduled according to this process to broaden and strengthen the committee views.

Box A—The iterative process of AFPCN

As illustrated in Fig. 4.1, each study day was organized by the AFPCN scientific committee with the help of partner organizations at a public destination with panels composed of experts as well as non-experts. One could find in the room representatives of the **public research sector** (e.g. the French Academy of Sciences and of Technologies, the *Institut Pierre Simon Laplace* specialized in climate, the *Institut de Physique du Globe de Paris* specialized on natural risks, the *Institut National de la Recherche Agronomique* specialized on agriculture, etc.), the **public administration sector** (e.g. the Observatory on Climate Change Effects (ONERC) from the French Ministry of Ecology and Sustainable Development, etc.), the **private sector** (e.g. the World Energy Council French National Committee, the company Fertiprado) and **NGOs** who act at the national level (e.g. GIP Littoral Aquitain) or the international level (e.g. ENDA, 4D). The organizing committee invited speakers with different views in order to tackle open controversies. It was a priority to work across scales whenever possible in order to identify possible difficulties in the practical translation of knowledge from research to action. The study days were therefore multi-sectoral and multi-scale. After each event, a synthesis of the discussions was written and shared publically on the platform website. Using this process, the AFPCN group designed the next event to address issues raised during the previous

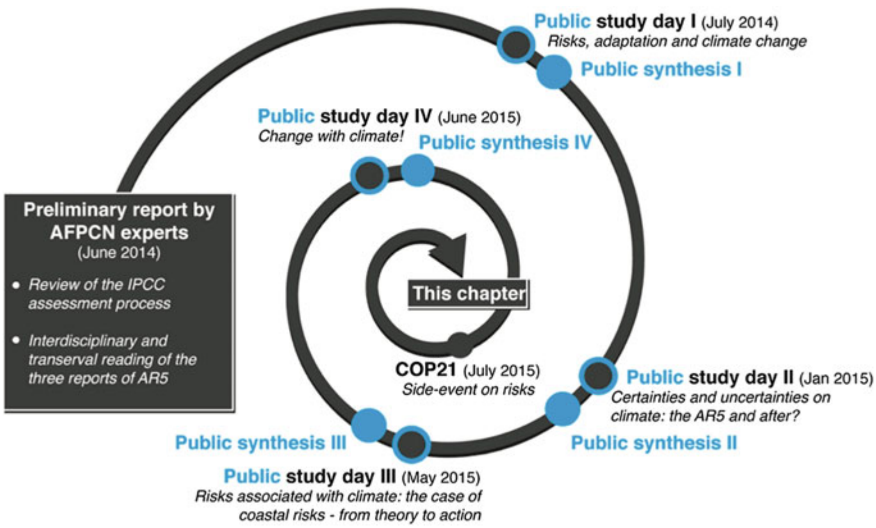

Fig. 4.1 Adopted approach was iterative and integrative as well as multi-scale and multi-actor

study days. The current chapter results from this integrative and iterative thinking process which, while the subject of continuous improvement, was found fruitful enough to be shared with the community.

4.3 IPCC, a Pioneer in International Expertise That Has Not Evolved Significantly in 30 Years

The IPCC provides the scientific basis for international negotiations within the United Nation Framework Convention on Climate Change (UNFCCC). The IPCC mandate is to be policy-relevant, not policy-prescriptive; however, in order to be relevant, experts must maintain links with policy-makers. The modalities of these interactions have already been abundantly commented on in the literature [e.g. Hecht and Tirpak (1995), Franz (1997), Agrawala (1998a, b), Skodvin (2000), Bodansky (2001), Demeritt (2001), Bolin (2007), Zillman (2009), Hulme and Mahony (2010), Hulme et al. (2010), Pielke (2010), Schiermeier (2010a, b), Beck (2011, 2013), Dahan (2013), Schiermeier (2014), Stocker and Plattner (2014), Beck et al. (2014), Dahan and Guillemot (2015) or more recently Aykut and Dahan (2015)]. In the following paragraphs, we summarize key points to consider while examining the organisation of the assessment process (see more on the IPCC website, http://www.climatechange2013.org/ipcc-process/).

It is important to note that the structure of the IPCC assessment process has not changed significantly since its creation (Agrawala 1998a, b; Devès et al. 2014). The IPCC has an intergovernmental status where all decisions must be unanimously agreed during plenary sessions of the General Assembly. The latter is composed of representatives from all parties to the UNFCCC. The experts are selected from a nomination list proposed by governments or observer organizations. They are chosen with respect to their scientific background but also to ensure countries representativeness, gender equity, etc.

The tasks of the Panel are divided between three main working groups (WG) and two special task groups, one dedicated to greenhouse gas inventories and the second to data management. WGI is in charge of evaluating available scientific information on climate change. WGII assesses the environmental and socio-economic impacts of climate change, and WGIII is responsible for formulating response strategies. The only significant change in that distribution occurred between the AR1 and the AR2 (Table 4.1) when a distinction was made between adaptation and mitigation strategies; WGII started to work on adaptation while WGIII was dedicated to mitigation. Except for that, the initial share has remained unchanged for almost 30 years. A small bureau oversees the work of the different groups, whose members are elected to represent the different working groups and to generally reflect the diversity of the parties.

Table 4.1 Evolution of the mandates of the WGs through the five assessment cycles

Assessment report	Working group I	Working group II	Working group III
AR1—1990 & 1992	Scientific assessment of climate change	Assessment of impacts of climate change	The IPCC response strategies
AR2—1995	The science of climate change	Impacts, adaptation and mitigation of climate change: scientific-technic analyses	Economic and social dimensions of climate change
AR3—2001	The scientific basis	Impacts, adaptation, and vulnerability	Mitigation
AR4—2007	The physical science basis	Impacts, adaptation and vulnerability	Mitigation of climate change
AR5—2013 & 2014			

The members of the bureau(s) are the experts with the most impact on the assessment. They design the skeleton of the reports and nominate the Coordinating Lead Authors (CLAs) and the Lead Authors (LAs) of each chapter. CLAs have a key role in coordinating the development of large parts of the reports. In carrying out this task, the CLAs rely on many contributing authors who, despite their greater number, do not really have significant control on the final output. But there are not just experts who write; some review. Review Editors (REs) are particularly important because they decide what should be changed, or not, in response to comments and criticisms. The review process occurs in three stages. A first-order draft is initially sent to the scientific reviewers. The second and third draft versions are sent to both scientists and governments. This is particularly important in drafting the *Summaries for Policy-Makers* (SPMs), which is firmly under the responsibility of the bureau.

The assessments are based on an extensive review of the academic literature. The choice was made to minimize references to non-peer-reviewed papers with the thought of enhancing scientific credibility. Three main types of IPCC documents are produced: scientific reports, technical summaries and summaries for policy-makers. They do not correspond to the same level of synthesis, are not intended for the same readership and are not involved in the same adoption procedures. The *scientific reports* are notoriously long (typically thousands of pages) and difficult to digest; however, they include a hundred-page *Technical Summary* and a *Frequently Asked Questions* supplement that are easier to manage. The SPMs are much shorter (typically under 40 pages) and more directly aimed at decision-making. SPMs play a very specific role in the process. Whereas reports and technical summaries are discussed, voted and accepted as a whole, SPMs are voted line-by-line during plenary sessions. Additionally, because the acceptance is subject to unanimity and not majority voting, a government can hold the whole process to ransom if it does not like a particular formulation.

The assessment is informed by models and scenarios, although strategies to articulate and use their outputs have changed through time. Before AR5, future emission pathways were estimated from socio-economical models and were input into climate simulations to assess the possible impacts of resulting climate change on societies. Beginning in AR5, four emission scenarios (called *Representative Concentration Pathways* or RCPs) were chosen from the peer-reviewed literature as plausible pathways to reach four distinct levels of change in energy in the atmosphere due to GHG emissions (radiative forcing) by 2100. Each RCP provides only one of many possible scenarios that could lead to the given forcing. Thus, four pathways were chosen to cover a broad range of possible futures. This change in procedure has allowed the adoption of a parallel working process reducing "the time lags between the creation of emissions scenarios, their use in climate modelling, and the application of the resulting climate scenarios in research on impacts, adaptation and vulnerability" (Moss et al. 2010, p. 747). At the same time climate modellers prepare simulations using the RCPs, integrated assessment modellers can develop a set of new socio-economic and emission scenarios to answer the question: "what are the ways in which the world could develop in order to reach a particular radiative forcing pathway?" (Moss et al. 2010, p. 747).

Having presented key steps of the IPCC assessment process, we can now discuss its limits in the context of today.

4.4 Opportunities to Strengthen and Enlarge the Existing Process

Based on a review of more than 10,000 climate papers in the peer-reviewed scientific literature from 1991 to 2011, Cook et al. (2013) showed that the number of papers rejecting the consensus on anthropogenic warming is a vanishingly small proportion of the published research (also see Oreskes 2004). Unfortunately, this relative scientific consensus is far from being shared by public opinion (see Howe et al. 2015 for an analysis of geographic variations in the USA; Cody et al. 2015 for an analysis of the "climate change sentiment" on Twitter). There is thus discordance between the scientific diagnosis and possible political treatments (e.g. Aubertin et al. 2015). In February 2015, the IPCC discussed the organization of its future work, stressing the importance of making reports more user-friendly and fostering closer involvement of developing countries (IPCC 2015). These are important points, but, as we will discuss now, deeper changes are likely required given the evolution of the expertise needs.

On the Interactions Between Science and Policy

The strategy adopted by the United Nations in claiming a clear separation between science and policy has been criticized because it was based on an idealized view of science–policy interactions (e.g. Jasanoff et al. 1998; Sarewitz 2011; Beck et al. 2014). The underlying belief is that science can give access to the real state of the world in a unique and unambiguous manner (a consensus can always be found on what is factually true or, at least, not false) and that a shared understanding of science should automatically bring about political consensus. Experts are thus expected to provide a solid basis of facts to policy-makers who are then expected to negotiate, depending on the system of values they believe in. If this view still dominates perceptions among scientists, policy-makers and advisors, it has long been dismissed by social scientists. The IPCC mandate is political, and the IPCC assessment process cannot be “purely scientific”. It has to be hybrid, as being politically relevant requires being able to take into account political realities. Defending a hypothetically clear separation between “pure” science and “dirty” policy can only lead to misunderstandings. This separation also provides easy arguments for sceptics. The Panel would undoubtedly gain from communicating more on the intrinsic constraints of its assessment process, notably in stressing the impossibility to separate completely the scientific and the political issues.

On the Categories of Actors Involved in the Assessment
The original mandate of the IPCC was primarily focused on mitigation. The issue of adaptation emerged later on (Beck 2011; Burton and DPUN 2005), and the protocol to include relevant expertise was only marginally modified by including the review of adaptation strategies within the tasks of WGII in AR2. However, under the pressure of developing countries, the issue of adaptation has progressively taken up centre stage. If adaptation used to be seen as the marginal cost of failed mitigation (Pielke 2005), it now appears as an inevitable complement to mitigation strategies which changes the overall mandate of the experts who bring their knowledge (e.g. Burton and DPUN 2005; Dovers and Hezri 2010). Research on adaptation has experienced explosive growth in the last decade, which resulted in a massive imbalance in the length of the reports of the three WGs in AR5 (the report of WGII being much longer than those of WGI and WGIII). A new balance between the groups could certainly be found to make the reports more accessible to readers. But the growing focus on adaptation hides a deeper issue. Solving climate problems requires involving an ever-greater diversity of actors—not just government agencies, international organizations, research centres and NGOs but also professional associations, local entrepreneurs, urbanists, start-ups, etc. The need for such diversification appears obvious in the case of adaptation but it also holds for mitigation. Such diversification would moreover provide new opportunities for strengthening the assessment process.

On the Translation from Research to Expertise
Experts and researchers do not do the same job. The dynamics of research are very different from the dynamics of expertise (Devès 2015). Researchers generally zoom in, while experts zoom out. In addition, their process of specialization can cause researchers to not consider large parts of the landscape that experts will have to take into account. Specialization also means that there are many points on which consensus cannot be found, simply because approaches are too different to be compared or because knowledge and know-how evolve too rapidly. Hence, the expert does not only aim to synthesize existing knowledge but also to articulate some aspects reasonably clearly to answer a question that is rarely formulated in a scientific way. There are always instrumental and epistemic uncertainties which leave

the door open to scientists' subjective judgment (e.g. see Tollefson 2013 on the exclusion of West Antarctic Ice sheet melting from the sea-level review in AR4). The assessment consists, therefore, in making a series of choices which cannot be strictly neutral. This is why the highly scrutinized SPMs have a specific status in the assessment process. When AR5 was released by WGIII, the long report was accepted without major difficulty, but there were "heated negotiations" (Wible 2014, p. 34) among scientific authors and diplomats on the redaction of the SPM, which led to substantial deletions of figures and text. The end-users of the assessments can expect transparency where all choices are made as explicit as possible. Again, the Panel would undoubtedly gain from communicating more on the difficulties that are inherent to the translation from research to expertise.

On the Need for a More Effective Interdisciplinarity

The decision to share the assessment between three working groups has never been really debated. It is rather classical in risk assessment to progress from causes to consequences, from hazard quantification to impact, from assessments of exposure and vulnerability to response strategies and the thematic separation between the working groups mimics the corresponding academic boundaries: WGI covers the domain of the physical sciences (physics and chemistry of climate change), WGIII is oriented towards the social sciences (socio-economics and policy), and WGII is slightly more hybrid (reflecting the topics it deals with, i.e. impact, risk and adaptation). One could however argue that this choice may have prevented the development of a truly interdisciplinary process as it tends to narrow the composition of the WGs to well-delimited research communities. Bjurström and Polk (2011) and Vasileiadou et al. (2011) have shown that integration occurs essentially between closely related disciplines, impeding the incorporation of the assessment results by the wider research community.[2]

The success of a truly interdisciplinary work also depends on the ability of an expert body to ensure a satisfying continuity in the transmission of its prerequisites and methods. Gray et al. (2013) report that only 7% of contributors have participated in more than one WG since the creation of the IPCC (the large majority (5%) between WGI and WGII, less than 1% between WGI and WGIII). If the number of "leading" contributors (CLA, LA and RE) has increased from AR1 (278) to AR5 (833), only 13 of these contributors were present in all five assessments, with slightly more continuity for experts coming from North America, Europe, Australia and New Zealand. Nearly half of them happen to belong to WG1, the latter showing generally much less diversity in the profiles of its contributors than the rest of the

[2]Vasileiadou et al. (2011) conducted a review of the citation rate of the four IPCC reports in the academic literature. Most citations come from the physical sciences (95%) and only 5% from the social sciences, including 2% from economics and 2% from sociopolitical science. This result directly echoes the under-representation of social sciences in the IPCC (Victor 2015); the few social scientists who at present belong to WGIII and focus on economics and CO_2 emission scenarios (Hulme and Mahony 2010).

working groups.[3] Effective interdisciplinarity is notoriously difficult to achieve but the ability of the Panel to harness and transmit knowledge depends on its ability to work accross all borders.

On the Usability of the Expertise
According to Vasileiadou et al. (2011), IPCC reports are less frequently cited in developing countries than in developed countries (except for China, which is 4th, and India 18th, in the top 20 countries quoting SPMs). This might result from an insufficient participation of scientists from non-industrialized countries in the IPCC (Hulme and Mahony 2010). Over the past 25 years, 129 countries have contributed to the IPCC. Of these countries, Gray et al. (2013) estimate that a small proportion has dominated the drafting and editing of the IPCC reports, where roughly 21 countries account for 80% of all bodies participating in the reports. Five countries only (USA, UK, Germany, Canada and Australia) account for over 50% of the participating bodies (not all of these countries have actually been very good at decreasing their GHG emissions). If emerging economies, such as China, India and Brazil, are playing an increasing role within the IPCC, one can wonder if changing the format of the assessment and of its products might not help to create a better balance in expertise. The reports continue to grow bigger with time and are now far too big to be studied in detail by most people. This can prevent the implementation of simple strategies that could be both scientifically well-informed and politically efficient. Usability of expertise is hence another point for improvement for the IPCC.

4.4.1 Opportunities for Improvement

This section summarizes the opportunities for improvement that arose from our iterative working process.

It will be useful to have more explicit understanding of the modes of interaction between science and policy and to introduce more reflexivity. This could be done with the help of social scientists and by opening the assessment process to other actors. Today, researchers and government representatives are the only two categories of actors who are directly involved in the IPCC report writing process. While observer organizations can attend general assemblies, but cannot vote, many other actors could also provide useful contributions. Why focus only on academic literature? As outlined by the Inter-Academy Council in 2010 (Shapiro et al. 2010), highly valuable information can be found outside of peer-reviewed sources. These

[3]The long-standing international cooperation of research on climate has led to a progressive standardization of the WGI procedures, which has not been the case for WGII and WGIII. WGI also has a clear leadership of the expertise on climate change science, whereas WGII and WGIII have to share their field of expertise with other institutions (e.g. the World Bank or the International Energy Agency).

include technical reports; working papers; presentations and conference proceedings; fact sheets; bulletins; statistics; and observational data sets and modelling results produced by government agencies, international organizations, universities, research centres, NGOs, corporations, professional associations and other groups such as associations, local entrepreneurs or start-ups. Of course, the peer-reviewed processes used to scrutinize this information ensure scientific credibility of the assessment reports, but there must be ways to assess the quality of grey literature. Inclusion of broader information sources, plus procedures to consult a representative group of stakeholders, could ensure greater operational relevance.

The knowledge and know-how of actors outside the academic field is necessary to link the results of global simulations with regional, national and sub-national realities. The recent change in scenario strategy reinforces the autonomy of the existing WGs. It might also be a good opportunity to reorganize the process. Studies on climate impacts require a constant exchange of information with climate simulations, and the assessments would certainly benefit from a rapprochement between WGI and WGII on this topic. In contrast, the topics of risk management, adaptation and mitigation policies can be treated relatively independently and could benefit from being opened up to a greater diversity of actors. Integrating adaptation and mitigation pathways is another key challenge where working at a well-thought-out scale, on well-designed questions, with the relevant groups of stakeholders, could shape a more pragmatic approach to this integration. As discussed above, actors do not all need the same type of knowledge to act.

End-users of expertise can expect all choices to be made as explicit as possible. So far, the IPCC provides a list of references and indications of uncertainty for most of its statements, thus grading the level of scientific consensus. However, it does not always set out the alternative options and the reasons they were not adopted. It also tends to concatenate uncertainties with a limited set of indicators, which tends to blur the different issues and scales (e.g. Curry 2011; Ebi 2011). This consensus-based approach is often criticized as being too idealistic. It actually leads to frequent misunderstandings, even within the scientific community (e.g. debate on the interpretation of sea-level projections and uncertainties, Church et al. 2013; also see Maslin 2013). Oppenheimer et al. (2008) advise against setting out a premature consensus that could lead to overlooking or under-emphasizing critical uncertainties. Cooke (2015) proposes using methods of expert elicitation and cross-validation to improve the treatment of uncertainties. Hollin and Pearce (2015) identify what they call the "certainty trap" and stress the importance for experts to acknowledge tensions between scientific and public perceptions of uncertainty when communicating (e.g. in answering a journalist's question, it might appear inconsistent to use a short time scale to illustrate global warming, while dismissing the observed short pause in temperature rise; Ekwurzel et al. 2011; Hollin and Pearce 2015).

Eventually, as pointed out by the IPCC, it is crucial to promote better integration between developing countries in the assessment process. This should start with the choice of experts but also concerns communication to the wider public. More sharply focused reports could involve a wider diversity of actors and better present the diversity of options and associated uncertainties. Shorter reports could be more inventive, more accessible and easier to manage and could be issued more frequently.

4.5 Conclusion

The panel of actors who can concretely contribute to develop and adopt climate change mitigation and adaptation strategies cannot only be approached "globally". They operate in different countries, in different sectors and at different scales; their actions respond to different rationales, and there is little chance that they wish to address the "climate problem" in the very same way. Therefore, solving the "climate problem" requires finding ways to link up these different scales of action beyond political, cultural, sectoral and institutional boundaries. To date, the IPCC provides the best elaborated expert narratives on climate change and useful "living maps" for deriving global policies; all parties to the UNFCCC unanimously recognized the quality of the IPCC work, which led to the adoption of the Paris Agreement. The Paris Agreement is based on a bottom-up approach that, to be successful, requires extending and reinforcing the existing process of using expertise. The change of needs for expertise is also an opportunity for the IPCC to surpass its current limitations. In this chapter, which results from an integrative thinking process that involved different categories of actors (researchers and engineers, as well as state administrators, NGOs and actors in the wider public), we tried to identify the key points of blockage and to propose opportunities for change. Our main message could be summarized as follows. Expertise would be better integrated into the IPCC process by undertaking more focused scientific reports, adapted to themes and scales that are practical for action, and by introducing more flexible management of the expertise and more reflexivity at all stages of the assessment process. This would require involving a greater diversity of academic disciplines and including the expertise of a more diverse range of actors who are better connected to the realities of the field, such as leaders involved with local populations. Implementing this co-production of knowledge is far from trivial, but it is valuable to have the advantage of the knowledge and know-how of diverse actors while keeping good quality control on the knowledge resulting from expertise. We recommend undertaking real-scale experiments focused on specific topics to identify and resolve difficulties linked to implementing these changes.

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Chapter 5
Computational Constraint Models for Decision Support and Holistic Solution Design

Carmen Gervet

Abstract The paradigm of constraint reasoning aims at modeling and solving combinatorial search problems. The methodology and principle of such models are based on relationships among data and variables, specifically as constraints that must hold for a solution to answer a decision or optimization problem. The relationships can be dependencies of any kind: geographical, engineering, environmental, or economic. Constraint models have been developed to provide proactive analysis of some climate change issues, such as investment planning in renewable energies over a given horizon. The challenge of computerized constraint models is their reliability and effectiveness to be used for real-world implementation. This is feasible if: (1) the modeling approach taken is holistic and specifies the complexity of real-world scenarios, and (2) the users feel involved and become actual actors in the decision process. Constraint models facilitate a holistic approach by focusing on the solution model, and allowing heterogeneous data, variables, and constraint types to be modeled independently of their solving. This chapter gives an overview of such approaches to foster the implementation of climate change solutions.

Keywords Actors · Climate change · Complexity · Proactive analysis
Solution model

5.1 Introduction

Climate change is a fact. Whether human behavior is the major cause of it or not is no longer the core question. The issues today are manifold: (1) monitoring the changes and contributing factors, (2) forecasting the evolution and assessing potential impacts, (3) modeling and implementing proactive solutions from a holistic perspective. This chapter is concerned with the latest one. Thus, it is not concerned with the causes or the problems of climate change, rather with solutions

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that can be put in place. The complexity lies in the interdisciplinary nature of the solution models, their scale, time span and of course, the cost effectiveness of their actual implementation. The main factors of climate change considered here are:

- Heat, both in terms of an abundant source of energy, and coping with increased temperatures.
- Water, both in terms of scarcity and flooding.

Regarding both factors, solutions can be global as well as local. As early as the 1920s, the Atlantropa project sought to bring together Europe and North Africa in one common electricity grid via a giant hydropower station in Gibraltar (Lehmann 2016). The support for this project was limited to architects and planners from Germany and some northern European countries. It never saw the light due to several issues, including the lack of involvement or cooperation of Mediterranean countries, and the poor study of the impacts it would have had on local communities of the Mediterranean coast. More recently in the same spirit, the Desertec project was founded in 2009 (Goudet 2009). It carried out several studies to develop a global renewable energy plan, which would create sustainable power plants in the Northern African desert, and transfer this energy through high-voltage current to Europe. Solar energy was the main source even though wind power plants were also considered. By 2014 however, 47 of the 50 initial shareholders had left the consortium (Tagliapietra and Zachmann 2016). Clearly, such visions come with a substantial financial commitment to become reality, but also require a strong level of involvement from all parties, who can see their own gains and benefits in the short, medium, and longer term. They are global and complex projects which not only require a holistic perspective but also simulation tools to study the multiple issues at stake, and to bring awareness and involvement of the potential partners.

Today smaller-scale solutions started to be implemented worldwide. Local initiatives are also developed to bring incentives to reduce home consumption of energy and water. Desalination technologies are also being developed using solar power plants, often referred to as solar desalination (El-Kordy et al. 2002; Garcia-Rodrıguez 2003). For such proposals to be actually effective in the longer term, many aspects and constraints need to be taken into account as part of the solution design, and to increase acceptance and awareness of the different possible actors.

5.1.1 How Computational Decision Models Can Contribute to Guide Effective Implementation of Solutions Under Climate Change

The methodology is illustrated by an example that was investigated: the issue of techno-economics in the implantation of renewable energy parks (Gervet and Atef 2012). Applied research in this field raises complex challenges of a technological, environmental, social, economic, and political nature. Thus, they involve many constraints among disciplines that do not necessarily interact. The case study took place in Egypt, a large country with a fast-increasing population, an increased level of heat, and an increased demand for electricity, including the use of air conditioning systems to reduce indoor heat in large cities. The national goal, back in 2010, was to determine "how to satisfy 20% of the forecasted energy demand in 2020 using renewable energies, at minimal cost." Even though this was a national project, it involved international technologies in concentrated solar power (CSP), photovoltaic systems, wind turbines designs, as well as investments and planning. Under an Egyptian funding, Gervet and Atef (2012) built a prototype tool based on constraint technology that served as much as a communication tool between the parties involved, as a simulation tool for the potential actors to evaluate the impact and effectiveness of their choices. The computational model specified the rules and conditions that must hold on the environmental, energetic, and economic levels, and the objective functions to optimize. Examples of possible constraint rules are:

- A solar park must be at a given maximum distance of a connection point to the national grid,
- A solar park cannot be built on a depression area in the desert,
- The production rate of a wind turbine is bounded by certain values,
- The maximum investment per year is bounded by a certain cost.

The potential actors in such problems range from investors, engineers, economists to local community representatives. This renders the actual implementation of a solution very complex in real life and often a source of conflicts. Hence, the benefits of a holistic computational approach are numerous to guide the decision process, improve communication, and address different challenges in one integrated model. Furthermore, the technology combines the computational efficiency of powerful algorithms, with the modeling and expressive power of heterogeneous constraints. It brings together complementary fields and experts.

In the second section, I will give an overview of constraint models and the methodological process to solve them. The third section will describe some existing solution designs under climate change. The fourth section will describe our vision for the next generation of holistic models coupled with interactive and persuasive interface to increase the involvement of the user and his/her active role in the implementation process.

5.2 Constraint-Based Reasoning in a Nutshell

The holy grail of constraint programming was "focus on the problem, the computer will take care of the solving." It is a powerful paradigm developed in the late 70s in the field of artificial intelligence, to tackle complex planning and scheduling problems in areas such as transportation, production, networks, bioinformatics, configuration, and logistics. The problems are of a combinatorial nature, which means that there is an exponential number of combinations of values to explore, when searching for a solution. The problem might end up being not satisfied: no solution that satisfies all the constraints exists. In this case, one will need to account for possible data uncertainties, or soften certain rules or constraints that render the problem unfeasible. The essence of constraint programming is to model the problem independently of its solving, by focusing on the properties a viable solution should have, and letting the underlying algorithms prune out combinations of values that can never hold. Today, the paradigm draws from areas wider than artificial intelligence and combines methods and models from graph theory, operations research, and multi-agent systems, to address real-world combinatorial search and decision problems. The field of constraint programming together with its application has been integrated in a comprehensive handbook (Rossi et al. 2006). I define the notion of a constraint problem modeled as a constraint satisfaction problem as follows:

Definition 1 A constraint satisfaction model is composed of a set of variables (unknown parameters), a set of domains where each variable can take its value from, and a set of constraints over the variables.

This definition has been extended to cases where the parameters defining the constraints can be uncertain, and with objective functions that turn the decision problem into an optimization problem. The methods to solve the decision problems are based on filtering and propagation techniques that prune the impossible values from the domains in a deterministic fashion. Let me illustrate this core technique through a simple example. Basically, if you are a Sudoku player, you do constraint propagation and search when filling up the grid cells. The Sudoku is a logic puzzle, which can be found in most newspapers today. There is a nine by nine grid, composer of 9 blocks each corresponding to a block of 3x3 cells. Each cell must take a value in {1,…, 9} such that no two cells in one column, row or block can share the same value. The model and techniques of constraint solving mimic at different levels of inferences (more or less global) the human reasoning. The basic approach is one of trial and error without accounting for the structure of the problem or the global nature of the constraints. A constraint model of a Sudoku problem corresponds to: (1) the data being the cells that have a known value, the decision variables that are the open cells with domains {1, 2, 3, 4, 5, 6, 7, 8, 9}, and (2) the constraints which simply state that any two pairs of cells cannot take the same value within a row, column or block. Thus, if the values 1, 3, and 5 are taken in a row, these will be removed from the related cell domains by filtering out the values and the domains will be reduced to {2, 4, 6, 7, 8, 9}. Any change in the domain of a variable triggers the constraints involving this variable to be checked again, to determine whether it propagates a change or not in the variables domain. Once a stage is reached where no more domains can be filtered, in this deterministic manner, a search procedure is triggered to find possible values for the non-instantiated variables. Global filtering techniques are available in the numerous systems that exist on the market today, leading to powerful filtering of domains before searching for solutions. For instance, if two of the variables in a given row share the same two values, these values can be filtered from the remaining seven variables denoting the other cells in this row, since none of them can take them or the problem would fail.

Constraint programming is very well suited for the kind of decision combinatorial problems where the number of potential combinations is large but few of them can lead to a solution (possibly none). Thus, it can be of substantial help to seek solutions to new problems particularly of a holistic nature, with complex and heterogeneous constraints involved. It is possible that for such problems, taking all the constraints at hand into account does not describe any solution, and thus the model needs to be refined. If one or several functions are added to the problem, the issue is one of optimization under constraints and constraint programming can then be combined with global optimization techniques from operations research (such as linear programming or mathematical programming) (Nemhauser and Wolsey 1988) (More information on constraint programming technology can be found in Rossi et al. 2006).

The methodological process of designing and implementing solution models to real-world problems is an iterative and incremental one, involving all potential decision makers, actors, and domain experts in the specification of the problem. It consists of three main iterative procedures: (1) specification of the solution requirements, (2) solution design and implementation, (3) evaluation and testing. The methodology aims at ensuring an effective development process in the presence of heterogeneous sources of data, interdisciplinary sources of information, and a complex decision-making process. It iterates over the definition phase, the construction phase and the visualization and interactive decision-making phase. The construction phase is itself composed of two activities, the solution design and the programming activities. This incremental and iterative methodology is necessary to ensure validation of the model by all the potential actors. An example of such a methodological process was developed by a consortium of academic and industrial partners to build solutions to large-scale combinatorial optimization problems, of which holistic constraint models for solutions under climate change is an element (Gervet 1998, 2011).

The methodology behind the models themselves focusses on the design and implementation of practical solutions, satisfying geographical, economical, or planning constraints at hand. In other words, by knowing the human factors that intensify climate change (e.g. factory farming, carbon dioxide emissions, energy sources), an expert can conceive means to reduce the impact of such factors. The idea behind constraint-based models and their design is to seek practical and viable socioeconomic solutions and identify realistic means to implement them. The key lies in the effectiveness of migrating from a current practice to new practices that would reduce the human impact factors on climate change, as well as provide viable means to cope with foreseen scenarios that will require drastic changes to our ways of living.

5.2.1 Designing a Constraint Model

Basically, a set of actors with complementary expertise, who seek the economic and societal viability of a new approach to water resource management, or migrating to renewable energy for a given country, needs to seek compromises between:

- Satisfying hard constraints such as ensuring that there will be enough resources to sustain the population, the demand can be fulfilled given the new means of production, and the cost of implementing a new approach does not exceed a certain limit. These constraints are heterogeneous and bring together technological, economical and societal aspects. They can often take the form of relational and linear or non-linear formulas, over the variables for which a value is sought (amount of production, potential relevant localizations), and what data are available in terms of existing resources and limitations.
- Reaching the objectives sought such as by 2030 a given percentage of water resources comes from a desalination process, or a given percentage of electricity production comes from renewable energy sources. Often the objective functions are multi-criteria ones, in the sense that a trade-off is sought to maximize for instance biodiversity, while ensuring a production level that is sustainable for the farmer. This multi-criteria approach ensures that all relevant actors are involved in the design of the model, that it is viable and represents a realistic transition from existing practices to more sustainable ones.

The iterative process of designing the model, evaluating the computerized solutions, and seeking experts and user feedback is a key component to the use of computational constraint technology to help guide the decision makers in the actual implementation of their solutions. It is also a valuable communication tool between the different actors who can see the effects of limitation of certain constraints on the solutions produced.

5.3 Example Cases and Thematic Studies

To date, a large number of computational constraint models are proposed in applied research to address different aspects of climate change solution designs. To illustrate the approaches and their potentials, a few examples are presented here. In the past 15 years, the novelty of these models is the motivation to design integrated systems that include many different aspects of real-life issues into one system, including existing data, environmental, economic, societal, and technological constraints. In this short chapter, one cannot be comprehensive in the survey of existing models. However, an overview can be given to provide an idea of existing approaches that investigate the means and viability of solutions implementation to different climate change issues. These include water resources management, migration to renewable energy sources, and biodiversity conservation. It is important to note that constraint-based models and decision support tools focus on helping different parties and decision makers become actors in the implementation of solutions to a given challenge and not on detecting the problem that could result from climate change.

5.3.1 Water Resource Management

This field seeks mean to handle water scarcity, costs, and migration toward different management systems. Some computational models have been proposed to help decision makers cooperate with a holistic perspective, including for instance the water resource components and the economic ones. A mathematical programming model with the objective of maximizing economic profits from water uses in various sectors is proposed by Cai (2008). Such a model aims at addressing both the environmental and economic issues. It is a typical example of large-scale holistic modeling for integrated river basin management. It raises also the issues of the complexity of holistic models, the handling of uncertainty ubiquitous in such problems, and the involvement of various decision makers (a thorough review of approaches to characterize the economic value of water usage, and to embed these in computational models can be found in Harou et al. (2009). It presents various hydroeconomic models addressing the issues of spatial and temporal dimensions of distributed water resource systems, infrastructure, management options, and economic values in an integrated manner. These models specify hydrologic-engineered systems while explicitly considering the economic nature of water demands and costs. Basically, they provide a support for decision makers to analyze costs and profits, while considering the value of water services in planning and operation. As the authors say (Harou et al. 2009, p. 28): "until now, hydroeconomic modeling has been practiced in academic and policy circles with limited implementation of study recommendations by water managers, operators, and practitioners. Hydroeconomic modelers can improve the impact of their work by collaborating with practitioners and extending existing (and trusted) operations models to include hydroeconomic components."

5.3.2 Renewable Energy Planning

Other computational models integrating economic, engineering and environmental aspects together are also being considered in relation to the migration toward renewable energies to produce electricity. The need for clean energy is recognized worldwide not only to face global warming and CO_2 emissions, but also to reduce grounds for international conflicts. National and international targets are being set (Bull 2001, 2004). There are many aspects of the development of renewable energy technologies which can be broadly categorized into engineering and technological advancement aspects, versus techno/economical and commercial ones. The engineering components deal with the construction of renewable plants that are reliable, effective, and realistic, including essentially hydro, solar (photovoltaic and concentrated solar power), wind and biofuel. The techno-economical study of renewable energy on the other hand, investigates gradual implementation of renewable energy (RE) systems for a given country such that the installation and maintenance costs are minimized and the short-/long-term returns on investment are maximized. Studies in this field investigate country profiles in terms of energy demand, available resources, anticipated renewable engineering cost reductions (Loiter and Norberg-Bohm 1999). However, more is needed as highlighted by Heal (2010, p. 139) because "there is little economic analysis of renewable energy." The main objectives of studying the economics of RE is to attract investments (national and international) and set realistic targets and strategies that will remain so in the longer term.

Comprehensive surveys are now available discussing the trends and current improvements in the cost, performance, and reliability of renewable energy systems (Bull 2001). Clearly, electricity from RE remains generally more expensive than from conventional fossil fuel sources. However, the cost of electricity from RE sources has been falling steadily for the last two decades and various estimates have been derived in terms of expected cost of electricity production from RE sources (Bull 2001). Today, wind energy is the least expensive option but requires more maintenance and is space consuming compared to photovoltaic solar panels which, however, are currently more expensive. Noting though that the forecasts in price reduction are promising (Bull 2001). This indicates that taking into account forecast measurements is a strong element of effective decision-making.

Based on existing forecast studies, and each country's renewable resources, in which REs or portfolio of RE should a given nation invest? How much should be invested now, or in 15 years time? These are questions at the heart of the "economics of RE" which this decision support tool aims to provide an answer for. It seeks the best trade-off cost/return on investment by taking into account physical installation constraints as well as energy requirements and costs.

The author in collaboration with the German University in Cairo and the New and Renewable Authority in Egypt (NREA) studied this problem focusing on Egypt, where data and a governmental interest were provided (Gervet and Atef 2013). The main objectives of this work are briefly described next. It aimed to build a decision support tool to provide private and governmental investors in RE systems with valuable insights to make informed short- and long-term decisions, with respect to the creation and placements of solar and wind turbine parks in Egypt. Egypt is growing at a fast pace and relies extensively on fossil fuel as shown in the REN21 (Renewable Energy Policy Network) global status report (REN21 2016). Egypt enjoys excellent wind and solar resources, and there is tremendous potential for investment toward local consumption and even export. Research and onsite projects are being carried out with a growing trend.

The optimization problem is defined as follows. Taking into consideration the country of Egypt with its available data and constraints, including: (1) Egypt map of populated areas; (2) wind and solar atlas; (3) electricity grid map; (4) current and forecast energy cost per RE resource; (5) current and forecast energy demand per month; and (6) a set of potential RE park locations, to subsequently determine the set of energy parks to be invested in today and the set of energy parks to be invested in the future (e.g., in the next 10–20 years), such that 20% of the current and forecast energy demand are covered for each month of the year, and the anticipated financial cost is minimized. The cost is determined in terms of the sum of total costs associated with each potential park, including the cost of connection to the grid, installation, and park maintenance.

The core contribution of this work was a model to select a portfolio of renewable energy parks to be installed. A key element was the account for both short and medium-term planning, based on the data available which consisted of the wind and solar atlas of Egypt (Mortensen et al. 2005; Mosalam Shaltout 1988). The different constraint models and algorithms developed can be found in Gervet and Atef (2013), along with the decision support interface designed to help decision makers simulate different scenarios to make informed planning and investment decisions (see Fig. 4 in Gervet and Atef 2013, p. 143).

Other approaches and research developments aim at using remote sensing data to monitor climate change (Posselt et al. 2012), and integrate such studies to build decision support systems for the planning of solar energy parks. For instance, a study combines geographic information system (GIS) tools or multi-criteria decision-making optimization models to determine the optimal placement of photovoltaic solar power plants in southeast Spain (Sánchez-Lozano et al. 2013). Such approaches bring together the analysis of data with the decision-making process. As in the Sudoku example, the power of constraint reasoning makes it possible to reduce the areas of study by discarding locations that cannot be used to implement RE plants, because the cost to reach the grid is too high, or the location is too close to living areas, or corresponds to a desert depression, etc.

5.3.3 Biodiversity Management

Another thematic strongly linked to human impact on climate change is biodiversity. A key challenge is the field of ecosystem services, and enhancing biodiversity depends on the policy and decision-making processes. An increased number of constraint-based models seeks to evaluate the feasibility of solutions and guide decision makers in relation to the environment and the actors involved. Some surveys article and specific case studies have been developed. These include studies in the European Union (Maes et al. 2012) and different constraint-based optimization models. Studies investigated computational models to help design reserve networks for the persistence of biodiversity, with the same idea of developing a tool that helps different actors communicate through the use of decision aid tools. In Cabeza and Moilanen (2001) a computational site-selection tool applied to conservation planning is proposed bringing together scientists, managers, and investors. Another set of computational constraint models also in the form of decision support tools relates to conservation planning tools to seek means to reduce species extinction and preserve biodiversity. These studies address similar challenges related to the necessary involvement of different parties and modeling of the constraints at hand in a holistic manner. These include budgetary, ethical, and other sociopolitical constraints (Sarkar et al. 2006).

5.4 Perspectives

In the future, there will likely be increased use of complex and holistic computational constraint models to implement climate change solutions, such as water-use efficiency, solar energy-use efficiency, or biodiversity management. They will involve many more actors and decision makers by integrating all components in one tool. Research efforts in this field of artificial intelligence and operational research address the technical and modeling challenges, to handle the spatiotemporal aspects of planning new solutions, as well as the handling of uncertainties in the data available and forecasted.

Additionally, to help foster such tools to be active support and communication tools among different actors, they will need to be easy to use, attractive, and interactive. Indeed, if current behaviors, local as well as global are still passive, reasons can be that individuals do not feel concerned, or information is not accessible (possibly to avoid nonproductive states of fear or panic), or individuals feel powerless. Some studies related to this aspect investigate the “knowledge ignorance paradox” (Ungar 2000). Recent research in the field of persuasive computing with serious games goes in this direction. Their aim is to help the user feel engaged, involved and active in the implementation of changes. In Krotoski (2010, p. 695), a set of approaches are discussed where various games are presented with different global warming scenarios: “Players explore geoengineering, alternative energy sources, and other options for protecting the planet over the next 200 years”. The game presents various realistic predictions for different climate change models and allows the player to engage with different climate change challenges. The ultimate goal is to bring awareness to the issues and make players, actors of change. Such approaches are to be used for local aspects of energy saving and water consumption in private homes.

However, they can also be embedded in large-scale constraint and decision models, which nowadays present a complex and integrated view of solutions design (economics, engineering, environmental), and be tailored to decision makers from different fields and expertise. As a conclusion, computational constraint models can help to simulate different scenarios and let the user see the impact of their actions or decisions. In general, they aim to answer questions such as “how, when, and where to migrate to new solutions (e.g., RE parks, hydroeconomic models, river basin plans), such that a set of environmental, social, technical, and economic constraints are satisfied simultaneously.” They are also a powerful communication tool among actors from different fields. The methodological process to build such models involves all the relevant parties to specify the requirements and existing constraints. The final tool can benefit from interactive interfaces to the computerized solutions. Enhancing such interfaces with techniques from persuasive computing and gamification can further involve end users, increasing their awareness and make them actors in the implementation of the solutions.

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Part II
Communicating Climate Change Information

Chapter 6
Uncertainty and Future Planning: The Use of Scenario Planning for Climate Change Adaptation Planning and Decision

Silvia Serrao-Neumann and Darryl Low Choy

Abstract This chapter reports on lessons on the use of scenario planning for informing long-term climate change adaptation planning and decision. Lessons are extracted based on the development and application of exploratory scenarios (multiple plausible futures) involving two different levels of stakeholder engagement in Australia: (i) a regional/institutional and (ii) a community level. Lessons from the regional/institutional level focus on the South East Queensland Climate Adaptation Research Initiative (SEQCARI) involving a multi-sectoral investigation of climate change adaptation in the South East Queensland (SEQ) region, comprising the sectors of urban and regional planning, coastal management, physical infrastructure, emergency management, and human health. Lessons from the community level are drawn from the recovery phase of the Cardwell town in far north Queensland in the aftermath of category five Tropical Cyclone Yasi. Findings indicate that at the regional/institutional level exploratory scenarios are useful to support the integration of different stakeholders' and sectors' perspectives concerning climate change adaptation. In particular, they provide opportunities for improved understanding of sector-specific as well as cross-sectoral issues to be addressed. At the community level, exploratory scenarios assist in the scoping of specific and tailored adaptation options. However, a limited number of options accounts for multi-dimensional challenges and longer-term future planning related to climate change impacts.

Keywords Community · Foresight · Australia · Natural hazards
Adaptation · Collaborative planning

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6.1 Introduction

Scientific uncertainty related to climate change comprises one of the most widely recognized barriers to effective climate adaptation (Milly et al. 2008; Quay 2010). Additionally, recent modeling indicates that climate change is likely to increase the intensity and frequency of extreme weather events but there are substantial limitations in terms of foreseeing when and where those events are likely to occur (CSIRO 2007; Tompkins et al. 2010). Climate change projections are often too broad and subject to errors when applied to finer resolution to provide certainty to policy development at the local and regional scales (Tang et al. 2010), especially to inform land use policies. Furthermore, decision-makers also have to deal with uncertain social and economic futures (Tompkins and Neil Adger 2005; Rydin 2013), and diverse political interests regardless of available scientific knowledge concerning climate change impacts (McFadden 2007; Measham et al. 2011).

Foresight and future studies are often suggested as suitable approaches to deal with both complexity and uncertainty, including those related to environmental and social change (Quay 2010; Floyd 2012). In particular, foresight methodologies such as scenario planning can assist in the identification of new challenges as they emerge and foster anticipatory rather than reactive strategies (Fuerth 2009; Bengston et al. 2012). Foresight can be understood as "the capacity to anticipate alternative futures, based on sensitivity to weak signals, and an ability to visualize their consequences, in the form of multiple possible outcomes" (Fuerth 2009: 17). This chapter aims to contribute to advancing foresight and future studies methodologies by distilling lessons on the use of scenario planning (Vervoort et al. 2014) involving multi-stakeholders[1] for climate change adaptation planning and decision. Lessons are drawn from two action research projects (Floyd 2012; Flood 1998; Reason and Bradbury 2006) carried out in the state of Queensland, Australia, namely the South East Queensland Climate Adaptation Research Initiative (SEQCARI), a multi-sectoral and regional scale project; and a disaster recovery study on the town of Cardwell following the category five Tropical Cyclone Yasi, a community-based project. By focusing on different projects, the study offers comparative evidence to investigate the effectiveness of scenario planning processes for different contexts (Bowman et al. 2013). Comparisons of this type are also important because stakeholders' interests vary across scales (Rounsevell and Metzger 2010).

To this end, the chapter is structured in three parts. The first part provides a summary on scenario planning as a type of foresight and future studies methodology (Sect. 6.2). The second part describes the use of scenario planning in the two abovementioned projects (Sect. 6.3). The third part reports on the lessons learnt from the two projects to guide future application of scenario planning for climate change adaptation planning and decision (Sect. 6.4).

[1]Stakeholders refer to all participants to the process, including practitioners, researchers, representatives from public and private sectors.

6.2 Background to Scenario Planning

There has been an increased use of scenario planning over the last 60 years in academic research, policy and decision-making processes, and corporate and community planning (Ramirez and Wilkinson 2014; Gidley 2013). Perhaps the uptake of scenario planning across so many sectors is related to its enlightenment to strategic planning for dealing with uncertainty and complexity (Bowman et al. 2013). In particular, through scenario planning, it is possible to carry out systematic exploration and description of a range of ways in which uncertainties may play out. These include their impacts on the sector or problem sought to be addressed, and how critical uncertainties may interact leading to surprising outcomes (Bowman et al. 2013; Schoemaker 1993).

Scenario planning can facilitate individual and group decision-making in light of uncertainty, especially from a long-term perspective (Raford 2015; Bai et al. 2016). Other benefits associated with the use of scenario planning include its ability to enable learning and awareness building (Raford 2015), being conducive to improving learning processes, identification of issues and decision-making (Evans 2011), encourage stakeholders to work cooperatively and creatively to overcome barriers and achieve change (Kahane 2012), and promote stakeholder engagement (Chirozva et al. 2013) to ensure more robust decisions are made (Ernst and van Riemsdijk 2013).

Scenario planning can be understood as "a process that brings stakeholders together to construct possible narratives about the future of their environment" with the purpose to create possible futures that can be used for the assessment of strategic options and capabilities (Evans 2011: 461). Hence, it is essentially a participatory engagement method that contributes to knowledge co-production and learning, ownership of problem and solutions, and dealing with power imbalances (Butler et al. 2014). It helps participants to challenge theirs and others' values and assumptions, enables better understanding of issues by lay participants, and provides a platform for integrating scientific information and local knowledge (Butler et al. 2014). It also facilitates mutual learning as a key outcome of transdisciplinary projects which equally accept the value of knowledge produced through science and practice (Scholz 2000). The effectiveness of scenario planning processes is underpinned by its connection to realities and complexities of the issue it refers to (Chirozva et al. 2013). Additionally, scenarios are instructive for a decision context that involves a particular question or problem demanding decisions now but will involve actions only to be realized in an uncertain future (Vervoort et al. 2014; Fuller and Loogma 2009).

While the majority of works reporting on scenario planning tend to focus on their successes, there are problems and limitations associated with scenario planning that should also be considered. For example, Raford (2015) discusses three methodological limitations associated with qualitative scenario planning: it is labor and time-consuming demanding substantial commitment from participants, it focuses on recruiting participants from senior professional levels that can bias the content of the scenarios, and it is dependent on the skills and experience of workshop facilitators and scenario writers. Limitations are compounded by the lack of formal evaluation methods that are suitable to assess scenario planning exercises (Raford 2015). Additionally, one of the key difficulties in undertaking scenario planning concerns the ability participants have to understand the scenarios and/or the systems they attempt to unfold (Wollenberg et al. 2000) or limited understanding and acceptance of long-term benefits of future strategies based on current actions (Floyd 2012). Hence, scenarios need to be truly understood by involved participants to enable learning to occur.

6.3 Research Approach

There is widespread variation on the understanding and types of scenario planning concerning quantitative and/ or qualitative approaches (Börjeson et al. 2006). A simpler systematization offers three categories and six types under which scenarios may be classified: predictive (forecast and what-if types), exploratory (external and strategic types), and normative (preserving and transforming types) (Börjeson et al. 2006). Predictive scenarios seek to predict what is likely to happen in the future to enable prior planning and adaptation to future expected conditions. Exploratory scenarios seek to explore situations or developments that may occur by generating multiple possible futures to capture a long-term perspective that enables structural or profound changes. Normative scenarios assist in the identification of targets and inherent pathways to meet those targets.

Additionally, there are conflicting definitions of scenario types in the literature (i.e., qualitative, quantitative, inductive, deductive) (Rounsevell and Metzger 2010). Findings reported in this chapter refer to a qualitative and inductive approach to scenario planning involving the development and application of exploratory scenarios (multiple plausible futures) (Vervoort et al. 2014). In particular, scenario narratives or storylines covering simultaneous possible futures were developed and used to test a range of options/ strategies, including the identification of potential outcomes brought by these options/ strategies over a long-term time horizon. The chapter reports on two action research projects (Floyd 2012; Flood 1998) involving stakeholder engagement in Australia at a regional/institutional and a community level. The regional/institutional project refers to the South East Queensland Climate Adaptation Research Initiative (SEQCARI project) which comprised of a multi-sectoral investigation of climate change adaptation in the South East Queensland (SEQ) region, including the sectors of urban and regional planning, coastal management, physical infrastructure, emergency management, and human health. The community-based project refers to the recovery phase of the Cardwell town in far north Queensland in the aftermath of category 4/5 Tropical Cyclone Yasi (Cardwell project).

Both projects adopted the 2×2 matrix method whereby the top two highly uncertain and highly important independent drivers were used to construct possible

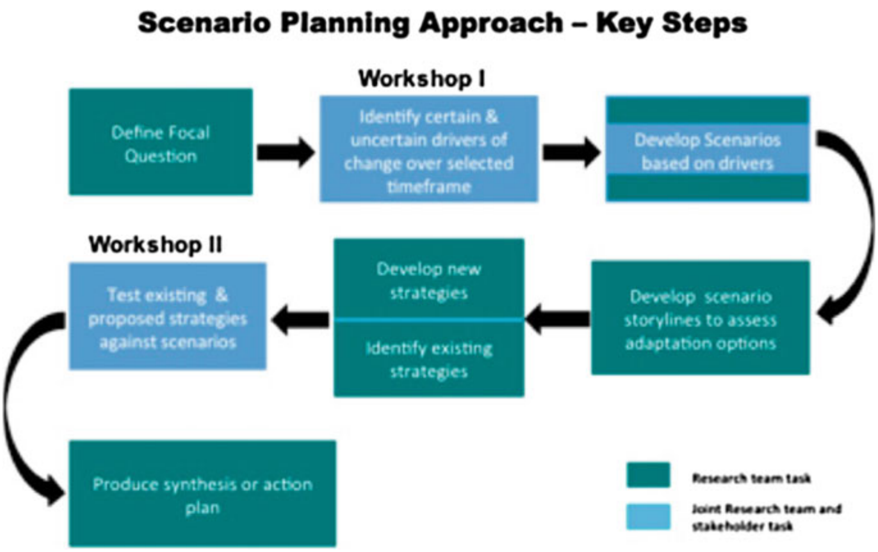

Fig. 6.1 Scenario planning process followed by the two research projects

futures (Ramirez and Wilkinson 2014). While four scenarios were identified as a result of the 2 × 2 matrix method, due to participants' time constraints to attend full-day workshops, only two scenario narratives were fully developed and used to test a selected set of strategies relevant to each project (e.g., adaptation options for the SEQCARI project; and future options for the Cardwell project). Following the inductive process, in the first series of workshops a focal question (long-term perspective of 20–25 years into the future) was placed to participants to guide: (i) the identification and ranking of drivers of change; (ii) the selection of the 2 × 2 matrix; and (iii) the outlining of key aspects of the scenario narratives. Scenario narratives were then fully developed by the research team and used in the second series of workshops to test new and proposed strategies (see Fig. 6.1). A description of the two scenario planning processes is presented in Table 6.1.

6.4 Using Scenario Planning to Inform Decision-Making for Climate Change Adaptation

As outlined by Butler et al. (2014), scenario planning is a participatory engagement method that contributes to knowledge co-production and learning, ownership of problems and solutions, and dealing with power imbalances. In particular, scenario planning can help participants to challenge values and assumptions they might have, improve understanding of complex issues by lay participants, and provide a platform for integrating scientific information and local knowledge (Butler et al.

Table 6.1 Overview of scenario planning processes of the two projects

Project title	South East Queensland Climate Adaptation Research Initiative (SEQCARI) (2009–2012)
Project description	A multi-sectoral investigation of climate change adaptation in the South East Queensland (SEQ) region, comprising the sectors of urban and regional planning, coastal management, physical infrastructure, emergency management, and human health. Focus on regional/institutional dimension
Stakeholders	Local and state governments, non-government and community-based organizations, peak industry bodies
Scenario development process	Two series of two workshops focused on coastal and inland human settlements (average of 20 persons per workshop). 2 × 2 matrix: form of governance (inclusive to exclusive) and community responsibility and involvement (low to high)
Selected scenario narratives	*Shared Path*—a scenario characterized by extremely high level of community acceptance and involvement in governance and in the management of community affairs operating in a political system offering high degree of inclusive governance for its citizens *Free Ride*—a scenario characterized by extremely low levels of community responsibility and involvement in governance and in the management of community affairs that operate in a political system offering high degree of inclusive governance for its citizens
Assessed strategies	Sectoral and cross-sectoral climate adaptation options
Project title	Improving adaptation of coastal communities through bottom-up approaches—a case study of the Cardwell community in North Queensland (2011–2013)
Project description	A partnership between the Cardwell community and researchers established to conceptualize and develop a long-term strategic action plan for the community's future. Focus on community dimension
Stakeholders	Community members
Scenario Development process	Two series of two workshops focused on the community recovery phase following Tropical Cyclone Yasi (average of 17 persons per workshop). 2 × 2 matrix: governance (inclusive to exclusive) and socio-environmental assets (high to low quality)
Selected scenario narratives	*By the People for the People*—a scenario where decisions regarding the management of the district's high-quality socio-environmental assets are driven from the bottom-up by communities in collaboration with local government and regional non-government organizations *Controlled Democracy*—a scenario where decisions regarding the management of the district's high-quality socio-environmental assets are driven from the top down by the local, state and federal governments with little opportunity, if any, for community involvement
Assessed strategies	Future options developed based on participants' aspirations for a future Cardwell

2014). Additionally, Bowman et al. (2013) also claim that the inductive approach to scenario planning enables trust building as participants incrementally introduce their different aspirations and debate them throughout the process. Based on this literature, there are four key lessons that can be gleaned from the use of scenario planning for climate change adaptation planning and decision in the two above-mentioned projects. Lessons included, but are not limited to: (i) co-production of knowledge and learning, including the understanding of cross-sectoral issues; (ii) integration of scientific information and knowledge; (iii) understanding of people's interests and values, and trust building and leadership issues; and (iv) ability to think strategically.

Similar to findings from other studies (e.g., Scott et al. 2012), stakeholder engagement leading to co-production of knowledge and learning through scenario planning was observed at the SEQCARI project. Perhaps due to its focus on the regional/ institutional dimension, scenario planning workshops provided opportunities for multi-sectoral stakeholders to interact and improve their understanding of the challenges confronting climate change adaptation for human settlements from a multi-sectoral perspective (Serrao-Neumann et al. 2014). In particular, for some participants the workshops comprised of the first opportunity they had to understand how specific sectors operate. For example, participants from the planning sector were able to gain a better understanding that land use and development control decisions that are taken under their portfolio often have significant impact on emergency management personnel for both disaster prevention and disaster response (Low Choy et al. 2012a). Comparatively, co-production of knowledge and learning was less evident at the Cardwell project. In particular, perhaps due to the fact that most participants in the project practiced some degree of volunteering activities within their community, most people indicated their awareness of issues affecting their community which in turn motivated their involvement in community matters in the first place.

Scenario planning is essentially a participatory process whereby symbolic texts are socially constructed (Fuller and Loogma 2009). It is therefore expected that scenario planning can provide a platform for integration of scientific information and local knowledge. In both projects, such integration is best demonstrated by the breadth and level of complexity that characterized the outputs of the "wind tunnel" testing exercise embedded in scenario planning, that is the suite of climate adaptation options in the SEQCARI project (Low Choy et al. 2012b) and future options in the Cardwell project (Serrao-Neumann et al. 2012). Nonetheless, separating knowledge co-production and learning and integration of scientific information and knowledge as different outcomes from scenario planning are not as straightforward because these are interlinked processes. However, considering the issues regarding climate science and inherent uncertainty, it is important to highlight the role that best available scientific information plays in informing strategic actions focused on minimizing future vulnerability of places and communities in light of climate change—as it was the case in the two projects. Additionally, it is important to acknowledge how the scale at which scenario planning focuses on may influence the learning process. For example, while the multi-sectoral/multi-stakeholder perspective adopted in the SEQCARI project enabled the interaction of stakeholders from across a range of sectors, it lacked a stronger community perspective. Conversely, the Cardwell project lacked the institutional perspective although the strategies the community was seeking to implement could be facilitated or hampered by the actual institutional capacity of their local and state governments.

Multi-stakeholder scenario planning processes are known to be time-consuming given participant's unfamiliarity with the method. However, it appears that it is this time-consuming characteristic of scenario planning that enables trust to be built as participants incrementally introduce their different aspirations and open up for debate. The extended number of workshops held at the Cardwell project confirmed this assumption as participants needed this time to understand how theirs and others' aspirations were aligned with, or contradictory to, achieving their set vision for the community. In this project, the ongoing interaction between community members facilitated the debate about, and understanding of, different individual's aspirations which had the same ultimate goal of improving the community's quality of life. Additionally, as indicated by Bowman et al. (2013), a strong, committed leadership in the Cardwell project was fundamental to ensure the scenario planning process did not fracture and enabled trust to be built to overcome participants' resistance in accepting other's viewpoints (at least at that point in time).

The issue associated with biased and narrow perspective in scenario planning based on the breadth of participants outlined by Butler et al. (2014) was evident at the Cardwell project. While many scholars (Scott et al. 2012; Schoemaker 1991; Quay 2010) highlight the benefit of using scenario planning to derive long-term strategic solutions for climate change adaptation, some workshop participants struggled to think of and accept the inclusion of strategies that could not be immediately implemented by their community. This situation may be related to the issue raised by Rounsevell and Metzger (2010) who emphasized that when participants involved in scenario planning do not have a defined conceptual model of the system that is being described in the scenario narratives there is a risk for the system interrelationships and feedbacks to be misunderstood. Rickards et al. (2014) also noted this difficulty which they attributed to the cognitive challenge for participants of scenario planning workshops to understand other's meanings and difficulty to grasp long-term thinking. In the Cardwell project, participants tended to focus on pursuing strategies needed to solve existing/immediate problems in their community. On the other hand, this "narrower" perspective enabled them to scope more specific and tailored strategies that were relevant for the community's reality and context. Comparatively, participants in the SEQCARI project were able to deal with the long-term perspective more easily probably based on their experience with dealing with strategic issues in their professional roles on a regular basis. Nonetheless, more locally based dimensions ended up being oversighted by the strategic, long-term focus. These issues related to bias and limited strategic focus in scenario planning can be traced back to the time constraint factor that permeates an essentially participatory process. Nonetheless, it is important to acknowledge that there are limitations as to what can be achieved through scenario planning, indicating that complementary foresight methodologies may need to be employed to obtain more holistic outcomes.

6.5 Conclusion

This chapter set to distill lessons from the use of inductive exploratory scenario planning processes involving two projects in Australia: a regional/institutional and a community-based project. Investigated projects included (i) the SEQCARI project —a multi-sectoral investigation of climate change adaptation in the SEQ region, comprising the sectors of urban and regional planning, coastal management, physical infrastructure, emergency management and human health; and (ii) the Cardwell project—a community-based project involving a partnership between researchers and members of the Cardwell community in North Queensland to develop a strategic action plan for the Cardwell community in the aftermath of tropical cyclone Yasi.

Findings from the SEQCARI project indicated that inductive exploratory scenarios enabled the integration of multi-stakeholder and sector perspectives related to complex challenges such as climate change adaptation for human settlements. In particular, in this project, the scenario planning process provided opportunities for improved interaction between practitioners and understanding of sector-specific issues. In parallel, community-based projects appeared to be better positioned for scoping more specific and tailored adaptation options that are specially focused on solving existing and future challenges relevant to local contexts. However, they may lack broader interaction between different layers of actors involved in decision-making, therefore hampering participant's ability to ascertain feasibility and envision the implementation of adaptation pathways. Multi-stakeholder scenarios processes are known to be time-consuming given participant's unfamiliarity with the method; however, longer interaction among participants is needed to enable trust building. In the community-based project, it was also noted participant's difficulty in grasping with both multi-dimensional challenges related to, and longer-term strategic thinking demanded for, climate change adaptation. Additionally, both projects needed to deal with the time lag between scenario generation and application demanding the allocation of sufficient time for participants to familiarize with scenarios.

The chapter concluded by signaling the suitability and limitations of scenario planning for climate change adaptation planning and decision. Given the limitations of scenario planning, it is pertinent to propose that complementary foresight methodologies are also employed and, more importantly, the efficacy of these methodologies be tested by more research projects to improve the overall applicability of foresight methodologies for climate change adaptation planning and decision.

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Chapter 7
Future Climate Narratives: Combining Personal and Professional Knowledge to Adapt to Climate Change

Liese Coulter

Abstract Ready access to scientific climate knowledge is important to inform climate change mitigation and adaptation planning. In addition, decision-makers use social and cultural understandings to evaluate what is plausible, possible, and desirable in the future. This study considered in what way do personal factors influence the incorporation of climate change knowledge in adaptation decisions. Professionals who work with climate knowledge were interviewed regarding their personal discussions and planning, focused on adaptation to climate change. Typological analysis concentrated on participants' relative attention to Future Thinking, Climate Knowledge, and Narrative Communication. Despite professional application of climate knowledge, the majority of participants found it challenging to imagine future societies situated in future climates, especially those who did not consider themselves at risk, or who found it difficult to discuss projected climate change impacts. This indicates that personal differences such as subjective assessments of climate risk and adaptive capacity, as well as relative engagement in future thinking, affect climate adaptation decision-making that may impact the wider society over time.

Keywords Adaptation · Episodic · Mitigation · Narrative · Semantic Typology

7.1 Introduction

The way climate-affected futures are understood, communicated, and assessed stands at the center of decision-making to manage climate change impacts and their consequences. To support climate change adaptation, useful climate knowledge must both accurately reflect current projections of climate patterns, and take into account how such information is received, evaluated, and used to inform decisions

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(Grothmann and Patt 2005). How climate knowledge is reflected in decision-making is not well understood, although differences between individuals have been shown to influence adaptation decisions, professionally, and personally (Wolf and Moser 2011). To understand adaptation strategies, much research has focused on climate information communication and its sectoral and community-level applications (Coulter et al. 2014). However, little is known about how those who are well-informed use climate knowledge in decisions that affect their own futures. Therefore, this study aims to better understand to what extent decision-makers include what they know of climate change in plans for the future that they share with family and friends.

Australian and Canadian professionals who work with climate knowledge in research, policy, and practice were asked how they talked within their family and social circles about adapting to climate change over the next twenty years. This timeframe is both long enough to anticipate climate-related changes based on current IPCC reports (Moser 2016), and short enough to include long-term plans relating to common family issues such as education, investments, and home location. Responses were analyzed using a Future Climate Narrative typology developed by the author and the results discussed from a pragmatic constructivist perspective. The chapter first sets out the typology structure and its application and gives a brief background to the primary types of future thinking, climate knowledge, and narrative communication. Then, it describes key expressions by people who work with climate information, evidenced by exemplary quotes regarding how participants reflect, and share that knowledge in personal visions of the future. The chapter concludes with a discussion of the implications and limitations of the findings.

7.2 Future Climate Narrative Typology

Decision-making for climate change adaptation is significantly shaped by three factors: the extent to which the future is imagined; what knowledge of expected carbon, climate, and social patterns influence risk assessments; and the ways this knowledge is exchanged with others. Therefore, this chapter considers challenges that affect engagement by decision-makers in future thinking, climate knowledge, and narrative communication.

7.2.1 Future Thinking

Decision-making for the future implies some degree of future thinking which has been recognized as a cognitive process linking memory to predictive mental activities (Tulving and Szpunar 2011). Research supports distinguishing between broad *semantic* future thinking that reflects general knowledge of the world, and more individualized *episodic* future thinking based on personal memories and imaginings. Combining the two, decisions about the future are influenced by the interplay between semantic and episodic knowledge, which can be considered in an iterative sequence of four modes. Szpunar et al. (2014) have organized these modes into a taxonomy of prospection that offers insight into how knowledge influences decisions through; *simulation*, which involves constructing mental representations of plausible futures; *prediction*, which estimates the likelihood of events and impacts; *intention*, which sets relevant personal or organizational goals; and *planning*, where the necessary steps are formulated and organized. Explicit consideration of future thinking offers avenues to understand how new knowledge is incorporated in climate change decision-making.

7.2.2 Climate Knowledge

For decades, knowledge of climate change has been categorized into antecedent factors, characterized by what is known about disturbances of the carbon cycle; and consequent factors, based on understandings of changing climate patterns and their wider implications. In this way, decisions to manage these physical systems have been categorized as relating to either mitigation of antecedents, or adaptation to consequences (IPCC 2014). However, it has become clear that many impacts from human-caused, or anthropogenic, climate change have become unavoidable (Kirtman et al. 2013). Therefore, the carbon and climate systems must now be understood in terms of changes in both their interactions, and their interconnections with human activities. These connections are not immediately obvious, as they are understood based on highly technical analyses of observations, paleoclimate archives, theoretical studies, and computer simulations. This understanding is further complicated by scientific caveats, projected uncertainties, and the complex mathematics needed for insights into the carbon–climate–human system (Raupach et al. 2011).

Policy-relevant emission and climate scenarios have been developed to make information more accessible and applicable (Coughlan de Perez et al. 2016). In addition, model simulations now offer guidance to manage even near-term climate impacts, expected within the next twenty years (Kirtman et al. 2013). When used to frame expectations for the next two decades, these models, scenarios, and simulations begin to connect the professional and the personal, aligning scientific semantic knowledge with more personal experiences and imaginings.

7.2.3 Narrative Communication

Researchers in Earth Sciences developed early narratives of climate change to communicate evidence and analytic conclusions about the future climate. These narratives were concerned with correcting a deficit in information for policy-makers, to motivate action to mitigate emissions to slow, or entirely avoid, climate impacts (Boykoff 2007). The communication emphasis has shifted to public engagement and direct calls to action (Moser 2016) which more often make appeals to personal and localized concerns (Newell et al. 2016). Communication research has shown that personal perspectives shape how climate information is received (Myers et al. 2012) and that narratives based on fear risk entrenching inaction or denial (Cook and Balayannis 2015). With the beginning of locally discernible climate impacts, climate adaptation narratives have emerged based on lived experience (Petrasek MacDonald et al. 2013). Increasingly, messages to avoid unmanageable climate consequences by limiting global warming to 2 °C or even 1.5 °C (Hulme 2016) are joined by messages that frame probable futures marked by anthropogenic climate change, in a new era coined the Anthropocene (Dalby 2015). Increasingly, experts exert less control over local climate narratives and plans, as communities formulate their own climate information to underpin decision-making (Pringle and Conway 2012).

Combining engagement in future thinking, climate knowledge, and narrative communication offers key challenges that shape both personally and socially constructed scenarios for the future. In recognition of this, innovative programs are supporting new methods for scenario development and cooperative ‘worldmaking’ (Vervoort et al. 2015) to guide both mitigation and adaptation. These future-oriented simulations aim to prepare climate change responses that are precursors to society-wide transformations (Gillard et al. 2016). Respecting these issues, the current chapter addresses how people who work with climate information reflect and share that knowledge in personal simulations that influence their adaptation decisions.

7.3 Methodology

7.3.1 Approach and Boundaries

This research is centered on the problem of reflecting climate information in personally relevant near-term adaptation decisions. This analysis reflects a pragmatic approach within a constructivist paradigm. Social constructionism is a theory of knowledge that examines jointly constructed understandings of reality (Berger and Luckmann 1966). The construction of meaning is fundamental to future-oriented thinking or foresight, with its focus on making meaning of symbols that represent as yet unrealized activities, influences, and outcomes (Fuller and Loogma 2009). An inclusive approach respects both Positivist perspectives, developed from natural science traditions of objectively observable and replicable positive proofs (Guest et al. 2012), and Interpretivist perspectives where reflexive and situated understandings are shaped by factors that influence both their conception and interpretation at any time (Reed 2008). This inclusive approach supports decision-makers to synthesize meanings informed by both physical science and imagined futures (Fratini et al. 2012).

Semi-structured interviews with professionals who work with climate knowledge for their jobs were carried out with 15 Australians between July and December 2014, and with 16 Canadians between January and April 2015. Interviews were transcribed verbatim and content was de-identified to encourage candor in participants, who were selected based on substantive professional and public contributions to climate change information and communication. An effort was made to include a balance in gender, regional locations, and in professional focus between research, policy, and practice (i.e., research communication).

7.3.2 Analytical Frame

Analysis was guided by the future climate narrative (FCN) typology (see Fig. 7.1), a conceptual framework constructed from three overarching types in climate change planning: how one thinks about the future (Future Thinking); what climate knowledge is reflected in one's understandings (Climate Knowledge); and how this knowledge is communicated with others (Narrative Communication). The intersections of primary types define four sub-types: first, Dangerous Futures (including Narrative Communication and Climate Knowledge), where climate communication is focused on how climate information is accessed, interpreted, and shared; second, Imagined Futures (including Narrative Communication and Future Thinking), where future narratives are focused on how visions and ideas of the future are

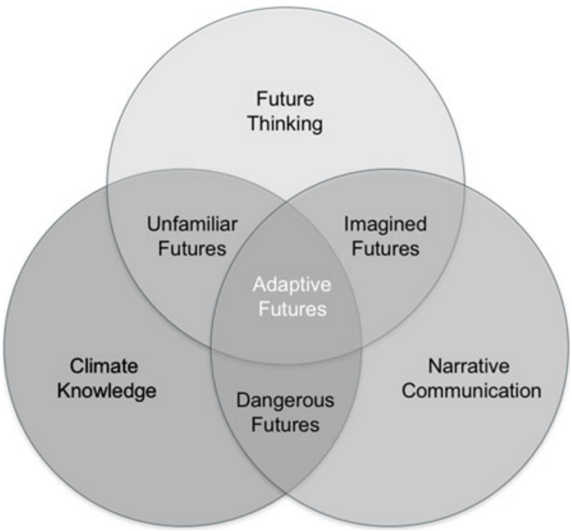

Fig. 7.1 Future climate narrative typology, showing relationships between types

accessed, interpreted, and shared; third, Unfamiliar Futures (including Future Thinking and Climate Knowledge), where expectations of future climate are focused on how visions and ideas of the future are affected by, and affect, interpretations of climate information; and fourth, Adaptive Futures (when all three primary types are represented), where adaptation narratives are focused on accessing, interpreting, or sharing images of the future that reflect climate knowledge.

7.4 Results

This analysis centered on challenges and opportunities that decision-makers acknowledge as they develop and share visions of near-term futures affected by climate change. These results drew on the experiences of Australians and Canadians who engaged with climate knowledge through working in research (i.e., climatology, ecology), policy (i.e., state planning, lobbying) or practice (i.e., consulting, communicating) as they describe and share their expectations of the next two decades affected by climate change. Passages were assigning to types inclusively so that most expressions were included in more than one primary type. Therefore, these exemplary quotations have been set out according to the secondary and synthesis Futures types which best indicate their main focus.

7.4.1 Challenge to Communicate: Dangerous Futures

The Dangerous Futures type, which is focused on Narrative Communication and Climate Knowledge, captured expressions that acknowledge there was low engagement in professional or personal discussions of near-term climate impacts, even when concern was high. Participants identified personal and emotional factors that affected both receiving and sending climate information, and most had only infrequent conversations about climate change with people close to them.

Considering how he talked about climate change, Policy-maker 11 (Can) felt his concerns were not shared by others in his immediate circle: “But I come back to how I talk about this. The short answer is … people have not engaged me, and I don’t bring it up with my wife in personal conversations, but I think about it.” Practitioner 4 (Aus) identified the social and professional boundaries of privacy as a limit on sharing her fears for the future: “That’s not something I can easily share with people who are more acquaintances or colleagues. I’m a very private person, so I don’t tend to talk easily about those kinds of things,” For Researcher 1 (Aus), personal discussions of climate change were influenced by what she felt able to say to family and friends about constraints on adaptation: “The change … has never been this rapid, ever … humans have taken up all the spaces. So those are the sorts of things that I’m trying to talk about with my friends. There is a lot of fear around.”

Avoiding too much exposure to climate information outside of the workplace was one strategy to minimize a sense of fear, as described by Policy-maker 10:

> It's very scary to internalize it … I do recognize it for myself, how I stop at a certain point in my thought process. You know watching these movies about changing ice and whatnot and … you think, okay, that's enough for tonight. I need to go to sleep.

7.4.2 *Challenge to Imagine: Imagined Futures*

The Imagined Futures type focused on Narrative Communication and Future Thinking to capture expressions of uncertain and conflicting information, which often made it difficult for decision-makers to develop clear images of likely futures. Some participants expressed reluctance to become concerned about issues they had not already faced, and most did not consider themselves personally vulnerable to climate impacts due to perceived high adaptive capacity and low vulnerability.

It was not easy to determine the future meaning of likely impacts even when the issues are well communicated. For example, Policy-maker 8 (Can) could imagine only first level implications of severe weather events: "So I think about if it floods. You know, more destroyed property, perhaps roads that need to be rebuilt. Or, transportation isn't that easy anymore, or it's different … But I don't know what that means." Most of the participants included themselves in social groups with a high adaptive capacity, such as Practitioner 9 (Can) who thought it will: "be really bad in some countries, and in some others, no-one is going to see anything … but some people say, we don't care, because we're in a rich country, so nothing is going to hurt us." This thinking was also reflected by Researcher 3 (Aus) who preferred to focus on existing issues rather than to be worried by new challenges: "If climate change means those risks get stronger … but one doesn't become concerned about things that I'm not already concerned about." The Imagined Future is also subject to different interpretations starting from similar starting points. Policy-maker 3 (Aus) considered these differences among colleagues:

> Biodiversity conservation, you get different experts in the area with very different views of things. Some who are really kind of thinking things could be very dire reasonably quickly, and others are going, well, you know, there's an enormous resilience in species … things might not be as bad as we might think …

7.4.3 *Challenge to Know: Unfamiliar Futures*

The Unfamiliar Futures type captured expressions including both Future Thinking and Climate Knowledge which often involved participants in creative thought. For many, this included an expressed need for projected information that can be confidently applied in local contexts. Some scientists acknowledged their challenges to develop more systemic and synthesized knowledge, and to usefully apply what can only ever be partially understood.

Researcher 6 (Can) acknowledged the challenge to combine isolated factors not usually integrated into systemic knowledge: "Because at the moment we're projecting changes in temperature and changes in precipitation, but we're not projecting changes in—at least not very often—in a way that an entire system would experience." Others commented that partial knowledge limited their ability to make definitive statements, such as Researcher 10 (Can): "It might just be the kind of person that I am … I would be hesitant to give a definitive answer as to how things would be exactly without being able to look into it a little bit more." Local knowledge was especially important as attention moved to adaptation. Policy-maker 9 (Can) explained: "We didn't abandon mitigation, but we said … let's get some scientifically reliable projections of where the climate in our region is going to go, let's just do all the stuff around assessing risk and start to identify programs." For scientists, such as Researcher 2 (Aus), the need for more detailed and local knowledge brought greater uncertainty in their view of the future:

> I can be really honest about saying we're very, very confident that there's going to be further warming, and increase in sea level, and changes in storm and ocean acidification. But at the regional level, we've got less confidence about the projected changes in rainfall for example, or some extreme events like tropical cyclones.

7.4.4 Adaptation Approaches: Adaptive Futures

The synthesis type of Adaptive Futures captured expressions where Future Thinking, Climate Knowledge, and Narrative Communication combined as participants developed and shared strategies to both mitigate emissions and adapt to climate impacts. This included positive factors to manage what could not be avoided such as combining mitigation and adaptation, supporting a local emphasis, and developing networked cooperation to share experiences as lessons to inform decision-making.

While working on a global problem some, such as Researcher 9 (Can), found a sense of agency by focusing on local issues: "I feel like it's better, if I spend my time advocating for both mitigation and adaptation to climate change for my municipality. Which is where things are going to hit close to home." Others focused on combining their concern for mitigation and adaptation including Policy-maker 4 (Aus) who asked: "How do we make changes that are more sustainable so we're not contributing as much to making the problem worse? … 'What's the adaptation part, what's the mitigation part?' and do they actually in some cases come together?" Co-operation featured in adaption strategies as Policy-maker 9 (Aus) explained: "I think resilience for communities and for families will involve not being isolationist, but creating networks that are co-operative, that can negotiate appropriate and maybe firm boundaries at times when necessary, in ways that does not threaten the on-going co-operation." Practical adaptation strategies included sharing information. Practitioner 8 (Can) wanted to share more than successes:

> It's great to hear about success stories, but … we might not get it right the first – right off the bat. And so we can learn as much from, even from what others have tried that didn't work. And how can we take those lessons and apply it to our own context?

7.5 Discussion

Research into individual factors in climate-related decision-making is growing (Werg et al. 2013; Rogers et al. 2012; Bradley and Reser 2016). Despite this, more research is needed that considers personal adaptation decisions in 'expert' communities, where members are well-informed but may have limited personal experience of climate impacts. Surveys have shown significant differences between those who considered they had direct experience of climate change and those who did not, across a range of factors including "climate change beliefs, perceived risk, objective knowledge, distress, psychological adaptation, and behavioral engagement" (Bradley and Reser 2016, p. 7). These differences pose a fundamental divide between the professionals who generate and communicate climate information, and affected communities already adapting. Case studies that draw on lived experience in impacted communities offer visions of the future informed by local knowledge, and contemporary experiences and concerns (Petrasek MacDonald et al. 2013; Wolf et al. 2013). However, climate change professionals may not have had any direct personal experiences of climate change impacts in their own lives.

To bridge this divide, some researchers actively work with communities to develop adaptation plans and explicitly connect bodies of expert knowledge with local knowledge (Serrao-Neumann et al. 2013), while others draw on sectors such as the wine industry, using industry experience to inform theories of adaptation (Park et al. 2012; Pickering et al. 2015). Results reported here suggest that imagining likely futures affected by climate change is challenging for professionals in both their work and personal lives. In a professional context, the emotional implications of projected changes are rarely acknowledged (Wirth et al. 2014), even as the need to manage difficult transitions is reconfirmed by sometimes overwhelming evidence of change. In a personal context, climate change was seldom a welcome topic for social or family discussions.

The Dangerous Futures type revealed that most of the participants would rarely initiate discussions about climate change with colleagues, friends, or family; and that others did not usually introduce the topic. This was partly because in social settings, discussing climate change was variously seen as depressing, contentious, and in bad taste; in work settings, it posed the danger of alienating colleagues; and in the home, it was avoided to 'not scare the children'. At the time of the interviews, both Australia and Canada had conservative governments with pro-fossil fuel connections, which were also mentioned as an influence in discourse. For these climate professionals, more communication barriers were identified through emotional, behavioral, and social factors than through the uncertain, complex, and probabilistic aspects of climate information (Preston et al. 2015). Reluctance to discuss climate change reduced opportunities to combine general narratives of semantic climate knowledge with episodic understanding from individual experiences, which could otherwise inform a more personal view of how climate change will affect the near-future (Milojević and Inayatullah 2015). The few participants who reported speaking frequently, freely, and publicly about climate change were also highly engaged in future thinking, felt personally vulnerable to climate change, and were very knowledgeable about climate projections, regardless of their profession.

In the Imagined Futures type, participants expressed frustration with deficits in the precision and applicability of the knowledge they produce, communicate, and apply; even as the demand for locally specific projections had also increased (IPCC 2014). In the expert community, broadly semantic scientific information has remained the knowledge focus, with little episodic or personal experience on which to rely. Both approaches are limited, as most new knowledge of the hugely complex and non-linear carbon–climate–human interactions either addresses some small component that can be positively evaluated, or yields only partially supported assessments that lead to a wide range of possible outcomes (Friedlingstein et al. 2011).

The Unfamiliar Futures type demonstrated that envisioning new possibilities is clouded by uncertain information and conflicting assessments of how much, and how soon, carbon and climate systems will become disturbed (Serrao-Neumann et al. 2013; Vervoort et al. 2015; Newell et al. 2016). When reflecting semantic knowledge based on climate information, combined with episodic knowledge based on personal experiences (Atance and O'Neill 2001), many of the more senior participants did not feel personally vulnerable to climate impacts due to their age, financial security, or home location. There were distinct individual differences in willingness, and possibly facility (Quoidbach et al. 2009), to imagine fundamental change, or engage in future thinking generally.

Responses attributed to the Adaptive Futures type demonstrated generally high levels of future thinking and climate knowledge, as well as narrative communication. Participants who contributed substantially to the Adaptive Futures type were actively engaged in sharing visions of possible futures and usually combined mitigation and adaptation actions in their reported future plans. These participants were most likely to offer positive strategies for possible futures, and many expressed the need to combine actions to both slow climate change, and prepare for some impacts. It was noteworthy that only those who expressed a sense of vulnerability to climate change for themselves, or their families reported applying what they knew to develop clear mental images of how they might be affected.

7.6 Conclusion

This study highlights the importance of personal factors in climate related decision-making, even when there is a high level of climate knowledge. Significant differences were identified in how participants combined broad and semantic climate knowledge and experiential or episodic knowledge, in assessing climate risks. Perceptions of low personal vulnerability and high adaptive capacity reduced motivation to imagine climate challenges as personal. Furthermore, social and emotional barriers to talking about future climate limited developing shared goals and plans to adapt, so climate knowledge was not usually applied in a personal context. Consequently, people who did not regularly engage in future thinking in other areas of their lives had very few opportunities to incorporate climate knowledge in their plans. A greater consideration of how to foster future thinking in the context of climate change may improve the development, communication, and application of climate information for adaptation decision-making.

There are many more insights to be gained by considering the application of climate change knowledge in light of advances in cogitative research of future thinking. In addition, the study demonstrated the use of the Future Climate Narrative typology to gauge relative engagement in reflecting and sharing climate knowledge to inform visions of possible futures affected by climate change. The results make it clear that even for expert groups, personal, and social factors influence decision-making. Therefore, similar research with other national, social, and culture groups would be expected to reveal quite different results and would be useful to extend our understanding of climate-related decision-making in other contexts.

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Chapter 8
Integrating Research and Practice in Emerging Climate Services—Lessons from Other Transdisciplinary Dialogues

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Abstract Because of their social and ecological impacts, complex issues of climate and broader environmental change have taken centre stage in public discourses and public policy. These issues typically transcend disciplinary problem-solving and call for cross-disciplinary as well as transdisciplinary research approaches, i.e. approaches that include practice partners and aim for solving real-world problems. A case in point are climate services, a newly emerging field that aims at delivering customised climate information, products and other services in relation to climate. This chapter proceeds on the assumption that climate services can benefit from experiences of integrating research and practice to solve real-world problems in other fields such as public health and social inequality. Based on this assumption, the aim of this chapter is twofold: we firstly describe selected results of a literature study that systematically reviewed and compared the use of transdisciplinary approaches across fields. We secondly derive a list of quality criteria for transdisciplinary dialogues from the literature and from the outcome of a workshop with practitioners that we organised in November 2014. Both may inform good transdisciplinary practice for climate services.

Keywords Transdisciplinary research · Practice partner participation
Climate change · Climate services · Literature review · Quality criteria

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8.1 Climate Services as a Transdisciplinary Approach—an Introduction

Because of their social and ecological impacts, complex issues of climate and broader environmental change have taken centre stage in public discourses and public policy. These issues, often labelled 'ill-defined', 'wicked' or 'messy' problems (Pohl and Hirsch 2006; Scholz 2011; Cuppen 2012; Jaeger 2008), typically transcend disciplinary problem-solving and call for cross-disciplinary[1] as well as transdisciplinary approaches, i.e. approaches that include a range of practice partners.[2] In the German-speaking world and originating from Jantsch (1972), transdisciplinarity has emerged as a concept which has as at its core the idea of 'different academic disciplines working jointly with practitioners to solve a real-world problem' (Häberli et al. 2001, 4). The inclusion of partners from practice, a problem-oriented approach and cross-disciplinary research in science are the defining and common features of transdisciplinary approaches (Brinkmann et al. 2015, 6ff; cf. Bergmann et al. 2012).[3]

Over the last couple of years, the new field of climate services has emerged, which is tightly connected to climate research. This field can be described as:

> the transformation of climate-related data – together with other relevant information – into customised products such as projection, forecasts, information, trends, economic analysis, assessments (including technology assessments), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. (European Commission 2015, Box 1)

Climate services programmatically rely on the participation of practice partners to produce climate-related information and to assess possible impacts and adaptation options as well as scenarios and strategies:

> The development of climate services (…) requires a trans-disciplinary approach of co-design, co-development and co-evaluation. (European Commission 2015, 22)

Successful climate services, one can assume, benefit from the diverse expertise that the parties involved bring in, as well as from the need to take into account

[1]We use the terms cross-disciplinary and interdisciplinary interchangeably to refer to research collaboration across disciplinary boundaries but among scientists only.

[2]These practitioners are often labelled 'stakeholders' in the literature. The term originates from the management literature where it denotes 'any group or individual who can affect or is affected by the achievement of a corporation's purpose' (Freeman 2010 [1984], vi). In transdisciplinary contexts, however, the term stakeholder is problematic in our view because it obscures the fact that scientists are as much stakeholders in this context as is everyone else. We therefore propose and use the term 'practice partner/practitioner' to denote non-scientific actors.

[3]A leading institutional player is the 'Institute for Social-Ecological Research' (ISOE) in Frankfurt/Main, Germany.

everyone's interests and value preferences. However, there is not yet enough evidence on how best to set up, organise and govern the integration of research and practice for climate services. We therefore propose that climate services can benefit from experiences in fields with considerable longer experience of working with practice partners such as public health and the social sciences concerned with social inequalities, minority empowerment and broader environmental issues (Brinkmann et al. 2015, 14ff).

When we analysed appropriate literature, we found that the communities and discourses in the different thematic fields are not yet interconnected. To our knowledge, neither theoretical insights nor empirical case studies on the transdisciplinary mode of collaboration have so far been systematically reviewed and compared across fields. While solution for real-world problems through including practice partners is at the heart of all approaches, the terminology varies widely and the approaches do not necessarily refer to themselves as transdisciplinary.

Indeed, in the English-speaking world, the term 'transdisciplinarity' is not distinct in meaning and 'a universally accepted definition for transdisciplinarity is still not available' (Jahn et al. 2012). Concepts such as 'integrative applied research', 'multidisciplinarity' or 'team science' (USA) are used to describe interdisciplinary research that is carried out in collaboration with practice partners. Welp et al. (2006) speak of 'science-based stakeholder dialogues', whereas in Australia Bammer (2013) criticises the 'scattered landscape of definitions' and advocates the term 'Integration and Implementation Sciences (I2S)' to overcome the fragmentation (cf. I2S). In the field of Earth system science and sustainability science, the science and technology studies' terms 'co-design' and 'co-production of knowledge' are becoming more commonplace (Mauser et al. 2013).

So, despite an increasing popularity of transdisciplinary modes of knowledge production, there is no consensus in the literature on terminology. Approaches in the environmental, social and public health fields apparently pursue rather similar goals but without referring to one another. The aim of our literature search therefore was to give a comprehensive review of existing approaches across fields, to derive a first set of quality criteria and to inform good transdisciplinary practice for climate services and the respective dialogues.

In the following, we present selected results of the literature review with a focus on the six distinct types of approaches that we identified in more than 400 publications across fields (Sect. 8.2). Based on this cross-field comparison, we will then list quality criteria for good transdisciplinary practice (Sect. 8.3) and present some conclusions and an outlook from this initial review (Sect. 8.4).

8.2 Selected Results of a Literature Review on Transdisciplinary Approaches in Different Fields

8.2.1 *Intensity of Participation*

A major issue in integrating research and practice is the form and intensity of practice partner participation. Stauffacher and colleagues (2008) have identified five different intensities of public participation in a classification that can be fruitfully applied to the involvement of practice partners in climate services (a similar participation spectrum has been developed in 2014 by the International Association of Public Participation, see IAP2 (2014)).

Figure 8.1 shows different degrees of participation intensity, ranging from mere information by way of unidirectional communication from researchers to practice partners over increasingly inclusive and balanced formats (consultation, cooperation and collaboration) to the highly inclusive empowerment of practitioners. In the first two formats, information and consultation, respectively, practice partners or scientists may or may not acknowledge the other parties' concerns and expertise. Stauffacher and colleagues (2008) furthermore differentiate cooperation (where the authority over the transdisciplinary dialogue is with the science side) from collaboration which they define as partnership on an equal footing and which they see as a prerequisite for 'true participation'. In the most inclusive format—empowerment—authority shifts from balance to the practice side and final decision-making within projects is left to the practice partners.

What can we learn from Stauffacher and colleagues? Even though there is a clear normative ideal behind the intensity scale, it suggests that there is no 'one-size-fits-all' approach to participation. Different intensities of involvement can be mixed and combined within one project and always depend on the specific research question and goal of the project.

8.2.2 *Characteristics of Different Transdisciplinary Approaches*

The major result of our literature review (Brinkmann et al. 2015) was a classification of six distinct types of approaches to the integration of research and practice:

- Participatory Action Research (PAR)
- Community-based Participatory Research (CBPR)
- Participatory Policymaking
- Transdisciplinary Case-Study Approach of ETH Zurich
- Transition Management
- Model developed by ISOE (Institute for Social-Ecological Research)

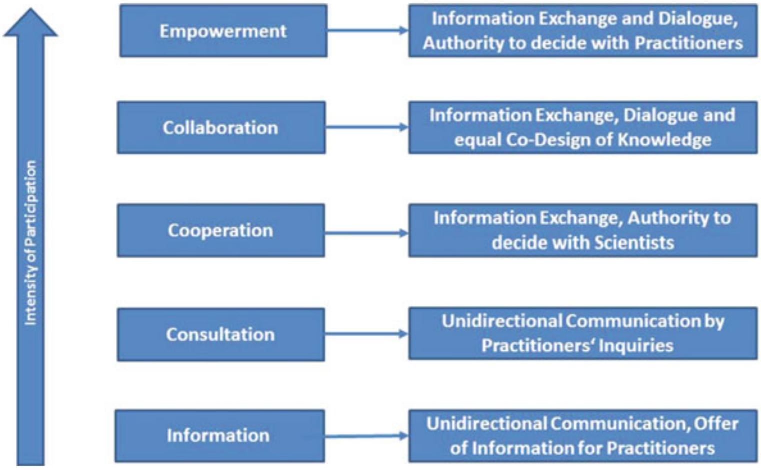

Fig. 8.1 Degree of public involvement in transdisciplinary approaches (Brinkmann et al. 2015, following Stauffacher et al. 2008, own translation)

The approaches have been developed since the late 1960s in different fields and each approach belongs to a specific community of scientists and practitioners. Only the latter three approaches refer to themselves as 'transdisciplinary approaches'. In the following, the approaches are presented in the order of their historical emergence.

In Participatory Action Research (PAR), practice partners are involved as 'co-researchers' with equal rights to find practical solutions for problematic conditions in their respective institutional or social environments and everyday life (Swantz 2008). Methodologically, this is sought by a cycle of intervening Action Experiments, and the consequences are reviewed in a dialogue between all parties involved. The overall aim is to facilitate mutual learning and to create a self-reliant lifestyle for the practice partners (Argyris and Schön 1989). Terminologically, PAR employs the term participation rather than transdisciplinarity.

Community-Based Participatory Research (CBPR) also strives for practically useful insights, which may lead to a sustainable improvement of life conditions and to an empowerment of the researched community. CBPR uses a broad range of research methods and explicitly expands the circle of involved people from scientists and community members to organisational or political representatives to inform and instruct on this institutional level (Israel et al. 2005). CBPR puts the conceptual focus on multi-perspectives and the equal value of lay and expert ways of knowing.

Participatory Policymaking involves practice partners in structuring evidence-based policy processes. In these processes, actors negotiate multiple interests, conflicting targets and often make decisions under uncertainty (Mayer et al. 2013; Thissen and Twaalfhoven 2001). The approach aims at producing reliable results grounded in communicative exchange and joint learning, despite different value perceptions and perspectives (Edelenbos 1999). Unlike in CBPR and PAR, the permanent involvement of practice partners is not mandatory in all project phases.

The Transdisciplinary Case-Study Approach of ETH Zurich (TdCS) deals with complex real-world problems from the field of sustainability. It focusses on mutual learning between all participants and attempts to integrate local, scientific and organisational knowledge to find so-called socially robust problem solutions (Scholz et al. 2000; Scholz 2011). The degree of practice partner involvement in the different project phases varies. In general, all parties involved are regarded as authoritative in their ways of knowing, and a knowledge synthesis is sought in a joint and discursive way (Scholz and Tietje 2002).

Transition Management sees itself as a governance tool for large-scale and long-term structural transitions of society towards a desirable state such as sustainability (Rotmans et al. 2001). By connecting diverse and innovative practice partners, interdisciplinary research teams stimulate their inventiveness and the rise of new networks. Mutual learning and dialogue are expected to free capacities that were hitherto undetected as well as action and solution potentials (Nevens et al. 2013).

The Model developed by ISOE (Institute for Social-Ecological Research) strives for combining the solution of real-world problems with the development of scientific knowledge and methods (Jahn 2005). The production of knowledge is mostly science-driven and takes place within disciplinary boundaries. However, an integrative concept is agreed upon from the start of every project and structures the entire approach, thus facilitating the subsequent integration of different kinds of knowledge in a joint effort with relevant practice partners (Bergmann et al. 2012). As in the TdCS approach, transdisciplinarity is seen as an integral part of the approach and sustainability serves as a leitmotif.

To systematically compare these approaches, they were analysed within several categories. The categories were compiled to reveal differences and similarities as well as typical patterns in application fields, participants, process design, scientific connectivity (i.e. proximity to academic discourses), methodology, normative principles and objectives. These characteristics form a specific pattern for every approach (Fig. 8.2). It is important to note that the six ideal types include greatly diverse individual case studies, in line with the overarching conceptual and methodological principle of context sensitivity.

8.2.3 Comparison of the Approaches in the Fields of Environment and Sustainability

What can we learn from our typology of approaches for the newly emerging field of climate services? As climate services are an applied field within the broad field of Earth system sciences, it can be assumed that the approaches that focus on

	Fields of Application		Practitioners involved					Process Design	Scientific Connectivity	
	Environment and Sustainability	Welfare, Health, Development	General Public	Locally Affected	Association Representatives	Policy Makers / Administrators	Other Experts	Phases of different Practitioners' Involvement	Systems Knowledge	Transformation Knowledge
Participatory Action Research		•		•						•
Community-based Participatory Research		•		•	•					•
Participatory Policymaking	•	•	•	•	•	•	•	•		•
Approach of ETH Zurich	•		•	•	•	•	•	•	•	•
Transition Management	•				•	•	•	•		•
ISOE-Model	•	•	•	•	•	•	•	•	•	•

	Methods			Normative guiding Principles			Objectives			
	System Analysis/ Modeling/ Scenario Analysis	Workshops/ Dialogues	Action Experiments	Sustainability	Strengthening Democracy	Integration of Underprivileged	Mutual Learning and Exchange of Views	Policy Design	Capacity Building (Empowerment)	Capacity Building (Awareness Rising)
Participatory Action Research		•	•			•	•		•	
Community-based Participatory Research		•	•			•	•		•	
Participatory Policymaking	•	•			•		•	•		
Approach of ETH Zurich	•	•		•			•	•	•	•
Transition Management	•	•	•	•			•	•	•	•
ISOE-Model	•	•		•			•	•	•	•

Fig. 8.2 Key characteristics of types of transdisciplinary approaches (after Brinkmann et al. 2015, 60)

'Environment and Sustainability' as their key fields of application are apt for climate services as well (cf. Fig. 8.2, column 1): Participatory Policymaking, Approach of ETH Zurich, Transition Management and the ISOE-Model. Indeed, these approaches show similarities in many categories:

- All try to involve a great variety and range of social groups (cf. column practitioners involved).
- All alternate phases of varying involvement intensity in the project (cf. process design).
- The approaches of the ETH Zurich and the ISOE-Model aim at creating what they call practical 'transformation knowledge' but they also aim at generalising the case's findings in order to integrate 'system knowledge' into academic discourses and thus to stimulate further research. Both approaches regard the connectivity to academic discourses as equally important as the solution of the real-world problem (cf. scientific connectivity).
- Methodologically, all four approaches use workshops with manifold 'tools for facilitating communication (communication tools) and tools for formalising actors' mental models and assessments (analytical tools)' (Welp et al. 2006). Among the latter are system analyses, modelling of specific system situations and scenario analyses. A discussion and evaluation of these models and scenarios by practice partners scrutinises the usefulness of the different steps in problem-solving within the project (cf. methods).
- In terms of objectives, the four approaches all intend to enhance mutual learning and aim for 'policy design' by way of information, counselling and supporting real-world decision-making (cf. objectives).

There is a broad range of approaches available to design a transdisciplinary process, but the above-detailed range emerges across the different research fields. Thus, despite the very different questions to be solved, the motivating idea, the process design, the objectives as well as the methods do not differ much. Also, scholars representing the models of ETH Zurich and ISOE, respectively, recently started to collaborate (for a fruitful attempt to compile their principles of transdisciplinarity see Lang et al. 2012).

8.3 Towards Quality Criteria for Transdisciplinary Dialogues

8.3.1 Integration of Experiences and Literature Studies

Successful mutual learning in transdisciplinary contexts is a challenge that needs to be tackled on a case-by-case basis. We were nonetheless interested in deriving criteria for how to best set up, organise and govern the integration of research and practice for climate services. Motivated by similarities in objectives and methodology as shown in Fig. 8.2, we organised a workshop including participants from research and practice across all fields and sectors. In mixed groups, they collected their experiences and reflected on the aspect of practice partner integration (Schuck-Zöller 2015). In this way, a set of criteria and success factors emerged. In a second step, this empirically derived set of criteria was compared to and integrated with discussions in the literature. In doing so, we found that many criteria were mentioned both by the workshop participants and in the literature. Thus, we could identify a combined set of quality criteria. In the following, we present a list of ten criteria. All seem of importance for the success of transdisciplinary processes, but they might carry different weight depending on the degree of involvement of participants (Fig. 8.1), the aim of the research project, and the transdisciplinary approach chosen (cf. Sect. 8.2.2, also Klein 2008). The presentation follows, as far as possible, the order of a transdisciplinary process.

8.3.2 Ten Quality Criteria for Transdisciplinary Dialogues

1. Constructive selection and involvement of participants—Are the groups and types of practice partners who are to be invited selected by a systematic analysis (often called 'stakeholder analysis' cf. e.g. Reed et al. 2009)? Is the range of different views from research and practice broad enough to tackle the real-world problem under study (Cuppen 2012)? Is the criterion for invitation made transparent to all parties (Scherhaufer and Grüneis 2014; Heimerl 2012; Froggatt 2013)?

2. Setting the scene for co-design and co-production—From the beginning, all participants must get time and space to articulate their needs, views and value preferences with regard to the issue under study (Scherhaufer and Grüneis 2014). This is a question of a good communication set-up and facilitation, and enough time must be factored in for initial negotiations of the project's aims, means and processes. It is crucial to find common ground in a shared conceptual repertoire: The terms that are used should be sufficiently popular and a shared understanding of key concepts is indispensable. Throughout the process, all parties should promote partnership on equal footing. Interactive authority which operates to marginalise participants should be counteracted, e.g. by the facilitation of dialogues by an experienced moderator (McDonald et al. 2009).

3. Problem definition and focus: clarification of mutual expectations—Against the backdrop of diverse interests, relevances, ways of knowing and value preferences among participants, the research object as well as the goals of the project should be clarified at the beginning of the project to prevent subsequent misunderstandings and disappointments (Scherhaufer and Grüneis 2014). Ideally, the research question is relevant for practice and science (Steinke 2000). This challenge takes time and needs ample discussion between all participants, but a joint formulation of the research question is a prerequisite for joint problem ownership.

4. Joint problem ownership—The motivation and commitment of the parties involved can only partly be influenced by the project management. If practice partners participate actively and responsibly in the project design, they will more easily be able to see their involvement as making a difference (Scherhaufer and Grüneis 2014). To achieve joint problem, ownership is key for safeguarding continuous engagement. It also increases acceptance of the project's activities and outcomes.

5. Professional planning and management—Communication within the project has to be managed professionally. This includes the application of appropriate and constructive communication and analytical tools (cf. 2) throughout the project and tailored to its different phases (Scherhaufer and Grüneis 2014). To achieve partnership on equal footing, it can be helpful, e.g. to enrol a professional moderator from outside the project to facilitate dialogue. While there is still a perceived lack of expertise in transdisciplinary work and professional facilitation in research communities, some capacity building activities have been initiated in recent years (e.g. by td-net, Australian National University and Future Earth).

6. Space and time for reflection and iteration, project flexibility—Self-reflection in workshops and other meetings is necessary to keep articulating and exchanging different viewpoints, to re-think the methodology and to keep all parties engaged. In the methodology of transdisciplinary processes, the monitoring of common work processes takes centre stage (Bergmann et al. 2012). Every milestone in the project should be complemented by a reflection and monitoring phase which, if necessary, allows for adaptations in the project direction. Flexibility is needed in the conceptual and temporal framing of the project to accomodate this challenge (Reitinger and Ukowitz 2014). As it is very difficult to foresee the development in detail, the project framing and structuring should allow for flexibility in terms of redesigning single parts and milestones by common agreement throughout the project.

7. Integration of different ways of knowing—This is a key success factor for transdisciplinary processes. As exemplified in the ISOE-Model, to negotiate an integration plan at the beginning and have it frame the entire project helps to ensure that the outcomes of different phases and methodologies can be interconnected and applied to the overarching research question (Bergmann et al. 2012).

8. Credibility, neutrality and trust—The managing institution has to act as neutral as possible to achieve credibility with all participants (Scherhaufer and Grüneis 2014; Schuck-Zöller et al. 2014). They must be able to trust that their involvement in the project, e.g. by way of providing knowledge and information, does not lead to personal or community disadvantages such as in relation to media communication or the provision of personal data. Trust is essential for transdisciplinary research, as it is for all spheres of communication (Swantz 2008).

9. Coherence and constructive handling of contradicting viewpoints—Contradictions in viewpoints, interests, value preferences or findings that might occur over the course of the project must be openly discussed and negotiated to create valid and useful findings and meet everybody's needs (Heimerl 2012;

Froggatt 2013). In transdisciplinary research, this is a greater challenge than in scientific research because of the broader spectrum of perspectives involved.

10. Transparency and overall project documentation—All steps in setting up and managing a transdisciplinary process should be open and transparent, both for all participants involved, and for subsequent evaluation (Reitinger and Ukowitz 2014). For this reason, every step should be communicated within the project and documented for future reference (Scherhaufer and Grüneis 2014). In transdisciplinary research, this includes documentation of initial negotiations, methodologies, processes and management activities.

8.4 Conclusions and Outlook

This chapter presents considerations on how to best set-up and govern the integration of research and practice based on a literature review and reflections of hands-on experiences in transdisciplinary contexts. We have categorised and presented six different types of transdisciplinary approaches, out of which four shows proximity and suitability for application in climate services.

In summary, the review and comparison of approaches from different fields and research areas confirm the following similarities between the approaches: the involvement of practice partners, a real-world problem-oriented design and interdisciplinary work in science. Approaches that alternate research phases without practice partners with phases of transdisciplinary collaboration appear more apt to feed findings back into academic discourses. This illustrates the great challenge of combining continuous practice participation with 'use-inspired basic research' (Clark 2007). Across all approaches, we can identify an ideal-typical frame for the design and process in both a social and a content-related dimension. Socially, the value of open and engaged mutual learning through knowledge exchange and changes in perspectives is promoted, which is perceived as expedient by all participants. With regard to contents, the knowledge that is produced by transdisciplinary collaboration should be both, practicably applicable in solving the original problem and of scientific value.

Having compiled a set of quality criteria of transdisciplinary research, it seems pertinent to go forth in the direction of evaluation and ask how the impact of transdisciplinary processes can be appropriately assessed. To move towards this direction, an evaluation framework for transdisciplinary processes must be developed. The ten quality criteria can provide a first scheme of what should be evaluated. To fuel this process, new indicators—both qualitative and quantitative ones—are needed to assess or measure the quality of processes, products (outputs) or outcomes, or impacts of transdisciplinary research (McNie 2013). A recent and promising initiative in this regard is the ISOE-led project TransImpact, funded by the German Ministry for Education and Research. An earlier discussion on this was triggered by the Annual Conference of the German Society for Human Ecology

(DGH) in 2005 (cf. Stoll-Kleemann and Pohl 2007). The discussion can further benefit from the systematic literature review presented in Wall et al. (2017) and recent work of Schuck-Zöller et al. (2017). What is still open to discussion is the field of how to assess societal impact of research and, above all, transdisciplinary processes. Here still some work has to be done.

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Chapter 9
Communicating Climate Information: Traveling Through the Decision-Making Process

Ghislain Dubois, Femke Stoverinck and Bas Amelung

Abstract Climate change forces society to adapt. Adaptation strategies are preferably based on the best available climate information. Climate projections, however, often inform adaptation strategies after being interpreted once or several times. This process affects the original message put forward by climate scientists when presenting the basic climate projections, in particular regarding uncertainties. The nature of this effect and its implications for decision-making are as yet poorly understood. This chapter explores the nature and consequences of (a) the communication tools used by scientists and experts and (b) changes in the communicated information as it travels through the decision-making process. It does so by analyzing observatories; the interpretative steps taken in a sample of 25 documents, pertaining to the field of public policies for climate change impact assessment and adaptation strategies. Five phases in the provisioning of climate information are distinguished: pre-existing knowledge (i.e., climate models and data), climate change projection, impact assessment, adaptation strategy, and adaptation plan. Between the phases, climate information is summarized and synthesized in order to be passed on. The results show that in the sample, information on uncertainty is underrepresented: e.g., studies focus on only one scenario and/or disregard probability distributions. In addition, visualization tools are often used ineffectively, leading to confusion and unintended interpretations. Several recommendations are presented. While climatologists need better training in communication issues,

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decision-makers also need training in climatology to adopt more cautious and robust adaptation strategies that account for the uncertainty inherent in climate projections.

Keywords Climate change · Communication · Uncertainty · Visualization Climate services

9.1 Introduction

Regardless of mitigation efforts, some degree of climate change is already inevitable (Füssel and Klein 2006), due to past emissions and lag effects in the climate system. As a result, there is a growing need for adaptation strategies, based on observed and projected climate information. Climate projections tend to be technical and science-driven, with considerable emphasis on the many uncertainties involved. Publications in peer-reviewed scientific journals determine a scientist's chances for promotion and success, and there is generally little incentive for scientists to communicate their findings to anyone outside their area of expertise. On the demand side of climate information, decision-makers have little time to search for scientific information, and they often struggle with the technical jargon. Moreover, scientific information faces 'competition' from other information inputs in the decision-making process and may not hold overriding priority (Tribbia and Moser 2008). There is therefore a mismatch between the supply and the demand side of climate information. On the one hand, there is climate data in a raw and inaccessible form; on the other hand, there is demand for highly applied and localized climate information. The connection between the two sides is as yet not specified and standardized and is therefore often filled-in in ad hoc and obscure ways. Bridging this information gap is the field of research and application in climate services (Hewitt et al. 2012).

This chapter addresses the issue of how climate information is communicated from climate scientists to policy makers developing adaptation strategies. It reviews a sample of 25 documents pertaining to the field of public policies for climate change impact assessment and adaptation strategies. The objective is to assess the nature and consequences of the interpretative steps needed to translate scientific knowledge into information that is useful to policy makers. The central theme of the chapter is: How do interpretative processes along the science–policy nexus affect the representation of climate information in the adaptation literature? In addition to exploring the central role of uncertainties, the chapter pays special attention to the role of visual representation of climate information. The chapter addresses the following three key questions: (1) How does climate information flow from climate models to adaptation strategies? (2) How is uncertainty communicated? and (3) How is climate information visualized?

The chapter is structured as follows. Section 9.2 provides an overview of the literature on communicating climate information and on visualization techniques. Section 9.3 describes the data and methods. The results are presented in Sect. 9.4 and discussed in Sect. 9.5, followed by a conclusion in Sect. 9.6.

9.2 Communicating Climate Information: Uncertainties and Visualization

Worldwide, there are only a few technical guidelines and little legal framework concerning the production of climate knowledge and its application in adaptation strategies and plans. For instance, the IPCC provides some detailed guidelines on the treatment of uncertainty (Mastrandrea et al. 2010). France is an example of a country that has legislation that makes an adaptation plan mandatory for governmental authorities, yet without any guidance on what climate information to use and how to use it. Originally, climate information was generated only in national meteorological institutes, universities, and research laboratories. Due to increased public availability of climate data and a rapidly increasing demand for climate information, specialized consultancy offices, local authorities, and NGOs are gaining the ability to use climate data and present it in more user-friendly ways. Together with the lack of guidelines or a legal framework, this increasing demand has led to an uncontrolled supply of climate information (Dubois 2011).

Public and private decision-makers operating in settings that require climate information are generally struggling to assimilate the available climate information (WMO 2009; Changnon et al. 1990) because 'raw' climate information is too difficult to be readily understood by lay people. Providers of climate information also face challenges. They need to provide the information in such a way that it is understandable and clear for decision-makers so that it is quickly understood. However, the information also has to be scientifically rigorous. Therefore, providers of climate information are caught in a dilemma: Should scientific rigor prevail at the expense of societal usefulness, or should societal usefulness be maximized at the expense of scientific rigor? Striking a balance between these two extremes can be rewarding, but it is a delicate undertaking (Dubois 2011).

Two factors that influence this dilemma are the concepts of uncertainty and visualization. Climate information is inherently uncertain; scientists emphasize this aspect, whereas decision-makers tend to ask for 'desired answers' to problems (McNie 2007). Visualization of climate information can enhance communication by quickly conveying strong and memorable messages and condensing complex information. Nevertheless, visualization also has its pitfalls (Nicholson-Cole 2005) and the question as to when and how visualization improves decision-making have barely been addressed by research (Lurie and Mason 2007).

9.2.1 Communicating Uncertainty

A large body of the literature has developed on the communication of uncertainty inherent in long-term climate projections, which in a way makes meteorology and climatology reference disciplines on uncertainty management (Allen and Eckel 2012; Budescu et al. 2009; Dessai and Hulme 2004; Dessai et al. 2009; Joslyn and Savelli 2010; Morss et al. 2008; Dessai and Van der Sluijs 2007; Risbey and Kandlikar 2007). This echoes a broader literature on uncertainty, pertaining to various disciplines like medicine, psychology, economy dealing with uncertainty in a context of decision-making, in the present or in the future (Spiegelhalter et al. 2011).

Most people prefer words over numbers as an intuitive way to describe the likelihood (probabilities) of events (Patt and Dessai 2005). Accordingly, the IPCC developed a methodology to express probabilities by using a set of words that refer to an equivalent set of probability estimates; for example, 'very likely' always means >90% probability. The very specific meaning that the IPCC attaches to these words, however, differs from their meaning in everyday life. The IPCC uses the qualitative descriptions to indicate only the *likelihood* of a climatic event to occur. Yet, when people express likelihoods, estimates are influenced by the events potential magnitude. In other words, the *likelihood* of occurrence is multiplied by the events *consequence*. In addition, people have the tendency to overestimate the likelihood of low-magnitude events and underestimate the likelihood of high-magnitude events (Patt and Schrag 2003). As a result, qualitative descriptions of probabilities are subject to a wide range of interpretations (Katz 2002; Budescu et al. 2009).

Patt and Schrag (2003) state that some assessment reports fail to mention climate information that is highly uncertain or avoid quantifying the uncertainty. Gradually changing means for temperature and precipitation are reported, while more extreme and less likely scenarios are ignored. Although the resulting information is easy to understand, it is incomplete, which can have dire consequences. Arguably, changes in the occurrence and intensity of extreme weather events are likely to affect society more and faster than changes in mean climate conditions.

Uncertainty can be expressed in simple terms (e.g., mean) or in more sophisticated ones (e.g., spread and probabilities). The latter ones are more difficult to communicate (Patt and Dessai 2005) but contain valuable information for decision-making (Katz 2002). Instead of leaving the users of climate information to their own devices, scientists are encouraged to elucidate the meaning of probabilistic language and their connection to everyday life (Patt and Schrag 2003). Zehr (2000) refers to this practice as the 'accountable representation' of uncertainties. If lay people are informed about the complex processes that give rise to the uncertainties, they may reject information that is overly certain (Pidgeon and Fischhoff 2011).

9.2.2 Visualizing Climate Information

Using visualization tools is a delicate business; however, visualization can enhance all kinds of messages, both intended and unintended. A significant body of knowledge on the effects of visualization tools has been developed. Unfortunately, key insights from this knowledge field are typically not observed when communicating climate information. Common pitfalls in visualization still remain (Kelleher and Wagener 2011).

It is known that visualized information receives greater weight than its textual counterpart, resulting in an overrating of visual information and underrating of textual information (Lurie and Mason 2007). Visual representation can alter the connotation of textual messages by using color (e.g., green for a 'good' message and red for a 'bad' one), instead of presenting the information in neutral black-and-white spectrum (Lurie and Mason 2007). There are several tools to achieve visualization: a colored map, a line graph, a bar chart, or a scatter plot. Cleveland and McGill (1985) found that people can more accurately judge length (of a line or bar) than an area or color. Therefore, maps are fit to attract people, but not for making decisions (British Department of Environment, Food and Rural Affairs 2011).

There has been little investigation into how and when visualization tools affect decision-making. Decision-makers often have a risk management perspective, and they need information on uncertainty, yet visualization tools inevitably simplify or ignore the message of uncertainty (Wittenbrink et al. 1995). On the one hand, visualization may support decision-making by making patterns and outliers easier to see and by highlighting key information (Lurie and Mason 2007). On the other hand, visualization can increase bias and lower the quality of the decisions by drawing attention to a particular part of the visualization (Glazer et al. 1992; Jarvenpaa 1990; Mandel and Johnson 2002).

9.3 Methods

For this study, climate information is defined as 'knowledge about future climates that is communicated, in written form, between scientists and any other players involved in the decision process, resulting from studies that focus on the projection, impact assessment, and/or adaptation strategy phases' (authors' definition). In this context, information is considered to have been communicated only if they are publicly available. Gray literature, such as internal reports and working documents, is not included in this review.

A sample of documents related to 25 climate change adaptation initiatives (see Fig. 9.1) was obtained through several sources:

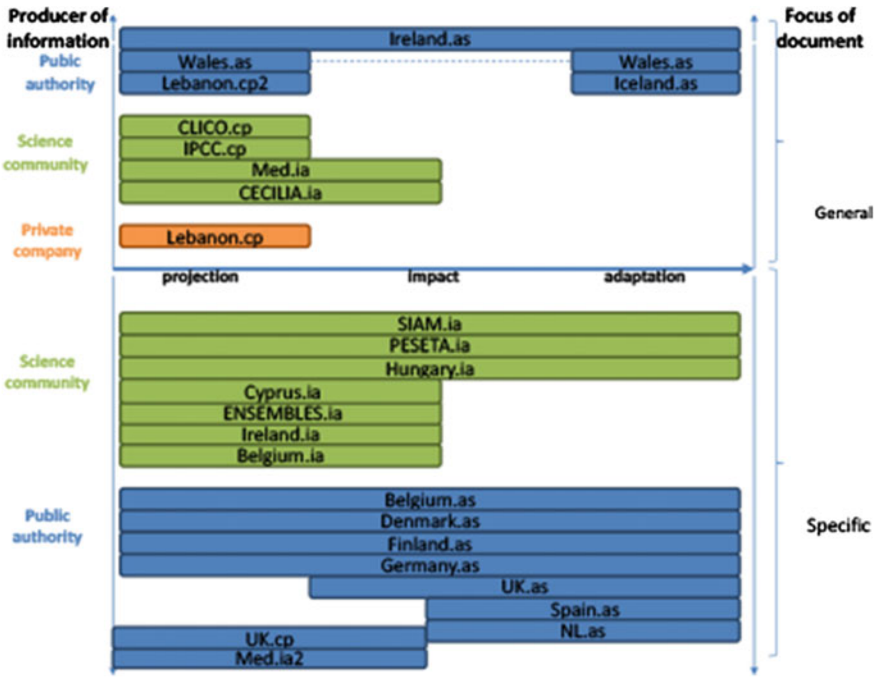

Fig. 9.1 Sample studied: authorship and place in the climate change adaptation process. [.as = adaptation strategy, .ia = impact assessment and .cp = climate projection. See Appendix for meaning of document abbreviations (detailed references)]

- from the European Environmental Agency (EEA) adaptation portal[1], designed as the main institutional entry point for European stakeholders in charge of climate change adaptation;
- through an open call to the CLIM-RUN project partners;
- and with a Web search of climate change projects on projections and impacts that had their results published by scientific institutions or governmental bodies.

The documents were subjected to content analysis. Here, since the issue was to study communication tools, and in particular visualization tools, the criteria developed pertained to maps and graphs (number of maps and graphs, type of graphs, color codes, etc.). Broadly, content analysis can refer to methods for studying and/or retrieving meaningful information from documents (Tipaldo 2014; Krippendorff 2004). While content analysis has clear merits in that it supports a systematic comparison of documents, some limitations are notable. The exercise is

[1]http://www.eea.europa.eu/themes/climate/national-adaptation-strategies Now replaced by the Climate-ADAPT portal http://climate-adapt.eea.europa.eu/.

limited to the content of the document. It does not consider the production process of the document nor does it consider the consequences of communication. Since there are no legal guidelines for the content and structure of climate projections and adaptation strategies, the documents of the sample varied greatly in length and scope, which hampered the exercise of comparison.

To classify the documents and to provide inferences, three dimensions were used that relate back to the study's three core questions: general criteria, uncertainty criteria, and aspects of visualization.

9.3.1 General Criteria

General criteria notably concern the flow of climate information between its creation by climatologists and its application in adaptation strategies by policy makers. By identifying if a climate scientist was (co-) author of a document, it becomes clear whether the communicator is in the realm of science or of that of society. This sheds light on potential differences in communication between the two. Between the creation of climate information and its application, there are several distinctive phases: projection, impact assessment, and adaptation strategy. By identifying what is communicated in the documents, it becomes clear whether climate information is present at all, which relative importance it is given and what the content is of this climate information (e.g., temperature, precipitation, extremes, short-term, or long-term projections). In addition, it is assessed whether climate information is present in one or several phases of the process, and how it evolves from one phase to another.

9.3.2 Uncertainty Criteria

The first criterion in this dimension is whether uncertainty is mentioned or not. As a follow-up, the documents for which the answer was 'yes' were assessed against five more detailed criteria:

- **Coverage of the cascade of uncertainty**. Uncertainties cascade to each other as the climate information flows from a projection to an impact assessment. In the study, it was determined which part of this cascade is mentioned and whether this is adapted to the objective of the document.
- **Use of models and scenarios**. According to current quality standards, a report on the future climate should include several climate models that are run for several socio-scenarios. This provides a full span of probabilities and therefore a more complete message on uncertainty. In the documents, even though it was not always clear how many models were used, the number of scenarios included could be derived.

- **Acknowledgment of the role of the time horizon used**. The magnitude of different sources of uncertainties depends on the time horizon used. Until around 2050, most uncertainty results from the inter-model spread. After 2050, the scenarios cause most uncertainty (Hawkins and Sutton 2009).
- **Ways to express uncertainty**. Uncertainty can be expressed in simple terms (e.g., mean) or in more sophisticated ones (e.g., spread and probabilities). The latter ones are more informative for decision-making.
- **Inclusion of extreme events**. Projections of climate extremes differ from extreme climate projections: They concern the provision of information on potential extreme events (for example, hurricanes and floods).

9.3.3 Aspects of Visualization

The content analysis helps to answer the question whether climate information is visualized, and if so, how it supports the textual information, if at all? As a follow-up, the documents for which the answer was 'yes' were assessed according to which visualization tool was used. In addition, the choice of color or other graphical details (width of lines for instance) was analyzed since they can influence the message that is communicated. During this analysis, it was concluded whether or not the visualization (tool and color) supported the textual message.

9.4 Results

9.4.1 Climate Information Flow in the Policy Process

Information on climate has spread beyond its initial scientific boundaries and infiltrated in all layers of society, in particular due to rising concerns about climate change. This study found that climate information encompasses a certain process when crossing scientific boundaries into society. Conceptualizing this process helps indicating more precisely where, by whom and how climate information is communicated.

The process by which information travels roughly consists of five phases (see Fig. 9.2). In the pre-existing knowledge, phase actors are mainly occupied with studying and understanding the relationships between compartments of the natural climate system, generating data from observations and building climate models. Projections, in the next phase, can be 'off-the-shelf', resulting from models and data that already exist (pre-existing knowledge) or they can be customized, being

Fig. 9.2 Framework of phases in the process chain

derived from models and data that are developed in the projection phase. Based on the climate projections, the following phase determines a range of impacts for specific sectors. In the adaptation strategy phase, public and private decision-makers design adaptation strategies to address the assessed impacts. The last phase consists of an adaptation plan, a detailed action plan associated with a set of indicators allowing performance evaluation.

Ideally, climate information flows through the process chain from pre-existing knowledge all the way down to adaptation plan. However, in practice this is not always the case (Dubois 2011). The chain starts with a dominant role for the natural sciences, halfway through the social sciences increase their influence and it ends with a dominant role for actors in society. After the release by climatologists, climate information is summarized and synthesized in order to pass it on to the next phase and actor. This causes a dilemma because, due to summarizing and synthesizing, the richness and completeness of the information are reduced. If not, the information transfer between phases is too big (Dubois 2011).

The objective of this study is to understand the transfer of climate information from the scientific world to the decision-makers. Supply and demand of climate information meet in the phases of projection, impact assessment, and adaptation strategy. In the sample, three out of the 25 initiatives do not contain any climate information and all three are adaptation strategy documents. This sample shows that documents that do not represent climate information are positioned toward the end of the process chain.

Two documents showed that summarizing and synthesizing cause great reduction of the message of uncertainty. As a result, the users of the adaptation strategy documents are not provided with this information, the so-called broken telephone phenomenon. A case study of Ireland is presented below. Ireland can serve as a case study where the projection/impact document (Environmental Protection Agency 2003, 22) and the adaptation strategy document (Irish Department of the Environment, Heritage and Local Government 2007, 44), that follow each other, differ in their message. The language in the second document indicates less uncertainty, and the figure on projected temperature change is different.

9.4.2 Underrepresented Uncertainty

Five out of 25 initiatives do not contain a message on uncertainty, neither as a general message nor in the outcomes of a projection or impact assessment. However, during the content analysis it became clear that even if the uncertainty is mentioned, it is still not always clear what the reader is looking at; the median, a 90% probability, or an average.

Uncertainties from the projection phase and impact assessment phase pile up and turn into a cascade. This study found that nearly half of the documents do not address all uncertainties that are applicable to them; uncertainties resulting from impact assessments turn out to be largely forgotten.

When focusing on the performance of climatologists on this topic, from this study it becomes clear that some documents produced by them also fail to mention the appropriate part of the uncertainty cascade. Of the nine documents produced by teams that had a climatologist on board, seven included a projection as well as an impact assessment. Therefore, they should discuss uncertainty for both phases, which only two of the seven actually did.

Half of the sampled documents (11 out of 22) represent only one socioeconomic scenario. For two of the eleven documents, single scenario use is less of a problem because the timeline is below or around 2050. Before 2050 most uncertainty stems from models, whereas after 2050 the scenarios cause most uncertainty. However, the other nine documents include projections for the period 2050 to 2100. In these nine cases, uncertainty is underrepresented.

When focusing on the nine documents coproduced by climatologists, three of them discuss only one scenario. However, their focus on only one scenario is not problematic because their aim was not to provide a projection but improving technical aspects (for example, models) or the timeline was below 2050. Thus, this study discloses that teams including a climatologist provided appropriate information in this respect.

Another aspect of uncertainty is the spread of possibilities that a projection can provide. Almost half of the documents represent only the mean estimate of all possibilities. Given that the ensembles of projections do not have a statistical distribution and cannot be used for full probabilistic analysis, nothing says that this mean estimate is more probable than others, and the use of mean is not scientifically very significant. The mean estimate should at least be accompanied by information on the spread of projections. For instance, the wettest projections of a given ensemble enjoy least probability; however, they potentially cause most damage and are therefore important information for decision-makers. Most documents in the sample paid attention to these extremes.

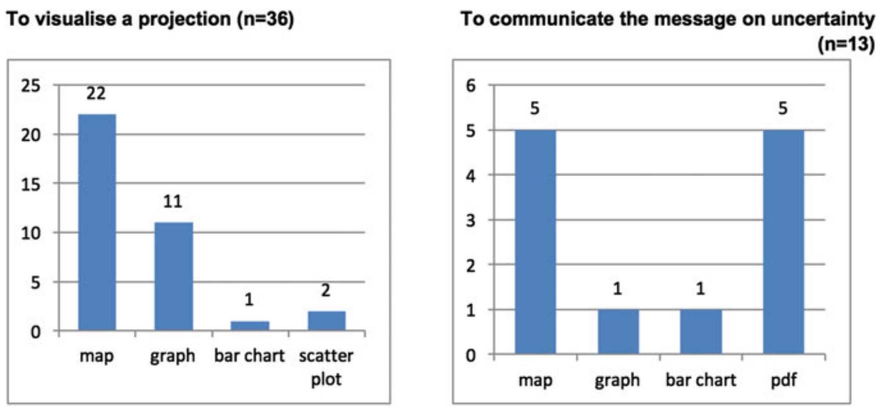

Fig. 9.3 Distribution of visualization tools according to their purpose. (pdf = probably distribution function)

Table 9.1 Frequency of colors used for a decrease or increase of *temperature* and *precipitation*

Color for decrease of *temperature*	Frequency	Color for increase of *temperature*	Frequency
Green	1	Red	7
Blue	1	Blue	2
		Yellow ranging till red	1
		White ranging till red	1
Blue (increase + decrease)	3	Blue (increase + decrease)	3
Color for decrease of *precipitation*	Frequency	Color for increase of *precipitation*	Frequency
Red	4	Blue	3
Blue	1	Green	2
Yellow/red	1	Red	1
Brown	1	Blue/green	1

9.4.3 Non-Facilitating Visualization

During the content analysis, it became clear that visualization of climate information can serve two purposes: to present a projection or to communicate the general message of uncertainty. This latter one can help the user understand the topic of uncertainty.

In the sampled initiatives, 49 examples of visualization were found. Colored maps are the most frequently used visualization tool (27 out of 49 visualizations), followed by the line graphs (12 out of 49 visualizations). Figure 9.3 shows these results, broken down into the purpose of visualization. Focusing on images made by climatologists, this study shows that the same preference for maps is visible.

There is no consensus on the use of color in maps for both temperature and precipitation projections (see Table 9.1). In maps that visualize *temperature* projections, green and blue are used for a decrease. Red is most frequently used to indicate a warmer temperature, but examples were also found in which blue was used for this. To complicate matters further, there were also maps that used different colors of blue to indicate both an increase and decrease. In one case, the scale range only indicated an increase of temperature, starting with a white color, while recent best practice literature suggests to use white to indicate no change/neutral (Kelleher and Wagener 2011). Also for projections of *precipitation*, there is no homogenous application of colors. Most frequent in this sample is the 'reverse' use of colors used for the temperature scale. For this application, red indicates a decrease and blue an increase.

In the maps from documents coauthored by one or more climatologists, colors are applied less inconsistently, but there is still no full consistency in color use. The range of colors used is smaller, but a color can still have several meanings (increase as well as decrease).

This analysis sheds light on the fact that the red–blue color scale is most frequently used for maps of temperature projections as well as maps that present precipitation projections. This dominant red–blue color scale could lead to confusion. When taking the IPCC as a benchmark, red and blue colors are used for temperature, and green and brown for precipitation (IPCC 2010). This is easy for people to relate to, since in our daily lives red and blue indicate warm and cold, think about water taps. And green and brown can easily be related to greenery (which require precipitation) and desert or dry soil (where no greenery exists due to lack of precipitation).

9.5 Discussion

This quantitative description of the sample opens a more critical discussion, with the most adequate options to communicate climate information. The human brain places more importance on visualized information than textual information.

Therefore, the basic decision to visualize or not will determine the amount of emphasis being placed on the various elements communicated.

9.5.1 Maps or Graphs?

Maps do not necessarily provide information fit for decision-making. For example, maps included in the German Adaptation Strategy to Climate Change (2008) illustrate the frequent contradiction between the way information is communicated and the way it is perceived intuitively. These maps show the trend of future climate change. However, a more obvious detection is the message that the individual models have different outcomes. The reader is probably able to detect the generally increasing trend in temperature in Germany. However, by how many degrees it is not easy to discern: It requires the reader to calculate the average of all the grids. In addition, to detect the level of uncertainty, all of the maps need to be studied in more detail for their differences. In comparison, maps included in the Finnish adaptation strategy reveal a far clearer message: Their visualization shows at once the magnitude of the different trends and the uncertainty between the scenarios.

This misuse, and frequent overuse (see Fig. 9.3), of maps by climatologists might be due to several factors including the influence of geography perhaps and also the power of the technical tools they use. Software like netCDF, frequently used to process climate data, makes it quick to create maps, while producing graphs may require some second-order processing (e.g., extracting data, averaging it, representing it on a graph).

9.5.2 Readability Issue

Results also highlight the need to finalize ‘prototypes’ of graphs for a better communication. Small details might deeply affect the efficient communication: The presence of scales, the presence of city names to allow readers to locate a map, the font size, the presence of full legend rather than acronyms understood only by climatologists (for instance, ‘Winter’ instead of ‘DJF’) are details that count for a sound information transfer.

Another example is the use of graphic software that allows for adding explanation to a technical graph. For instance, when scientists and assessors elucidate on the probability information, a probability density function (PDF) may serve as a good tool (see Folland et al. 2001, Fig. 2.32). It provides probabilistic information, and words, arrows, and colors are used to assist in the interpretation of information.

This is a good example of how visualization techniques can help to reconcile scientific rigor and societal usefulness.

In the same vein, some documents present from the sample the message of uncertainty in ways that are easier for the user to relate to or to understand than other documents. These examples do this by linking the message of uncertainty to an example of uncertainty in everyday life (for example, planning a picnic according to possible weather conditions), clearly stating that the projection is one plausible outcome, explaining what the reader is looking at (i.e., the 50% or central estimate) and what this represents, or indicating the factors that constitute the uncertainty.

9.6 Conclusion and Recommendations

The transfer of climate information from science to society is a vital but complex process. The initial sender and final receiver of climate information are often far apart in terms of the contexts they operate in. This study focuses on the chain of events that take place between the production of climate information and its final destination. It conceptualizes this chain as consisting of a number of steps and assesses the representation of climate information in each of them. Climate information flows through five different phases: pre-existing knowledge, projection, impact assessment, adaptation strategy, and adaptation plan. Each phase is dominated by different actors who reuse the initial information, create new information, and summarize and synthesize this information. In this process, information is unavoidably lost, sometimes including vital information on uncertainty. This goes at the expense of societal usefulness of the climate information.

The study focuses not only on what is communicated but also on how that is done. In particular, it focuses on visualization techniques, concluding that these techniques are not always effective when the images disrupt an easy interpretation of the visualized information. These results are of importance for adaptation policies, given that climate information is the foundation of adaption: The choice of projections, of time horizons, the presence or absence of a message on uncertainty can deeply influence the form of response to climate change decided by stakeholders.

Several recommendations can be drawn. Firstly, for the elaboration of adaptation strategies, it is current practice that the flow of information is cut up and divided over the phases of the process chain, but it could be beneficial to try to maintain the flow by making the different actors work in parallel instead of sequentially. This would reduce the necessity to summarize and synthesize information. Some more participative approaches are required for this; for example, stakeholders should have a say in methodological choices. The choice of a reference time horizon for adaptation for instance, or the decision to cover x% of potential climate futures through the choice of an ensemble of projections, are not neutral, and should not be scientists' choice only. Moreover, the uncertainty is largely underrepresented or represented in heterogeneous ways and visualization does not always facilitate an easy uptake of information, as shown by our research. Development of best practice guidelines on these aspects for national, local, or sector-specific communication of climate information could help adaption specialists better responding to this issue. This could be the task of institutional climate change portals, such as the European Environment Agency Climate-ADAPT portal, for instance (http://climate-adapt.eea.europa.eu).

Additionally, in the fields of training and awareness raising, climatologists are now caught in a dilemma between scientific rigor and societal usefulness. Informed lay people might reject climate information that is overly certain. Therefore, training the end user in the basics of climatology and defining what a decision-maker can and cannot do with climate information might reduce the need to choose between scientific rigor and societal usefulness. Conversely, training climatologists to understand users' needs and communicate better could help bridging the gap. Introducing communication courses in climate curricula or associating communication specialists with climate projection exercises might help.

Further research could focus on users' perception of uncertainty messages and more generally of visualized information. This could provide insights whether visualization is helpful or not, and in which occasions it facilitates communication. Guidelines are needed to help communicators decide which visualization tools facilitate accurate and easy uptake of information.

Appendix 1

Table of sampled documents

Doc	Code	Full title
1	Belgium.as	Belgian National Climate Commission, 2010. Belgian national climate change adaptation strategy
2	Danmark.as	The Danish government, 2008. Danish strategy for adaptation to a changing climate
3	Finland.as	Ministry of Agriculture and Forestry of Finland 2005. Finland's national strategy for adaptation to climate change
4	Germany.as	The Federal Government 2008. German strategy for adaptation to climate change
5	Iceland.as	Iceland's ministry for the environment, 2007. Iceland's climate change strategy
6	Ireland.as	Department of the Environment, Heritage and Local Government, 2007. Ireland national climate change strategy 2007–2012
7	Spain.as	

(continued)

(continued)

Doc	Code	Full title
		Spanish ministry of Environment and Rural and Marine Affairs, 2008. The Spanish national climate change adaptation plan
8	Wales.as	Welsh Ministry of Environment, 2010. Climate change strategy for Wales
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Chapter 10
Transforming Climate Change Policymaking: From Informing to Empowering the Local Community

Michael Howes

Abstract Adapting to the impacts of climate change is such an all-encompassing problem that it is beyond the capacity of the entire public sector, let alone a single local government or agency. If a policy is to be effective, it will therefore need to constructively empower the local community to participate in building its own resilience. This chapter is based on a synthesis of findings from three research projects that were conducted over the last fifteen years and included comparative case studies from Australia, the USA, and the UK. A three-step policy proposal is derived from this synthesis that uses climate change knowledge to inform, engage, and support democratic local community-based adaptation. It entails the strategic use of the Internet, public participation events, and targeted local community grants. If adopted, this three-step policy could help to develop effective, efficient, and appropriate adaptation responses that tackle some of the unique challenges inherent in applying climate change knowledge by empowering local communities.

Keywords Community-based adaptation · Resilience · Public participation Democracy

10.1 Introduction

What kind of policy could use knowledge to democratically empower communities so that they can adapt and build their resilience to climate change? This is the question addressed by this chapter. The claim that knowledge is power has been made so many times that it has become something of a cliché. But how does this

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claim stand up when the knowledge is crucial for policymaking but is difficult to understand, has become publicly contested, and contains uncertainties? This is the dilemma presented by climate change knowledge, and it manifests itself most obviously in the lack of progress in adaptation and resilience building at the local level of government (Howes and Dedekorkut-Howes 2016).

For more than a quarter of a century, the Intergovernmental Panel on Climate Change (IPCC) has collated the best available climate change knowledge and presented it in a series of reports that are designed to assist governments, businesses, and communities around the world to formulate responses. The essential message is that human greenhouse gas emissions are leading to changes in temperatures, heat waves, droughts, sea levels, rainfall, and extreme weather events, among other things (IPCC 2012, 2013). These changes will have significant environmental, economic, and social impacts (IPCC 2014a). In order to avoid the worst effects, there needs to be: (1) a reduction in greenhouse gas emissions to mitigate the worst impacts; and (2) effective adaptation to increase resilience to impacts that cannot be avoided (IPCC 2014a, b). These findings have been backed up by national agencies and scientific academies around the world (NOAA 2016; AAS 2015).

So far so good, but there are three problems. First, the scientific research on which this knowledge is based is quite difficult for nonexperts to understand, which has contributed to a proliferation of people who deny the science, several of whom now occupying positions of considerable power (Howes 2013). Second, the forecasts for future climate change increase in uncertainty over time [e.g., average temperatures have been forecast to rise between 1 and 4 °C by the end of the century, depending on the model and scenario used (IPCC 2013, 1037)]. Third, the resolution of current climate change knowledge is limited and cannot detail the exact impacts on a specific local community (IPCC 2014a).

The climate change knowledge presented by the IPCC is clearly crucial for adaptation policymaking at the local level. Local governments need to use their power to help prepare their communities for the impacts of climate change, but the problems outlined above make this difficult. In addition, there is often a lack of public resources and a hostile political environment (Howes and Dedekorkut-Howes 2016). This chapter addresses these problems via a synthesis of three different research projects spanning 15 years that involved relevant case studies in Australia, the USA, and the UK. A three-step policy is derived from this synthesis that will allow climate change knowledge to be utilized in a way that empowers communities to build their own resilience. The next section outlines the method by which this is achieved. Subsequent sections discuss the relevant results, analysis, and synthesis.

10.2 Methods

This chapter is a synthesis of the findings from three research projects led by the author with the support of his colleagues over the last fifteen years. All three were centered on the use of knowledge to improve policymaking and dealt with climate change adaptation in various ways. Standard social science data collection methods were used throughout (such as surveys, interviews, focus groups, or charrettes) and all involved comparative case study analyses. The aim of these projects was to produce some original academic research as well as generate recommendations for practical policy improvements. Hence, there has been considerable collaboration with stakeholders within government organizations and community groups. All results were subjected to a peer review process by scholarly journals and international academic conferences. Some were also reviewed by practitioners.

The first project ran from 2001 to 2012 and investigated the effectiveness of the Australian National Pollutant Inventory (NPI), which requires major polluters to publicly report their annual emissions of specified hazardous substances online. Data was collected from interviews with key government stakeholders, a survey of community organizations, and focus groups made up of students enrolled in environmental studies degrees. Comparisons were drawn with the Toxics Release Inventory in the USA (Howes 2001, 2005; Thorning and Howes 2007). A spatial analysis was then undertaken that combined NPI data with flood maps for the Brisbane region to provide a useful adaptation tool for disaster risk management, climate change adaptation, and land-use planning (Howes et al. 2014).[1] The early results of this project were given back to the practitioners within the state and federal public sectors, and the author was also asked to chair the Technical Advisory Panel for the second 5-year review of the inventory (Howes et al. 2006).

The second project ran from 2010 to 2015 to investigate the use of scientific knowledge in climate change policymaking. Data was collected from interviews with key stakeholders within government and the scientific community in two case studies: South East Queensland, Australia, and the Southeast region of England. A comparative analysis was then undertaken to determine the key factors that influenced the use of scientific knowledge in policymaking (Tangney and Howes 2016).[2] The results were published and formed the core of a PhD thesis by the coresearcher, Tangney (2015), who was also involved as a researcher in a related project led by the author that is described below. Tangey later went on to help establish a program in science policy and communication at Flinders University, Australia.

The third project ran from 2012 to 2014 and investigated ways to integrate disaster risk management with climate change adaptation policy. Data was collected from interviews with key government stakeholders, charrettes with stakeholders

[1]The author would like to thank the following colleagues for their collaboration on the later stages of this project: Peter Thorning (Queensland Department of Environment) and Professor Jago Dodson (RMIT, Australia), as well as Dr. Deanna Tomerini, Dr. Leila Eslami-Endargoli, and Dr. Johanna Nalau (Mustelin) at Griffith University. This research was funded by Griffith University and the Commonwealth Department of Environment.

[2]The author would like to thank Dr. Peter Tangney (Flinders University, Australia) who undertook much of this research as part of his PhD and his co-supervisor Associate Professor Michael Heazle (Griffith University, Australia). The research was supported by funding from Griffith University and the Commonwealth Government of Australia.

from both the public and community sectors, and the final reports of official investigations into three major disasters: the 2009 Victorian Black Saturday Bushfires; the 2011 Brisbane Floods; and the 2011 Perth Hills Bushfires. A comparative case study analysis was undertaken, and the results were used to create recommendations for better policy integration (Heazle et al. 2013; Howes 2015, 2016; Howes et al. 2015).[3] The results of this project were fed back to senior policymakers in forums in Canberra, Brisbane, Sydney, and Melbourne that were run by the National Climate Change Adaptation Research Facility (which also funded the research).

The synthesis of the results from the three projects provides fairly generalizable insights given the range of different institutions that were studied, the comparative analyses that stretched across three countries (Australia, the UK, and the USA), and the number of years over which the research was undertaken. Having said this, all cases were drawn from countries where there was consolidated democratic governance, a free media, relatively low levels of poverty, and relatively peaceful communities. The findings will therefore be less applicable to countries that have authoritarian governments, a restricted media, a high degree of poverty, or are ravaged by war.

10.3 Results

The first project on the National Pollutant Inventory produced three key findings that are pertinent to the idea of democratic local community empowerment. First, publishing information online is a necessary first step, but not sufficient. The information needs to be presented in a way that is easy to access and understand by avoiding technical jargon, providing clearly written explanatory notes, and using a well-designed graphical user interface (Howes 2001). Second, when presented with information about specific environmental risks, community organizations in Australia tend to put pressure on governments to take action, rather than focus on the private sector (Thorning and Howes 2007). Third, governments could combine their environmental reporting with hazard mapping and zoning data to create a spatial analysis tool that would help with both disaster risk management and climate change adaptation (Howes et al. 2014). This could be useful for the emergency services, local government planning, and the local community.

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[3]The author would like to thank his research team for this project: Dr. Deanna Grant-Smith (Queensland University of Technology, Australia), Dr. Kimberly Reis (Griffith University, Australia), Dr. Peter Tangney (Flinders University, Australia), Associate Professor Michael Heazle (Griffith University, Australia), Professor Darren McEvoy (RMIT, Australia), Dr. Karen Bosomworth (RMIT, Australia), and Professor Paul Burton (Griffith University, Australia). This project was funded by the National Climate Change Adaptation Research Facility, Griffith University, and the Queensland Department of Community Safety.

The second project on the use of climate change knowledge in policymaking also produced some useful results. This project tested the framework put forward by Cash et al. (2002, 2003) which argued that scientific knowledge is most likely to influence policymaking when it is seen as credible (i.e., scientifically plausible), legitimate (i.e., the process by which the knowledge is produced is seen as unbiased and fair), and salient (i.e., it is relevant to, and meets the needs of, decision makers). This project found that of these three, legitimacy is preeminent in climate change adaptation because the conflicting norms and politics that pervade this policymaking domain undermine the willingness of political leaders to act (Tangney and Howes 2016). It can also impact on the willingness of the local community to acknowledge a problem and take action.

The third project on integrating disaster risk management and climate change adaptation policies revealed that the local community has a key role to play in building resilience because of the limited capacity of governments to respond. This requires well-designed democratic community engagement that moves well beyond public education programs in order to be effective. One proposal was to have small-scale climate change adaptation grants where the local community could use publicly available information to propose and vote on projects that would help to build local resilience (Howes et al. 2013, 2015). This would require some significant reforms in the way the public sector operates in order to give the local community some sense of ownership of an issue and the response (Howes 2015, 2016; Heazle et al. 2013). The proposal was designed to improve the public awareness of issues as well as empower the local community to take its own adaptive actions.

10.4 Discussion

Governments are increasingly being asked to do more with less, and they are already unable to fulfill many public expectations. One way to address this challenge is to adopt policies that constructively engage the local community as a partner in democratically developing and deploying responses. Such policies require a well-informed and motivated local community that sees the engagement process as legitimate. This is where the link between knowledge and power is important, but there are problems when it comes to climate change knowledge. Governments collect a great deal of data that is relevant to adaptation, but it is scattered across many different levels and organizations. In addition, the data is often highly technical and difficult for nonexperts to interrogate in order to find salient, credible information. The combined findings of the three research projects outlined above can offer a three-step policy solution.

10.4.1 Inform

The first step would be to create an online 'one-stop-shop' Web site that would provide essential information to the local community in an easy to understand and well-integrated format. Visitors could simply enter their postcode or zoom into find their local community on an interactive map that would reveal:

- The geography of the region (e.g., major landforms, vegetation cover, waterways);
- Land use patterns and zoning (e.g., for recreation, residential, or commercial use);
- The distribution of natural hazards (e.g., floods, bushfires, landslides);
- The location of hazardous sites (e.g., where pollutants are stored or released);
- Key infrastructure (e.g., roads, hospitals, schools);
- Emergency management information (e.g., evacuation centers); and
- Current warnings and advice (e.g., for storms, cyclones, heat waves, or bushfires).

There are some prototypes of this kind of policy approach starting to emerge. The National Pollutant Inventory Web site (at http://www.npi.gov.au/) already uses interactive maps to identify sites releasing and storing hazardous substances. There is also an interactive test site called *Coastal Risk Australia* (at http://coastalrisk.com.au/) that indicates areas at risk of flooding under different sea-level rise scenarios. In addition, the National Climate Change Adaptation Research Facility offers a *Coast Adapt* test site (at https://coastadapt.com.au/) that has useful information on how to assess risks and adapt. On top of all this, most local governments provide online flood maps, zoning schemes, and city plans, while many government agencies, such as the Australian Bureau of Meteorology and emergency services, have useful online information. The idea is to bring this all together in a single Web site that the local community would find easy to use.

10.4.2 Engage

Then next step is to get the message out there so that the local community knows about the Web site, realizes its salience, learns how to use it, and factors it into decision making. A multimedia campaign could raise public awareness of the site. It could be similar to the very effective public information campaign run during the Millennium Drought 2001–2010 in Queensland, Australia, that encouraged the local community to significantly reduce its water use by offering practical changes in behavior (Walton and Hume 2011). This could be coupled with a series of local events to help volunteers learn how to use the site and then promote it to other members of the local community through their networks. The European Climate Knowledge Innovation Community (KIC) ran a worldwide Climathon on October

28, 2016, in 59 cities simultaneously around the world. This attracted 1495 participants who were asked to identify climate change issues and propose adaption initiatives. The event was promoted through social networks and online (at https://climathon.climate-kic.org/). The author of this chapter helped to facilitate sessions in Brisbane, Australia, and spoke about ways to get ideas implemented in regional planning. These kinds of events build the legitimacy of climate change knowledge by giving the local community a sense of ownership of the process that generates understanding of the problem and creates solutions.

10.4.3 Support

The final step would be to provide appropriate financial incentives and support for communities to get involved in building their own resilience. Local, state, and federal governments already offer community grants for various purposes. Landcare, for example, has been a very successful program that enabled thousands of communities to rehabilitate degraded land using their own volunteer labor supported by funding from the federal government. The program uses a network of nongovernment organizations to administer the grants and has its own Web site (at https://landcareaustralia.org.au/) to help with networking, applications, and reporting. A similar set of grants could be offered by local governments but focused on climate change adaptation and resilience building and with more of the decision making in the hands of the local community. The Web site created in step 1 would provide the necessary information about local risks and the events run in step 2 would get local people using this information and proposing solutions. The grants would then offer a way to implement these ideas. Communities could get together to view all the proposals either face-to-face in town hall meetings or online then vote on the projects they preferred. The top ranked projects would be funded in turn until the total pool of grant money was spent. Projects might be quite simple, such as organizing a network of volunteers to check on elderly people during a heat wave, flood, or bushfire.

10.4.4 Limitations

Three notes of caution should be sounded here. First, although increasing local community involvement in adaptation is important, governments should not be permitted to vacate the field. The public sector has the relevant knowledge, trained personnel, financial resources, and coercive powers that are essential to supporting successful responses. Second, empowering communities may not lead to the optimal outcome with regards to building resilience. Democratic decision making is not always rational, and some communities may actually choose to either ignore or increase their risk to the impacts of climate change. One example would be the popularity of a housing development that offers waterfront homes despite the location being at risk of sea-level rise and coastal erosion. This is something that is a real issue for many coastal cities and towns. The three-step policy proposal outlined above should reduce the likelihood of such perverse outcomes, but it would not be eliminated. In such situations, governments will still have the ability to act for the public good despite adverse public opinion, but it will be politically risky.

On the positive side, governments have found ways of implementing unpopular polices in the past while deflecting blame. One example that springs to mind is the setting of official interest rates in the banking sector. A decision to raise rates is very unpopular because it increases the costs to households and businesses but there are times in the economic cycle when it is necessary. By giving the power to set rates to an independent organization, such as the Reserve Bank, the unpopular decision can be implemented when needed, while elected politicians distance themselves, criticize the move, and proclaim that they have no power to change it. So, there are effective strategies that can address such political difficulties. The third point is that this three-step policy is a proposal based on research and if implemented they would need to have some process by which to be evaluated in order to identify what is working and what is not. Althaus et al. (2013) offer a standard set of processes that could easily be applied to this proposal if it were adopted in order to ascertain whether it was effective, efficient, and appropriate.

10.5 Conclusions

If knowledge is power, finding a way to turn that power toward building local community resilience is crucial for effective climate change adaptation. It is also important to support more democratic decision making. The inherent complexities of climate change knowledge, however, make this challenge all the more difficult. Added to this are the limitations imposed on governments by a hotly contested political environment and limited public resources. This means that the task of adaptation cannot be left to governments alone and requires the assistance of local communities. Over fifteen years, a series of research projects have revealed the importance of three pertinent factors in policymaking that can improve democratic local community empowerment:

(1) Provide credible, salient, and legitimate public information that is easy to use;
(2) Create decision-making processes that are participatory and transparent; and
(3) Provide well-targeted financial support and incentives.

On the positive side, the rapid spread in the use of the Internet has opened up a new range of opportunities in the design of effective and cost-efficient policy instruments that can support democratic decision making. The three-step policy proposal outlined in this chapter (i.e., inform, engage and support) takes advantage of these opportunities to empower the local community and build resilience in a way that also supports the principles of democratic decision making. The question now is whether existing governments would be willing to take such a step. Only time will tell.

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Chapter 11
Resilience and Vulnerability Assessment as the Basis for Adaptation Dialogue in Information-Poor Environments: A Cambodian Example

Chris Jacobson, Stacy Crevello, Chanseng Nguon and Chanthan Chea

Abstract Community preparedness for the impacts of climate change on livelihoods in the Asia-Pacific region is largely unknown. Scientific impact projections and quality data (at a scale relevant to local adaptation decision-making) are rare in countries such as Cambodia, particularly in rural areas. Adaption (including mitigation, adaptation, transformation and maladaptation) therefore predominantly occurs in an information-poor environment. In this chapter, we present some findings of a collaboration between two projects: first, the UN FAO Life and Nature watershed management project—a project incorporating vulnerability assessments, improved land use practices, and climate-smart agricultural adaptation, with a gender focus; and second, The Community Resilience and Climate Adaptation project—a small research project that developed a rapid assessment of community resilience to inform adaptation planning. Our common aim has been to address the absence of quality climate information for adaptation planning through the use of vulnerability and resilience assessment and policy dialogue. We demonstrate the importance of adaptation dialogue processes as mechanisms for introducing climate change information into decision-making. We argue that such processes are paramount to communicating quality information when and if it does become available, given that communities already recognize the impacts of climate change upon them, and in addition, they create a sociocultural context conducive to adaptation and transformation, exposing the limitations of existing mitigation strategies.

Keywords Asia-Pacific · Climate change · Decision-making · Rapid assessment

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11.1 Introduction

Cambodia is a climate change hot spot in Southeast Asia. While impacts are not expected to be as high as other areas (such as the Mekong Delta), adaptive capacity and vulnerability are rated the lowest of any country in the region (Yusuf and Francisco 2009). Over 80% of Cambodian communities are reliant on subsistence agriculture (Kingdom of Cambodia 2014). While predicted sea-level rise could inundate coastal towns, the majority of the population will be affected by changes in the length, timing, and intensity of the wet season, and their ability to supplement prolonged dry periods with irrigation (largely dependent on inflows from the Mekong River). Predictions of increased rainfall for the wettest three months vary under different IPCC scenarios, from 9–76 mm increase (2000–2050) resulting in predicted losses in rice production of 2.3–9.9% (Thomas et al. 2013). High variability in predicted impacts makes localized adaptation planning difficult. This is compounded by the reliance on donor aid for climate change information and adaptation. It is widely acknowledged that a national level science–policy gap exists in Cambodia related to climate change (Dany et al. 2016). This gap is echoed among agriculture extension more broadly where science is often fragmented between organizations, training and knowledge are limited, and funding prevents these issues being addressed (Preston et al. 2015; Jacobson et al. 2015).

In the absence of detailed local climate change predictions, adaptation programs occur in an information-poor environment (Dany et al. 2016). At the local scale, participatory assessments of vulnerability and resilience [e.g., community-based adaptation planning tools such as Care's *Climate Vulnerability and Community Adaptation Handbook* (Daze et al. 2009)] play an important role, helping to understand risk exposure and sensitivity to impacts. Understanding resilience is especially important in remote areas, where communities must largely be self-reliant (Nunn et al. 2014). Community resilience builds on the concept of vulnerability through greater attention to governance and social dynamics (Magis 2010). Understanding each community's assets and how they can be mobilized is critical to addressing the climate change—development nexus in poor rural communities (Friend and Moench 2013). Simple monitoring and evaluation tools (e.g., Jacobson and Ngoun 2016) can provide a baseline against which to consider the effectiveness of aid projects (especially after donors leave). Cross-scale communication and awareness of climate change impacts and opportunities for addressing these are critical to long-term adaptation success. While much of the climate change literature focusses on the policy–science communication gap, an equally significant gap exists in communicating information with communities and supporting them to adapt in the absence of information. We demonstrate the importance of adaptation dialogue processes as effective mechanisms for introducing climate change information into decision-making.

11.2 Case Study Context

11.2.1 Socioeconomic and Governance Context

Socioeconomically, Cambodia is a least developed country, ranked 143 of 188 by the United Nations Development Program. While annual gross domestic productivity per capita is $1158.7 USD, daily per capita consumption varies from $0.70 to $3.75 in the lower and upper quintiles, although extreme poverty is decreasing. At least 22% of households are headed by women, whom generally have less accessible and lower quality lands (Asia Development Bank 2014). Migration is also a significant issue, with a reported 22% of rural households experiencing migration of one or more adult (Kingdom of Cambodia 2014). Socioculturally, Cambodia is recovering from years of occupation by Thai, French, and Vietnamese armed forces and from the Khmer Rouge led genocide. Legacy impacts included ongoing internal fighting (particularly in the North West), and the destruction of all land title documents and all paper money. In 2015, Transparency International ranked Cambodia 150/168 countries for corruption. This context provides significant challenges for communicating climate information and adaptation itself.

Administratively, the Cambodian government operates using a centralized funding scheme at National, Provincial, District, and Commune levels, while Ministerial departments are mirrored at provincial levels albeit often with limited budgets. Departments most relevant to climate change include Environment; Agriculture Forestry, and Fisheries; Water Resources and Meteorology; Women's Affairs; Education Youth and Sport; and Rural Development. Climate change adaptation is informed by the 2014–2023 Strategic Plan; its implementation is led by the Ministry of Environment as chair of the cross-ministry National Climate Change Committee. At the commune level, bipartisan Commune Councils work to develop and implement commune plans and to support Provincial government to implement government and aid project priorities in their commune; it is rare for large-scale aid projects to approach Commune Councils directly, although non-government organizations (especially local NGOs) may work directly at this level.

11.2.2 Project Context

A policy dialogue process was developed involving Provincial Government and Commune Councils in two North Western Cambodian provinces: Siem Reap (with Lvea Krang Commune) and Battambang (with Chamkar Samrong Commune). The former commune was one of four involved in the four-year Global Environment Fund sponsored United Nations Food and Agriculture Organization's (FAO) Life and Nature watershed management project; detailed gender focussed vulnerability assessments undertaken using FAO's vulnerability impact assessment tool. Lvea

Krang is a commune of an estimated 3000 inhabitants about a 2 h drive from the provincial capital of Siem Reap. It is a particularly poor commune, with little health or sanitation infrastructure, no electricity and suffering from flash floods and severe droughts; in 2016, many families were walking 4 km to access drinking water. The latter was funded through an Asia-Pacific Network for Global Change Research (APN GCR) project focussed on understanding community resilience and is a peri-urban community of around 17,927 inhabitants on the outskirts of Battambang city, only 30% of which is agricultural land, with a diversity of comparatively richer and very poor families.

11.2.3 Project Methods

The methods developed (see Jacobson and Nguon 2016 for additional detail) included:

(1) a needs assessment and prioritization comparison conducted with Commune Council and Village leaders—including a needs prioritization ranking, vulnerability ranking, and existing investment ranking;
(2) a survey of migration (including drivers and consequences) and food security coping mechanisms, using an adapted version of the Food Security Coping Strategy Index (Carletto et al. 2013; Heady and Ecker 2013), conducted at the household scale with 10% of households in each commune; and
(3) an assessment using 39 questions regarding resources, planning, governance, and outcomes related to the outcome themes of livelihoods, infrastructure, community, and climate and disaster management, conducted as a workshop with Commune Council and Village leaders, using a four-point rating scale for each question, and informed by prompts relating to (1) and (2).

The adaptation dialogue process occurred after these activities, in an attempt to share and verify results and to identify innovative opportunities for adaptation within existing resources. In the case of the Lvea Krang, where significant investment to adaptation actions supporting improved watershed management already existed, we focussed on social and other adaptation issues beyond the scope of the FAO project.

The dialogue process included representatives from relevant provincial departments noted in Sect. 11.2.1, as well as appropriate donors (for Siem Reap this included FAO, and for Battambang, Ptea Teuk Dong [a local NGO and our entry point into the community] and a visiting Rotary Club interested in working in the community), and university staff with related projects. The format followed (i) an overview of activities and a discussion of climate impacts; (ii) an overview of key results; (iii) a presentation of the assessment scores related to each outcome theme, with comments on score justification and issues by commune representatives; and (iv) a discussion on how these issues might be addressed (with prompting questions including related provincial/NGO/University projects addressing issues identified, what would need to occur to enhance a particular score, whether existing planned activities are likely to improve scores, what can and cannot easily be changed about drivers of the issues). At the end of the process, we asked participants to summarize the most poignant issues and describe adaptation actions that could address them, identifying who should be involved, where further research or monitoring was needed, and the appropriate follow-up process.

This entire method is rapid and cost-effective, taking only around 15 person days to complete and minimal workshop hosting and per diem costs. As mentioned by participants, it could easily be conducted by trained government staff without aid worker intervention. However, the limitations and constraints include a lack of scientific information on local climate impacts and sometimes narrow mind-sets of those involved.

11.3 Results

11.3.1 Lvea Krang Commune

The resilience analysis identified that the outcome of community self-reliance was weakest, followed by economic development and ability to manage for climate change. Key factors affecting these were:

- Community understanding about climate change;
- Resources for addressing climate-related crises (e.g., sufficient food) and support for community groups;
- Ability to address the needs of the most vulnerable groups within plans and to implement plans; and
- Linkages within the commune and between the commune and NGOs.

Our prioritization exercise and household survey exemplified these concerns. While drinking water was the second highest priority (irrigation was top), funding allocation from the commune investment plan was lowest (irrigation was also low). Migration and food security analysis revealed migrants from >45% of commune households in 2015, mostly male, 69% of which is attributable to climate-related factors, leaving female-headed households more vulnerable and not always more food secure (despite remittances). Households with migrants had less access to micro-finances or investment resources they could sell in times of crisis (e.g., stock).

The FAO Climate-Smart Agriculture and Watershed Management planning project addresses many needs identified within our assessment, including

- Ecosystem-based approaches;
- Conservation agriculture;
- Integrated nutrient and soil management;

- Mulch cropping;
- Cover cropping;
- Alterations in cropping patterns and rotations;
- Crop diversification;
- Using high-quality seeds and planting materials of adapted varieties;
- Integrated pest management;
- Integrated weed management;
- Grasslands management;
- Water and irrigation management;
- Organic agriculture;
- Land fragmentation (riparian areas, forest land within the agricultural landscape); and
- Improved forest and protected area management.

In addition, our policy dialogue identified existing provincial programs and mechanisms for building community resilience by thinking 'outside the box.' Migrant households face higher rates of food insecurity because of insufficient labor. As such, children miss some school days because they need to fill labor gaps on family farms. This means they can fall behind and become too ashamed to return to school. Adaptation mechanisms to address this include student–student study clubs. Students could use their school or village leader homes, where solar electricity exits, to catch up on their studies outside school hours. A 'study club' program exists in the Province, but not in this District, and was proposed as a result of the dialogue.

The policy dialogue also provided opportunity to discuss inter-commune irrigation canal management options; it appeared that infrastructure management was as important as access to irrigation. Much publicized low rice prices were also an issue for farmers, who saw limited economic benefit from growing additional paddy. While farmer cooperatives have a very vexed history in Cambodia, given they were the foundation mechanism of the Khmer Rouge genocide, farmer agricultural community groups (the term used for bottom-up cooperative movement) were identified as a mechanism to: (i) share existing best practices in farming; (ii) invest in climate-resilient seed; (iii) discuss who plants and when to get best price; (iv) share information (IT) about market prices so they can bargain with buyers (mobile phones are common place in communities, and access is very inexpensive); and (iv) provide a mechanism through which to attract infrastructure investment to value add to produce within the community. This could be supported through integration of existing provincial activities between agriculture, water resources, and environment departments.

Drinking water resources investment was identified as comparatively cost-effective means of improving resilience that could be supported within the existing commune plan or by NGOs; the dialogue ensured the significance of this need was made clear to provincial authorities whom coordinate NGO investment. In addition, the Provincial Department of Water Resources Management and the

Commune Council identified a need to promote weather monitoring in the community to enhance and share understanding about climate change.

11.3.2 Chamkar Samrong Commune

The resilience analysis identified the outcomes of community self-reliance, economic development, and infrastructure meeting current and future needs as equally low. Key factors affecting these were:

- Resources to manage in times of crisis;
- Quality of housing, access to water, and support for community groups during and after crises;
- Resources for addressing climate-related crises (e.g., sufficient food) and support for community groups; and
- Ability to address the needs of the most vulnerable within plans and to implement plans.

While managing climate change was viewed as a lesser concern than other outcomes, it is clearly linked to all of these issues. Similar to Lvea Krang, while drinking water and irrigation were the highest priorities, related funding allocation from the Commune Investment Plan was low. Migration and food security analysis revealed >46% of households had migrants in 2015, mostly male, 47% of which is attributed to climate-related events, leaving women and youth more vulnerable.

Community-oriented adaptation suggestions were similar to Lvea Krang, including the suggestion of study clubs, with Provincial departments offering after-hours teacher support. NGOs were seen as a key player in developing drink water infrastructure, and irrigation was reliant on private investment.

Communication of climate information was also directly discussed during this workshop. When asked for an overview of climate change, none of the provincial department officials or university staff in attendance could explain the changes in wet season timing and intensity nor had they seen recent information that suggested early rains were becoming less frequent; this information was, however, known to the facilitators through discussions with agricultural research project leaders. Thus, a significant information gap appears to exist around climate change among supposed knowledge leaders.

During the workshop, it was revealed that over half of the commune agricultural lands (30% of the land area) were seized as collateral against micro-finance loans and are now farmed under contract; this has increased disparities between wealthy and poorer community members. Strong NGO presence in the community provides an avenue to address food insecurity through community gardens. This is also a win–win avenue for addressing adult education on climate-resilient agriculture, with suggested training support from Provincial government. As per Lvea Krang, 'agricultural community' was seen as a means of teaching climate resilience agriculture (e.g., through a rice bank of drought-tolerant seed). A novel opportunity also exists for introducing high-value organic tea production that may halt the decline of agriculture in the commune. The engagement of University staff, Provincial Department of Agriculture, NGO, and international rotary clubs provides a means to facilitate this.

11.4 Discussion

In the absence of local-scale information, development practitioners (including government, NGOs, and donors) must conceive of alternative mechanisms to proactively support adaptation. Our dialogue process was identified by participants as having the following benefits:

- It raises awareness of the broad and interconnected nature of climate change impacts
- It raises awareness of commune issues with provincial government, NGOs, donors, local universities, etc;
- It identifies opportunities for adaptation that exists within current programs and subsequently can enhance self-reliance; and
- It can create transformative adaptation options once immutable barriers are identified (such as education outside of school hours, or community gardens for microenterprise).

In poorer countries such as Cambodia, government is often not the main provider of climate information or action. Further, there may be more than one actor in any given community, operating simultaneously or sequentially but not necessarily building on the work of the other/s. This creates disconnections between understanding the 'status' of development outcomes (such as community resilience) and the effectiveness of actions to support them (such as adaptation to climate change). While implementers of climate-related projects must monitor and evaluate, they often do so within the short-term context of a project's key result indicators, and not in terms of broader community development or aims identified by a community. Tools and processes such as community resilience assessment and policy dialogue address this information gap.

Participants involved in our project felt that the assessment provided a simple, cost and time efficient means of considering climate impacts as part of existing commune planning that could easily be replicated by government without aid support. The process can be used to monitor changes in vulnerability and resilience over the long-term, highlighting actions that are needed and opportunities for donors and others to contribute to adaptation responsiveness. In the absence of technical information, Dany et al. (2016) and Meyer et al. (2010) argue for the co-production of climate adaptation knowledge and the inclusion of knowledge brokers in such processes. Our examples provide a process for context and scene setting, for sharing existing knowledge and understanding of climate change, for bridging the gap between national and local climate science–policy dialogue so that communities are receptive to detailed information in the future, and for supporting dialogue on local adaptation options.

Communicating climate change in a development context like Cambodia and the ability to develop appropriate adaptation responses is not without challenges. Firstly, contextual understanding is critical. The most poignant example in Cambodia is the cultural association of ‘cooperative’ with the Khmer Rouge, which has required donors to rethink how this concept could be applied. Another example is the statistics we generated for climate-related migration and its impacts and links to food insecurity; these are some of the only survey-based data we know of in the region, and the results are significantly higher than those reported by government (Kingdom of Cambodia 2014). Our decision to collect this data was based on comments made during focus groups but proved to be significant in identifying climate change as a systemic issue for the communities, requiring both long-term responses (such as climate-resilient agricultural practices) and short-term responses (to address the reenforcing feedback between climate variability, food insecurity, migration, labor shortages, and education deprivation).

Secondly, we must recognize that low levels of literacy and education (in part a historical legacy) do not mean a community which is without knowledge. While the term climate change is new for many community members, the concept is not and we must find better ways to work with existing knowledge about its impacts and coping mechanisms, while at the same time, communicating that future events are likely to be different in nature to past ones.

Thirdly, we need to recognize issues associated with aid reliance and how they impact on attempts to communicate climate change information. In aid-dependent nations such as Cambodia, donors become known for particular resources, and both government and commune representatives working with donors lead to ‘conditioned’ responses. These include (i) they do not have knowledge, (ii) they do not have the ability to help themselves, (iii) someone else will tell them their issues and how to address the issues, (iv) it is best to receive some funding, irrespective of whether it addresses priority needs (this may free up money for other activities), and (v) survival is paramount to long-term solutions with no immediate benefit (in many cases, this is probably a very real need!). Empowering local communities to recognize their own knowledge and skills, to identify how they can use existing capacity, and to share constraints and barriers may be as important to communicating climate change as a program where information and solutions are provided, and communities revert to previous practices once donors leave. The best example is irrigation; this is the simplest adaptation mechanism to ensure food security during drought. However, our workshops highlighted that resolving irrigation issues is more complex and requires consideration of inter-commune conflict, access, and power to pumps to take advantage of irrigation, and a favorable cost/benefit ratio compared to other crops, e.g., cassava.

Transformative approaches to adaptation are larger scale, more novel and/or have greater spatial reach (Gillard et al. 2016). This requires thinking beyond currently recognized solutions. The policy dialogue in Chamkar Samrong provided a more innovative response to adaptation. By working together, international donors, NGOs, and University staff were able to identify a pathway for developing a more climate-resilient alternative livelihood that could address concerns about lack of resources and could be developed in conjunction with community gardens that also improved food security. Policy dialogues such as ours raise awareness of alternative options and opportunities, rather than reinforcing a community, to ask for what it knows it might receive. What is more, they alert government to development gaps generated when donors have left communities. These dialogues also provide opportunities for extension agents and the engagement of knowledge intermediaries, as suggested by Meyer (2010). However, a clear knowledge gap exists for professionals in understanding the likely future climate changes and impacts of them, in addition to considering the best way to coordinate local responses.

11.5 Conclusions

In conclusion, this chapter has demonstrated that communicating climate information in the global south (poorer, less developed countries) often occurs in the absence of technical information, with low levels of formal education. A lack of integration across government activities and economic status raise many barriers—if quality information did exist, how would it be enacted? Communicating climate change information within a development context clearly should not be considered separately to a broader development agenda.

The absence of dialogue on integrating climate change adaptation with community development is leading to ineffective mitigation strategies, such as migration, that undermine the social fabric of rural communities. Initiating policy dialogue processes prior to the existence of detailed information creates an environment where actors are ready to consider its implications at a later stage. Dialogues raise broader understanding about the interconnectedness of climate-related impacts and empower communities to interact in more meaningful ways, ensuring project actors work ‘with’ rather than ‘for’ them. In this way, context is better understood, and barriers to change are more obvious, and adaptation might be more proactive when information does become available.

Climate-related hazards such as ‘abnormal’ drought and flood are not new to many communities. What is new is the extent of uncertainty around extreme events, and the ability for communities to manage the cumulative impacts of these events. This requires dialogue between communities, government and experts (e.g., scientists) to both build a collective understanding about potential impacts and to identify and manage barriers to adaptation. Future research directions for Cambodia include the need to develop simple information products that can be widely shared that outline these uncertainties and potential adaptation options (e.g., through electronic infographics or radio programs). Research also needs to address how we can communicate climate change and support adaptation in communities where growing economic disparities attenuate existing vulnerabilities. For example, the specific vulnerabilities and adaptation needs of households with migrants may be different to those without migrants. Much could be learnt from mainstreaming climate extension processes alongside those used in agriculture development.

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Part III
Applying Climate Change Information: Case Studies

Chapter 12
Scalable Interactive Platform for Geographic Evaluation of Sea-Level Rise Impact Combining High-Performance Computing and WebGIS Client

Agnès Tellez-Arenas, Robin Quique, Faïza Boulahya, Gonéri Le Cozannet, François Paris, Sylvestre Le Roy, Fabrice Dupros and François Robida

Abstract As the climate is changing, more applied information on resulting impacts are required to inform adaptation planning. Over the last decade, the amount of information relevant to climate change impact assessment has grown drastically. This can particularly be illustrated in coastal areas, threatened by sea-level rise due to climate change, where a key recent development has been the delivery of precise and accurate topography obtained by Light Detection and Ranging (Li-DAR) at regional and national scales, i.e., respectively, large and small scales. However, using such large, complex, and heterogeneous coastal data sets in a contextual manner is far from straightforward. It is the reason why these developments have not led to easier assessment of coastal climate change impacts so far. In this chapter, we address this interoperability challenge by developing and describing a prototype of Web service combining Li-DAR, tidal, and sea-level rise data to quickly communicate spatial information on the exposure to future coastal flooding along the French coastal zones. We discuss several issues related to data architecture, on-the-fly (geo)-processing capabilities, management of asynchronous workflows, and data diffusion strategies in the context of international standards such as Infrastructure for Spatial Information in Europe (INSPIRE). We believe that our flexible architecture mainly reusing off-the-shelf components is able to improve both complex scenarios' analysis for experts and dissemination of these future coastal changes to the general public.

Keywords Coastal climate services · High-performance computing
Standard web services · WebGIS client

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12.1 Introduction

Climate change will represent a major challenge for coastal zones over the twenty-first century and beyond. Among all its impacts, sea-level rise is recognized a key concern for coastal risks such as shoreline changes and coastal flooding (Gattuso et al. 2015). Today, the rate of sea-level rise is limited to 3 mm/year (Cazenave and Le Cozannet 2014). However, it is expected to rise from as much as 1 to 3 m per century over the next millennia, depending on the dynamics of melting ice sheets (Clark et al. 2016).

To adapt to the adverse impacts of sea-level rise and climate change, coastal stakeholders need validated information regarding past, current, and future coastal changes. To respond to this need, the climate science community is currently developing climate services, one component of which being Web portals, providing access to heterogeneous data and processing tools validated by the scientific community (Brasseur and Gallardo 2016). In the case of coastal zones, the baseline data are mean and extreme sea levels and the local coastal topography (Gornitz 1991). Other information is needed for precise assessment of coastal flooding (e.g., waves, surge, and bathymetric data). However, sensitivity analysis has shown that a first requirement to provide reliable coastal impacts' assessments remains the access to very high-resolution topographic data such as Li-DAR (Yates et al. 2011). This presents a challenge to geographic information systems, which need to manage these large amounts of data while providing a user-friendly Web interface allowing coastal engineers and managers to quickly appraise the exposure to sea-level rise in any given coastal area. Indeed, computer-aided decision support systems remain a major tool for quick assessment of natural hazards and climate change. The ability to process the amount of information from earth observation systems at different scales is key for the reliability of the numerical models and for the interactivity of the Web portal.

Although research infrastructures such as Copernicus or the European Plate Observing System (EPOS) provide resources or services to tackle data sets at the global scale, the ability to design Web-based geographic information system (WebGIS) at the regional scale is of great interest. Such systems showing sea-level rise scenarios should be built with open source components to ensure their future integration in larger systems. This paper presents a scalable architecture using a high-performance computing system as a cornerstone. We will discuss several issues such as data management for different scales of interest, scientific workflows, and the integration of processing capabilities. The paper proceeds as follows. In Sect. 12.2, related work is examined while Sect. 12.3 illustrates the main features of our Web application and underlines our pre-fetching mechanism for the management of the tiles. Section 12.4 investigates the technical background related to the main component of our architecture. Then, Sect. 12.5 presents an overview of our implementation and discusses the challenges we must overcome when dealing with the integration of processing facilities in a Web-based workflow. Section 12.6 puts forward both conclusions for this chapter and some perspectives.

12.2 Related Work

Regarding spatial data infrastructures, several initiatives have been dedicated to the deployment of robust architectures in various domains (i.e., transportation, defense, space). This is particularly true for the geosciences community where the spatial component plays a significant role. At the European level, research infrastructures like Copernicus (Earth Observation) or European Plate Observing System (EPOS) provide resources and services to the associated scientific community. Most of these platforms rely on geospatial standards from the Open Geospatial Consortium (OGC)[1] ensuring interoperability and reuse across data and the associated services. At global scale, initiatives like the Global Earth Observation System of Systems (GEOSS)[2] and OneGeology[3] represent a long-term effort for research data architectures in geosciences.

The trend to enhance sharing of research data is also materialized by several organizations or initiatives promoting working groups, tools, or architectures in this direction. For instance, the Research Data Alliance (RDA) and the European Data Infrastructure (EUDAT) are very active in terms of community building. In the context of climate change and the impact of rising sea levels, coastal areas are a key issue for risk prevention policies. Several online coastal information systems have been set up. For instance, the information system managed by the US National Oceanic and Atmospheric Administration (NOAA[4]) is focused on sea-level rise and coastal flooding impacts for the national territory. The viewer provides access to several layers including socioeconomic data and significant efforts which have been devoted to public dissemination. This information system is designed in a static way meaning that all the tiles available are pre-computed. In the same area, the Australian coastal information system provides information on sea-level rise.[5] Some pre-computed maps are available for download (in image format) depending on the region of interest. Introducing flexibility and scalability in such information systems remains a challenge.

[1] http://www.opengeospatial.org/.

[2] http://www.earthobservations.org/geoss.php.

[3] http://onegeology.org/.

[4] https://coast.noaa.gov/slr/.

[5] http://www.ozcoasts.gov.au/.

12.3 Illustration of Usage of the Scalable Interactive Platform for Geographic Evaluation of Sea-Level Rise Impact

Before describing the technical architecture, this section illustrates our approach by presenting the functionalities proposed by the WebGIS client, and how the flood maps are computed.

12.3.1 WebGIS Client

The French coastlines display contrasted geomorphologic features and have different vulnerability to sea-level rise (Paskoff 2004). Concerns are especially high in the southwestern and Mediterranean coasts, which display low-lying areas and erodible beaches and wetlands. Adaptation guidelines must be applied at local and regional scales, and climate-compliant land use practices are encouraged (Le Cozannet et al. 2013a, b; 2015).

The tool described in this chapter proposes a first evaluation of sea-level rise impact and allows scientists to identify local areas where more detailed studies should be applied. This Web portal is not available on Internet yet. It will be publicly released once the pedagogic and scientific texts allowing interpreting the risks illustrated by the computed flood maps are available. Our architecture combines Web approach, GIS functionality, and a capability to process large data sets. The main input is a Digital Terrain Model (DTM) of French coastal area, composed by 25,000 tiles.[6] Functionalities are accessible through a Web portal proposing an interactive interface. All the tiles for the French coast are pre-computed using the DTM at 25-m pixel size. A user selects the area of interest at regional or local level by zooming in and out. At a scale smaller than 1:50 k, the Web browser automatically displays pre-computed data sets. If the user zooms into a more detailed scale (for example, 1:10,000) for which no tiles are already computed, the process can be launched to compute new flooded tiles on the DTM at 1-m pixel size. A user may easily choose what sea-level rise increment to display from a list depending on the current scale; this does not require any new computation, as every level is computed in the same process.

[6] A DTM tile is a grid representing a surface of 1 km^2 on which each pixel stores the elevation value for an area depending on the scale; in a 1-meter DTM tile, each pixel represents 1 m^2.

12.3.2 Tile Management

The computation of local flood maps is based on high-resolution topographic data (Li-DAR)[7]: a 1-meter DTM covering the French coastal area and composed of 25,000 tiles (each file being 20 MB in size, totaling 86 GB) covering a one square kilometer area. We also associated the Highest Astronomical Tide (HAT)[8] to each tile. In order to deal with different scales, we use a 1-meter DTM (local scale) to derive a 10-meter DTM (regional scale) and 25-meter DTM (national scale). At the national scale (scale smaller than 1:50 K), the end user visualizes pre-computed. French coastal flooding for a sea-level rise of 50 cm and 100 cm, and from 2 m to 10 m (1 m step).

At regional scales (smaller than 1:5000), flooding is computed on-the-fly on the 10-meter DTM. In the same way, at local scale (more than 1:5000), flooding is computed on-the-fly on the 1-meter DTM. At this high-resolution scale, flooding is computed for a sea-level rise from 10 cm to 90 cm (10 cm step), and from 1 m to 10 m (1 m step). When computation is running, the resulting new flooded tiles are displayed as they are made available. Even at local scale, when flooded tiles are already available because computation was previously launched by another user, they are automatically displayed.

12.4 Technical Background

In this section, we will briefly present the technologies and standards used for the implementation of the prototype.

12.4.1 Web Services

The implemented Web services are components publishing processes and distributing georeferenced data sets through the Internet. We can distinguish two main categories. Firstly, there are static Web services which always publish the same pre-computed data. They are synchronous and requested using parameters such as the area of interest and the required output format. A client application will request the service and then wait for the answer. This answer is fast delivered since the data was pre-computed. A second category of Web services is relative to "on-the-fly" computation. Such services are usually asynchronous as execution time may be long. For each request, a session is launched, which can then be requested for

[7]The product used is RGE ALTI® by IGN: http://professionnels.ign.fr/rgealti.

[8]Highest Astronomical Tide (HAT) is computed from SHOM data (product RAM 2014 v3 http://refmar.shom.fr/).

intermediate results or to get the status of execution. In the end, the result produced is a new data set. In order to provide standard Web services which can be registered in official registries such as the Global Earth Observation System of Systems (GEOSS) Component and Service Registry, we implement Web services according to standards defined by Open Geospatial Consortium (OGC):

- Web Map Service (WMS): services delivering pre-computed data sets as geo-referenced map images;
- Web Feature Service (WFS): services delivering pre-computed data sets in a standardized text format; and
- Web Processing Service (WPS): (a) synchronous services executing a process, allowing on-the-fly computing.

We also plan to publish Web services in the European initiative Infrastructure for Spatial Information in Europe (INSPIRE) such as a WFS delivering pre-computed data about flood risk computed for administrative areas and land cover, according to the INSPIRE official data specification on Natural Risk Zone. We use open source software to implement standard OGC Web services: MapServer (WMS1.3.0) and GeoServer (WPS 1.0.0 and WFS2.0).

12.4.2 Geoprocessing Orchestration

Standard Web services are stand-alone final products which can be registered in official registries. As for end users, we implemented a Web client displaying pre-computed data sets, and for large scale, allowing the launching of on-the-fly computation to obtain high-resolution data sets which are not pre-computed to spare disk space. The orchestration tool is a cornerstone to handle these interactions, and it has to meet several requirements:

- Handle orchestration of requests to the Web services;
- Manage both synchronous and asynchronous requests to the computing architecture;
- Consume intermediate results and handle possible fails and delays in the process;
- Be able to cancel the process during the computation.

We tested several scientific orchestration tools and finally implemented Taverna[9] (Horváth et al. 2014). This open source software includes several connectors and a graphical interface to build the workflow. Taverna also offers a server to run the processes. On the other hand, for each request made through Taverna, there is a few seconds time lag before the server is launched. As a result, it is only suitable for asynchronous usage.

[9]http://www.taverna.org.uk/.

12.4.3 High-Performance Computing

The need for large-scale processing capabilities in order to shift from static (pre-computed) to dynamic spatial data architecture has been widely recognized. Indeed, the challenge of delivering detailed information at local scale relies on the availability and the efficient exploitation of parallel-processing resources. Data transfer between the dedicated storage attached to the computing system (i.e., high-performance parallel file system) and the heterogeneous and virtual storage space associated with the Web components (i.e., virtual machines accessing classical networked storage) is consequently critical. The data have to be kept as close as possible to the processing facilities in our distributed system. Efficient scheduling of the computing tasks represents another issue. The batch scheduler is in charge of both the correct usage of the physical resources available and the provision of information to the Web client in terms of job status, execution time, or failure.

12.5 Implementation

12.5.1 Architecture Overview

We designed our scalable architecture based on the components described in Sect. 12.3. The challenge was to propose a user-friendly interface maintaining good performance and interactivity while computations are running on big data sets. The Web client is not waiting for an answer while computations are running. The user can still add other layers, zoom in and out, or change the sea-level rise. When the data sets are computed, they are automatically displayed by the Web client. The management of the complex workflows involved represents another challenge (Mattoso et al. 2015). In order to fulfill those requirements, we implemented a distributed architecture composed of:

- In the public network, a Web server[10] running the Web applications described below:
  - The WebGIS client.[11]
  - The Web Map Service (WMS)[12] and Web Feature Service (WFS).[13] These services publish the flood maps through the Internet according to Open Geospatial Consortium (OGC) standards. The pre-computed data sets are manually configured in the software. As for the on-the-fly computation, the WPS automatically deploys and configures data sets resulting from the

[10]Software used are apache (https://httpd.apache.org/) and tomcat (http://tomcat.apache.org/).

[11]Implementation with Javascript language.

[12]Software used: MapServer (http://mapserver.org/).

[13]Software used: GeoServer (http://geoserver.org/).

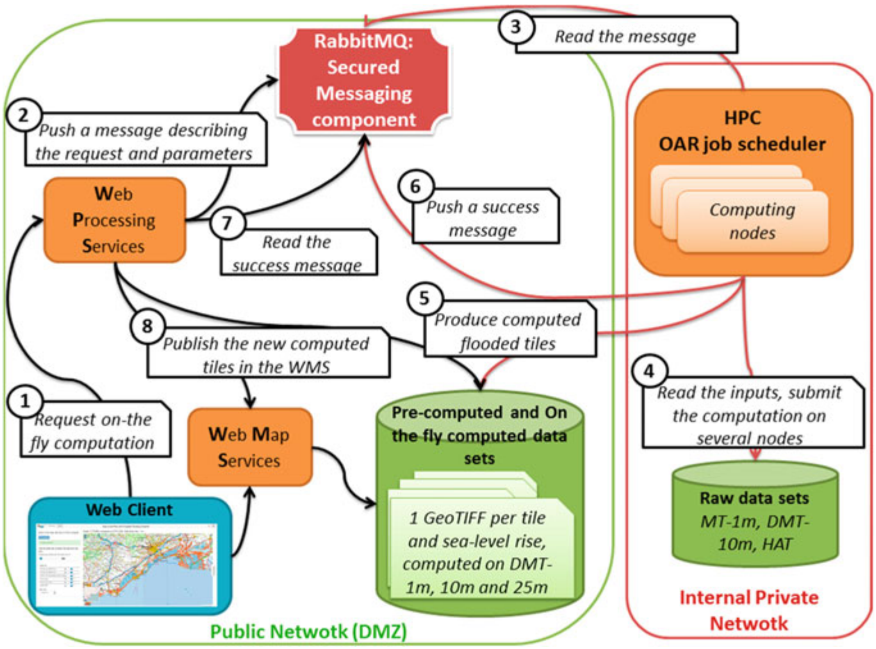

Fig. 12.1 Architecture of the application, showing the main workflow: Web client request, to the HPC through the RabbitMQ messaging component, then back to the display of results. The arrows from HPC represent communications from the private (protected) network to the public network

process through WMS and WFS: The Uniform Resource Locators (URLs) of these WFS and WMS are part of the WPS answer.
- The Web Processing Service (WPS).[14] This service publishes the flooding computation process according to the OGC standards. The parameters of this service are the area of interest and scale.

- High-Performance Computing facilities dedicated to fast processing of data and hosted in the protected private network. The process itself is implemented in Python and exploits GDAL library to deal with GIS formats.
- Messaging components allowing secured communications between Web services (hosted in the public network) and the processing architecture (hosted in the intranet-protected network). This component allows to avoid any direct communications from the public network to the private one.

The detailed workflow is illustrated in Fig. 12.1. Implementing a Web processing service (WPS1.0.0 from OGC standard) allows the launching of asynchronous computation on the HPC components on large data sets: high-resolution Digital Terrain Model (DTM) in our case. The WebGIS client does not wait for the

[14]Software used: GeoServer (http://geoserver.org/).

Table 12.1 Hardware characteristics of the high computing cluster used in this study

Peak performance	# computing nodes	# cores per node	Network	File system	Storage
10 Teraflops	30	24	Infiniband	Luster	15 Terabytes

result while computation is running so the user can continue to interact with the client by displaying other pre-configured data sets, and by zooming in and out. As intermediate results are provided, they are automatically published in the WMS and WFS and displayed by the client. The user may also choose to stop the ongoing computation by sending a specific dismiss request to the WPS. The Web client always displays the map automatically created from the tiles by the Web Map Service, as they are made available. The client can still switch from one data set to another, from one sea-level rise to another, while the HPC is computing new tiles.

All data sets are shared between the Web application server and the high-performance computing component through a networked storage. Throughout the computation, a dedicated parallel file system (Luster) is being used in order to maximize the I/O throughput speed.

12.5.2 High-Performance Workflow

Table 12.1 details the characteristics of the high-performance computing architecture available at BRGM. Following the PRACE[15] European HPC pyramid, this 10 Teraflops system corresponds to a Tier 2 architecture mostly available at universities and regional computing centers level.

Using this architecture allows an efficient calculation of flooded tiles by parallelization of the process on several nodes and cores. This strategy allows us to fully benefit from the underlying computing power available and significantly speed up the overall workflow even for finer resolution scenarios. The result of the computation for one tile is up to 20 new flooded tiles in GeoTIFF format: one per sea-level rise increment.

These computing resources are shared between several users. In order to meet the requirements of heterogeneous workloads, we use the OAR[16] job scheduler to distribute the requests of computation over the multicore nodes. The specific computations corresponding to our Web-based information system are scheduled with a highest priority. Depending on the available resources, the estimated execution time is sent to the Web application. Otherwise, the application is notified that the computing request is pending and a warning message is provided to the end user.

[15]http://www.prace-ri.eu.

[16]http://oar.imag.fr/.

Usually, such HPC resources are hosted within intranet-secured networks, while Web applications are in a public network (also called the Demilitarized Zone—DMZ[17]) accessible via the Internet, only protected by a firewall. In order to protect the main infrastructures and databases, **no** communication from DMZ to internal secured resources is ever allowed. Servers installed in the DMZ network do not see servers in the internal network; they cannot communicate. In our architecture, a secured communication between these two areas is based on a central messaging component (RabbitMQ[18]) implementing one-direction-only communications between Web services and HPC components. The Web components push messages. The internal HPC component checks and reads new messages. There is no direct connection from the Internet area to the internal network, only connection from internal network to DMZ. This is illustrated in Fig. 12.1: All the communications between internal-protected networks and other servers are initiated by the HPC component; network communication from DMZ to internal network is not allowed.

In our architecture, the WPS server submits two kinds of requests: the submission and the cancelation of a calculation. The submission of a calculation means that the WPS server submits a request message to the RabbitMQ component. The HPC cluster is always checking for new messages. Whenever it gets a request, it copies all the input data (including DTM tiles) to the Luster file system and then submits the flood calculation job to the OAR job scheduler. Depending on the number of tiles to process, the resolution, and the available computing resources, the HPC cluster pushes a message in the RabbitMQ component describing the ongoing jobs (identifier, estimated time start date, status). The information is updated at each step of calculation, through to the end of the job. Figure 12.1 summarizes this workflow.

12.6 Conclusions and Perspectives

This chapter presents a scalable spatial data architecture devoted to coastal climate services. Mainly reusing off-the-shelf components, we designed a dynamic information system able to deliver accurate sea-level elevations at various scales. By making sure the system is built in compliance with OGC standards for Web services, there is a guarantee to maintain interoperability between our architecture and other initiatives. At the heart of our Web-based GIS, the exploitation of supercomputing architecture provides scalability and performant processing for the user. The efficiency of this strategy strongly depends on having fine control over both the scheduling of the processing tasks and the location of the data. Our efforts to extend the capabilities of our architecture are ongoing and twofold. The processing

[17]Demilitarized Zone: network area protected and separated from internal network by firewall which filters or forbids network connections from Internet network.

[18]http://www.rabbitmq.com/.

capabilities of our system could be extended to take into account the growing amount of environmental data available.

Climate services to support coastal adaptation decision-making will require developing spatial data architectures such as those presented in this chapter. In this work, we have shown that the challenge arising from the large amount of data (especially Li-DAR digital elevation models) can be addressed in a way that preserves the system ergonomics for non-specialized users. In future upgrades of similar systems, physically based modelling tools including uncertainty quantification strategies should be implemented. Combinations with other data sets such as spatial descriptors of the economy, urban planning, and geology will be very valuable and required by decision-makers to improve communication on climate change impacts in coastal areas. Notwithstanding the necessary simplifications of such large-scale semi-automated systems, we believe that their ability to provide predictive analytics regarding coastal climate change will be extremely useful to support coastal adaptation.

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Sylvestre Le Roy is a French engineer specialized in natural hazards. Working for the French Geological Survey BRGM for 11 years, he has specialized in hydrodynamic numerical simulations applied to coastal hazards evaluation in complex areas (urban areas, nuclear facilities). He is mainly involved in the subject of coastal flooding from various origins such as tsunamis, storms and cyclones, as well as wave overtopping.

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Chapter 13
Coral Reef Monitoring Coping with Climate Change, Toward a Socio-ecological System Perspective

Gilbert David and Jean-Pascal Quod

Abstract Coping with climate change is a crucial issue for coral reef monitoring. This chapter advocates a holistic approach based on a Driver–Pressure–State–Impact–Response (DPSIR) model in order to build a dashboard of indicators. Coral reefs should be studied as a social ecological system, which means to (a) monitor the ecosystem and the socio-system in the same areas, (b) involve stakeholders and citizens to improve the spatial representativeness of monitored stations, (c) monitor the dynamics of watersheds, including mapping the land use changes and modeling the soil erodibility. The dashboard of indicators should prioritize adaptive management at the local scale instead of reporting at the worldwide scale.

Keywords Climate change · Coral reef monitoring · Social ecological system
Citizen science · Adaptive management

13.1 Introduction

Coral reefs are not only one of the best productive ecosystems in the world, they also provide a wide range of ecosystem services and uses to coastal populations. Thus, they can be seen as a social ecological system (Cinner et al. 2009; Shackeroff et al. 2009; McClanahan 2011; Kittinger et al. 2012). Their future is highly questionable. Everywhere the health of coral reefs has declined (Bellwood et al. 2004; Carpenter et al. 2008; Wilkinson 2008). Faced with this evolution, monitoring of reef health status has been carried out since 1998 on a regular basis by the Global Coral Reef Monitoring Network (GCRMN). Since 2003, human pressures

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on reefs are commonly monitored on a regional basis under the SocMon initiative (Global Socioeconomic Monitoring Initiative for Coastal Management). Both monitoring systems are organized separately and lead to a dual vision of coral reefs, composed, respectively, of an ecosystem and a socio-system with no mention of any social ecological system.

Climate change introduces a new deal in the future of reef ecosystems (Van Hooidonk et al. 2016). Firstly, ocean acidification is a new threat (Gattuso et al. 1998; Guinotte and Fabry 2008; Anthony et al. 2011; Kleypas and Langdon 2006). Coral calcification could decrease by 17–35% between 1990 and 2100 (Kleypas and Langdon 2006). Secondly, the mechanical destruction of branching corals by waves and cyclonic swells as well as coral bleaching could be more frequent and intense (Hoegh-Guldberg 1999; Hoegh-Guldberg et al. 2007). These growing threats induced by climate change will increase the risk of weakening the resistance and resilience of coral reefs when they are still exposed to human-induced threats. A holistic perspective is required in this context. Coral reefs should be studied as a social ecological system which means to bridge coral ecosystem monitoring and social system monitoring and to build a dashboard of indicators devoted to the local management of coral reefs.

Ideally, this dashboard should help to build a Driver–Pressure–State–Impact–Response (DPSIR) model (Kristensen 2004; Pirrone et al. 2005). It should include five types of indicators dealing with: (a) the *driving forces* (anthropogenic activities and climate change) causing pressures on the reef; (b) the *pressures* which are stresses affecting the functioning of the coral reef ecosystem as pollution and coral bleaching; (c) the *state* of the coral reef ecosystem which reflects its usual environmental conditions, including temperature, salinity, acidity level; (d) the *impacts* of pressures on the coral reef heath; and (e) the *responses* to give in order both to reduce them and decrease the vulnerability of reefs to these pressures. Building such a monitoring system requires assessing firstly the protocols used for monitoring the reef ecosystem and its social system, and secondly their ability to produce accurate indicators which fit with the DPSIR model. This is the purpose of this chapter which is structured in three parts. The first deals with the reef ecosystem monitoring, the second with the reef social monitoring, the third with recommendations to build holistic monitoring devoted to the coral reef social ecological system.

13.2 The Reef Ecosystem Monitoring

The first worldwide reef health status assessment was presented in Guam in 1992 during the seventh symposium of the International Society for Reef Studies (ISRS). The responsibility of human pressures in the ongoing degradation of reefs has been clearly demonstrated (Richmond 1993). In 1994, these alarming results led eight countries (Australia, France, Japan, Jamaica, the Philippines, Sweden, the UK, and the USA) plus the United Nations Environment Programme (UNEP) and the World

Bank to propose an International Coral Reef initiative (ICRI).[1] The initiative aims to improve management practices and environmental awareness of politicians and encourages the sharing of information on the health status of reef ecosystems. In 1995, ICRI has set up the Global Coral Reef Monitoring Network (GCRMN). It includes six partners of ICRI[2] and is organized in four regional nodes (Caribbean, Indian Ocean, Pacific East, and South East Asia). Their task is to coordinate the coral reef health monitoring by mobilizing national stakeholders, mainly scientists, engineers, and consultants.

The standard method proposed is based on visual observation of the seascape (reef flat and reef slope) carried out on a regular basis (at least once a year) along transects of 20 m length for benthos and 50 × 5 m for fish according to Conand et al. (1998). Benthic organisms (hard corals, soft corals, algae), mobile invertebrates (starfish, sea urchins, shells) and abiotic substrate (dead coral, sand, detritus) intercepted on the transect in modes Line Intercept Transect (LIT) or BELT transects are noted (Fig. 13.1). Other protocols using the Point Intercept Transect (PIT) can also be applied, but they produce the same kind of datasets. When skills are available, data are processed at local and national levels and stored in national or regional databases. They are also supposed to be transmitted to the Wordlfish Center Reef base for storage and analysis at the world scale. These results are used for regional and global syntheses conducted by the GCRMN (Wilkinson 1998, 2000, 2002, 2004, 2008; Chin et al. 2011; Jackson et al. 2014).

These GCRMN standard protocols are operated mainly by marine-protected areas (MPA) managers and marine experts, including scientists. Outside MPAs, which benefit from dedicated resources, this type of expert monitoring is expensive in terms of technical and scientific resources. In fact, the ability to carry out ecological monitoring at the national scale every year (which is the original aim of GCRM) is reduced to a very small number of countries. Thus, there is a critical need for training to improve this situation and sustain the collection of data in both space and time on a regular basis. What is required is less expert-level training, where the emphasis is put on taxonomy of marine fauna and algae than ‘medium tech training’ found in Reef Check, in order to involve more and more local stakeholders to monitor activities and improve the spatial representation of monitored stations.

Reef Check is the only worldwide program of participatory science dedicated to coral reefs monitoring. It began in 1998. Today, more than 4000 sites are surveyed with the same protocols. Once collected and certified locally by the country coordinator and by the Reef Check foundation headquarters, data are shared on an

[1]Since 2016, 35 governments, 17 NGOs, and international or regional organizations such as the Pacific Community Secretariat and the Convention on Biological Diversity are members of ICRI.

[2]The World Fish Center (previously International Center for Living Resource Management), UNESCO International Oceanographic Commission, UNEP, IUCN (World Conservation Union), International Meteorological Organization (IMO) and Australian Institute for Marine Science (AIMS).

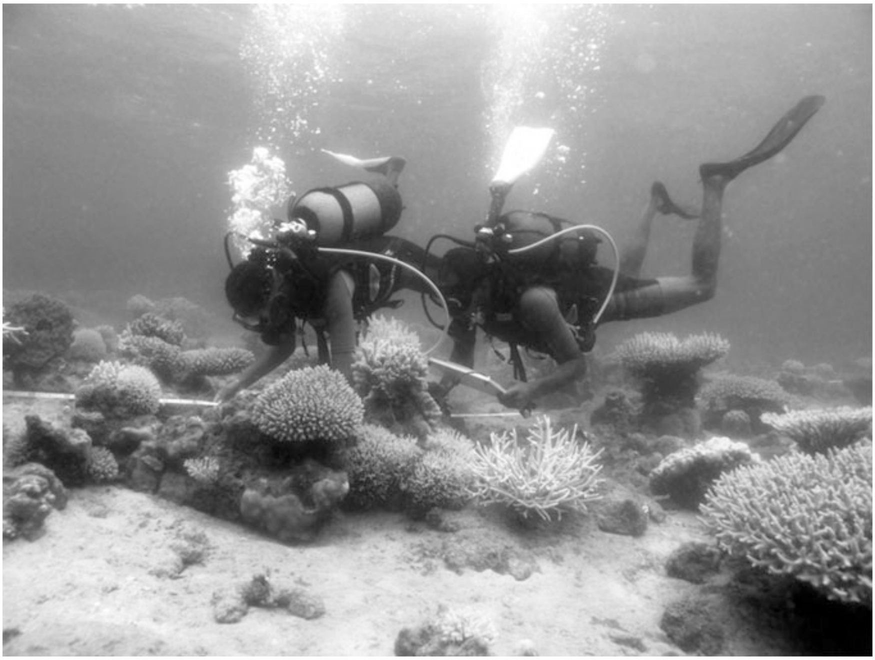

Fig. 13.1 Point intercept transect implemented by young volunteers in Mayotte, to monitor changes in coral cover (image: A Jamon)

open access portal named « global reef tracker » where raw data can be downloaded (http://data.reefcheck.us/).

At the expert level, as at the Reef Check level, all the protocols of coral reef monitoring use the Coral Cover of Hard Corals (CCHCS) as the main indicator of coral reef health status. Changes in CCHC reveal impacts of natural and/or anthropogenic pressures on the coral reef ecosystem. Coral bleaching is a key threat identified in relation to seawater warming. Massive coral bleaching events have been reported during the last decades, especially during the 1997–1998 El Niño event in the Indian Ocean where large areas of coral reefs died. 2015–2016 is considered the third global coral bleaching event of the last 100 years. Its impacts on the coral health are not yet assessed at the global scale, but it seems extremely severe in some Pacific Ocean islands. For instance, all shallow reefs of New Caledonia were affected during the 2015–2016 austral summer. The causality chain (driving force, pressure, state, impact) can be easily identified when such acute events occur (e.g., El Niño, cyclones). This is not the case when the impact observed on the transect line is chronic and/or multi-sourced. First, protocols focus on CCHC, which are supposed to assess the coral reef health status. But all the changes in coral reef health are not clearly revealed by CCHC. Thus, by increasing temperatures and the weakness of hard corals, climate change will increase the occurrence of coral diseases and microalgae blooms such as those involved in ciguatera fish poisoning (which can significantly affect human health), with no impact on CCHC. Second, in the case of human pressures not previously identified, it is impossible to establish a causal link between the unidentified pressure, the coral reef health status assessed by CCHC and the impact of this pressure. Consequently, no response can be carried out to reduce the driving forces responsible for the pressure.

In their manual *Monitoring Coral Reef Marine Protected Areas*, Wilkinson et al. (2003) pointed out that marine-protected areas are a great place to jointly conduct ecological and human pressure monitoring. This assumption is relevant, but reality shows two facts. First, the socioeconomic monitoring protocols are still rare, even in MPAs. Thus, the natural reserve of Réunion is the only MPA of the French overseas where a socioeconomical monitoring was carried out for assessing the impact on the reserve (Thomassin and David 2008). Second, trying to establish a bridge between an ecological monitoring and a sociological monitoring is not easy when such monitoring systems have been designed to operate independently. This is the case of the SocMon protocol, whose GCRMN made the promotion at the world scale from 2003 to 2013 to become the international standard for socioeconomic monitoring.

13.3 The Reef Socio-system Monitoring

13.3.1 The SocMon Initiative, for a Global Socioeconomic Monitoring of Coral Reefs

The SocMon initiative was launched in 2003 and was largely driven by the socioeconomic manual for reef management published 3 years ago by AIMS (Bunce et al. 2000). A guide was produced in each of the five regions involved in SocMon. Guides for Caribbean and Asia were published in 2003 (Bunce and Pomeroy 2003; Bunce et al. 2003). The Indian Ocean and Pacific guides were published in 2006 (Malleret-King et al. 2006) and 2008 (Wongbusarakum et al. 2008). It should be noted that the guide for West Africa is not yet published, but the Caribbean guide is widely used in Central America and Brazil. These five regional guides are completed by two kinds of methodological documents (Fig. 13.2). The SocMon Trainers' guides aim to provide methodological materials to be used during SocMon training workshops where the target audience are field workers in charge of data collection.[3] The SocMon Dissemination Guidelines aim to improve the dissemination of SocMon results to local populations. Over the years, the SocMon initiative has become a worldwide system for collecting data and

[3]The Socioeconomic Monitoring by Caribbean Challenge MPA Managers Project offer several good examples of such trainer's guides (Pena and Blackman 2011; Daniel 2013; Harvey et al. 2013).

knowledge on the socio-reef system and its relationship with the reef ecosystem. Data collected by field workers are planned to feed a global database whose implementation was initiated in 2008. This 'global Socioeconomic Monitoring database' aims to provide knowledge for advocacy at the international level and decision-making at the local level. The ambition of its promoters is to raise SocMon to a global monitoring network of the coral reef uses which could be the counterpart of the global coral reef health status monitoring network implemented by the GCRMN.

The implementation of SocMon has faced two major constraints: firstly, the scarcity of economic and social scientists, experts on the coral socio-system; secondly, the lack of financial resources to pay for field investigations conducted by newly trained SocMon experts.

A solution was found in the creation of a small technical team of SocMon experts in each of the five SocMon regions: the Caribbean and South America, Asia, the Western Indian Ocean (which integrates eastern coast of Africa), the Pacific Ocean and West Africa. Its purpose was twofold: firstly, write a SocMon guide adapted to the regional context; secondly, carry out intensive training at the community level in order to involve in the SocMon monitoring activities people with the ability to implement the guide's instructions and collect the information required for local management and for reporting at the global level. This emphasis put on the participation of local people to collect data derives from the increasing development of participative sciences. It fits much more with the Reef Check model of reef health monitoring than with the GCRMN model. However, the very large number of parameters to be collected and the willingness of its promoters to store these data in a global database managed by GCRMN for reporting at the world scale level transforms the SocMon initiative in a model much more ambitious than Reef Check.

13.3.2 The SocMon System on the Ground, the Utopia of Genericity

GCRMN and SocMon share the same philosophy in terms of as to how and why monitor reef ecosystem and socio-system. As emphasized Wilkinson et al. (2003, p. 2), "the monitoring is the gathering of data and information on coral reef ecosystems and its users on a regular basis, preferably for an extended period of time". For their part, Malleret-King et al. (2006, 3) specify that:

> …Socioeconomic monitoring is about measuring and detecting changes over time in order to make timely and informed management decisions. It involves the long-term collection of social, cultural, economic and governance information of people, groups, communities and organizations at regular intervals, which is analyzed and fed back into the planning and decision making process. Monitoring is not an end in itself but a means to improve or evaluate management.

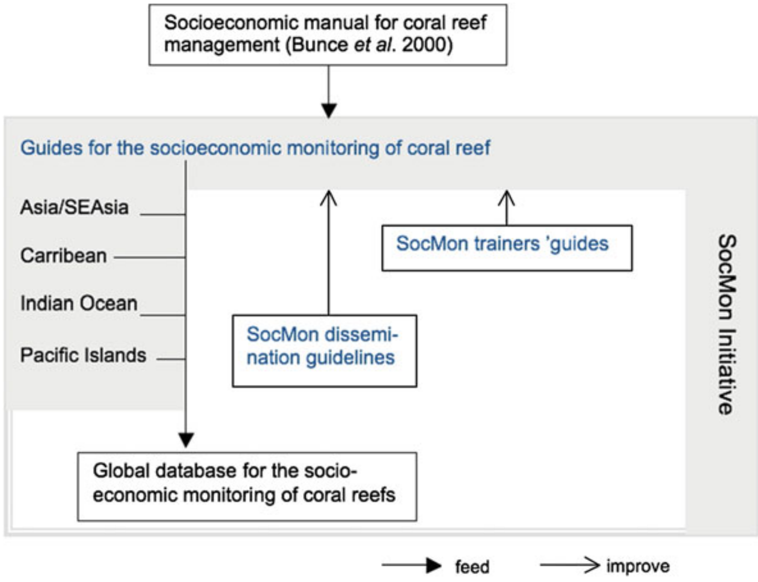

Fig. 13.2 SocMon initiative system

This will to use the results of monitoring in the management of coral reefs (why) raises questions as to when we observe the implemented protocols within the framework of GCRMN or SocMon (how).

Indeed, these protocols are intended to be versatile enough to bridge two purposes for data collecting: (a) reporting on a global scale, leading to send the information gathered locally to a global database, and (b) local management of coral reefs. But each of these uses has its own logic in terms of relevance of the information collected. Reporting requires that implemented protocols are the most generic as possible in order to compare the monitoring stations. Local management requires the social, economic, and local environmental contexts to be taken into account by the survey protocol.

These two approaches are contradictory a priori. On one hand, the monitoring protocol may favor the genericity of collected data and drive the reporting as the main objective. Assuming that this kind of protocol can be applied to the land and resources management, and to decision-making on all the coasts of the tropical zone, from Caribbean to Pacific, issues a simplified assumption: the management of tropical coastlines shows little spatial and time variability. But this assumed homogeneity in terms of coastal management is purely intellectual construction that does not stand in confrontation with reality on the ground. Even in the case of MPAs, the heterogeneity of geographical, administrative, socioeconomic and cultural scapes, and the stories of different institutional arrangements, often lead to contrasting governance and management contexts that vary from one site to another. This finding, which applies to the MPAs, also applies to all coasts of the tropical zone. The only way to try to reconcile this great heterogeneity of governance contexts and the need of genericity of indicators supposed to sustain management is to multiply the variables collected. This reduces the risk of assuming that some of them may not be relevant. In contrast, this increases the risk of many variables being either completely useless or of little use to coastal managers because they do not suit the local conditions or do not meet the needs of the managers. In this context, any attempt to build a dashboard of indicators also proves illusory because it is impossible to organize over a hundred, or even hundreds, of indicators into a coherent whole allowing the control of the coast, especially if only a small portion of these indicators is relevant. On the other hand, the monitoring protocol may favor local management. This is what the SocMon manual for the Indian Ocean suggests,[4] but then the monitoring protocol lacks genericity and it becomes difficult to use the data collected for reporting at the regional or global scales.

Another weakness of the SocMon protocol stands in the fact that the study of the reefs' uses is not done 'in situ' by observing these uses but by questionnaires administered to coastal populations who are supposed to be potential reef users. This method drives a true sampling problem. While the size of a community can be approached by the population census, the breakdown of population according to the uses they make of the coral environment is unknown. Without knowing the total number of practitioners for each use, it is not possible to set the minimum size of the sample to investigate to be representative of the 'mother' population of practitioners. The problem is even more complex when the same person practices several uses (which is common). In urban or peri-urban areas, the use of reefs can be very casual. The population of users is extremely difficult to identify. It includes part of the local coastal population and inland people who can drive or be driven to the reef coast. In this context, sampling the population to identify practitioners of each coral reef use is a very time-consuming task and results are unsatisfactory, especially when investigators are not adequately trained or are not competent enough. Thus, the risk is high that the information collected is hardly robust.

But then how to explain the global success enjoyed by the SocMon initiative? This success may be a clear proof of the relevance of indicators produced by SocMon. This argument is easily refuted. SocMon, being the first socioeconomic coastal monitoring protocol which is worldwide implemented, provides new information for MPA managers who are its main users. Essentially biologists by training, they discover the world of socioeconomics and have little incentive to criticize the initiative.

[4]It is important to emphasize that SocMon is not a rigid set of guidelines. The user of SocMon, the socioeconomic monitoring team, is expected to select variables and methods appropriate to their site needs (Malleret-King et al. 2006).

13.4 Socioeconomic Monitoring of Reefs Taking into Account Climate Change Risks

As highlighted in the introduction, climate change requires rethinking the protocols of coral reefs monitoring. So far, little has been done in this area. There has been only an addendum to SocMon guide which deals with social indicators of the vulnerability of communities to climate change (Wongbusarakum and Loper 2011). However, the SocMon logic remains unchanged. To overcome the weaknesses which have been highlighted, four recommendations can be made, knowing that the main purpose for coral reef monitoring remains its improved management:

- Rather than a single protocol performed to collect a large number of variables, which is assumed to be generic enough to satisfy all coastal managers but which is in reality scarcely relevant to the specific needs of the latter, it is far better to build protocols which are targeted to local realities. Such protocols can only collect a reduced number of variables. But they are all relevant and can be used to draw a dashboard of indicators, which is a very relevant coastal management tool (Pelletier et al. 2004).
- Surveys such as SocMon are based on random sampling. They aim to identify potential users of the coral reef ecosystem among the local population. They are mainly designed for small communities of rural areas where most people are reef users. At the opposite scale, in urban or peri-urban areas which are highly populated, they are very time consuming and finally inefficient. In such crowded places, the probability of meeting the different kinds of reef users in the sample is very small. It is much more relevant to approach users by observing their uses of the reef,[5] as was done in Réunion Island. During the VALSECOR program (socioeconomic value of coral reefs of Réunion Island) from 2002 to 2005, the reef users were directly investigated on the seafront or on the beach (Mirault 2006). This was also the case during the socioeconomic characterization of the zero state of the marine park of Réunion island (Thomassin et al. 2011). Ultra-light overflights offer new opportunities. They provide a comprehensive picture of the reef frequentation by its users (Lemahieu et al. 2013). Once identified the population of practitioners, the survey of each use could then be conducted by questionnaires and interviews with a representative sample, geographically stratified according to the places of practices.
- To understand the changes of the Coral Cover of Hard Corals (CCHC), a socioeconomic monitoring should be associated with the ecological monitoring in order to assess the human-induced pressures which may impact on the coral reef health. When the causality chain driving the forces, pressures, impacts, and states can be identified, it will become possible to provide an answer by asking users to reduce their riskier practices and uses that could impact on the reef.

[5]This is the opposite of the SocMon method which comes from the users to the use.

- In islands with high elevations, no effective socioeconomic monitoring of coral reefs can be carried out without consideration of the watershed. The soil leaching is enhanced by human activities, including changes in land use associated with agriculture dynamics and urbanization. The latest considerably increases impervious areas and runoff. Knowing the soil type, duration and intensity of rainfall, topography, and land cover, a soil erodibility model can be performed using the revised universal soil loss equation RUSLE (Dumas et al. 2010; David 2012). A runoff model could bridge the RUSLE model in order to build a DPSIR model coming from the rainfalls to the turbid plumes impacting the coral reefs and to the responses in terms of erosion risk reduction to improve the reef health.

The search for a causal relationship between the natural and anthropogenic dynamics of watersheds and the damage observed on coral reefs requires a broader perspective that encompasses the entire watershed upstream of the reef monitoring station. Two key elements must be considered: (a) the origin of hazards, be they pollution, erosion, and runoff; and (b) the concentration of these hazards when they come in contact with the coastline via the hydrographic system. Their study requires a two-step protocol: first, mapping the land use dynamics using satellite imagery; second, modeling the erosive potential risk via the RUSLE.

This coupled monitoring is a significant problem in terms of cost and availability of human resources. In the framework of expert protocol, the risk is high that only few stations are monitored by country. The collection of data by citizens can greatly reduce the cost per station and thus allow to increase the number of stations being monitored (Theobald et al. 2015; Roelfsema et al. 2016). Yet, it is necessary to organize this participative data collection. Regarding ecological monitoring, the Reef Check protocol is already widely used (Done et al. 2017). In the socioeconomic field, students from universities or high schools have been involved in this investigation. Positive results in this area have already been obtained in Réunion Island (Thomassin et al. 2010; Cillaurren et al. 2015). Regarding the dynamics of watersheds, the use of remote sensing to assess changes in land use and RUSLE modeling to estimate soil erodibility confirm that experts play a vital role. However, there is a place for citizen science to observe the practices of watershed users and watching episodes of erosion and runoff after heavy rains. Using a GPS for spatializing the information which is then processed in GIS with data coming from satellite imagery is another way to investigate. It implies the establishment of agreements between the experts who lend GPS and process data and the users who collect the geographical information in situ.

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Chapter 14
The Experience of the Brazilian Climate and Health Observatory: Seeking Interaction Between Organizations and Civil Society

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Abstract This chapter assesses the availability and usefulness of environmental, climate, population and health data in Brazil, with the aim of enabling the construction of indicators for monitoring the health-related effects of environmental and climate changes. This task was performed by means of thematic workshops held between 2009 and 2011, aiming to define the data to be made available, the data sources to be used and the integration strategies. Sentinel sites were highlighted, where some local problems relating to possible impacts of environmental and climate change were being studied. These workshops involved the participation of potential data users and producers, such as civil society members, governmental institutions and researchers. The local studies showed close correlations between climate variables and the incidence of vector-borne diseases, respiratory and cardiovascular diseases associated with exposure to smoke generated by fires, and waterborne diseases. The indicators selected provided support for academic studies and the development of technological innovations in the fields of climate and health. An integrative platform was built in order to disseminate health and climate information, original data, environmental and epidemiological indicators, news and technical publications. The Website also made it possible for these changes to be followed and debated within civil society.

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Vector-borne disease · Distributed data · Public participation

14.1 Introduction

Global environmental and climate changes have gathered pace over recent decades and are likely to impact on human health in various manners and intensities. Some of these changes have a direct impact on the health and well-being of the population, including the occurrence of extreme events such as heat waves, hurricanes, storms and floods. However, their impact may be mostly indirect and mediated by changes in the environment, such as changes to ecosystems, their biodiversity and their biogeochemical cycles (McMichael et al. 2006).

The groups of diseases that may be affected by environmental and climate changes include vector-borne diseases, respiratory and cardiovascular diseases, waterborne diseases and a variety of health problems resulting from prolonged drought or floods, such as hunger, malnutrition and mental illness. Vector-borne diseases, which are more prevalent in countries with a tropical climate, have been singled out as one of the main public health problems that may be worsened through global warming. The transmission areas of these diseases may expand towards temperate regions and higher-altitude zones, which is of special concern for the developed countries of North America and Europe (Hales et al. 2002; Peterson and Shaw 2003; WHO 2004). Likewise, changes in temperature, humidity and rainfall patterns may exacerbate the effects of respiratory diseases, along with altering the exposure conditions relating to atmospheric pollutants (Ignotti et al. 2010; Artaxo et al. 2005). Global climatic changes may also increase the incidence of waterborne diseases by increasing the vulnerability of water supply systems and threatening water sources by contamination or shortages (Lee and Schwab 2005).

In these and in many other cases, climatic events and cycles are closely related to land use patterns and societal appropriation of natural resources. For example, the process of urban densification produces and concentrates heat over a portion of the land surface, at the same time climatic changes will particularly affect cities. It is also important to emphasize that the impact of these changes on people's health varies enormously, depending on the degree of vulnerability of population groups, their capacity for adaptation and their resilience (Tong et al. 2010). It is clear that different populations living in differentiated spaces present distinct constitutions for their vulnerabilities (Wilhelmi and Hayden 2010), i.e. the capacity of individuals, groups and communities to respond to potential danger triggered by events relating to environmental and climate change, over the course of health-disease processes (WHO 2010).

Observations on the population's spatial distribution and their dynamics, the local poverty indicators and social-spatial segregation, the situation of monitoring and control programs and the dynamics of the ecosystems surrounding the population are important components of climate change impact on health. The monitoring of these factors makes it possible to describe, measure and follow up the health-related vulnerabilities of population groups to potential future climatic scenarios and prepare the health care sector to cope with these vulnerabilities.

According to Vera et al. (2010), the main challenges relating to disseminating climate data are as follows: construction of partnerships between administrators, users and civil society and climate data producers; translation of long-term data into information at regional and local scales, in accordance with decision-making levels; maintenance of a global climate observation system; and procedures for integration, quality assessment, processing and analysis of databases of relevance for climate forecasting.

Despite the warming tendency at the global scale, a diversity of impacts is forecasted at the national level. Regional models predict some important impacts of climate change on the Brazilian territory such as the intensification of El Niño-Southern Oscillation (ENSO)-related events; an overall reduction of rainfall in the Northeast region; the increase of rainfall and floods in the Southern region; significant changes in mangrove, the Pantanal wetlands and the Amazonian ecosystems (Marengo 2007).

In view of the complexity of the processes involved between global environmental and climate change and its effects on health, it is essential to bring together and analyze data in such a way so as to provide society, government agencies and the media with information on these changes. To achieve this, a set of data on the dimensions of the climate, environment, population and health is required. The aim of the present study was to identify sources of data and options for making these data available and analyzing them, so as to make it possible to assess medium- and long-term trends. This chapter focuses on activities involved in the process of constructing the Brazilian Climate and Health Observatory, which is described here from the perspective of building predictive models and disseminating sentinel sites for monitoring climate and health.

14.2 Methodology

Given the diversity of sources of information on climate, environment, population and health, it was necessary to select a minimum dataset that would make it possible to identify medium- and long-term trends. This task was developed through thematic workshops and empirical studies on the relationship between climate and health involved in the stages of constructing a Climate and Health Observatory. An initial assessment of the possible impacts of these changes on infectious diseases was made by a group of public health researchers (Barcellos et al. 2009).

The aim of the Observatory is to integrate databases and bring together information obtained by teaching and research institutions to foster academic studies and develop technological innovations within the fields of climate and health. This platform will enable shared assessment of the information and production of knowledge on this subject. It is also expected that the Observatory will conduct analyses to identify the health effects of climatic changes so that warnings about health emergency situations caused by climatic events are issued, with subsequent monitoring.

The different phases involved in the implementation of the Observatory are shown in Fig. 14.1. In the first phase, data on climate, environment, population and health needed to be gathered and assembled. The second phase comprised data analysis and was the meeting point between experiences and theories, backed by access to data. It is important to emphasize that in Brazil, although few researchers have become acquainted with the topic of climate change and its impact on health, this issue has been gaining attention among the lay public and specialists in other fields. Researchers in the fields of entomology, sociology, public health and climatology, among others, can be mobilized to meet the growing demands for data on the relationships between climate and health (Strand et al. 2010). The Observatory promotes the use of data among these partners in order to foster studies on the impact of climate change on population health. These studies can evidence ongoing climatic processes, changing patterns of disease due to the climate events and produce early warning systems, such as recently performed for dengue fever (Lowe et al. 2012). Thematic workshops are important opportunities for gathering the previous experience of researchers and the needs of civil society in order to select the indicators and to foresee the contents and language of alert messages to the general public. The third phase, aimed towards communication, targeted the possible users of the system: public health managers, specialists and citizens. It was thus noted that simply making the data available would not allow full achievement

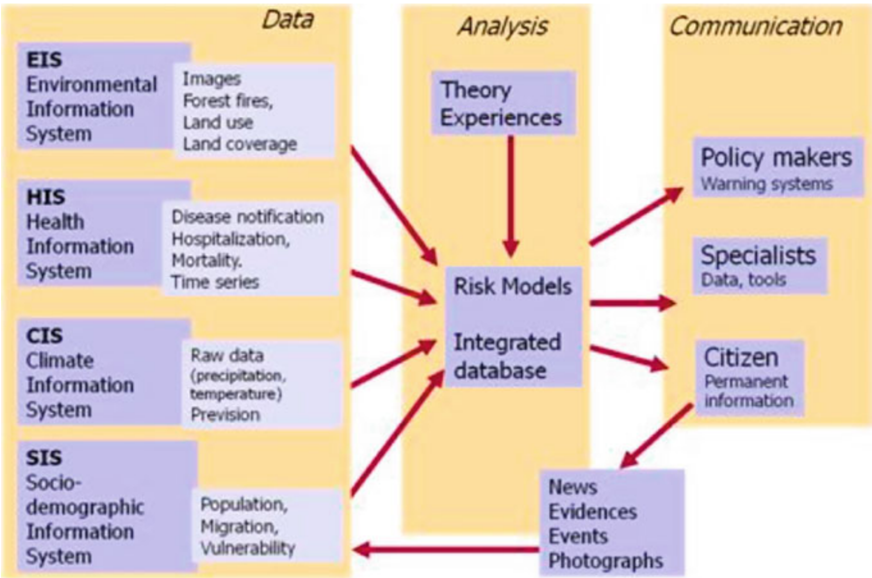

Fig. 14.1 Implementation phases of the Brazilian Climate and Health Observatory

of the Observatory's objectives: promotion of debate among these users regarding the trends and events relating to climate change was also necessary (COEP 2010).

The stage of evaluating the data available and establishing targets and inter-institutional protocols was accomplished through a workshop held in Brasilia, the national capital, in May 2009. Institutions that produce data in all fields of interest for the project (climate, environment, health and demographics) presented how they produce, store, update and make available their data and showed some of the applications used for generating information. The following were evaluated as information selection criteria: how up-to-date the data were; the period covered by the data; the data quality; the coverage at national level; and the levels of disaggregation and spatial resolution of the data.

The parameters established between data producers and potential users served as the basis for organizing new workshops of thematic nature, i.e. addressing health problems that might emerge or worsen through global environmental or climatic changes. In July 2010, a workshop was held in Manaus with local specialists and stakeholders with the aim of defining climate and health indicators that would be used to monitor the possible effects of climate change on the hydrological regime of the Amazon region and associated waterborne diseases, being Manaus a large city affected by extreme river events like droughts and floods. During this workshop, the results obtained through analysis of secondary data on climate, environment, society and health were discussed. Participants identified the relationships between the river water system and transmission of selected diseases, their seasonality and their long-term trends. The Observatory's third workshop took place in Porto Velho in October 2010, with support from the state and municipal health departments. The city has been affected by the coincident occurrence of forest fires, dry periods and atmospheric pollution. The main aims of the workshop were to discuss the situation of forest fires in the Amazon region, focusing on the state of Rondônia; and to select health indicators based on the data and models available, in order to evaluate and monitor the effects on human health and their relationship with exposure to atmospheric pollutants and the climatic variability of the region. The fourth workshop was held in Rio de Janeiro in November 2010, with the aim of identifying changes to the dynamics of vector-borne diseases, with emphasis on dengue fever, malaria, leishmaniasis, Chagas disease and yellow fever, as caused by climatic changes. The workshop was attended by specialists from the whole country who identified the diseases that are most sensitive to climate change, along with the environmental and social factors that affect this relationship. In December 2011, the Observatory's fifth thematic workshop was held with the aim of identifying the main health hazards relating to disasters and extreme climatic events. Rio de Janeiro was chosen to host this workshop because of the recent impact of disasters due to heavy rainfalls, causing landslides and flooding.

Due to the diversity of ecological and socio-economic situations over the country, local projections of the project were provided, focusing on specific health outcomes of climatic processes. The workshops also made it possible to identify sentinel sites where in-depth local studies on the relationship between climate and health, and their social and environmental intermediations, could be conducted.

14.3 Results

At the workshops involving data-producing institutions, data-loading models and the design for the Observatory's Website were established. The workshops identified priority data for monitoring the health-related effects of environmental and climatic changes, including:

(1) Environmental data: Spatial databases, containing information on deforestation and forest fires, produced and maintained by the National Institute of Space Research (INPE).
(2) Climatic data: Meteorological data, such as precipitation, temperature, humidity, as well as basic air quality indicators, produced and maintained by INPE and the National Meteorological Institute (INMETRO).
(3) Health data: Data from a variety of health information databases, such as mortality, hospitalization, disease notification and health service infrastructure, maintained by the Health Informatics Department (DATASUS) of the Brazilian Ministry of Health.
(4) Socio-economic data: Demographic census data as well as supplementary spatial features such as political boundaries, river and water bodies and highway maps, etc., produced by the Brazilian Institute of Geography and Statistics (IBGE).

Currently, access to these data is possible through consulting specific Websites on the Internet, on different platforms and with different formats. Users have to access each of these websites separately and establish relationships between these data using the database management tools of their own computers, along with statistical analysis and geoprocessing. This set of procedures is slow and demands a large investment on personnel training for specific sets of tools.

The Website portal of the Brazilian Climate and Health Observatory has the main purpose of integrating the various data sources relating to the environment, climate, socio-economic data and public health data, so as to allow users to make inquiries that simultaneously use data originating from the different data sources connected to the Observatory.

The main product from the project is the Observatory's Website portal, at the address www.climasaude.icict.fiocruz.br. This Website contains texts (in Portuguese) that make it possible to comprehend the Observatory's aims (*Presentation* and *Methodology*) and the *Technology* used to access the distributed data sources. In the *Participation* section, the procedures that need to be followed by citizens or administrators for entering data are described. In the section *Technical Texts*, access to published studies on the relationship between climate and health in Brazil is provided.

Data can be accessed through a map window, or in the *Indicators* section, where health indicators that can be viewed on the map are listed. In the section *Sentinel Sites*, the three sites that are initially being monitored by the project are listed:

vegetation burning and respiratory diseases in the Amazon region; waterborne diseases in Manaus; and extreme climatic events in the southern region.

The Observatory operates differently from other solutions for access to these types of data that are currently available (Davis 2007). The data are available in the I3Geo, which is a free software.

From the workshops, sentinel sites distributed across the national territory according to the biomes were identified. These sentinel sites have the aim of acting as warning posts for changes in health conditions (Teixeira et al. 2003) relating to climate and were selected according to the quality of data available and level of participation of local social players, which generally involves research institutions and organizations within civil society.

At the sentinel sites, the temporal association between climatic variables and diseases is being studied. Among the areas selected, the following can be highlighted: Rondônia and Mato Grosso for studies on respiratory diseases; Salvador for studies on leptospirosis; Manaus for studies on waterborne diseases; Rio de Janeiro for studies on dengue fever; the semiarid zone in the northeastern region for the health effects of drought; and the south for studies on the effects of disasters caused by extreme climatic events. The results from these studies will make it possible to validate and establish parameters for modelling the behaviour of these diseases at national level, and to identify partners that might act as catalysts for new studies, as the local social players become integrated into the project. In these sentinel sites, the discussion on vulnerabilities and adaptation measures is encouraged.

For each sentinel site, climate and health indicators have been put forward to be monitored by means of dynamic graphs. User requirements for information are transformed into inquiries distributed in real time to the source producers responsible for the data.

Thus, the dynamic graph application does not maintain any static information database. Through this method of execution, as soon as data have been validated and made available through the Internet, they are represented graphically to correlate the climate and health variables on two axes such that the abscissa is used to represent time. This tool allows users to raise hypotheses regarding seasonality, associations between variables and long-time trends. The research at the sentinel sites is being coordinated by local institutions in partnership with the Observatory project.

For example, for the city of Manaus, waterborne diseases and the water level in the Negro River were prioritized. Figure 14.2 shows the structure of the system.

The data requisition is sent to the Tabnet system and the hydrological information system of the ANA (National Water Agency), the response provided is a data matrix containing the number of cases of the disease selected and the level of the Negro River (in metres) over the year selected. The application has been completely developed using free software, thereby following the guidance of the Brazilian federal government (Brasil 1999).

Figure 14.3 shows the graph of information resulting from the inquiry. This graph demonstrates the dynamics of the variables of climate (level of the Negro River, using data from the National Water Resources Agency [ANA]) and health

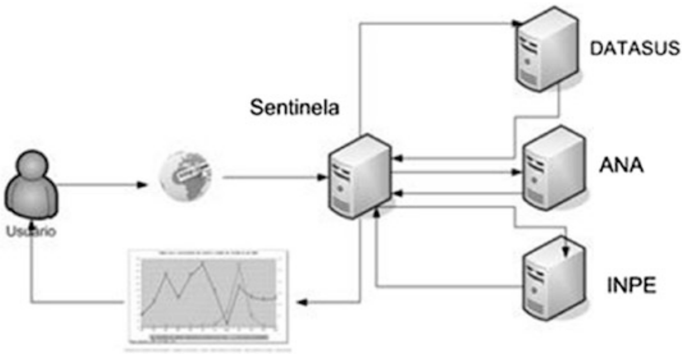

Fig. 14.2 Data-loading model for sentinel sites

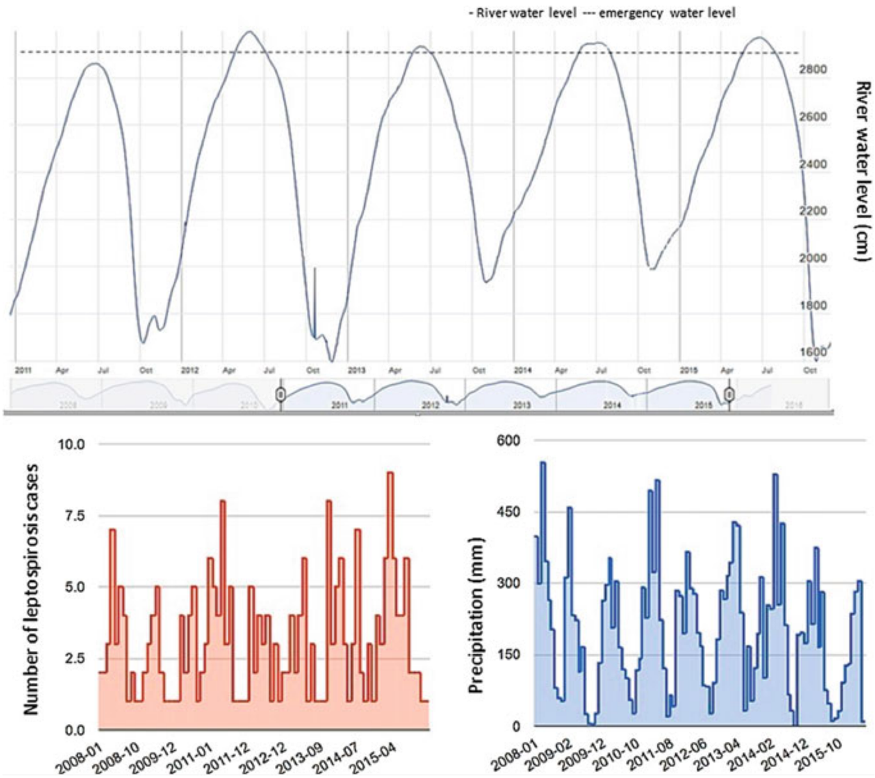

Fig. 14.3 Graph showing correlation between leptospirosis incidence, precipitation and river water level in Manaus

(hospital admissions due to leptospirosis using data from the National Health Informatics Department [DATASUS]) over time. In the months of May to July, the river reaches its annual maximum level, which is immediately followed by an increase in the number of cases of leptospirosis.

The level of the Negro River is a strong regulator of the city's social and economic dynamics that the city has grown accustomed to living with. The persistence of houses built on stilts, as a traditional low-cost housing option, demonstrates the local population's capacity to adapt to climatic variability. In this and in several other cases, the changes in river level are assimilated by the inhabitants, provided that these variations occur within a range that does not compromise the functioning of the transportation, water supply, food supply and sewage systems. Greater variation in situations of both extreme drought and extreme flooding may cause these systems to collapse. Elevation of the river level above the level of the sewage outfalls paralyzes and compromises the general sewage collection system and may also cause contamination of the city's water supply system (Oliveira et al. 2006). Both of these extreme variations were experienced by the city in the years 2005, 2010 and 2012, during which prolonged periods of both drought and high rainfall were recorded. These events have been occurring with greater frequency over the last two decades. This may constitute evidence that the environment is more favourable for transmission of leptospirosis on these occasions, with flooded creeks and compromised water supply and sewage networks. In this case, some adaptation measures have been discussed by local social actors, such as the implementation of early warning systems, the establishment of a minimum level above which new buildings should be located and actions oriented to the population living in houses on stilts in order to alleviate the impact of floods.

The city of Porto Velho forms a sentinel site focusing on the issues relating to the problems of vegetation burning, warming and air pollution. In this case, the application makes it possible to retrieve data on hospital admissions due to respiratory tract diseases among children under the age of five years, or circulatory system diseases among elderly people over the age of 65 years, through consulting the DATASUS database. The climatic variable that is made available comprises data on the number of foci of vegetation burning (INPE) for the Porto Velho microregion.

Information on morbidity and mortality profiles and their relationship with environmental problems in the Amazon region is scarce and incomplete, in a geographically extensive region in which the population presents great genetic and cultural diversity. During the workshop in Porto Velho, participants were encouraged to discuss the quality of the secondary data relating to diseases and the limitations and advantages of the indicators. Community health agents and representatives of the local communities pointed to differences in respiratory morbidity between the dry and rainy seasons in the Amazon region. It was noted that upper tract respiratory infections and ophthalmological problems are characteristic of the dry season and coincide with forest fire intensification. During the rainy season, acute respiratory diseases such as asthma and bronchitis are prominent among individuals under the age of five years. However, these differences are not evident from outpatient data. This example emphasizes the importance of the participation of community and health agents in selecting indicators for surveillance systems.

The effects of extreme climatic events in the southern region are being monitored and studied by the Geotechnology Research and Application Group for Natural Disasters and Extreme Events (Geodesastres-Sul), at the Southern Regional Center for Space Research (CRS) of INPE, located in Santa Maria, Rio Grande do Sul. The group aims to prevent and mitigate the impact of natural hazards and extreme events through the aid of geotechnology (Sausen et al. 2009). The main motive for this initiative is the increasing numbers of disasters related to natural hazards that have been occurring over recent decades in Brazil. Data and information on these disasters that have occurred in the southern region of Brazil since January 2007 are being gathered on a daily basis. These data are obtained directly from 33 online periodicals with regional and local coverage in the southern region, along with data made available by the state civil defence organizations. The number of deaths, displaced people and economic damage is recovered from these data sources.

In Brazil, one of the data sources on disasters caused by natural hazards is the declaration of public emergency, which are recognized by the federal government. The criteria for decreeing emergency situations or states of public calamity are based on the intensity of disasters and comparisons between the need for and availability of resources for reestablishing a situation of normality in the municipality. Continuation of this systematic approach over the long term will make it possible to create an important database on disasters related to natural hazards (Xavier et al. 2014). The results from research in this field have demonstrated through collection and systematization of news reports that occurrences of disasters extensively affect the states of the southern region of Brazil (Saito et al. 2009). In partnership with CRS/INPE, it is expected that the Observatory will extend the monitoring system in order to quantify the burden of health hazards observed in these events, in order to guide intervention policies, taking into account that the frequency and magnitude of extreme climatic events in Brazil are increasing.

14.4 Discussion

Gathering and analyzing data on climate and health, and information on socio-economic and environmental factors, is essential for planning actions to adapt to and mitigate climate change. The Brazilian Climate and Health Observatory project is making information on climate and health available through an Internet page where data from different origins can be accessed on a common platform. This technology is innovative in that it allows users to make inquiries that simultaneously use distributed data, i.e. data generated and maintained by different institutions. This platform enables users to process integrated inquiries of information and knowledge related to a desired theme.

Building the capacity to adapt and introduce mitigation measures in the light of climate change, require information to be brought together so as to improve the effectiveness of planning actions to increase socio-environmental resilience. This planning needs to be a democratic process that allows participation of different sectors of civil society, administrators and researchers, with guidance towards motivating present-day changes with short-, medium- and long-term consequences. Involvement of local social players, and their participation within the context of the project, is fundamentally important for structuring and developing subsequent stages of the Observatory. In the project, participation is proposed as a path leading to integration between citizens, researchers and administrators. This is likely to enable better interactions with other individuals within the community, develop reflective discussions and propose new ways of comprehending the process of climate change. Participation is a skill that should be learned and developed, and this requires a continual process of knowledge construction among involved parties which, in turn, demands reliable and easy-to-understand information channels (Bordenave 1994). In our case, civil society is involved in the process of building the observatory, by participating in the workshops, suggesting content for the Website and posting comments in the news reports.

In seeking interaction between administrators, researchers, citizens and health care professionals and managers, their different academic training, languages and interests need to be taken into consideration. Citizens are encouraged to feed the Observatory with information on extreme climatic events and new data giving warnings about the population's health conditions. The Observatory's various workshops held in different regions of the country have included participation of organizations operating within local and national civil society.

Furthermore, the project has acted as a means of assembling researchers interested in the debate on the effects of climate change on health. The workshops held within the project have made it possible to identify and mobilize researchers who could contribute towards understanding the relationships between climate and health. Recent occurrences of extreme events, such as the torrential rainfall on the coastal mountain range of the state of Rio de Janeiro, the fluctuations in river levels in the Amazon region and the intensification of vegetation burning in the arc of deforestation, have raised awareness among researchers and citizens regarding the need for preventive action to reduce the impact of climate-related disasters.

On the other hand, the long-term and indirect effects of climate change on health, such as the expansion of transmission areas for vector-borne diseases, are limited studied by researchers and rarely publicized by the media. This makes it difficult to bring citizens into the discussions about the long-term effects of climate change and the possible measures to adapt to these changes. Participants involved in the Observatory, including civil society and health professionals, have been contributing to this debate by suggesting which weather events and diseases should to be monitored according to both their understanding of climate and health processes and priorities.

The results from the studies under development at the sentinel sites have shown how climatic factors influence the transmission of waterborne diseases in Manaus;

how atmospheric pollution associated with vegetation burning influences respiratory diseases in the states of Rondônia and Mato Grosso (do Carmo et al. 2010); and how rainfall and temperatures affect vector-borne diseases such as dengue fever (Lowe et al. 2012). These studies may promote greater depth of debate on the effects of climate change on health, and on the role of the health care services, primarily the Brazilian National Health System (SUS), in reducing these impacts.

The maintenance of the Observatory project, with a broad participation of the public and as a basis for research development remains a challenge. New sentinel sites should be created and new research on emerging diseases should be promoted. For example, the recent emergence of epidemics such as those caused by the Zika and Chikungunya viruses should be analyzed in the face of climate change. The Observatory should also foster the exchange of information on climate change adaptation and mitigation policies between civil society and government.

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Part IV
Conclusion

Chapter 15
Informing Decisions with Climate Change Information

Liese Coulter and Anne Coudrain

Abstract This chapter offers a synthesis of perspectives to better communicate climate information for decision-making. Climate communication does not begin by considering how projected climate change influences long-term investments for infrastructure planning, or what far-sighted policy can manage social and environmental change. When centred on useful application, climate change communication begins by considering what information is already known and what drives the need for new knowledge. Traditionally driven by scientists, communicating what is known about climate change is increasingly influenced by the decision-makers who will use this information. Better understanding is needed of the ways in which existing and new mechanisms develop observations and analytic outputs to become the knowledge needed, especially considering the limits of what can be known. How information is derived influences how it can be communicated, from numeric model outputs to scenario visualizations. By involving stakeholders in both generating and communicating climate information from its initial development, many more actors can consider when, and how, to use knowledge of climate change.

keywords Adaptation · Application · Evidence-based · Mitigation
Policy · Stakeholder

15.1 Introduction

This book addresses many questions about climate information, always in the context of useful application to manage climate change issues. However, communicating climate information for decision-making does not begin by considering

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questions such as how projected climate change influences the long-term investments needed to plan for infrastructure, or what far-sighted policy is required to manage social and environmental change. At the outset, what must be considered is what information is already known and what are the circumstances driving the need for new knowledge. Traditionally driven by scientists, communicating what is known about climate change is increasingly influenced by decision-makers who will use this information. This leads to ask how observations and analytic outputs are developed into the knowledge needed to make informed decisions, using both existing and new mechanisms, and considering the limits of what can be known. How information is derived influences how it can be communicated, from numeric model outputs to scenario visualizations. As the understanding of what expertise is needed has broadened, it has also become important to consider who is involved. Climate change adaptation initiatives are now coming from civil society, as well as through researchers, practitioners, and governments. Those who have a stake in the outcome of any decision, as well as those who contribute and need information, are important actors to determine what is useful knowledge. Information is most readily accepted when communicated by trusted sources, who may be other decision-makers rather than scientists. Finally, the important question is when can climate information usefully influence any decision, to be prioritized among a wealth of other constraints that have to be considered. By involving stakeholders in a two-way process of both generating and communicating climate information from its initial development, many actors can have the opportunity to consider when and how to use knowledge of climate change.

This chapter addresses these questions and draws together a range of research perspectives and practical experiences, articulated throughout the book. Communication issues affect both the understanding of climate change and the development of policy options to manage the causes and consequences of this global phenomena. These inquiries explore a range of tensions that shape what knowledge is developed, how new knowledge is derived, who contributes to knowledge creation and communication, and when climate change information can be useful.

15.2 What Climate Change Information Is Needed and Known?

Information to support decisions accounting for climate change has been characterized as climate services, guided by a global framework initiated through the World Meteorological Organization (Hewitt et al. 2012). In tracing the path of such climate services from inception to application, Dubois et al. (Chap. 9) distinguished the first two phases of providing climate information as identifying pre-existing knowledge found in climate models and data, and developing climate change projections. Users may ask for increasingly detailed and precise information however, inherent uncertainties constrain what can be known about patterns of future climate, to such an extent that climatology has been characterized as a discipline in uncertainty management (Swart et al. 2008).

While climate research and observations form the scientific foundation of knowledge for decision-makers, useful climate change information is not simply a translation of scientific data and discoveries. Schuck-Zöller et al. (Chap. 8) discussed how providing climate services to underpin tailored information products requires involvement of, and between, disciplines to co-develop useful knowledge. Drawing on experiences of integrating research and practice from one area to solve real-world problems in other fields, they offered a list of quality criteria for effective transdisciplinary dialogues. Common practices identified across the literature that supported real engagement centered on ensuring that scientific work was interdisciplinary, focused on real-world problems, and involved practice partners throughout the process.

Considering the complex interrelations of climate change in multiple systems, at multiple scales, and with many drivers and feedback patterns, truly useful information requires paradigm shifts in how these systems are conceptualized. As pointed out by Fargette et al. (Chap. 3), fundamental changes in the earth's systems arising from human activities are being framed as signifiers of the Anthropocene (Bonneuil and Fressoz 2016), a new epoch where plausible and desirable futures are being reimagined (Bai et al. 2016) and reframed (Dalby 2015). In Chap. 3, Fargette et al. discuss the concept and practice of observatories, research hubs where adaptation initiatives and interventions can be monitored and reviewed to support coordinated global adaptation networks with local-global gateways. This is reinforced by Gracie et al. (Chap. 14) who show how a functioning observatory combines many data sources to inform climate change adaptation in population health.

On a regional level, Serrao-Neumann and Low Choy (Chap. 6) showed how developing explorative scenarios allows diverse stakeholders to shape knowledge and take part in strategic planning while considering multiple plausible futures. Although useful online platforms enable participants to engage and contribute qualitative data (Raford 2015), stakeholder engagement involves time-consuming practices to build trust. Many participants in these studies found it difficult to invest the time needed to deeply consider scenarios and to develop rich information. However, local knowledge was used to inform specifically tailored plans, which in turn could be used for interactions with higher levels of government to attract funding and other resources.

15.3 How Is New Climate Change Information Developed and Shared?

New information to support climate change decisions builds on fundamental scientific analysis of empirical evidence, collected from natural and social systems. However, the quality of this new information depends on the scale, depth, and reliability of data; the appropriate development of analytic processes to include diverse factors; and transparency of both source data and analytic outputs. This book presented examples of how the big data of earth observation systems is analyzed to give useful regional information, how combining a range of data sources can illustrate changes over time in interacting systems, and how mathematical models can focus results on the most plausible outcomes, from a range of probabilities.

Many coastal communities now want to reflect climate change in planning and seek to better understand current and projected changes in coastlines, but few have had access to mapping at the fine scales needed. As Tellez-Arenas et al. (Chap. 12) demonstrated, the coast is a complex environment where the effects of tides and river outflows are affected by the shape of land forms, seasonal cycles, and weather events, as well as by climate change induced sea-level changes. The French coastline provides an example where fine scale and precise topography mapping has been made available, aided by satellite observations. To be broadly useful, this climate information has been communicated through the Internet using platforms and architecture that are widely shared by a range of European Union initiatives (Schnase et al. 2017). While focused on physical information, these platforms may be usefully combined with other data sets such as those relating to the economy, urban planning, and geology to produce additional information.

Moving offshore to aquatic communities, David and Quod (Chap. 13) have shown how coastal information and marine observations can be combined to do more than monitor how coral reefs are coping with climate change. Here, the interactions between society and the environment are shown by connecting two monitoring systems, observatories that link diverse communities to both develop and communicate new information. However, tensions between competing interests at different scales and sectors highlight the need for even greater connectivity of information systems. To deliver locally relevant information, practices and protocols to capture and analyze data must be tailored to local needs, and include economic information. On a physical level, regional models including typology, rainfall and runoff, and erosion profiles can help predict changes such as soil losses and related turbidity plumes that impact reef health.

In the probabilistic field of projected climate change, models are often necessary to manage the complexities of multiple possible trajectories in social and ecological processes, and their interactions. Setting parameters for these models shapes what is included as data and the kinds of questions that can be answered. Considering computational models in Chap. 5, Gervet noted that the wealth of available data can be overwhelming, and the field of inquiry must be constrained by factors that limit possible outcomes. For complex problems involving large-scale, multi-actor systems, computational models are needed that deal with numeric abstractions of the real world.

To be relevant for practical decisions, Gervet (Chap. 5) showed that model outputs must be constrained; first, by what is possible; then, by what is plausible; and finally, by what is probable. This process must be managed based on existing knowledge so that when computations create permutations that are not possible in the real world, they are removed from consideration. Similar to participatory processes to delimit what is acceptable and desirable in scenario planning, model constraints limit scenarios to what is possible. While this may seem obvious, mathematical computations must set out the parameters for what is possible, to streamline outputs into usable information, usually focused on addressing a particular problem. Deciding what to exclude will change over time, involving an ever-increasing host of engaged stakeholders.

15.4 Who Shapes and Applies Climate Change Information?

For observations and data to become accepted as scientific or factual information, they must be made visible and articulated by someone, traditionally through a logically explained process of testing, analysis, and review. As information becomes incorporated in accepted knowledge, facts can be difficult to single out and become an expression of expertise, something that an expert knows. When it comes to climate information, the Intergovernmental Panel on Climate Change (IPCC) is the central source of expertise. Although the IPCC does not conduct original research, the Panel was tasked in 1988 with vetting and coordinating the available scientific information, shaping what is counted as known and who is considered an expert.

It has been suggested that for the IPCC, expertise has for too long been too narrowly defined. A critical examination by Devès et al. in Chap. 4 considered experts as those intimately involved in the process of decision-making, who tailor information to be particularly useful for a set of issues and actors, rather than limiting the term to researchers who develop fundamental climate change information. Many who work to manage climate change mitigation and adaptation issues are not actively involved in academia and research, which raises the question of their role in shaping information for climate change. New roles have been suggested to bridge this divide with calls for scientists to become more involved in knowledge brokering through supplying, bridging, and facilitating information exchange (Stuiver et al. 2013).

Information exchange cannot be a one-way conversation so the roles, rights, and responsibilities of all actors in climate policy are subject to examination and adjustment. Many authors in this book argued for more collaborative approaches, to better shape both climate change information and the policies it can inform. Looking at the interface between science and policy, Morgan and Di Giulio (Chap. 2) acknowledged a wide range of stakeholders seeking to influence climate change debate and actions, from activists to industry. Collaboration and co-learning can allow researchers to better design investigations in order to support evidence-based policy. At the same time, extended dialogue and transparency can enable stakeholders to better understand to what extent information can be applied. As not all experts are equal in the decision-making process, the politicized nature of policy design highlights that scientific information is not always presented and received as entirely objective and value-free. Scientists are increasingly asked to reconsider their areas of research to both see themselves as interested stakeholders, and to recognize the expertise of other actors experienced in dealing with the issues (Jasanoff 2010).

When the focus shifts to who uses climate change information, communication often aims to empower actors and communities to reduce their impact and build their resilience. As Howes (Chap. 10) pointed out, much climate information is scattered among agencies, is highly technical, and is rarely delivered through tailored climate services. He argued that higher levels of government should take on more active roles to inform local communities with relevant and useful information, involve and engage them in the decision-making process, and invest in the changes needed to support adaptation.

It must be pointed out that not everyone is prepared to consider climate information in their decisions. A number of authors (Morgan and Di Giulio; Howes; David and Quod) mentioned the politicization of the policy process where some influential stakeholders minimize or dismiss the need to manage climate change. These actors must also be acknowledged among those who shape the availability and acceptance of climate information for decision-making (Oreskes and Conway 2010). Although their relative influence will vary at different times and places, it seems unlikely that some resistance to incorporating climate information in future adaptation and mitigation planning will disappear entirely.

15.5 When Is Climate Knowledge Useful from Local to Global Scales?

Due to its interconnected nature, climate change information is applied to some extent by all of the involved actors; the researchers, policymakers, and other practitioners who span these fields to communicate and consult. As Coulter (Chap. 7) argued, personal differences play a role in how the future is imagined and in turn, how information influences future-oriented decisions that relate to climate change. A useful framework to identify when climate change information may influence future thinking is through a simple taxonomy of such prospection, simulation, prediction, intention, and planning (Szpunar et al. 2014). In the initial phases of simulating future scenarios and predicting how likely they are to happen in reality, climate change information is essential. Otherwise, as in the past, problems are imagined as happening in an environment where the climate does not exceed natural variability. When intentions and goals are being set, and detailed plans made for action, climate services are useful however; if projections were not counted in the early phases, the problems will not be well defined.

To develop adaptation strategies, climate information is continually being analyzed, framed, and reframed to become more useful. In the process of developing new knowledge, data is communicated from observations and model outputs, tailored as climate services, and sometimes incorporated in policy instruments. As pointed out by Dubois et al. (Chap. 9), resulting assessment reports sometimes fail to either mention climate information that is highly uncertain or avoid quantifying the uncertainty that gives essential context. While the gradually changing averages for temperature and precipitation are frequently reported, scenarios that have low-probability outcomes with large consequences (IPCC 2014) are often ignored. Although the resulting information is easy to understand, it is incomplete, which can have dire consequences. Arguably, changes in the occurrence and intensity of extreme weather events are likely to affect society more than will the mean value changes of climate conditions. Especially when planning to adapt to climate change, dialogues in resilience and vulnerability need to be informed with the full range of whatever locally tailored information is available.

Particularly in places of high vulnerability, climate information is needed now to shape decisions. Developing countries with low incomes have been identified as less resilient and more vulnerable to near-term climate change related to impacts on population displacement and health (IPCC 2014). The most vulnerable face an immediate need to adapt but have limited procedural, financial, and information resources. Drawing on examples from Cambodia, where there is little history of science informing policy, Jacobson et al. (Chap. 11) showed that barriers to closing the gap between science and policy include both the lack of locally scaled climate change information and expertise to interpret it. They pointed out that if quality information did exist at the right scale, it would need to apply to a broad web of interconnected climate-related impacts. In these communities, severe weather is not unfamiliar; however, the uncertainty surrounding the emerging patterns of cumulative impacts poses new and far-reaching problems. In many countries, governments, NGOs, and aid agencies need more inclusive dialogue to effectively communicate climate information and build a collective understanding of adaptation options in civil society.

Climate information relating to health impacts is needed now for populations already identified as at-risk. Considering Brazilian examples, Gracie et al. (Chap. 14) concentrated on population health as a focal point for climate change adaptation, taking into account clear links between incidence of certain diseases and climate-related patterns of water and animal vectors, heat waves, and smoke from fires. Understanding that useful climate information requires input at all levels, the Brazilian Climate and Health Observatory was developed to enable information exchange between researchers, managers, and civil society. This interactive space allows citizens to participate by both accessing and contributing potentially relevant information on climate and health. The observatory allows environmental, climatic, health, and socioeconomic data to be jointly considered by drawing on diverse data sources. By making the data widely available, this information can inform decisions whenever it is needed.

15.6 Climate Change Information Promotes Actions

This book has clearly highlighted a diversity of approaches and disciplines actively developing, communicating, and using information to understand and manage climate change. The principle objective in developing this book has been to share experiences and insights to support the active application of climate change information. To do this, researchers must involve other stakeholders from the outset to consider what formats and scales are meaningful for both the processes studied and the relevant decisions. Already, observatories are developing into communication networks that incorporate social and economic information to represent the human dimensions of climate change. These transdisciplinary exchanges rely on the input from civil society, business, and government, as well as the results of good research, to foster informed climate change mitigation and adaptation.

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