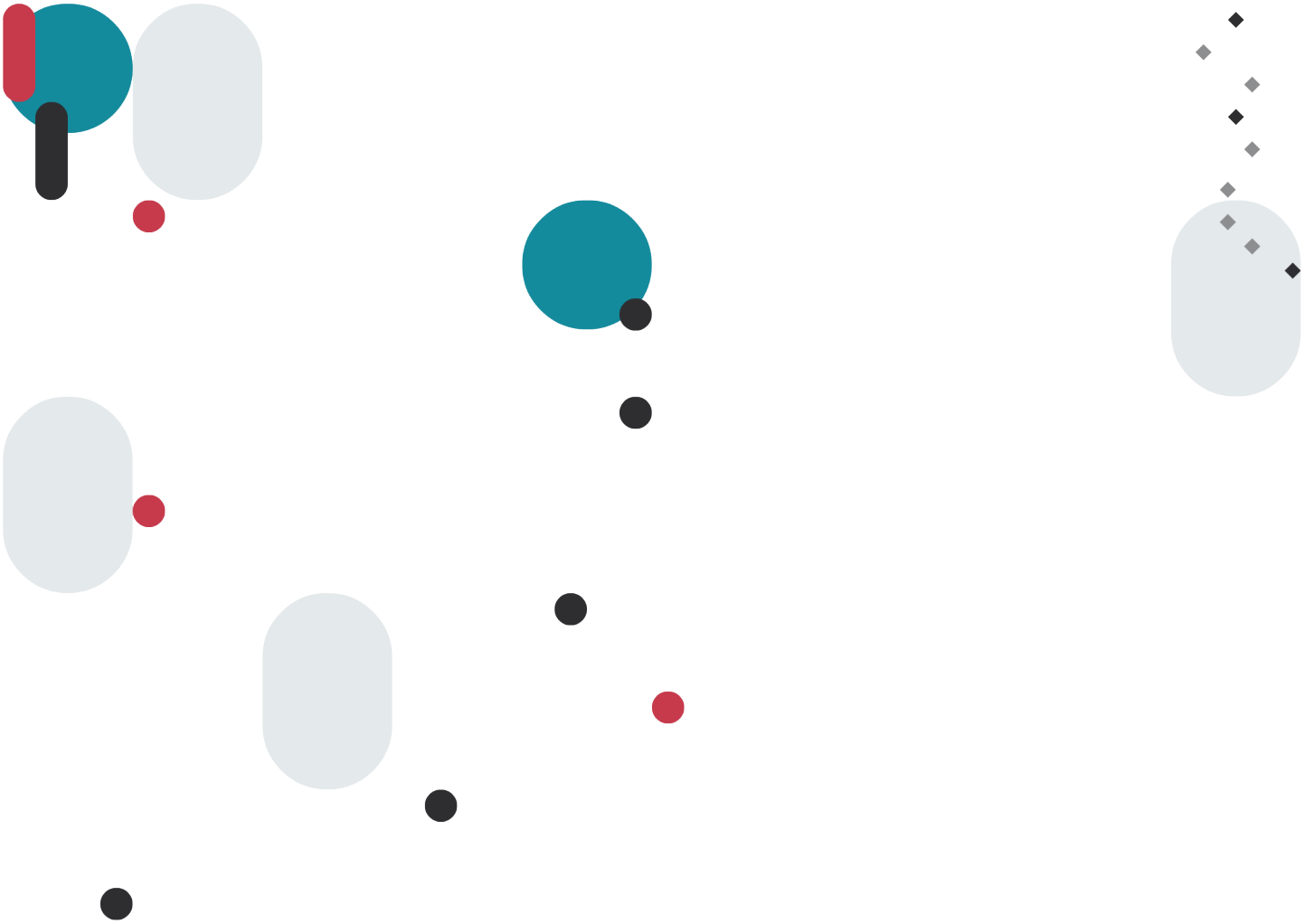

A Better understanding of Interdisciplinary research in Climate Change

Dorothy Sutherland Olsen, Siri Brorstad Borlaug, Antje Klitkou, Catherine Lyall and Steven Yearley

Working Paper 15/2013

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Preface

This report is the position paper from a preliminary project financed by the Research Council Norway initiative “Kreative og dristige forprosjekter om klimaomstilling” as part of the research programme on climate change “Klimaforsk”. The project, called “A Better understanding of Interdisciplinary research in Climate Change” (BICC) was a collaboration between researchers from NIFU, Antje Klitkou and Siri Brorstad Borlaug, and from the University of Edinburgh, Steven Yearley and Catherine Lyall and was led by Dorothy Sutherland Olsen from NIFU (corresponding author: dorothy.olsen at NIFU.no). Our external advisor was Christian Pohl from ETH Zurich.

Oslo, October 2013

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Table of Contents

1 Abstract

This paper is divided into two main parts, the first of which reviews some of the literature on interdisciplinary research collaboration and categorises articles according to their contribution. Some studies suggest that interdisciplinary collaboration is only a temporary phenomenon before a new discipline emerges; others suggest it is a necessity in order to resolve global problems or that it is a new discipline in its own right or an important source of creativity and innovation within research. Finally, the articles developing methods for studying interdisciplinary research are reviewed and discussed. The second part of the paper reviews the development of the field of climate change and examines the increasing importance of collaboration both between scientific disciplines, between physical and social scientists and with other stakeholders. Finally, the potential contribution of taking an interdisciplinary approach to studying climate change research is discussed. The paper concludes that an interdisciplinary approach can indeed provide a new understanding of some of the challenges facing climate change research and that some of the methods developed to organise and manage interdisciplinary research and particularly the concept of transdisciplinarity may be particularly useful with this field.

2 Introduction

The idea of interdisciplinary research producing new creative solutions is pervasive and interdisciplinary research has recently been put forward as a potential recipe for solving grand societal challenges such as climate change and curing cancer (Lyall & Fletcher 2013). Climate change is considered an interdisciplinary field of research (Hadorn et al. 2008), i.e. its development is viewed as being dependent on the knowledge and skills of people from a variety of different disciplinary backgrounds. Researchers working on climate change are increasingly organising themselves into interdisciplinary centres and networks, while research funding organisations are calling for more and better collaboration between scientists and social scientists. This paper reviews some of the literature on interdisciplinary research in general. We then examine more recent literature on the field of climate change in an attempt to understand the current involvement of different disciplines and the viewpoints of climate change researchers on interdisciplinarity. Finally, we discuss how the concepts of interdisciplinary collaboration might be used in further studies of research collaboration within the field climate change.

3 Interdisciplinarity

There is a large body of literature on the theme of interdisciplinary research; these papers often have different starting points, address different challenges and make different assumptions about the contexts and aims of interdisciplinary research. The works discussed here are grouped under different themes.

A process of emergence of new disciplines

Some have viewed interdisciplinary work in science as a natural phase in the development of new disciplines (Lemaine *et al*. 1976; Lenoir 1993; Klein 1996), suggesting that scientists branch out beyond the limitations of their existing field for some reason and work with others for a period of time until a new discipline or sub-discipline becomes established. This perspective is based on the understanding that communities of scientists, organised into disciplines and sub-disciplines, develop specialised knowledge and in this way contribute to the continuous development of their own field of expertise. It assumes that there is a disciplinary basis and that participants have a solid foundation in the theories and methods of one discipline. Interdisciplinary work is therefore seen as something temporary, not anything that scientists should strive towards. This conceptualisation views interdisciplinary work as something which happens frequently and not as anything new, rather as something which has existed as long as disciplines have existed. This concept of interdisciplinary research is based largely on historical case studies tracing the emergence of new fields.

A new trend in knowledge production

Other studies see greater collaboration between the different disciplines in terms of a new trend in knowledge production (Gibbons *et al.* 1994), not just as a temporary situation. In The *New Production of Knowledge (ibid*) the authors see what they regard as a new trend in the development of science and technology. They place interdisciplinary research within a wider framework of the democratisation of science. They see the process of knowledge production as a process involving multiple participants, iterative patterns and lots of feedback at all stages throughout the process. They call this “mode 2 learning” and present it as a new way of working whereby research is carried out closer to the

application or to the user of the technology. Research is no longer viewed as being embedded within a traditional discipline. They suggest that the close links a researcher might have had to the academic discipline within which he or she was educated are becoming weaker and that researchers and developers must learn to work with others, who may have a very different education and work experience. Mode 2 learning, which they also refer to as transdisciplinarity or "mode 2 knowledge production", is distinct from "mode 1". Mode 1 is viewed as a sequence of isolated phases of knowledge generation occurring in academic environments then passed on to the outside world in order to be further developed in new phases. In mode 1, academic researchers are seen as trying to increase their understanding from within the framework of their own discipline. Their results are then typically picked up and developed into technological applications by industrial actors. Mode 2 on the other hand is multidisciplinary, indeed it includes all stakeholders, users and the public. One of the important aspects of this concept is that it includes knowledge production outside academic environments. The authors suggest that any attempts to understand the development of technological knowledge should not be limited to academic or to industrial environments, but should take account of both. The ideas in this book have been criticised particularly for their lack of empirical data, however in spite of all the criticism the concept of Mode 2 knowledge production has been very influential in shaping recent research policy in Europe.

Knowledge production including non-scientists

The concept of transdisciplinarity[1] has been further developed by among other Hadorn and colleagues, who published The Handbook of Transdisciplinary Research (Hadorn *et al.* 2008). Many of the cases described in this handbook are from research into climate, environment and sustainable energy. The concepts developed around these initiatives are very much based upon integration – integration of theories, methods and developing shared understandings of societal problems. They suggest that some of the main challenges are that too little attention has been paid to finding how institutional arrangements designed to promote collaboration are affecting learning. They also highlight the need for better methodologies for integration and better support for institutions.

Non-scientists can contribute to the knowledge production process in different ways; they can for example take on the role of knowledge brokers as suggested by Pohl (2008). He discusses the role of intermediaries in transdisciplinary processes, these intermediaries can be organisations such as governmental agencies or NGOs. His approach is based on the approach of interacting policy cultures used by Jasanoff and Wynne (1998). This approach is used to study the interaction between civic, academic, economic and bureaucratic cultures. Pohl's studies led him to differentiate between activities of reorganising existing knowledge and co-producing new knowledge. This is interesting because it suggests that groups from different disciplines do not always need to work together in order to make their knowledge useful to each other. Sometimes it is sufficient to share this knowledge. He concludes that both these ways of collaborating are suitable ways of bridging science and policy and suggests that "if transdisciplinary research is a process of co-production of knowledge, then research

[1] This term has not become standardised and is not commonly used in English speaking countries. This does not mean that the concept does not exist, it might be called 'stakeholder involvement' or 'public participation in science'.

will go beyond the role of providing information and the academic policy culture must find ways to interact with the other cultures and their policies" (2008:48).

Although English speaking countries do not use the term transdisciplinarity as frequently or as consistently as the German speaking countries, the concept behind the term is well-known and understood in most countries. It is sometimes referred to as stakeholder participation and the term participatory interdsiciplinarity (O'Brien 2013) has also been used to describe collaboration including non-scientists.

A new discipline?

It has been suggested that a new specialist field might be emerging which includes most of the terms and the issues normally grouped under the heading of interdisciplinarity. Gabriele Bammer (2010; 2013) suggests that this field, which she calls 'integration and implementation' (2010:95) has become increasing important in recent years and that a community of researchers has emerged with a shared interest in this field. University courses are becoming available and conferences on this theme are being organised. She also mentions the td-net[2] or transdisciplinary net, which was established in 2003 in Switzerland and has been a driver for conferences and workshops on this theme. Bammer characterises the new field as combining systems thinking, participatory methods and knowledge management, exchange and implementation. Bammer compares the potential development of this new speciality to the field of statistics. Statistics has its own experts and researchers, but it is used and taught in many other university departments.

An important source of novelty

Weingart has studied the discourse on interdisciplinarity and points out that many studies praise the creativity of interdisciplinary work, or highlight the necessity of input from multiple sources to solve modern problems. Weingart suggests that interdisciplinary research has perhaps always been there and that it is not disciplinarity versus interdisciplinarity that is the important issue here, but rather that interdisciplinarity be acknowledged as an important part of innovation or new thinking in science and technology. Barry *et al.* (2008) have also suggested that contact between disciplines may be the creative mechanism within science which creates change.

Hollingsworth and Hollingsworth (2000; 2004) carried out 200 interviews and 24 case studies in bio-medical research institutes in the US. They identified a correlation between disciplinary diversity and new discoveries. They describe how, at the Rockefeller Institute, scientists with broad experience, often in different disciplines, were recruited. They describe the open and unstructured organisation of offices, laboratories and tasks and in particular the rich interactions, including the less formal ones such as conversing over lunch, between scientists of different disciplines. They suggest that commonalities, such as all being scientists made it easier to communicate than in colleges such as those in Oxford and Cambridge where arts and sciences are expected to mix.

[2] http://www.transdisciplinarity.ch/e/

The idea of interdisciplinary research producing new creative solutions persists and interdisciplinary research has recently been put forward as the recipe for solving grand societal challenges such as climate change and curing cancer (Lyall & Fletcher 2013).

The context of interdisciplinary research

Some studies are related to the challenges of research management, stimulating interdisciplinary research, evaluating it and of course funding it. Papers on this theme are largely concentrated on discussions of changes in existing institutions and are not related specifically to climate research. There is not much data from the evaluation of interdisciplinary research programmes carried out at a micro level, but Bruce *et al*. (2004) analysed the projects in the 5th EU framework programme. Their analysis was based on data gathered in workshops, questionnaires and interviews with researchers and research managers. Their study identifies many barriers to practising interdisciplinary research. They note, among other things, that the main motivation to collaborate is the interdisciplinary nature of many of the research questions, but at the same time they note that career progression is traditionally associated with specialisation within one discipline. They suggest that interdisciplinary cooperation does not happen by itself, but needs conscious effort to overcome communication problems and promote greater cohesion.

Studying interdisciplinarity - Frameworks and Methods

Klein (1990) suggested that there are phases of development of interdisciplinarity tending towards convergence or integration, she called this the Integrative Process Model. Klein's model started out as a linear model, however she refined this as a result of new findings in her research. She described the process as one including disciplinary depth and transdisciplinary breadth resulting in a synthesis.

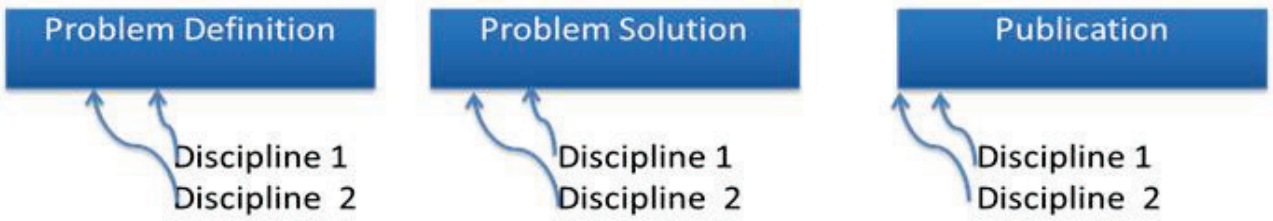

Figure 1 Adapted from Klein's Integrative process (Klein 1990)

The idea is that multiple disciplines, including stakeholders are involved right from the beginning including defining the research question. In reality this has proved challenging, traditionally the initial formulations and plans would be made by one scientific discipline and others joined in at a later stage, by which point it was difficult to influence the research question. This is frequently the case with social scientists (Pohl 2010), who were just added on in order to include "the human dimension". Bibliometric studies also suggest that the above model might not work so well in practice and the end results are seldom integrated.

Klein's model was elaborated upon by Pohl and Hadorn (2008).

Forms of collaboration / Means of integration	Common group learning	Deliberation among experts	Integration by a subgroup or individual
Mutual understanding (Everyday language, glossary...)			
Theoretical concept (Transfer of concepts, mutual adaptation of concepts, bridge concepts...)			
Model (Qualitative model, quantitative model, scenarios...)			
Product (Technical device, database, regulation, exhibition...)			

Figure 2 Forms of collaboration and means of integration (Pohl & Hadorn 2008)

One of the questions Pohl and Hadorn raise is whether transdiciplinary research can be self-organised or if it should be facilitated, echoing the questions of Bruce *et al.* (2004).

Participatory Interdisciplinarity is the concept introduced by O'Brien *et al.* (2013) to study how stakeholders participate in interdisciplinary collaborations. They find that stakeholders learn from their participation, information is shared and behaviour is changed through collaborative work. One of the most valuable activities in an interdisciplinary project is the way they are forced to articulate research goals much more clearly so that other participants who do not have a background in the same discipline, will understand. They also conclude that the holistic approach taken from the beginning of the project enabled them to address real-world issues together. However they find, like Lyall *et al.*(2009), that success takes time; relations need to be built and trust developed between researchers of different disciplines and between stakeholder and researchers. They also observe that the epistemological differences between the academic disciplines can be greater than the differences between stakeholders and researchers.

There are some other interesting studies that do not fall into the categories above. One example is the ethnographic study by Rhoten (2004), which raised the question of how much contact people from different disciplines actually have with each other in interdisciplinary research projects. There are also some studies which looked at the different ways of organising interdisciplinary research, such as Palmer (1999) or Lengweiler (2006). The former found that strategies could be developed to facilitate boundary crossing between different disciplinary groups. The latter studied the relationship between organisational culture and interdisciplinary practice and concluded that interdisciplinary research is much more nuanced than many earlier studies imply and suggested a typology of interdisciplinary research styles based on the cognitive differences of the participants and the projects' need for intense collaboration.

Some studies have taken some the idea of the integrative approaches mentioned earlier and tried to develop them by carrying out micro-studies of interdisciplinary collaboration. Some of these have found that researchers develop particular ways of communicating, such as a common language or

pidgin Galison's (1997). While others such as (Matilla 2005) found that degree and nature of communication changed greatly as the object of research was changed and developed. Olsen (2009; 2010) found that go-betweens and short-cuts were used to bridge the gaps in knowledge between the different disciplines, while Enberg (2006) found that shared project histories also served to help different researchers integrate their knowledge in R&D projects.

In summarising these works on interdisciplinary collaboration, one can mention the main reasons for this type of collaboration put forward by Hansson (1999) 1. People of different disciplines are put together in a new organisation to promote creativity 2. Deliberate attempts are made to view a specific problem from multiple perspectives, such as e.g. environmental pollution, or 3. A specific technical problem requires skills and experience from people from different disciplines.

4 Climate change research

In order to understand the importance of interdisciplinary collaboration in climate change research it is important to understand how climate change research has developed in recent years. There are some bibliometric studies on the involvement of different disciplines in climate research (Bjurström *et al.* 2011a and 2011b) as well as narrative studies on the development of the relatively young field of climate research. (Weart 2012; Mooney *et al.).* Some of the challenges are investigated, such as communication and translation, research funding and evaluation, while others studies are more normative, suggesting how interdisciplinary research should be organised and managed (Lyall 2013). Some of the main themes and arguments will be presented here. The following analysis identifies three challenges to climate change where interdisciplinary collaboration might be relevant. These are between the various scientific disciplines involved in climate research, between physical scientists and social scientists and lastly between scientists and non-scientists.

The development of climate change as an academic field

Weart (2012) has carried out a detailed study of how the field developed from isolated areas of expertise such as meteorology, oceanography, geography, hydrology, geology, glaciology and plant ecology. Meteorologists recognised the need for interdisciplinary work and began to recruit students from physical sciences such as physics, chemistry and mathematics. Climate models were developed, but the climatologists continued working with practical observations and were often far removed from the academic developments. In the 60s and 70s more predictions were needed for example for civil engineering projects building dams and oil platforms, needed to know how high a 50-year flood might be or a 100-year wave. More analytical methods were needed. The “old descriptive climatology” which was concerned mainly with statistics and verbal interpretation of the weather began to evolve into, “a new mathematical, or dynamic, climatology with predictive capability based on physical-mathematical processes rather than extrapolation of statistical measures” (Weart 2012:3661). A new research community was emerging, a community which accepted that there was not “one” way of explaining climate change, but many and most of them were interlinked. However the biggest challenge to this new community was that they needed huge and complex models with data from a range of different

sources and they needed to communicate with different groups in new ways. It is in the 1980s that we begin to see a more conscious effort to create interdisciplinary research programmes; an international geosphere-biosphere programme was initiated, coordinating researchers from many different disciplines. This programme introduced a new approach of viewing the climate system of the whole planet, including everything from minerals to microbes.

Another reason for increased collaboration in the 1980s came about when the world's governments demanded a formal advisory procedure and the Intergovernmental Panel on Climate Change (IPCC) was created. The IPCC was unique in its global ambitions and its inclusion of a broad range of researchers from different fields, including social sciences, all with the objective of developing projections of future climate change. It has been described as "a great engine of interdisciplinary research" (Weart 2012: 3663).

During the 1990s it became increasingly common to fund interdisciplinary climate research, interdisciplinary workshops became more common and Science and Nature journals contributed to building acceptance of this interdisciplinary field. Testing of climate models frequently involved different disciplines (one discipline developing the models and the other testing) and empirical data from different fields was used to validate and correct computer models.

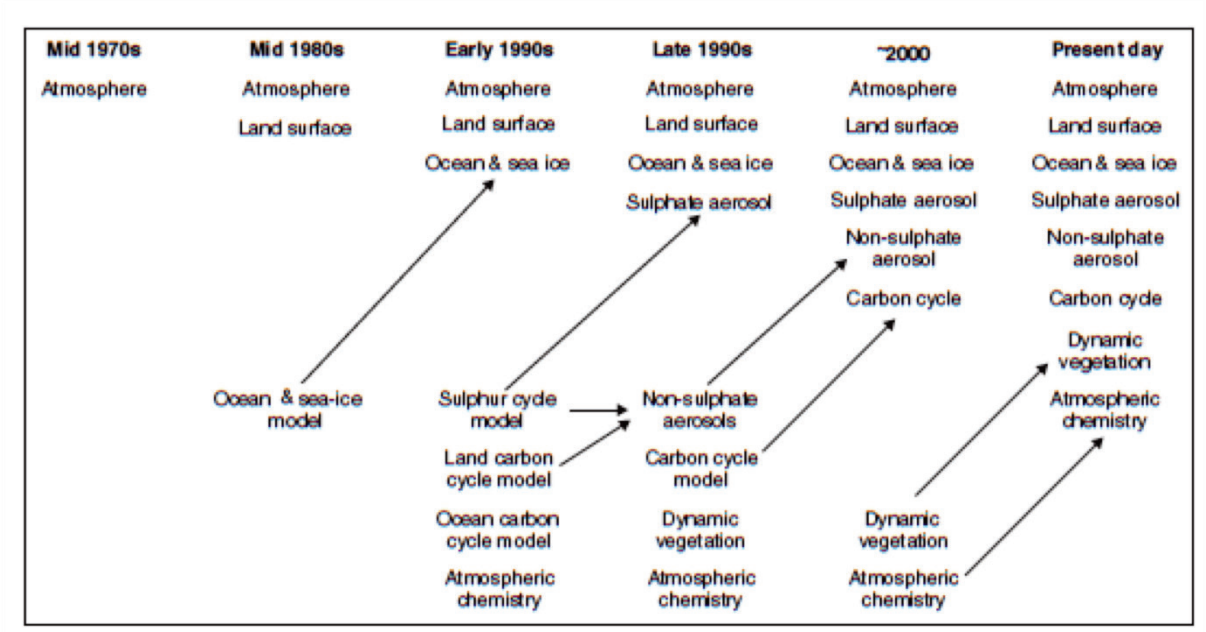

Figure 3 Development of Climate Models Based on IPCC (Cornell 2010:118)

The diagram above shows how the number and complexity of climate models has increased since the mid 80s. The various elements included in the models also give an indication of how the kind of expertise needed in order to develop climate research expanded over that period.

Towards the end of the 1990s scientists began to use the term "environmental scientist" which stood for "a widely admired attitude, with concerns embracing the earth as a whole" (Weart 2010:3663), this

title was added to their disciplinary category. By 2000 some scientists began identifying themselves primarily as “climate scientists” even although they had no professional organisation or institutional framework.

The role of social scientists was examined more closely by Mooney *et al*. (2013). Those modelling climate change realised that they needed data from social sciences; this was based on the gradual understanding that climate change could not be explained by natural phenomena alone, but was to a great extent influenced by human behaviour. Once the lid was lifted on this theme, there were all kinds of different parts of the social sciences, which became important – human behaviour, culture, ethics, education, economics and politics as well as population growth, human mobility and land-use. Mooney *et al*. (2013) suggest that some of the impediments to collaboration in climate research are the unrealistic expectations partners have of each other, the nature of the data and the tendency for one discipline to dominate the process of framing research questions and formulating research programmes. Another challenge identified was the need to address both local and global issues of adaptation and these both required a different type of analysis; for example adaptation can be carried out at the level of a national infrastructure or in a more dispersed way getting local communities or individuals to make smaller changes. A recurring issue in the early days of attempting to involve the social sciences in climate change research was the difference between working in parallel or working in a more integrated way. Mooney *et al*. (2013) suggest that the changing perceptions of climate change mirror the increasing need for involvement of other disciplines, illustrated in the following figure. The figure attempts to give an overview of the different participants in climate change research and who they interact with. The overview begins with the early period A and shows the development through until C in 2013.

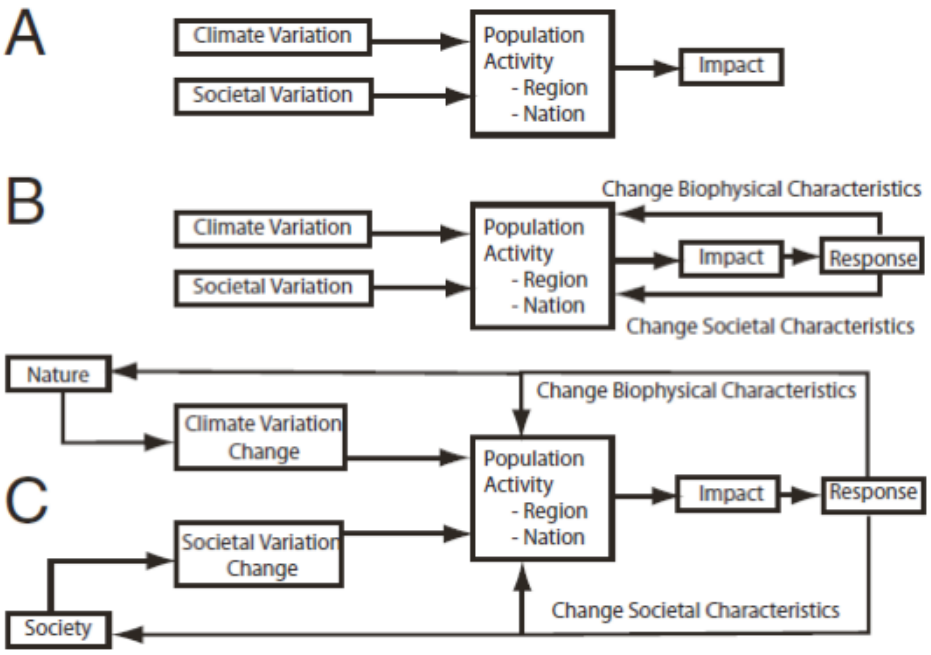

Figure 4 (Mooney *et al.* 2013: 3667)

Mooney suggests that it has become common for climate change researchers to view their field in terms of changes arising, both in nature and society, which might affect each other and view the responses to climate change as also having a potential affect both on nature and on society. This is reflected in modec C above.

In 2011 Bjurström and Polk (2011a; 2011b) carried out a bibliometric analysis of IPCC publications in an attempt to assess how closely integrated the participating disciplines were. They mention the emphasis on physical aspects of climate change and suggest that the framing of research problems is not conducive to social science research (2011b: 15). A co-citation analysis of the assessment reports from the three working groups[3] of the IPCC was also carried out by Bjurström and Polk. In this analysis the cited journal references are the main unit of analysis, allowing a reasonable level of aggregation for studying relations between scientific disciplines and more reliability of the analysis.[4] They found that the 1st working group was strongly dominated by natural sciences and here especially by the earth sciences, while the 2nd working group produced a report displaying a complex pattern of partial integration of scientific fields, including earth sciences, biology, agriculture, medicine, the interdisciplinary fields environmental science and energy and resources, and social sciences. The assessment of the 3rd working group displayed a clear separation between natural sciences and social sciences. Where social sciences were included, they were dominated by economics. Bjurström and Polk concluded that interdisciplinarity is not a prominent feature of IPCC climate research and preferred to define it as a "loose cooperation between disciplines with limited integration" (2011a: 543). This does not necessarily mean that they are not collaborating, but that the articles they cite are more likely to be classified within the same discipline as the authors.

Although there is more attention to the involvement of social scientists in climate change research, there is still potential for improvement. This is argued by Yearley (2009) who contends that the contribution of social scientists should not be limited to the provision of input to climate modelling, but a greater effort should made to understand the social processes occurring. Climate change scientists are confronted with new challenges, new data and new problems; they have to continually make choices on what is important, what is valid and how to proceed. The questions being asked, the data being analysed and the way it is interpreted are all shaped by the disciplines in charge. He cites the example of how economists developed cost-benefit analyses based on different valuations of human lives in the western world and in Asia. He points out that economists are not the only social scientists and suggests that we need more studies of scientific communities working on climate research and greater reflection on the role of social scientists in climate change models. Yearley concludes that "the important question of how knowledge is 'represented' applies with equal significance to social scientific and economics aspects of the knowledge and also to the design and operation of the institutions through which scientific knowledge is warranted in the first place" (Yearley 2009:401).

[3] From the Third assessment report of the IPCC
[4]. This is possible because the scientific disciplines of the journals is classified in an international database, the subject category description of the Journal Citation Report provided by Thomson ISI.

Related to the creation of the IPCC, a four-volume work by Raynor and Malone (1998) was produced, which addressed a similar problem, but with social change as the starting point for studying climate change rather than the opposite. This event suggests that by this stage social scientists were not simply the invited guests of the natural scientists, but were a group of researchers with their own interests in climate change.

It is not only the involvement of participants from different disciplines which is important, but also the involvement of many other stakeholders including policy makers, national and local government and not least NGOs. There has been a gradual move away from understanding climate for its own sake, towards generating knowledge for action (Cornell 2010: 122). Policy studies discuss the challenges of knowledge production in climate change (Jasanoff & Wynne 1998) and later the co-production of knowledge (Lövbrand 2011). The global nature of problems and the often local nature of mitigation and adaptation is emphasised and thus the need to involve many different types of stakeholder and in most if not all phases of climate change research. Lövbrand (2011) writes of the co-production of knowledge and analyses an example of transdisciplinarity; the ADAM project, which attempts to involve stakeholders, in particular policy makers. Instead of improving communication between the scientists and policy makers, the opposite occurred. She describes a process whereby the policy makers attempted to redirect the scientists to help them with implementing research in practice. The scientists were unable to and ended up withdrawing to a more remote academic theme. She points out that literature suggests that the aim of co-production of knowledge is to create an environment where questions can be opened up, debate can be provoked, differences exposed and assumptions interrogated. The reality was different. Firstly it was difficult to get any stakeholders to participate. Then the environment appeared to close in rather than open up. The researchers found that they had to "respond to a restricted policy community's interpretations of useful knowledge" (Lövbrand 2011:234).

She suggests that this situation may be related to the stage in the policy cycle i.e. in the early stages policy design should be subject to debate, but in a later stage policy makers might be more taken up with the practicalities of implementation. She summarised her conclusions thus - "in order to compel academics to venture into the wild and to produce knowledge in the context of application, it is important that we expose and reflect upon the differences and potential problems that may arise when prescriptive ideals are translated into practice" (Lövbrand 2011:235).

Challenges to climate change research

The themes of communication and translation are frequently mentioned as challenging in climate change research. These themes are not limited to particular actors, nor are they limited to certain phases in development or change processes. Indeed they range from the production of scientific knowledge, the formulation of descriptions of climate problems, risks assessment, policy development to policy implementation. Discussions on communication and translation are broadly based upon the idea that all the right people should be involved and they should develop ways of communicating. Huzir *et al.* (2013) study the concept of knowledge translation by taking an interdisciplinary perspective

in order to gain a better understanding of knowledge translation in scientific research. They examine, among other things, the institutional arrangements conducive to translation and they analyse the cultural codes and the power relationships and how they influence the process.

The composition and the organisation of the IPCC is in itself a challenge to climate research. Although the IPCC has been committed to including social science aspects in its core activities it has been organised in parallel streams along disciplinary lines addressing the physical sciences, the socioeconomic impacts and possible policy responses (Yearley 2009:400). Within these streams the contributions of physical sciences, ecology, socio-political sciences and economics are clearly separate (Cornell 2010:131). This suggests that the acceptance of Mooney's Model C (Figure 4) has not yet been turned into action within the IPCC. The need felt by social scientists to produce a companion publication to the IPCC (Raynor & Malone 1998), suggests that there is a need for more and better communication between these scientists and social scientists and indeed that this communication should be taking place at several levels and at all stages from formulating research themes to analysing impacts. Another challenge relating to the involvement of social scientists is the assumption within the IPCC that economics is the most relevant social science, ignoring the potentially important contributions of social anthropology, and sociology to our understanding of human consumption patterns (Yearley 2009:400).

Cornell (2010) talks of the need for an increased level of tolerance needed to develop a certain amount of mutual understanding between earth scientists and social scientists. She also talks of "the deep interdisciplinarity needed for climate research" (ibid:127), suggesting that that this is much more than a flow of information and that there is a need to develop a deeper understanding. Cornell also points out that physical scientists are ill-prepared for critical reflection on the knowledge creation process and believe that scientists should be neutral and value free.

The challenge of organising and managing research into climate change is important and there are many aspects which should be considered. Some key success factors are suggested by Lyall *et al.* (2013) such as the locus of interdisciplinarity, catalysis, inspiring leadership, active management, learning and continuity. Others concentrate on integrative approaches, such as Pohl & Hadorn (2008) and Klein (1996). Bhasker (2010) goes much further than trying to include all the right actors and get them to work together productively. He expects that interdisciplinary climate research is going to produce new paradigms and allow researchers to break away from all the dependencies built into existing climate models. Cornell, on the other hand, is critical to the idea "that a research community can bolt together conceptual tools" (Cornell 2010:127) without reflection and deeper understanding.

5 Discussion

Although the views of interdisciplinarity vary within the literature reviewed, all the studies see collaboration between the disciplines as being a source of new solutions and the involvement of multiple disciplines is seen as something, which will have a positive effect on the outcome. If we look back at Hansson's categories of research we can say that our review suggests that types 2) and 3) are common i.e. deliberate attempts are made to view a specific problem from multiple perspectives or a specific technical problem requires skills and experience from people from different disciplines.

Our studies of interdisciplinary research in general allow us to conclude that the concepts of transdisciplinarity or interdisciplinary participation are not only useful for ascertaining the participation of multiple disciplines, but can provide the basis for an approach to studying collaboration processes within research. The studies reviewed here show that the various concepts of interdisciplinary participation and transdiscplinarity all make common assumptions about the heterogeneity of the participants and all assume that this influences both the way that research is carried out and its outcomes. Within the studies there are different ideas on how disciplines should interact and whether or to what extent they should be integrated.

It is clear that many researchers from different disciplines are involved in researching climate change, but some of the literature reviewed here suggests that there is a long way to go before the desired integration suggested in the studies of interdisciplinarity is reached. The many disciplines involved in climate change research appear to be working in parallel rather than integrating theories and methods. Bjurström & Polk summarise this well, in their description the IPCC work as a "loose cooperation between disciplines with limited integration" (Bjurström & Polk 2011: 543).

Our study of the literature does suggest some reasons for the lack of integration in climate change research. Many of these boil down to issues we find in all research, i.e. that of having limited time to develop relationships, develop trust and learn about a partners field of expertise. Some of the papers reviewed suggest that there are different nuances of interdisciplinary research and it is not certain that all disciplines actually need to be integrated in order for a research programme or project to be successful. We need to understand more about the degrees of closeness in different areas of climate

research and what is necessary for different kinds of research problems. It is possible that an awareness of the differences in the various disciplinary approaches is all that is necessary in climate change research. However there are also indications that some form of closer involvement *is* necessary, such as involving social scientists in the formulation of research problems, which currently appears to be challenging and more work is obviously needed here.

With regard to stakeholder involvement, including the involvement of policy makers, there are success stories and failures, either way the studies suggest that it entails a lot of hard work. The concept of transdisciplinarity appears to be useful in that stakeholder's participation is viewed in terms of their knowledge or lack of it. However, the term transdiciplinarity is used differently in different studies; there are also problems of comprehension of the term *disciplinary* when talking of the involvement non-scientists. What disciplines do policy makers or NGOs belong to? However, the concepts behind the term transdisciplinarity take their starting point in heterogeneity among participants. It is assumed that there will be a variety of different disciplinary cultures or epistemic communities with their own well-established ways of doing things and of understanding things and it is assumed that these differences will affect the outcomes of the research. In this way both the cognitive differences and the differences in practice are typically addressed by concepts of transdisciplinarity. By taking a transdisciplinary approach, there is also the assumption of integration at one or multiple levels. This might be in terms of sharing information on climate models; it might be on negotiating guiding principles on cost-benefit analysis or it might be involving a broad range of stakeholders in defining research themes based on real world problems. All of these aspects make a transdisciplinary approach potentially useful for carrying out a more systematic study of climate change research.

The holistic approach used in some studies of interdisciplinary research, might also be well suited to studying climate change. As O'Brian et *al*. (2013) say that an interdisciplinary perspective allows the "messiness" of research problems and research projects to exist. The holistic approach to all stages of research collaboration suggests that a *participatory interdisciplinary* approach or a *transdisciplinary* one might be the best way to study climate research and particularly adaptation to climate change. With regard to an analytical framework, several were identified within the studies, but their applicability appears to be dependent on the research question being investigated and perhaps the context being studied. However these frameworks could be developed or be used to provide inspiration for future studies.

The papers studied range from studies of disciplines developing, to studies of particular projects. We have not observed many multi-level studies. Future research in this direction might provide new insights into why interdisciplinary collaboration is so challenging in climate research. A multi-level study might look at how research units are organised on one level and how individual scientists are interacting on another level.

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