Global warming in the public sphere

BY JAN CORFEE-MORLOT1,*,†, MARK MASLIN1 AND JACQUELIN BURGESS2

1Geography Department, University College London, Pearson Building, Gower Street, London WC1E 6BT, UK
2School of Environmental Sciences, University of East Anglia, Norwich NR4 7TJ, UK

Although the science of global warming has been in place for several decades if not more, only in the last decade and a half has the issue moved clearly into the public sphere as a public policy issue and a political priority. To understand how and why this has occurred, it is essential to consider the history of the scientific theory of the greenhouse effect, the evidence that supports it and the mechanisms through which science interacts with lay publics and other elite actors, such as politicians, policymakers and business decision makers. This article reviews why and how climate change has moved from the bottom to the top of the international political agenda. It traces the scientific discovery of global warming, political and institutional developments to manage it as well as other socially mediated pathways for understanding and promoting global warming as an issue in the public sphere. The article also places this historical overview of global warming as a public issue into a conceptual framework for understanding relationships between society and nature with emphasis on the co-construction of knowledge.

Keywords: global warming; climate change; social theory and the environment; co-construction of knowledge; environmental policy

1. Introduction

A 1959 Scientific American article by Gilbert Plass suggested that the world’s temperature would rise by 3°C by the end of the century and featured a photograph of coal smoke belching from factories (Plass 1959). The caption read ‘Man upsets the balance of natural processes by adding billions of tons of carbon dioxide to the atmosphere each year’ (as cited in Weart 2003). This coverage resembles what has become routine media coverage of global warming in recent years. Yet global warming, as a clear social and political issue, did not emerge until much later in time. The question investigated here is: why did global warming emerge as an issue in the public sphere at all and how did this occur?

* Author for correspondence (jan.corfee-morlot@oecd.org).
† Jan Corfee-Morlot currently of the Environment Directorate at the OECD; the article was written while she was on academic leave with UCL. The views contained in this article are solely those of the co-authors and do not represent the views of the OECD or of its member countries.

One contribution of 9 to a Theme Issue ‘Climate change and urban areas’.
Much of the scientific knowledge needed to understand global warming has been in place since the early 1960s (Weart 2003; Maslin 2004). Following early scientific discoveries on the ‘greenhouse effect’ at the end of the nineteenth century, the basic physical science underlying the theory and empirical evidence for global warming was supported through wartime and post-World War II scientific enterprise to master nuclear weaponry and understand how nuclear radiation and fallout would travel throughout the atmosphere and terrestrial and marine environments. Given this basic set of scientific facts about global warming available by the 1960s, the issue of global warming could have emerged at least on the western social and political agenda much earlier than it did. At this time, media attention had also begun to include coverage of global warming as an emblematic public environmental issue.

This article traces the emergence of global warming in the public sphere. One of the common themes throughout is the role that science plays in policy decisions. In tracing the relationship between science and climate change policy over time, one sees a transition from ‘policy for science’ to ‘science for policy’ (Agrawala 1999). Climate change policy originates in a policy for science mode where the aim of initial policy is to ensure that relevant scientific research moves ahead in a coherent manner to better understand the nature of the problem. By contrast, emphasis in the policy agenda has more recently shifted away from problem recognition to problem solving. In this context, one aim of scientific endeavour to answer relevant policy questions. Both models for thinking about the science–policy relationship are important for answering questions about emergence of global warming in the public sphere.

We conclude that science and scientists shape the understanding of global warming in the public sphere but their influence alone is insufficient to explain the timing of attention to global warming as a policy issue. Rather the emergence of climate change as a public policy problem is a result of a variety of socially mediated pathways that interact with scientific knowledge to shape public understanding and drive political attention to the issue.

The article begins with a brief outline of social theory as background for this discussion. Next, the article reviews key scientific developments in their historical context with a particular focus on the science community in the United States (US). This is followed by an exploration of three different yet intertwined socially mediated pathways that shape global warming in the public sphere: (i) political and institutional processes and change, (ii) the rise of environmentalism as a mass social movement, and (iii) heightened attention in the mass media. The article has a particular focus on developments in the United States and on the international context; reference is also made to key developments in the United Kingdom as a point of comparison. The article

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1 We use here Habermasian notion of the public sphere as the area of public life which mediates between and connects the political system to the private sphere on key ‘public’ issues such as the environment. While the private sphere operates largely behind closed doors through face-to-face interactions that are outside of public scrutiny, the public sphere is ‘a highly complex network that branches out into a multitude of overlapping international, national, regional, local and subcultural arenas’ (Habermas 1998, p. 373).

2 These terms were originally introduced by Brooks (as cited in Agrawala 1999): Gieryn (1999), Guston (2001), Jasanoff (1990).
closes by returning to the discussion of social theory to relate the emergence of global warming in the public sphere to theoretical questions about relationships between society and nature. We conclude that social understanding of climate change and its prioritization as a public policy problem is co-constructed through an intertwining of growing scientific knowledge and a variety of social and cultural practices.

2. Science, society and climate change interactions: a conceptual perspective

Theory regarding interactions between science, environment and society is messy at best and conflicting at worst. The conflict stems in part from the nineteenth century origins of social and political theory, which aimed to distance its interests and central tenets from the positivism that had dominated social thought during the Enlightenment. At this time, contemporary social and political theory placed culture and society in opposition with biological thinking and nature (Benton & Redclift 1994; Goldblatt 1996). Humanist social thought emerged in part as a reaction to positivism, as part of a conscious effort to counter pervasive biological thinking, which was dominant at that time. The primary ecological concern in this classical social theory was to understand how nature constrains society and, more particularly, how to separate and transcend society from the constraints of nature (Goldblatt 1996).

Understanding of global environmental change is built upon interdisciplinary research (Chen et al. 1983; Parson & Fisher-Vanden 1997; Liverman 1999; Edwards 2001). In the area of climate change, the authoritative IPCC reports demonstrate efforts made by governments to bring together key research findings in areas ranging from physical climate modelling to economic dimensions of the problem and possible solutions. Despite much breadth of coverage, however, IPCC’s limited treatment of social science literatures on the subject of climate change demonstrates the dominance of techno-rational or predictive analytical traditions in the field of environmental policymaking. A techno-rational approach is based on a ‘linear’ model of decision making, aiming to inform policymakers about the latest available expert information so that they may improve their decisions. An open question is what insights for policy, if any, might derive from the ‘missing’ pieces of social research, notably the interpretive and constructivist views which give a more central role to societal processes for understanding policy problems. From this perspective, society defines and directs scientific endeavour to some extent (Kuhn 1962; Latour 1987). More importantly for policy, environmental decision making is part of a social and cultural struggle to bring lay knowledge together with expert knowledge in the policy process to collectively reflect on problem definitions and to define priorities for policy (Fischer & Forester 1993; Hajer & Wagenaar 2003; Jasanoff 2003; Wynne 2003; Jasanoff & Martello 2004).

Several authors now argue that to understand and better advance responses to global environmental change problems, it is necessary to find a middle ground that combines interpretive, constructivist views with the power of scientific discovery (Latour 1987; Benton & Redclift 1994; Stern & Fineberg 1996; Jasanoff & Wynne 1998; Woodgate & Redclift 1998; Lorenzoni et al. 2000; Wynne 2002).
Table 1. Dimensions of social theory and the global environment.

<table>
<thead>
<tr>
<th></th>
<th>positivist/realist</th>
<th>interpretive/constructivist</th>
<th>co-construction—hybrid</th>
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<tbody>
<tr>
<td>characteristics of global environmental change</td>
<td>science—identifies the ‘problem’, characterizes the environmental risk—which must then be dealt with by society</td>
<td>GEC—risk problem—what is environmental risk is socially and culturally based; communicated through language and discourse</td>
<td>coevolution and coexistence of the physical and social world. Physical environment shapes intellectual development and needs and vice versa</td>
</tr>
<tr>
<td>science and expert knowledge</td>
<td>science as the source of truth—uncertainty and complex systems as risk problems</td>
<td>‘claims’ rather than ‘truths’—all knowledge is socially created</td>
<td>circular interaction between science (rationalist) and policy (socially constructed understandings of science). Science for policy has influence</td>
</tr>
<tr>
<td>policy process</td>
<td>linear process where science informs policy; policy acts upon new science as it emerges. Strong state required. Top-down</td>
<td>calls for more deliberative, participatory approaches—expert knowledges not ‘trusted’, bottom-up</td>
<td>iterative, recursive model; emphasis on institutional change and interaction between social and natural systems</td>
</tr>
<tr>
<td>methods/approaches</td>
<td>world systems modelling; pressure-state response; ecological modernization—economic efficiency (optimization)—benefit–cost assessment</td>
<td>discourse analysis, communicative rationality, deliberative democracy; analysis of discourse coalitions and storylines. Identification of narrative interpretation in policy processes—framing in controversial problem solving</td>
<td>analytic deliberative process is a starting point—allowing interface between people and place, science and understanding to identify and manage risk. New institutionalism (more descriptive than explanatory) combined with ethnographic approaches (interpretive, qualitative). Aim to understand how global change occurs, to actively design policy process to frame problems and solutions that are meaningful in local/regional contexts</td>
</tr>
<tr>
<td>some key contributors</td>
<td>this is the dominant view in climate policy and science community working together in the IPCC process. Ehrlich; Holdren; Sabatier (on policy processes); Spaargen and Mol (on ecological modernization)</td>
<td>Douglas and Wildavsky (on cultural theory); Hajer; Kuhn; Burgess and Harrison; Beck (reflexive modernization); Giddens; Foucault, Habermas</td>
<td>Woodgate and Redclift; Norgaard; Ostrom; Dietz; Stern and Fineberg; Rydin; Jasanoff and Wynne; Liverman; Schneider Hajer; Schon and Rein; Fairhead and Leach; Fischer</td>
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An unproductive divide also exists within different strands of social theory accompanied by different methods and languages. The ongoing struggles, both within communities of social researchers and between the social science and science communities, mean that potentially important connections can be completely ignored or drowned in discussions that focus on differences rather than areas of agreement. These conceptual perspectives are outlined in figure 1 and table 1. This conceptual background provides a starting point for this review and we will return to it to conclude.

3. Scientific discovery and confirmation of global warming

(a) Early science of global warming

Global warming was officially discovered more than 100 years ago. The pioneering work of a Swedish scientist Svante Arrhenius in 1896 is attributed with the discovery of the greenhouse effect (Bolin et al. 1986; Weart 2003; Maslin 2004). Two other early scientific efforts had also discovered elements of the puzzle that eventually became the theory of the atmospheric greenhouse effect theory, French scientist Joseph Fourier and British scientist John Tyndall. Early in the nineteenth century, Fourier pointed to the Earth’s atmosphere as the reason for the Earth’s mild temperature compared to the heat of the Sun’s rays (Hart & Victor 1993; Weart 2003). In 1859, Tyndall investigated how the atmosphere of the Earth stayed warm and was the first to show that the atmospheric gas of CO₂ was opaque to infrared radiation from the Sun and could thus warm the atmosphere. Tyndall’s conclusions were independently confirmed by Arrhenius and Thomas Chamberlin between 1897 and 1899 when they
calculated that human activity could substantially warm the global atmosphere by adding carbon dioxide to it (Hart & Victor 1993; Weart 2003). However, Arrhenius was the first to identify the link between climate change, fossil fuel burning and rising atmospheric concentrations of CO₂. He estimated that cutting concentrations into half would cool the world by 5–6°C (Bolin et al. 1986; Weart 2003; Maslin 2004). This theory still stands today.

Maslin (2004) points out that the discovery of the greenhouse effect was an ‘accidental affair’. The major aim of both Arrhenius and Chamberlin’s work was to offer a theory that might explain the rise (and fall) of the great ice ages. It was not until 1987 that the Antarctic Vostok ice core results confirmed the pivotal role of atmospheric CO₂ in controlling past global climate (Maslin 2004). As no one else took up the issue in their time, Arrhenius and Chamberlin turned their attention to other challenges and the theory of a greenhouse effect was laid dormant for several decades. From 1938 to 1942, a true theory of the greenhouse effect began to emerge in a series of lectures and papers to the Royal Meteorological Society by British engineer Guy Stewart Callendar. Using meteorological data, Callendar showed that warming was already occurring and identified links between global warming, CO₂ emissions and fossil fuel burning to raise concern about the potentially harmful greenhouse effect (Bolin et al. 1986; Hart & Victor 1993; Weart 2003). Despite the prescient nature of these findings, neither the broader scientific community nor the public at large had much interest in the greenhouse effect at this time.

Nascent scientific concern about the influence of human activities on the climate did not initially raise public alarm about the greenhouse effect. At least three reasons may explain this. First, scientists had identified many natural and human-induced influences on global climate, including sunspots and water vapour in the atmosphere to ocean circulation, thus influences by human beings were considered insignificant when compared with greater natural forces (Maslin 2004). Second, western society’s attention was fixed on World War II and scientific enterprise was overwhelmingly focused on wartime issues, such as nuclear physics, weaponry and weather modification. Third, the prevailing scientific belief was that any climate change resulting from human-made emissions was likely to be benign, relatively small and easy to control with the vast technological means available to humans (Hart & Victor 1993). Indeed, in 1957, Roger Revelle, one of the pre-eminent scientists working on the carbon cycle, wrote: ‘Our attitude towards the changing content of carbon dioxide in the atmosphere that is being brought about by our own actions should probably contain more curiosity than apprehension’ (Hart & Victor 1993, p. 656; citing Revelle 1966).

(b) Cold War fuels global warming research

These fundamental questions about the nature of global warming were eventually debunked through scientific discovery. In particular, with the advent of World War II, new techniques and technologies emerged to refine understanding of the radiative properties of CO₂ in the atmosphere as well as the role of oceans in removing atmospheric CO₂. In large part, these advances came in the pursuit of military interests—either in the use of weather modification as a strategic weapon for geopolitical warfare or in the need to understand diffusion of
potentially destructive agents—e.g. chemicals and nuclear radiation—in atmospheric and marine environments (Hart & Victor 1993; Kwa 2001; Weart 2003; Maslin 2004).

Wartime scientific advances provided carbon dating tools that helped to propel climate change science forward by providing insights into the carbon cycle and atmospheric–oceanic exchange of CO₂. Three scientists were notable in these efforts: Swiss scientist Hans Suess and two American scientists Roger Revelle and Charles Keeling, with Revelle becoming a main research entrepreneur out of Scripps Institute in La Jolla, California (Hart & Victor 1993). Using carbon dating in the 1950s, Hans Suess showed that the oceans were acting as the huge sink for atmospheric CO₂ that had been predicted; in what became the ‘Suess effect’, he concluded that atmospheric concentrations of CO₂ were on the rise (Hart & Victor 1993; Weart 2003). From 1955, Revelle and Suess collaborated to show the limits to oceanic–atmospheric exchange of CO₂, raising concern about the possibility for an unprecedented rise of CO₂ in the atmosphere (Weart 2003); they noted the ‘large-scale geophysical experiment’ being carried out by human beings with the Earth’s atmosphere and climate and advocated a programme of monitoring to understand and track developments (Hart & Victor 1993; Agrawala 1999; citing Revelle & Suess 1957; Weart 2003). In the late 1950s, Revelle hired Charles Keeling to measure the concentration of atmospheric CO₂ in Antarctica and in Mauna Loa, Hawaii. These Keeling curves have become one of the major icons of the global warming debate documenting the annual climbing trend of CO₂ concentration since 1958 when measurement began (Hecht & Tirpak 1995; Maslin 2004).

Revival of CO₂ theories of climate change came in 1956 when Gilbert Plass published a paper estimating that global mean temperature (GMT) could increase 1.1°C per century and, in 1959, updated estimates to 3°C (Hart & Victor 1993; Weart 2003). Plass concluded that adding more CO₂ to the atmosphere would indeed intercept more infrared radiation and warm the atmosphere (Weart 2003). Interestingly, these climate change predictions, already available from mid-1950s, are in the range of those that we have today built upon much more sophisticated modelling tools.

Also in the 1950s–1960s, an atmospheric modelling community began to provide corroborating evidence on global warming (Hart & Victor 1993; Edwards 2001; Weart 2003). Research originally focused on war-time possibilities for weather modification and John von Neumann, at Geophysical Fluid Dynamics Laboratory (GFDL) in Chicago, was a main research entrepreneur in this area. He gathered sufficient government research funding to institutionalize research on mathematical modelling of meteorology and weather modification techniques (Hart & Victor 1993; Weart 2003). Atmospheric modelling was built upon the rapid increases in computing power in this period, which increased several thousand fold from the 1950s into the mid-1970s (Weart 2003). Emerging ‘general circulation modelling’ (GCM) tools provided initial results relevant to climate change published in the mid-1960s. Although the models ignored many important factors, the crude general circulation modelling exercises corroborated Plass’ conclusion that global warming would accompany human-induced increases in atmospheric CO₂ (Maslin 2004) and by the end of the 1960s, this modelling community had confirmed the usefulness of this tool for global warming research (Edwards 2001).
Cold War politics in the 1950s also opened the way for international cooperation on relatively neutral topics of scientific interest. In a period dominated by policy for science the World Meteorological Organization (WMO) was created in 1950 (Agrawala 1999). In 1957/1958 with the leadership of Roger Revelle, the WMO worked with other government organizations to support the International Geophysical Year; this significantly boosted funding and attention to climate change science, even prior to any formal recognition of climate change as a political or social issue, within a much broader programme focused on meteorological issues (Hart & Victor 1993; Agrawala 1999). This period was also known for competing theories and debate about causes of the rise and fall of the different ice ages and whether shifts between ice ages were gradual or rapid (Weart 2003; Maslin 2004).

(c) Global warming in the public sphere: 1960s

The 1960s ushered in a range of scientific results to confirm the greenhouse effect or global warming theory as well as the beginning of broad-scale interaction between scientific and policy communities on this issue (Weart 2003). Keeling’s Antarctica and Mauna Loa data amassed to show a rapid rise in atmospheric CO₂. These data provoked first signs of concern about global warming within the scientific community. In a 1965 scientific meeting hosted by the National Center on Atmospheric Research, MIT scientist Lorenz showed that the climate may not be a stable system or ‘deterministic’ system, while other scientists advanced theories about how radical climate change had occurred at the close of the last ice age, 11 000 years ago (Weart 2003). Scientists showed that climate had warmed 5–10°C in less than 1000 years, marking the end of this ice age. Revelle summed up by highlighting the ability of slight, transitory changes in the atmosphere to flip the climate to quite radically different states and calling for pluridisciplinary approaches to climate change research. Shortly after, in 1967, the International Council for Science (ICSU) and WMO created a collaborative international research programme on the global atmosphere, which included climate change along with weather prediction (Weart 2003).

A number of other trends also emerged in the 1960s to link a policy discourse to the scientific discourse. First, scientists began to interact more closely with civil society and policymaker audiences, thus marking what could be considered the first phase of science for policy collaboration.³

Second, also in the United States, military sources of funding for climate-relevant scientific research were cut back and civilian sources, such as the National Academy of Sciences which oversaw the National Science Foundation (NSF), emerged to replace the military sources of previous decades (Hart & Victor 1993; Weart 2003).

Finally, government-sponsored analysis of the science began to emerge, linking the rise in CO₂ and global warming to fossil fuel use and receiving separate attention in government budgets (Hart & Victor 1993).

³For example, Weart (2003) notes a workshop hosted by Conservation Foundation in 1963 may have been the first of its kind on climate change featuring scientists interacting with nongovernmental organizations and policy analysts in the US. The workshop conclusions warned that climate change could be harmful to society.
From the end of the 1960s, the fundamental nature of scientific endeavour on climate change issues became more intertwined with the public sphere. Agrawala (1999) explains this transition as a shift away from policy for science to science for policy. In this transition, the science and the politics of the issue become closely intertwined and affect one another. Thus the account of scientific developments that follow can only be understood in the context of other socio-political developments.

(d) Global warming confirmed as a problem: 1970s on

Palaeoclimatological investigations began to reveal evidence that radical shifts in climate had occurred in the distant past. For example, palaeooceanography (study of past oceans) demonstrated that there were at least 32 glacial–interglacial (cold–warm) cycles in the last two and a half million years, not four as had been previously assumed (Weart 2003; Maslin 2004). However, there was no possibility of estimating how quickly the ice ages came and went (Maslin 2004). Perhaps due to evidence of multiple ice ages, many scientists and the media ignored convergence about the science of global warming. Even as late as 1980, in part due to the cooling trend shown by GMT data over the period 1940–1970, conventional wisdom as reported in government science-based reports was that cooling would be as likely as warming (Hart & Victor 1993; Mazur & Lee 1993).4

The intense scientific drive to understand past climate change eventually led to developments in the 1980s that began to dispel theories about global cooling in favour of warming. Technical advances led to high-resolution past climate records from deep-sea sediments and ice cores, which in turn shaped understanding about how past climates had changed (Maslin 2004). These records showed that ice sheets are slow to build up, taking tens of thousands of years, but that a transition to warmer climates can be geologically quick—of the order of one to a few thousand years. This is due in part to positive feedbacks that accelerate the warming process, for example, sea-level rise which can lubricate and help destroy large ices sheets. As Maslin (2004) notes, ‘the realisation occurred in the paleoclimate community that global warming is much easier and more rapid than cooling. It also put to rest the myth of the impeding next ice age.’ In 1985, Broecker and others at Lamont Laboratories had linked the start of the Younger Dryas ice age to the shutdown of the Atlantic Ocean’s heat conveyor belt, known as the thermohaline circulation. This suggested that multiple equilibrium states of the climate may have existed across time (Weart 2003).

In the mid- to late 1970s, other scientific investigations led to improved GCM models. This included taking into account the role of particles, clouds and ocean exchange of CO₂ in affecting the global climate. Despite the cooling effect thought to be associated with particle pollution (Weart 2003 citing Rasool & Schneider 1971), new ocean–atmosphere coupled GCM tools emerged with revised and higher estimates of the warming that would be associated with a doubling of CO₂ in the atmosphere (Weart 2003 citing Manabe & Bryan 1975).5

4 Both citing Global 2000 report commissioned by the Carter administration and issued in 1980.
5 This parameter is known as ‘climate sensitivity’ and is a key input in climate change modelling today (see van der Sluijs et al. 1988).
By the 1980s, scientific concern had emerged about CH$_4$ and other non-CO$_2$ greenhouse gases as well as the role of the oceans as a carrier of heat. GCM continued to improve and the numbers of scientific teams working on such models increased over the 1980s and the 1990s (Hecht & Tirpak 1995). In 1992, a first overall comparison of results from 14 GCM models was undertaken; the results were all in rough overall agreement, confirming the prediction of global warming (Weart 2003).$^6$

(e) Convergence and contestation in climate science

Scientific developments since this time have largely confirmed the theory of global warming and increasingly documented observed effects (e.g. IPCC 2007). However, the remaining uncertainties in the exact nature of climate change as it is expected to play out in the future and the scientific explanations of past developments have left room for climate sceptics to influence the debate. The advent of climate sceptic arguments has strengthened the vigour and debate about the science in the public domain and may have stimulated growth in non-governmental organization activities to support action on climate change (Carpenter 2001; Gough & Shackley 2001; McCright & Dunlap 2003; see also below).

Perhaps the most persuasive of scientific developments came in the 1980s with the emergence of a clear warming signal from interannual data on GMT. GMT data were compiled in the early 1980s in the US by Hansen, Madden and Ramanthan (Weart 2003). The data showed a low point in mean temperatures from the Northern Hemisphere in mid-1960s to 1980s, but an upturn beginning in 1981. By 1986, British scientists Wigley and Jones also succeeded in compiling 134 years of GMT data to show an unprecedented global warming trend starting in 1980, with the first 3 years the warmest on the record (Jones et al. 1986). They had used different data and methods from those of the Lamont team, an approach that served to increase confidence within the scientific community that global warming was underway. By 1990, it was generally accepted in the scientific community that human-induced global warming was underway and likely to continue in the future. In addition, it appears that scientists were also increasingly worried about the risk of climate ‘surprises’ or abrupt change (Weart 2003 citing Chagnon et al. 1992, survey of scientific experts), as the rate of warming observed over the last century was unprecedented historically. This raised the question of whether such an alarming rate could potentially lead to abrupt change.

Although the upturn in the global annual mean temperature and its link to human activities is still contested by some, it is an issue around which the majority of scientific opinion has converged and become a benchmark indicator of global warming (Hecht & Tirpak 1995; Maslin 2004). This GMT trend is based on sea surface and land–air temperature measurements from disparate measuring stations and these data must be manipulated and combined to discern a single average trend of annual change. A number of critiques of these data have emerged in the last decades, but each has been addressed so as to strengthen confidence within the international scientific community in the overall

$^6$For a different perspective on GCM see Shackley & Wynne (1995) and Demerritt (2001).
conclusions that the Earth’s climate is warming at an unprecedented rate (Maslin 2004). 7

Known as the ‘hockey stick’ graph of GMT change, a new round of criticism recently raised questions about the quality of data and accuracy of methods used to estimate trends in GMT (McInytre & McKitrick 2003; IPCC 2007). This debate has taken place between experts but in an unusually public manner (Crowley 2005). One US scientist—Michael Mann, who has widely published on GMT trends—has been the centre of the criticism and active in responding to it (Mann et al. 1999, 1998, 2003). 8 Despite Mann’s strong rebuttal and the weight of scientific evidence that bring into doubt the validity of the critique (National Academies of Science et al. 2005), both the media (WSJ 2005a, b; Revkin 2006b) and US and British politicians (Crowley 2005; House-of-Lords 2005) have continued to bring attention to the questions raised by McInytre & McKitrick in their critique.

There are two possible explanations for this extraordinarily public scientific debate. First, political sceptics who do not want to see political action to address climate change may find this debate about methods and scientific uncertainty a convenient hook on which to hang their case for delay (McCright & Dunlap 2003; Crowley 2005). The GMT millennium scale trend is a particularly important target for such criticism owing to its emblematic role in the policy debate. Second, the media’s ethical commitment to the balanced reporting may unwittingly provide unwarranted attention to critical views, even if they are marginal and outside the realm of what is considered ‘good’ science (Boykoff & Boykoff 2004; Antilla 2005).

This case demonstrates the public nature of scientific enterprise especially on issues that are politically relevant. When combined with increased ease of communication, from conventional media, such as newspapers, radio and television to more informal websites, what is normally a relatively private debate among scientists and experts can easily be shifted into the public arena. Overall such exchanges contribute to a public image that the science of global warming is ‘contested’ despite what many would argue is an overwhelmingly strong scientific case that global warming is occurring and human activity is a main driver of this change (IPCC 2001, 2007; Kolbert 2005; National Academies of Science et al. 2005).

7 As highlighted by Maslin, several of the main criticisms of the data are: (i) many of the land monitoring stations have subsequently been surrounded by urban areas, thus increasing the temperature records because of the urban heat island effect, (ii) there have been changes in the ways ships measure the sea-water temperature, (iii) there was not an adequate explanation for the cooling trend in the 1970s, (iv) satellite data did not show a warming trend from 1960 to 1990 and (v) the global warming model overestimated the warming that should have occurred in the Northern Hemisphere over the last 100 years. Since the early 1990s, the urban heat island and variations in sea-temperature measurements have been taken into account. We now know that the cooling trend of the 1970s is due to the decadal influence of the sunspot cycle. It turns out the satellite results for a number of reasons that were spurious and greater understanding of the system and recalibrated data shows a significant warming trend. Lastly it was discovered that other pollutants such as sulphur dioxide aerosols have been cooling industrial regions of the globe and as the models of the early 1990s did not take them into consideration they were overestimating the amount of warming.

8 See also Mann’s website: http://holocene.meteo.psu.edu/Mann/ [accessed 2 November 2005].

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The IPCC’s most recent Fourth Assessment Report (AR4) demonstrates overwhelming scientific consensus about global warming and its links to human activities. The assessment shows an ‘unequivocal warming trend’ that has continued from for more than a century until the present day. Extending the record over roughly the last millennium (and more for the Northern Hemisphere) the temperature increase observed in the twentieth century is likely to have been the largest of any half a century in ‘at least 1300 years’. Importantly, most of the unprecedented warming observed in the twentieth century is attributed to human causes (IPCC 2007).

4. Scientific leadership, political and institutional change

The foregoing discussion highlights the emergence of leadership among scientific elites on climate change, calling initially for more research and eventually for policy attention to the issue. Hart & Victor (1993) argue that by 1957, two distinct scientific discourses and elite scientist followings were firmly established, working quite separately, but both responding to research opportunities offered by the Cold War to create new political alliances and to gather resources to establish autonomous research institutions. One was on the carbon cycle, led by the oceanographer Roger Revelle of Scripps and the other was on atmospheric modelling which was led by the mathematical meteorologists, particularly the ‘father of modern computing’ John von Neumann and meteorologist Smagorinsky at GFDL. Research and leadership from both the groups helped to propel the science of climate change forward often in indirect ways and, eventually, to pull the issues of global climate change onto the public agenda (Hart & Victor 1993).

From the 1970s onwards, these leaders joined others in an increasingly active policy debate and policy process, both in the US and internationally, where scientists joined political leaders, government and civil society groups (non-governmental organizations) to promote first research and later action on climate change. This was intertwined with media attention to global warming as scientists, politicians and activists, acting as entrepreneurs, often promoted climate change through the media (Hart & Victor 1993; Mazur & Lee 1993; Bodansky 1994). Although it was the same scientific elites still leading the charge, with essentially an unchanged message from previous years, by the late 1970s, the political audience had started to listen (Hart & Victor 1993, p. 665). The US government also increased funding by 400% between 1971 and 1975 for climate change research (Hart & Victor 1993). In 1978, the US National Climate Act was passed, establishing the National Oceanic and Atmospheric Administration (NOAA; Weart 2003). However, all this came at a time when there was perhaps more uncertainty than ever before about the nature of the greenhouse effect. Given the decline in GMT from 1940 to 1970, some scientists still believed that a cooling effect of particles was outweighing the warming effect of CO2 and there was ongoing disagreement between cooling and warming advocates (see below; Hart & Victor 1993; Weart 2003).

Despite ongoing scientific debate, the 1970s marked the start of close collaboration between scientific experts and policymakers. Two examples of collaboration between science and the policy-relevant discourse, or science for
policy in the US, were the 1970 Study of Critical Environmental Problems (SCEP) and the 1971 Study of Man’s Impact on Climate (SMIC; Hart & Victor 1993; Bodansky 1994; Weart 2003). Neither study was particularly novel from technical or scientific viewpoints, but both were interdisciplinary efforts to draw together science and policy perspectives and had an environmentalist tone. Critical leadership had been provided for each of these studies from well-known scientists and academics, notably Roger Revelle, Thomas Malone, Caroll Wilson and (on SMIC) Bert Bolin. Thus, a number of research ‘entrepreneurs’ emerged in the relatively new role of mediating between the scientific and policy communities. Hart & Victor (1993, p. 663) suggest that these developments mark paradigm shifts, where scientists were increasingly seeing their work as part of the social community and providing new insights for policy.

The UN Conference on the Human Environment (UNCHE) in Stockholm in 1972 was a landmark event for the politics and policy of climate change (Hart & Victor 1993; Bodansky 1994; Weart 2003). Although the weight of the meeting was on local and regional environmental and pollution problems (Liverman 1999), it was the first high profile, intergovernmental conference to address the global environment. Both SMIC and SCEP had been designed to contribute to this international conference and both reports called for the establishment of global atmospheric monitoring networks. Swedish scientist Bert Bolin emerged from both the SMIC and the UNCHE as an international team leader and a diplomat within the climate science community (Weart 2003). This is a leadership role that he continued as the first chairman of the Intergovernmental Panel on Climate Change when it was created in 1988 by WMO and UNEP (see below). At the close of the 1972 international conference, global warming was recognized as a potential public threat and pledges of public funding were forthcoming to support further research and international science cooperation.

In 1979, the first World Climate Conference sponsored by the WMO resulted in the establishment of a World Climate Programme, establishing international collaboration for monitoring and data collection (Hecht & Tirpak 1995). The declaration of the conference, cited by Hecht & Tirpak (1995, p. 378), concluded ‘there is serious concern that the continued expansion of man’s activities….may cause significant extended regional and even global changes of climate.’ At about the same time, UNEP initiated a small climate impact programme (Hecht & Tirpak 1995). In addition, the (unrelated) energy crises of the 1970s were used to promote arguments for renewable energy and energy efficiency during the Carter administration in the US in what Carter had termed the ‘moral equivalent of war’ (on imports of foreign oil; Carter 1977).

From the 1980s onwards, science for policy emerged to blur the boundaries between the climate change science on the one hand, and policy on the other, in the US and elsewhere (Agrawala 1999). In 1983, two US government-sponsored science reports had conflicting conclusions about the need for policy action to address global warming. A US Environmental Protection Agency (EPA; EPA 1983) report stressed the urgency of dealing with global warming problems, while a National Academy of Sciences (NAS) report saw no need for immediate steps despite concern about the issue (NAS 1983). Despite differences in interpretation of the science and its implications for policy, by 1988 the United States Congress was debating details of legislation to address climate change through the window of energy policy; by
1992, the National Energy Policy Act was signed into law by President Bush (Sr) (Hecht & Tirpak 1995). This followed earlier US legislation acknowledging climate change as a policy problem (i.e. the US National Climate Act).

In parallel developments in Britain, the Thatcher government identified global warming as a key issue (Weart 2003, p. 157). In a speech to the Royal Society in 1988, Prime Minister Thatcher echoed Revelle’s earlier warnings when she highlighted that we have ‘unwittingly begun a massive experiment with the system of this planet itself’ (as cited in Bodansky 1994). A principal response by the Thatcher government to the threat of global warming was to set up the Hadley Centre at the British Meteorological Office, a centre for scientific research on climate change that is world-renowned today.

International attention also began to turn to the issue of climate change in the 1980s. A series of landmark international scientific conferences were organized by UNEP, WMO and ICSU in Villach, Austria between 1980 and 1987 and finally in Belagio, Italy in 1987. These meetings brought policymakers together with scientists to debate the policy implications of climate change.9 In Belagio, the international scientific community called for political action on climate change, focusing on responses rather than on the nature of the problem (Ramakrishna & Young 1992; Hecht & Tirpak 1995). These were significant meetings from a scientific point of view, as they helped to lay out for the first time in a comprehensive manner the emerging science of climate change. However, they were also viewed with scepticism from some official quarters, especially within the US government, where there was suspicion that the meetings’ conclusions were driven by green politics rather than by science (Bodansky 1994; Hecht & Tirpak 1995).

In 1988, another turning point came in the Canadian-hosted international conference on the ‘Changing Atmosphere: Implications for Global Security’, focused almost entirely on climate change and brought international political recognition to the subject of global warming. It concluded with a non-binding statement of government participants to work towards a 20% reduction in CO2 emission reduction by 2005 compared with 1988 (WMO/OMM 1988). This was a significant political development as it was the first international meeting of western governments to call for restrictions on greenhouse emissions (Hecht & Tirpak 1995) and it sent shock waves throughout the energy establishment that the issue of global warming could no longer be ignored.10 This was the first of what was to become a series of intergovernmental meetings to call for international action to mitigate climate change (e.g. Noordwijk, Netherlands 1989; Second World Climate Conference 1990). Looking across these events in the 1980s, Haas & McCabe (2001) attribute the new focus on the policy dimensions of climate change science to leadership from a handful of experts and scientists that tied the various events together through their consistent participation. Inadvertently, the attention brought to climate change by the Toronto, Villach and Belagio meetings may also have led to the creation of the Intergovernmental Panel on Climate Change (IPCC) in its present institutional form.

9 In personal communication, both Renate Christ (currently head of the IPCC) and Dennis Tirpak (formerly with USEPA and UNFCCC climate change secretariat) have indicated that the Villach 1985 meeting was a landmark event.

10 Note this observation is based on the lead author’s own experience, as she was working at the International Energy Agency on energy and environmental issues at this time.
The IPCC was created in 1988 by the UNEP and WMO to lead international scientific cooperation on climate change and in particular to conduct coordinated assessment of impacts and response strategies (Bodansky 1994; Agrawala 1998). Some analysts interpret the creation of the IPCC, and its particular institutional design as a direct result of governmental interests to limit non-governmental, scientific control over the policy debate on climate change (Hecht & Tirpak 1995; Haas 2004). In this design, governments exert control and oversight over the scope for and the content of its assessment products (Agrawala 1999; Haas 2004). Since its establishment in 1988, IPCC have broadly assessed science and other expert literatures on climate change resulting in a series of assessment reports in 1990, 1996, 2001 and now 2007, all of which confirm the human footprint on the Earth’s climate with increasing certainty over time. These reports are shaped by the scientific elite from around the world, but they have also benefited from important leadership of successive chairmen, first Bert Bolin from Sweden, then Robert Watson from the US (though he is British national, he is a naturalized US citizen) and now Dr Pachauri from India. IPCC reports helped to provide the basis for international political negotiations on climate change which began in the late 1980s (Hecht & Tirpak 1995). Given their mandate to work between science and policy communities, the IPCC functions as a boundary organization and continues to have significant influence over climate policy discourse in different parts of the world and internationally today (Agrawala 1999).

International negotiations on a climate change convention were begun shortly after establishment of the IPCC, under a UN General Assembly mandate (agreed in 1990). Rather than being initiated under UNEP, the UNGA established a self-standing Intergovernmental Negotiating Committee (INC) (Hecht & Tirpak 1995; Agrawala 1999). This may be due to the broad scope of the climate change problem and its obvious relation to other social and economic issues as well as to the environment (Hecht & Tirpak 1995). However, it may also be attributed to the interest of certain powerful governments (e.g. those in the OECD) to limit the influence of environmental coalitions and green politics in these negotiations. Negotiations eventually led to the formal signature of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Earth Summit in 1992 and which entered into force in 1994. Subsequently at the Third Conference of the Parties (COP) in Kyoto in 1997, the Kyoto Protocol was formally signed by 186 countries and eventually entered into force in February 2005 (Depledge 2000b; Yamin & Depledge 2004).

The period from 1970 to late 1980 was also characterized by a rise in post-war multilateralism, East–West diplomacy and détente (Levy 1993). One of the drivers for the relatively early multilateral environmental agreements in the 1970s, such as Long-Range Transboundary Air Pollution, was the overall political environment that advanced science cooperation—and eventually the protection of the environment—as an area for neutral exchange and collaboration between the East and the West in this Cold War period (Levy 1993). This rise in multilateralism was particularly noticeable on environmental issues. Keohane et al. (1993) observed that more than half of 140 international

\[11\] For a discussion of boundary organizations and their functions as mediators between these two communities, see Gieryn (1999), Guston (2001), Jasanoff (1990).
The dramatic rise in the number, and scope of the participation, in international environmental agreements supports social theory suggesting that this period of society is characterized by human–nature relationships taking a more central and defining role in society (Giddens 1991; Beck 1992).

Shabecoff (1996) highlights the end of the 1980s as a turning point where there was a fundamental shift in the appreciation for the interlinkages between economic well being and the environment. Rio was a landmark event as it confirmed a shift in understanding among developing and developed nations alike that local and global environmental issues were central to international relations, security and development. While he attributes this change to a variety of sources, ranging from the media to political leadership from a few individuals and international organizations, he sees much of the pressure on the political system as coming from grass-roots organizations (Shabecoff 1996).

Brown et al. (1992) in International Environmental Law estimate a much larger total number of multilateral environmental agreements, putting the number at 900 agreements in force in 1992; however these include regional and bilateral treaties. The author is grateful to the CIESEN website for pointing to these sources: http://www.ciesin.org/TG/PI/TREATY/envagree.html. See also, UNEP, GEO Yearbook 2006; http://www.unep.org/geo/yearbook/yb2006/084.asp—[last accessed 13 September 2006]—documenting trends in the participation in multilateral environmental agreements since the 1970s.
5. The environmental social movement

The environmental social movement of the 1970s and 1980s played a significant role in establishing climate change as an issue in the public sphere. A focus in the non-governmental organization sector on global environmental issues is relatively recent and follows much earlier political interests in natural resource conservation and local environmental issues. Hajer (1995) traces the origins of growing environmental awareness to a few key metaphors or emblematic issues in environmental discourse over the last 150 years. This starts with nineteenth century concern about deforestation. At the end of the nineteenth century, public concern had moved on to focus on the destruction of the countryside in the UK or wilderness in the US. In the 1930s, the predominant concern was soil erosion, for example, during the post-dustbowl drought period in the US. And in the 1960s, the publication of Rachel Carson’s *Silent Spring* in 1962 raised widespread public concern over the extent and pathways for chemical pesticide pollution. Early ecologists were politically marginal; however, the political constituencies supporting the environmental movement shifted over time crossing and recrossing the boundaries from left to right and back again, eventually gaining strength in numbers and political influence (Bramwell 1994; Brulle 2000; Weart 2003). Carson’s book was important in part because it united different strands of the US environmental movement, encompassing both the conservationists’ and the preservationists’ concerns about ecosystem threats with other public concern about human health (Brulle 2000).

The advent of human space travel followed and the widespread diffusion of the image of Earth seen from the Moon came in 1969. Ultimately this powerful image is attributed with help to change the way lay publics see themselves, and society, in relationship to the Earth and the global environment (Dryzek 1997; Jasanoff 2001). This may have helped to spread the view that humans were but a small tiny part of a much greater Universe. In this period, the influential notion of ‘spaceship Earth’ emerged from Kenneth Boulding (Boulding 1966; Dryzek 1997; Brulle 2000), who stated ‘man must live in the whole system, in which he must recycle his wastes and really face up to the problem of the increase in material entropy which his activities create. In a space ship there are no sewers.’ (Boulding 1965). A spate of other influential books on environment and society also emerged starting in the late 1960s (Brulle 2000) including Barry Commoner’s *Science and Survival* (1966) and *The Closing Circle* (1971) as well as Garret Hardin’s influential article on ‘The Tragedy of the Commons’ which links overexploitation of common resources to problems of overpopulation (Hardin 1968). Also in 1968, Paul Ehrlich published his Malthusian predictions about similar issues in *The Population Bomb*. In the 1970s, resource depletion became the chief metaphor following the publication of the Club of Rome’s 1972 report on Limits to Growth and British scientist Schumacher’s vision of the world as outlined in his *Small is Beautiful* (Bramwell 1994; Hajer 1995; Dryzek 1997). Dryzek considers these developments as part of a broader environmental discourse which he refers to as ‘survivalism’ (Dryzek 1997).

13 Interestingly in the same essay, Boulding also implies that putting a person on the moon would be a waste of intellectual resources and a low-priority achievement compared with the challenge (and apparent urgency) of understanding how social systems interact with the physical systems of the Earth.
Survivalism recognizes finite stocks of resources and the limited carrying capacity of ecosystems along side of the risks of overpopulation. Beyond the spaceship Earth image, key metaphors include the commons, images of overshoot and collapse as well as doom and redemption. This view of environmentalism is consistent with Yearley’s (1994) observation that one of the specific features of the environmental social movement is its critique of capitalism and these influential works substantiate this view. Bramwell (1994, p. 2) also notes ‘a scientific basis for ecological ideas was an essential precondition for the growth of environmentalism, which postulated a sickness, a wrongness about Western industrialised society’. These perspectives demonstrate a confluence of social, political and scientific thought that shape understanding of environment, and the finite nature of natural resources, from this period of the late 1960s on.

From the 1960s onwards, a number of events continued to reinforce our notions about the quality and sustainability of human life being intertwined and dependent upon natural resources. In the 1970s, the environmental movement focused attention on conventional, yet transboundary, pollution issues. One emblematic issue was that of acid rain which was found to be widespread and transboundary in its causes and effects (Levy 1993; Hajer 1995). Industrial emissions from the UK, Central and Eastern Europe and the Soviet Union were first suspected of affecting the health of ecosystems in Sweden in 1968. Later, in 1982, acid rain was also identified as the cause of forest dieback in Germany. The Long-Range Multilateral Agreement on Transboundary Air Pollution (LRTAP) was established in 1979 as the international legal framework to manage this problem and this led to a series of international protocols to control emissions of acidic pollutants.

In 1989, the ‘Exxon Valdez’ oil spillage had dumped 35 000 tonnes of oil into the Prince William Sound of Alaska (Mitchell 1993). This disaster, along with the discovery of acid rain, had exposed the fragility of natural systems to regional pollution from human industrial activities and raised awareness about dependence of human systems on natural resources. The Valdez disaster also stimulated a broadening of the environmental social movement to include socially and environmentally responsible investment as a theme for progressive business interests through the signature of the ‘Valdez Principles’ (CERES 2004).14

The 1980s ushered in a new set of concerns grounded in scientific knowledge about global environmental issues, and these were the subject of increasing press coverage (Mazur 1988; Mazur & Lee 1993) and attention from non-governmental environmental organizations (Liverman 1999). The 1980s was a time of rapid expansion of the membership and influence of environmental organizations in leading OECD countries (Brulle 2000). A dramatic demonstration that the global environment is affected by humans came with the 1985 discovery through the British Antarctic Survey of the ozone hole over this part of the world (Maslin 2004; Weart 2003). This was later confirmed by the US Antarctica scientific expedition in 1987 (Hecht & Tirpak 1995). These discoveries confirmed the destructive effects of chlorofluorocarbons (CFCs) on the Earth’s atmosphere, an idea that had been advanced more than 10 years earlier by Mario Molina and Sherwood Roland

14 This movement has become increasingly active on climate change issues, with activities such as the Carbon Disclosure Project starting to yield results that include a range of shareholder initiatives calling for companies to act to manage emissions even where governments have not mandated them to do so (see CERES 2004; Innovest 2005).
In 1987, an international protocol on limiting the production and emissions of CFCs as the main instigator of depletion of stratospheric ozone was signed in Montreal. Thus, the ozone issue had not only raised the spectre of public attention and awareness about the global environment, but also opened the way for multilateral cooperative responses to manage the global atmosphere (Litfin 1994; Hecht & Tirpak 1995).

Beyond scientific developments, the environmental social movement built part of its raison d'etre upon student social unrest and calls for nuclear disarmament of the late 1960s (McCormick 1989; Brulle 2000). Antinuclear sentiment was further boosted in the 1970s and 1980s due to two high profile and high-risk accidents in civilian nuclear power facilities, first, in 1979 at Three Mile Island in Pennsylvania (Patterson 1983) and later, in 1986, at the Chernobyl facility in what was then the USSR (Wynne 1992a). These events fed pre-existing public scares about the risk of a nuclear winter (Mazur & Lee 1993). In addition, technocratic approaches to managing nuclear risks and lack of public debate about nuclear power and the risk of radiation from these accidents furthered public fears and scepticism about the ability of humans to effectively control nuclear power (e.g. Wynne 1992b). Thus the rise of the environmental movement was stimulated in part by growing public fear and opposition to nuclear power as well as opposition to technocratic control over public choices concerning nuclear power (McCormick 1989; Brulle 2000), an issue that eventually came to be linked to climate change mitigation policy questions.

Environmentalism, at least in western nations, gained momentum and membership from the 1960s on, and by the 1980s had become well recognized as a mass social movement (McCormick 1989; Yearley 1994; Shabecoff 1996; Liverman 1999). Tracing developments from Stockholm in 1972 to Rio in 1992 indicates a shift in environmental attention from local and regional issues to global issues, which was also accompanied by a broadening of the environmental debate to include participation in international negotiations from a range of previously unheard voices (Shabecoff 1996; Liverman 1999). These extended beyond business and scientific communities to include environmental non-governmental organizations, women and local communities as well as social scientists.

Post-Cold War environmental awareness grew in parallel with rapid globalization of economic development characterized by the emergence of global markets for goods and services and interdependence of national economies within a major global network of supply and demand (McCormick 1989; Liverman 1999). Liverman (1999, p. 112) writes that the global environmental movement ‘can also be seen as a response to economic and political restructuring associated with the internationalizing of trade and the Cold War. Environmental degradation changes comparative advantage, and domestic environmental policies can influence competitiveness and create nontariff barriers to trade.’ The structural changes of the world economy in this period was accompanied by a large number of international environmental agreements (see above), reinforcing stable conditions for globalizing economic development, while also providing international platforms for public debate that continued to raise global environmental awareness. In part due to the transboundary nature of the problems and their solutions, and to the international institutions that have developed to manage these problems, environmental social movements came to
be characterized by an international structure, unlike other forms of social movements (e.g. labour movement; Yearley 1994). The environmental social movement is associated with a powerful transnational networking among individuals and organizations within which rapid and spontaneous communication is facilitated by the growth and ease of access to internet and telephony (Giddens 1990; Yearley 1994; Hajer & Wagenaar 2003; Betsill & Bulkeley 2004).

Public support for non-governmental environmental activities intensified in the 1980s and increasingly environmental organizations were calling for policy targeting CO₂ reductions. In the US, this was through organizations, such as Sierra Club, Union of Concerned Scientists and Environmental Defense Fund (with Michael Oppenheimer in the lead who was an ozone activist). These calls were challenged by the Bush administration, which had by the late 1980s, realigned themselves with industry dissenters. Public awareness also grew during this period. A public survey, reported on by Weart (2003, p. 156), showed public awareness of global climate change had doubled since 1981 when compared with 1989: 79% of Americans had heard of the greenhouse effect by 1989 when compared with 38% in 1981. Commenting on how extraordinarily novel it is that global warming became a public issue at all, Weart (2003, p. 156) notes how ‘discourse had in many ways grown more sophisticated.’ Although global warming was an invisible and distant threat based on complex science and data by the end of the 1980s, it had clearly moved into the public sphere and had been established as a problem of public policy.

Given the complexity of these global issues, science plays a central role in political debate about climate change; science is also a main source of the expertise offered through the environmental social movement (Bramwell 1989; Yearley 1994; Gough & Shackley 2001; Weart 2003). Yearley (1994, p. 162) reminds us that ‘many objects of environmental concern are only knowable through science. Without a scientific worldview we would know nothing of the ozone layer and would certainly be unable to measure its diminution; the same is true of the greenhouse effect.’ Yet the science of global change can be used to promote quite different ends by friends and foes of environmental action alike (Yearley 1994; Herrick 2004). Although scientific knowledge is essential to global environmental problem identification and to solution design, there is malleability in the way it is interpreted and used. This was demonstrated by Carson in Silent Spring where she criticized the politics of science and exposed scientific controversy about the effects of chemicals to public scrutiny (Brulle 2000, p. 183). This points to the importance of argument and interpretation in the use of science by both the environmental social movement and more broadly policymakers and other representatives of civil society to bring about change (Yearley 1994; Herrick 2004). In the public sphere, the media is another important pathway for relaying scientific knowledge to the lay public and for promoting political debate and understanding about global warming.

6. The role of the media grows

Climate change first emerged as a media issue in the late 1970s, stimulated by a first round of ‘popular’ books that targeted the general public (Schneider & Mesirow 1976; Bryson & Murray 1977; Weart 2003). These generated scientific
and public debate and increasingly media attention about whether climate change was a warming or a cooling issue (Weart 2003). Combined, these books boosted public interest and credibility in climate change as a public issue, which in turn led to public sector consensus that it warranted further research attention.

The media was vacillating at this time between different scientific views on cooling versus warming. For example, in 1976, a Business Week report highlighted scientific convergence around global cooling as a result of the change atmosphere; 1 year later they confirmed that warming would occur (Weart 2003). The world energy crises of 1973 and 1979, stemming from disruption in oil supplies and related price hikes, also acted as a driver for public attention to the energy–climate linkage. A number of academic studies on the influence of media on the climate change policy debate indicate that science combined with emblematic events and wide media attention has also helped to raise public concern about local and the global environmental issues (Mazur 1988; Mazur & Lee 1993; Dunlap 1998; Weingart et al. 2000).

Media coverage does not tell people what to think; however, it is able to direct public attention towards specific policy concerns and in this way to influence agenda setting for social concerns and policy issues. Mazur & Lee (1993, p. 682) note that agenda setting is not powerful per se rather it is ‘limited to raising an issue to salience’. Most viewers and readers will carry away simple images, thus it is also important to distinguish in media coverage between the ‘substantive’ content and a ‘simple image’, which is conveyed from visuals and from lead text in reporting (Mazur & Lee 1993, p. 683). Cognitive psychology tells us that simple images repeated often become ‘availability heuristics’ of real and potent danger (Tversky & Kahneman 1973; Mazur & Lee 1993). A similar notion is that of ‘affect heuristics’ where affect refers to a person’s feelings about a particular risk; when combined with images, this notion describes how a person may draw on experience and feelings to quickly bring meaning to an image (Leiserowitz 2006a). Further, the ‘quantity of coverage theory’ says that increased coverage turns public opinion in a negative direction, increasing the fear of environmental hazards or technology, whether or not the reporting of an environmental or technology issue is positive or negative (Mazur & Lee 1993). This implies that even when media coverage of global warming may report on the potential benefits of global warming in certain regions for agricultural crops or people’s lifestyles, there is a tendency for lay publics to interpret this negatively.

Burgess (1990) and later Carvalho & Burgess (2005) present a ‘circuit of culture’ model to understand social change with respect to global environmental issues and the role of media (figure 2). Such a model starts from media production of news stories (in a private sphere with respect to methods, data and opinions), moving on to public dissemination, for example, through broadcasts, internet, newspapers and finally to a consumption stage where different kinds of specialist and non-specialist audiences mediate interpretation of the news stories (Carvalho & Burgess 2005). Media attention and political action have also been shown to be closely interrelated (Mazur & Lee 1993; Carvalho & Burgess 2005).

In a review of key events in media coverage of global warming in the US, Mazur & Lee (1993) show that variation in quantity of coverage is linked to other issues of

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social importance, such as extreme weather or other emblematic external events (table 2). They also show that from the 1970s, media attention paralleled political attention to global warming in the US. For example, the 1979 energy crisis is considered by many analysts to be a turning point in media and political attention in the US, as global warming arguments were promoted in tandem with energy security issues to urge consideration of new alternative energy options (Hart & Victor 1993; Mazur & Lee 1993; Weart 2003). In 1981, a front-page story in the New York Times (NYT) featured James Hansen, a NASA scientist, documenting the 100-year increase in GMT from 1880 to 1990, and boldly predicting that ‘almost unprecedented’ warming would occur in the coming century (Mazur & Lee 1993; Weart 2003). The timing of this unusual science media coverage was a direct result of Hansen’s entrepreneurship, working with the NYT reporter to share findings as they were released in Science magazine. The NYT article also cites a counterpoint by Stephen Schneider of NCAR in Boulder. The event marked emergence of high-profile media exposure of scientists in an increasingly public debate about global warming (Mazur & Lee 1993).

Despite the ‘scientific’ controversy that remained about global warming, there was a drop in media attention in 1984 due in large part to vanishing energy crisis. This may explain in part why the scientifically important meetings in Villach and Belagio in 1985 received relatively little mass media coverage. Oil prices had dropped and cheap oil was plentiful and overall there was less attention in the media to the risks of synthetic fuels (which had been promoted as alternatives to oil during the energy crisis), CO₂ and global warming (Mazur & Lee 1993). In parallel, other issues began to dominate the environmental coverage in the media, including a debate about banning sale and stockpiling of nuclear weapons. In the mid-1980s, leading scientific authorities that had previously been pushing the global warming agenda advanced the risk of nuclear winter (Mazur & Lee 1993). The nuclear weapons freeze and the discovery of the ozone hole may have competed with climate change in the mid-to late 1980s as well as carried it along with them as ‘sister issue’ (Mazur & Lee 1993).

Another turning point year came in 1988. A first event was when James Hansen testified before the US Congress (Mazur & Lee 1993; Bodansky 1994; Weart 2003). Senator Tim Wirth had scheduled congressional hearings on the greenhouse effect on the anniversary of the hottest day ever recorded, 23 June 1988 and the weather set a new record high for Washington DC. In another bold interpretation of the science, Hansen linked the drought with high probability to global warming (Mazur & Lee 1993; Weart 2003, p. 155). There had been a series of heat waves and droughts in the US that had devastated certain regions. Prominent coverage of the story was carried by leading newspapers, notably on the first page of the NYT and in television news (NBC; Mazur & Lee 1993). A few days later, the press descended upon the international Toronto Conference on the Changing Atmosphere (Weart 2003, pp. 54 and 155), which was the first international meeting of governments on climate change to receive widespread media attention.¹⁶

¹⁵ Mazur & Lee (1993) look in-depth at the US roughly over the period 1980 to 1990, focusing on coverage in the New York Times as it is shown to be influential with respect to overall national media coverage.

¹⁶ The Toronto Conference was held on 27–30 June 1998; see WMO/OMM (1988).
Meanwhile Hansen and Schneider were highly visible scientists in the US media coverage of the blistering hot 1988 summer temperatures with images portraying polluted beaches and a devastating fire in Yellowstone National Park (Mazur & Lee 1993; Weart 2003). As Weart (2003, pp. 155–156) states: ‘The story was no longer a scientific abstraction about an atmospheric phenomenon: it was about a present danger to everyone, from elderly people struck down by heat to the owners of beach houses. Images of blasted crops and burning forests seemed like a warning signal, a visible preview for what might hold.’ These images combined to amplify the public image of (human induced) global warming in the US and elsewhere.

Growing public concern about the issue was further stimulated in 1989 coverage when the NYT reported that Hansen had been pressured by the Bush administration to alter testimony before Office of Management and Budget (OMB), a federal watchdog agency for internal management of the US government operations, to emphasize the uncertainty of human-induced climate change. Thus by 1989, the media was confirming the role that global warming had in the public sphere and playing a watchdog role to publicize political meddling with the science. Reports of such meddling continue today (Revkin 2006a) but with less influences on political developments. In 1989, this media attention helped to propel global warming onto the US political agenda.
Bodansky (1994) suggests that heightened media coverage in this period, combined with rising public concern, to lead to President Bush Sr’s 1988 election year pledge to respond politically to global warming. In 1988, Bush publicly stated that the greenhouse effect would be countered by the ‘White House effect’ (Hecht & Tirpak 1995). Under criticism led by Senator Gore in an increasingly public forum, the White House shifted positions on the issue of global warming and this eventually opened the way for negotiations on the Rio Agreement on the UN Framework Convention on Climate Change. However, the US has now flip-flopped by several times on its willingness to engage internationally to address climate change, with events eventually leading to their walking away from the Kyoto Protocol in 2001 (Depledge 2000a,b; Yamin & Depledge 2004). This raises a question about whether media attention is able to increase the long-term salience of an issue in the political realm (Kingdon 1984) and its interaction with shifts in public preferences and norms (Mazur & Lee 1993; Carvalho & Burgess 2005).

Carvalho and Burgess studied UK media coverage of global warming to trace the interactions between science, politics and media on the issue over roughly a 20-year period (Carvalho 2002; Carvalho & Burgess 2005). They point to the media’s role in framing the public sphere issues and show how the media roughly tracks social learning and socio-political developments on the climate issue through time. Carvalho (2002) identifies a pattern in British broadsheet press coverage with the number of articles rising and falling with key international conferences or scientific/expert publications, such as the release of IPCC reports.

In an update of this study to 2003, Carvalho & Burgess (2005) underscore the overall role of the media and social contexts in shaping public risk perceptions, where culturally mediated views of risk a shape social action especially on global ‘mega-hazard’ issues such as global warming (citing Beck 1992). Three ‘critical’ discourse moments are identified from 1985 to 2003 (table 3). Carvalho & Burgess (2005) believe that media representations of climate science–policy nexus show signs of social learning having taken place by 1997, when the media began to focus less on risk construction and more on issues associated with managing or limiting the risks of climate change (Carvalho & Burgess 2005, p. 15). The media itself is responsive to social learning and changing political agendas, and UK political developments and institutional, editorial biases of the newspapers have largely driven quantity and type of media representation given to climate change (Carvalho & Burgess 2005, p. 18). Finally, although the trends in media attention to global warming show that problem recognition was achieved over this period, it also indicates that solution formulation in the public sphere is still in very early stages of development (Carvalho & Burgess 2005).

The media not only appears to follow key events, but also appears to play an important role in shaping risk perception about climate change and public understanding. Despite ongoing scientific and political debate, media attention to global warming has served to legitimize it as a public issue and to establish it as a mainstream concern within society. Media have also influenced our use of words. From 1988 onwards, the use of global warming and climate change gained support, while greenhouse effect has lost its appeal and by 1997 it is rarely mentioned at all in the press (Maslin 2004). Yet how issues are presented in the media is shaped by the institutional position and biases of the particular media.
player(s) in question (Carvalho & Burgess 2005), and by disciplinary biases, such as the notion of ‘balanced’ reporting (Boykoff & Boykoff 2004).

Figure 3 shows that worldwide major newspaper coverage of global warming rose rapidly in the last decade or two. Consistent with the studies noted earlier, these data show that the quantity of media coverage tracks well with major international climate change developments such as in the international negotiations (e.g. 1997 Kyoto Protocol signature; 2001 US pulls out of Kyoto) and the release of major IPCC reports (e.g. 1996 and 2001). They also show the influence of major weather-related extreme events such as Hurricane Katrina late in 2005. Yet reporting that links climate change with shifts in patterns of extreme events have risen only slightly in recent years as a share of total global news coverage of climate change, suggesting that reporting of major world new services has followed the lead of the scientific community to be cautious about making these links.

Perhaps more powerful than newspaper coverage are other forms of media that rely on visual information, such as film, television and the internet. Recently researchers have studied the effects of the Hollywood blockbuster 2004 film *The Day After Tomorrow*. With a huge viewing public (estimated at 21 million people in the US alone), *The Day After Tomorrow* was a commercial success and also appears to have helped to promote climate change from an obscure scientific issue to one of popular public concern (Leiserowitz 2004; Reusswig & Leiserowitz 2005). Leiserowitz, Reusswig and others surveyed public opinion in several different western countries and concluded that the film shifted public risk perceptions on climate change among the viewing public. In addition, the media coverage in glossy magazines (e.g. *Vanity Fair*, May 2006, and *Time* magazine, 3 April 2006 has begun to convey a sense of urgency about climate change).17 Finally, widespread media coverage of emblematic impacts of climate change has also been stimulated by the international release of the documentary film *An Inconvenient Truth* by Al Gore and by a growing number of television documentaries on climate change (e.g. ‘60 Minutes’, ABC News and HBO documentaries in 2006).18 This rise in ‘visual’ media coverage suggests that in the last decade the ‘availability heuristics’, such as melting mountain glaciers and Arctic ice sheets, stranded polar bears and flooded river basins and coastal zones, for promoting public understanding of climate change have risen dramatically.

Table 3. Temporal trends in UK broadsheet coverage of climate change (based on Carvalho & Burgess 2005).

<table>
<thead>
<tr>
<th>Year Range</th>
<th>Description</th>
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<tbody>
<tr>
<td>1985–1990</td>
<td>From silence to the political construction of risk and problem recognition</td>
</tr>
<tr>
<td>1991–1996</td>
<td>Back to the future as climate change risks recede; belief in win–win sustainable development policies and outcomes to address the problem</td>
</tr>
<tr>
<td>1997–2003</td>
<td>‘Danger comes close to home’; a renewed sense of urgency; more frequent and intense extreme events observed; recognition of need for more radical shift in society to address climate change; potential conflicts and trade-offs with some options, e.g. nuclear</td>
</tr>
</tbody>
</table>

17 *Time* magazine of 3 April 2006, where the cover page headline read: ‘Special Report: Climate Change—Be Worried, Be Very Worried’.

18 For details and internet resources on each of these, see www.net.org/warming/earthday.vtml [accessed 6 June 2006].
Ungar (1992) and others have shown how public awareness is enhanced through chance events or ‘scares’, such as experience of extreme weather events of droughts or heat waves or, alternatively, independent events in linked areas (Mazur & Lee 1993; Ungar 1992, 1995, 2000). Examples noted above include the energy crises in 1973 and 1979, which heightened attention to energy–climate linkages, and the discovery of the ozone hole in the mid-1980s, generally raising awareness about the potentially destructive nature of human activities for the global atmosphere.

Social research in the US also suggests the existence of different ‘interpretive’ communities. These communities have implications for the debate about how severe and immediate the problem of climate change is and what should be done about it (Leiserowitz 2005, 2006b). Interpretive communities range from ‘naysayers’ to ‘alarmists’ but even for those people who believe climate change is real, its risks are largely perceived as distant in both space and time. To overcome this dilemma, Leiserowitz (2005, 2006b) suggests a need for active communication on regional implications of climate change risk and on its links to shorter-term issues, such as human health and extreme events. In this view, the rise in media attention to extreme weather events and climate change more generally (figure 3), combined with increasing use of images, may play a critical role to sway public opinion in coming years.

7. Discussion

This review of science–society interactions on climate change demonstrates the intertwining of parallel streams of different types of information, expert and lay
understandings, social and scientific knowledge to co-construct understanding of the issue of global warming in the public sphere (table 4). Scientific discoveries and theories accumulate and are corroborated by physical evidence of observed climate changes. Leadership provided by the scientific and political elite, along with growing media and political attention, combine to promote public concern and policy initiatives. Additionally, the force of the environmental movement of the 1970s and 1980s swept climate change forward as an emblematic issue demonstrating the risks of uncontrolled economic development and human pressure on Earth systems. And growing media coverage of the issue, with an increasing use of visual media, has kept climate change in the public eye. All of these forces have helped to propel climate change into the public sphere and onto the public agenda.

Looking across early scientific discoveries, it is clear that the science of global warming has leapt forward in fits and starts. A base of knowledge was built through careful empirical and theoretical analysis of very small components of larger questions that may not even be directly related to climate change (Weart 2003). Theory, built on new data and concepts, may be used to forge ahead in one direction, while awaiting confirmation or defamation from the next study. Errors in a previous study become the inspiration for one that follows. Meanwhile attention and efforts of the scientific community are not fixed on climate change questions alone, but may be diverted to new pressing issues that are raised by social developments (such as wartime efforts). In this dynamic and often unpredictable way, science is a process of trial and error, repetition and confirmation, slow and methodical in its efforts to build knowledge about the physical world.

Although a global environmental problem is initially identified and advanced by science, it inevitably becomes intertwined with society, with politics and policy. Scientific research is also inevitably shaped by society, as demonstrated by the close relationship between wartime politics and public funding for scientific research in the 1940s and 1950s. These contextual issues demonstrate the give and take recursive relationship that exists between society, science and the policy-making process.

Some explanation for the delay in public concern about climate change can be found in the ambiguity of early scientific knowledge about the greenhouse effect. Up until the 1960s, competing scientific views and recognition of general uncertainty about the greenhouse effect prevented much of the scientific elite from communicating latest scientific findings to both the press and the policy elite (Weart 2003; Maslin 2004). The elite scientific community transformed its concern into pleas for more funding and attempted to set up autonomous research institutions to pursue greater understanding (Hart & Victor 1993), leading to a powerful interface between science and politics which continues today. Almost all of the earliest climate policy initiatives were ‘policy for science’, aiming to facilitate research and collaboration amongst researchers to clarify the nature of climate change and its causes (Agrawala 1999).

One or two decades later that the same scientific leadership, more and more convinced about the ability for human activity to warm the Earth’s climate, worked hand in hand with political elites to advance climate change as a policy issue. In the 1980s, a scientific consensus converged with a series of meetings providing opportunities for experts to convey and discuss scientific findings with policymakers. In the 1990s, a human fingerprint was identified in the overall

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Table 4. Key developments in climate change across scientific, political, media and environmental movement domains: 1950–2000

<table>
<thead>
<tr>
<th>1950s–1960s</th>
<th>1970s</th>
<th>1980s</th>
<th>1990s</th>
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</thead>
<tbody>
<tr>
<td><strong>science</strong></td>
<td>advances in carbon cycle research. Suess and Revelle question extent of oceans as a sink for atmospheric CO₂. Revelle notes the ‘large-scale geophysical experiment’ that humans are conducting with the Earth’s atmosphere. Keeling data reveal rise in atmospheric CO₂; Plass predicts links between global warming and fossil fuel use</td>
<td>cooling trend (1940–1980) in global mean temperatures continues to muddle the scientific case for global warming. Attention to role of non-CO₂ greenhouse gases, particles and clouds</td>
<td>ozone hole discovered (1985). Concern about abrupt climate change emerges from palaeoclimatology. Observed GMT data show rapid global warming. Contested nature of climate science emerges</td>
</tr>
<tr>
<td><strong>leadership and key political events, institutional developments</strong></td>
<td>scientists begin working with policymakers and NGOs to raise awareness about scale and nature of the greenhouse effect; 1963—Conservation Foundation workshop joins environmental organization effort with science to gain policy attention to climate change</td>
<td>scientific elite entrepreneurs succeed in raising funds for climate change research. SMIC and SCEP studies 1972 UNHCE—recognizes climate change risk. First World Climate Conference. Government consensus emerges on need for research on climate change</td>
<td>early 1980s: science–policy advice split about the need for immediate climate policy action. Late 1980s: science–policy advice converges on the gravity of global warming problem and need for policy attention. Villach and Belagio Conferences. Toronto statement—governments pledge to achieve CO₂ emission reductions. WMO/UNEP (governments) create IPCC. UNGA resolution begins international negotiations on climate change</td>
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(Continued.)
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<tr>
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<th>1950s–1960s</th>
<th>1970s</th>
<th>1980s</th>
<th>1990s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>media coverage</strong></td>
<td>little or none on the greenhouse effect <em>per se</em> or to global warming</td>
<td>popular books on climate change issued by Schneider and Bryson—first scientists to publicly bring attention to human role in greenhouse effect</td>
<td>political construction climate change as a risk problem and as part of broader set of global environmental changes. Climate change linked to energy (e.g. follow on from 1970s energy crises). Hansen in NYT links observed warming trends and extremes to human causes</td>
<td>high level of media attention returns—focusing on sense of urgency and problem solving. Climate change increasingly linked to extreme events</td>
</tr>
<tr>
<td><strong>environmental social movement</strong></td>
<td>stimulated by antiwar and nuclear arms protest, the environmental movement of past times establishes the beginnings of a mass social movement. Rachel Carson—<em>Silent Spring</em>. First images of the Earth from orbit—K. Boulding terms ‘spaceship Earth’</td>
<td>survivalist discourse emerges, e.g. Club of Rome’s Limits to Growth, Erhlich’s Population Bomb, Hardin’s Tragedy of the Commons. Concern focuses on environmental degradation, population and development</td>
<td>massive growth in the environmental movement. Acid rain, ozone and global climate change become emblematic issues. Recognition of global environmental risks and rise in multilateral environmental cooperation. Progressive business goes ‘green’</td>
<td>environmental movement increasingly institutionalized, politically fractured and weak. Action on climate change characterized by transnational/international action, working from within policy institutional processes</td>
</tr>
</tbody>
</table>
scientific assessments conducted under the auspices of the IPCC. Major
international political agreements followed, starting with the signature and
entry into force of the UN Framework Convention on Climate Change in 1994
and the Kyoto Protocol in 2005. These agreements build not only on the science
but also on the social and political momentum that has grown up around climate
change in recent decades (Yamin & Depledge 2004). It was in this period, 1980s–
1990s, that science for policy emerged as a major force in the climate change policy
debate (Agrawala 1999).

This review outlines a variety of socially mediated pathways that build on
scientific knowledge to develop and expand social understanding about climate
change. These pathways combine and interact with the science of climate change
to explain the emergence of climate change in the public sphere. They operate in
the public sphere, interfacing between the core political system and the private
sphere touching on individual lives and perceptions as well as collective, social
institutional activities and norms (Habermas 1998). The pathways include
environmental social movement and the media as well as individual leadership
from scientific elites and other policy entrepreneurs championing ideas on
climate change (Kingdon 1984). Examples highlighted here show how these
pathways intertwine and sometimes merge, for example, when scientific leaders
have stepped forward to influence policy debate working through the news
services and other forms of mass communication.

The rise of environmentalism, as a mass social movement in the 1980s, helps
us to understand the timing of the emergence of global warming as an issue in the
public sphere. This is not to comment on questions about the ‘effectiveness’ of
the environmental social movement, which is a relatively new area of social
research (e.g. Hall & Taplin 2005). A number of researchers are raising questions
about the ability of the movement to promote change and appropriate policy
responses to issues such as climate change (Yearley 1994; Gough & Shackley
2001; Shellenberger & Nordhaus 2004).

Accompanying the emergence of the mass environmental movement is the
general rise in prominence of non-state actors—from environmental and business
organizations to local and regional governments and other social organizations—
that promote a particular ‘take’ on climate change (Newell 2000; Carpenter
To some extent, this pathway for knowledge production and understanding
exerts its influence through sub-politics, remaining outside of the domain of
formal political scrutiny and beyond responsibility in the public sphere for
transparency (Beck 1992). This occurs in part through transnational and national
networks of non-state actors and organizations (Smith 2002; Betsill & Bulkeley
2004). Through these transnational subpolitical networks, the environmental
social movement has played a fundamental role to help raise the salience of
global warming as policy issues.

Transnational networks also extend to government and scientists forming part
of what Haas has called epistemic communities (Haas 1990, 2004). For climate
change, these networks began to emerge in the 1980s and have played an
increasingly important role in global and local politics of climate change (Haas
1990, 2004). Much activity and interaction within the epistemic community on
climate change is formally institutionalized through the IPCC, which is operated
as an intergovernmental institution. As such it is clearly in the public sphere. Yet
the essential practice of climate change science as a knowledge generating activity remains in the private sphere, operating independently of public scrutiny and debate. Thus, there exist transnational epistemic networks on climate change that exercise their influence through political and subpolitical processes. These transnational networks traverse the public and the private spheres, and various scales of governance.

Finally, the media is another distinct pathway to promote social understanding of an issue, often working forward from scientific discovery to help make expert information accessible and relevant to a lay public. The media operate through formal social and institutional means, but they affect individual consumption and reproduction of knowledge in the private sphere (figure 2). The studies reviewed here highlight the media’s capacity to reflect social learning on climate-change issues and the adeptness of certain actors, such as the scientific elite, in learning to use the media to achieve desired ends. Beyond the role played by the media is the question of ‘take-up’ of expert knowledge by lay publics. This ‘consumption process’ is mediated by cultural parameters and local knowledge, such as understanding and experience with pollution or global environmental issues (Wynne 1992b; Dunlap 1998). This includes understanding through heuristics—images, metaphors and metonymys—which in recent years include melting glaciers, stranded polar bears, heat waves and hurricanes. In this way, public (mis)understandings of climate change have also helped to propel climate change into the public sphere and onto the political agenda (Carvalho 2002; Antilla 2005; Carvalho & Burgess 2005).

This review confirms the intimate relationship between science and society especially on complex issues such as global environmental change. The interactions between science and society argue for a hybrid model of social theory on the environment where the power and influence of scientific discovery and developments are mediated through social means. Tracing the emergence of climate change in the public sphere supports the notion of co-production of knowledge and understanding, a process which combines the strengths of realist, scientific discovery with contextual insights and knowledge, where society and science co-construct meanings of global warming (Latour 1987; Benton & Redclift 1994; Stern & Fineberg 1996; Jasanoff & Wynne 1998; Woodgate & Redclift 1998; Lorenzoni et al. 2000; Wynne 2002). These pathways advance meaningful framings of climate change as a policy problem and a range of responses that are meaningful in local and regional contexts through structured interface between a wide variety of stakeholders (human agency), institutional change and scientific endeavour (table 1; figure 1). Though likely to be slow and cumbersome, these pathways also shape understanding at the international level of action.

The conceptual model outlined here suggests opportunities to promote social learning and adaptive responses to climate change over time as knowledge, individual preferences and social norms shift. A key question for policy then is whether co-constructionist perspectives have potential to help improve policy outcomes. For example, many have commented on the ‘policy gap’ between the scale and type of policy action being taken today and the action needed to adequately respond to climate change. How can social theory and the rich range of social research be used to help tackle this and other questions most relevant to global environmental policymaking? What can be done differently in the policy arena to build a more reflexive ‘policy spaces’ that lead to effective collaborative
action and social learning to protect the global climate? The insights provided by this article suggest that social research on global environmental change can move beyond descriptive and explanatory objectives to take a more practical and proactive role. Such research can inform science, policy and lay communities on ways to improve communication, understanding and decision-making on global climate change issues.

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