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Global Warming Potentials: ambiguity or precision as an aid to policy?

Simon Shackley*, Brian Wynne

Centre for the Study of Environmental Change, Lancaster University, Lancaster LA1 4YN, United Kingdom

ABSTRACT: It is widely assumed that the more certain and precise the scientific knowledge-base for predicting and understanding climate change, the better defined and robust will be the policy measures undertaken in response. In this paper we argue to the contrary that in the case of Global Warming Potentials (GWPs) ambiguity in their precise meaning is a major reason why they have been developed and continue as scientific policy tools [although this is not how they are commonly represented in the reports of the Intergovernmental Panel on Climate Change (IPCC)]. We survey and analyse the range of opinion on GWPs with respect to their scientific stability and comprehensiveness and argue that the utility of GWPs has to be evaluated in terms of their symbolic, interactional and heuristic effects as well as with respect to their direct instrumental uses. In addition, we argue that scientific discussion of GWPs commonly incorporates elements of the social and policy contexts of their application and provide several examples from detailed discussions at the IPCC. We endeavour to account for the ambiguous identity of GWPs and draw out several implications from the findings of the paper for the construction and use of scientific tools in policy.

KEY WORDS: GWPs · Scientific ambiguity · International climate policymaking

1. INTRODUCTION

The need for relatively simple scientific tools for policy in the climate change domain is widely recognised. This is because the scientific knowledge on climate change is frequently complex with many different disciplines and issues involved, requiring synthesis, integration and interpretation for the policy audience. It is usually assumed that to be effective such tools need to be precise, clearly defined, and technically robust in content. The policy actions that are proposed, partly on the basis of the scientific tool, are more likely to be widely accepted by all parties if the tool has the above characteristics, or so it is conventionally assumed. A robust tool provides policy actors with the confidence that it represents real processes sufficiently well for good policy analysis; a precise tool permits policy decisions to be precise also; and clarity allows the various assumptions and commitments behind the analysis, including those of the participating parties, to be expressed in a transparent and open fashion.

*E-mail: s.shackley@lancaster.ac.uk

In this paper we explore one such tool for policy—the Global Warming Potential (GWP) index for comparing the climatic properties of different greenhouse gases (GHGs). Our analysis, however, challenges the assumptions of precision, clarity and technical robustness in 3 ways.

- The technical definition and content of GWPs is hotly debated amongst specialists, in terms of what variables should be used to calculate the index and how. According to some scientists GWPs are not technically robust.
- GWPs are not clearly defined but subject to multiple interpretations. Hence they are ambiguous rather than clearly defined or precise.
- Discussions over GWPs in policy contexts often incorporate implicit policy and value judgements: hence GWPs can be characterised as 'hybrids' between science and policy, rather than being purely scientific in content, or incorporating explicit policy choices in a transparent way.

Rather than perceiving these features to be a 'problem', which stands in need of solution, we will argue that they are an almost inevitable component of scientific tools for policy and suggest why that may be the case. First, however, we should explain why we think the reader should be interested in our analysis. There has been considerable scientific and policy attention to GWPs over the last 6 or 7 yr, including discussions and controversies, workshops and IPCC deliberations. We know, therefore, that those in influential positions in the climate change science-policy dialogue believe there is something important about GWPs to discuss and argue over. It is fair to assume from the attention they have received that GWPs have also been reasonably important to the way in which climate policy has been thought about and developed. We are also faced with some fascinating empirical facts: that very simple indices were being proposed for policy making even though millions of dollars have been spent on developing much more complex policy-relevant science (climate models for example); that the calculation of GWPs changed rather dramatically over very few years; that social scientists became involved in the debate and a struggle over what should be included in a greenhouse gas index emerged; that some scientists dismissed GWPs as being over-simple or unrealistic; and so on.

Our purpose is to shed some light on the debates over GWPs from a somewhat different perspective, that of the sociology of science. We are interested in the meanings given by scientists and policy makers to GWPs, why they thought about them in a particular way, how they related to the other concerns of those participants, and so on. But this is not just an exercise in academic sociology. There are also important implications for how scientists and policy makers conceive of the role of climate science in policy, not just in the case of GWPs but more widely. The debates over GWPs concern much more than the development of an instrument for producing numbers for optimal GHG-emission control policies. Other important unanticipated effects have emerged from the development of GWPs, including the creation of a new community for relating science and policy. Such social dimensions are not divorced from the way in which GWPs are constructed, presented and used, a finding which has important implications for the range of policy options considered, the ways of assessing alternative policy choices, and the development of knowledge to assist policy.

Our intention therefore is *not* to assess GWPs in a narrow sense, for example with respect to the criteria of precision, clarity and robustness, or vis-à-vis the policy ambitions of the Framework Convention on Climate Change (FCCC), or to suggest how they might better fulfil that role. To do so would require us to take our own position on what *should* be the goals of the FCCC given that they are presently unclear, and for ourselves to judge the scientific credibility of GWPs. We are more interested here in interpreting scientific debates about the credibility of GWPs, and in understanding those arguments in their social and policy context, than in engaging in such a debate ourselves. Nor are we attempting to address a specific, highly focused 'problem', in large part because the real-life science and policy discussions do not present us with discrete, well-defined problems, but rather messy, ambiguous, changing and interrelated problems. What the 'problem' is changes depending on whom you speak to, where, when and in what circumstances. Our interest is in understanding how problems are defined by the scientists and policy makers themselves, and the implications of this for the development of climate change science and policy. We urgently need better understanding, interpretation and reflection upon the 'wicked problems' which emerge from real world policy debate if climate change science is to have more effective impact upon policy making. For convenience the key questions which guide the paper are listed below.

(1) What features of GWPs have influenced their role as scientific tools for policy? And why?
(2) What role do GWPs play in the provision of scientific advice for policy making?
(3) Are GWPs precisely and clearly defined, or ambiguous?
(4) Are the positions taken, and debates over, GWPs only technical and scientific in character or do they also involve social and policy preferences and/or commitments, some of which are 'hidden' rather than deliberately chosen?
(5) If social and policy elements are part of the debate over GWPs what are they? Where do they come from? And have they been openly debated or do they emerge by default?
(6) What are the implications for the development of scientific tools for climate change policy making?

In Section 2 we define GWPs and chart their development from 1990 to 1996, paying attention to the debates and controversies which GWPs have sparked off, and use a typology to characterise these. In Section 3 we argue that GWPs have an ambiguous meaning, and provide an interpretation of *why* this may well be helpful to their continued development and use. In Section 4 we turn our attention to the hybrid mixture of scientific, social and policy choices and commitments incorporated in discussions over GWPs. In the final section, we argue that GWPs may be unintentionally supporting certain approaches to climate policy analysis, especially a focus on greenhouse gas emissions, but that if GWPs were appraised more realistically then other policy options might become more attractive.

2. KEY DEBATES SURROUNDING GWPs

The rationale for GWPs is that a range of gases contribute to anthropogenic climate change and that policy under the FCCC to reduce emissions therefore requires: 'An index to compare the contribution of various "greenhouse" gas emissions to global warming ... to develop cost-effective strategies for limiting this warming' (Lashof & Ahuja 1990: p 529). This 'comprehensive approach' has been advocated strongly and developed by the US government from the late 1980s to the present day (and now by other governments) and is incorporated into the FCCC (United States Department of State 1989, Informal Seminar 1990, Stewart & Wiener 1990, Morgenstern 1991, Task Force 1991).

2.1. GWPs as scientific tools for policy

To go beyond the early focus of analysis and policy on CO_2 required a metric for comparing the properties of different GHGs. They all have varying emissions and atmospheric concentrations, radiative forcing properties per molecule, and life-times so that to compare their greenhouse effects requires a method for taking these differences into account. GHGs with a relatively large radiative forcing but short life-time, such as methane, diminish in importance as contributors to the enhanced greenhouse effect as the time horizon for the calculation of effects increases, whilst CO_2, with a relatively small radiative forcing but long life-time, increases in relative significance. An important further complication is that some GHGs and non-GHGs have indirect effects, whereby a particular gas influences the concentration or life-time of another gas (or even of itself, in the case of methane) and, therefore, its GWP.

In principle, it should have been possible to use complex climate models, such as General Circulation Models (GCMs), to assess the relative contributions to radiative forcing and warming of different scenarios of GHGs after a given time period. In practice, however, this use of GCMs as a comparative tool went far beyond the technical and scientific capabilities and resources then (or now) available. An important precedent in developing a simple model was the comparison of different ozone depleting chemicals using Ozone Depletion Potentials (ODPs). In the late 1980s / early 1990s, a similar approach was adopted in the development of GWPs for each GHG (Lashof & Ahuja 1990, Derwent 1990, Rodhe 1990). Much of this analysis was motivated by the need for such an index in the 1990 report of the IPCC (Intergovernmental Panel on Climate Change), reflecting the US government's commitment to the comprehensive approach. In 1990, the IPCC defined GWPs according to the following equation.

$$GWP = \frac{\int_0^n a_i c_i dt}{\int_0^n a_{CO_2} c_{CO_2} dt}$$

where 'a_i is the instantaneous radiative forcing due to a unit increase in the concentration of trace gas, i, c_i is concentration of the trace gas, i, remaining at time, t, after its release and n is the number of years over which the calculation is performed. The corresponding values for carbon dioxide are in the denominator' (IPCC 1990: p 58). The numerical value of GWPs is dependent on the time horizon used in their calculation. So, for example, as one advisory scientist to the IPCC has put it, if a long time horizon is used:

> relatively short lived and powerful greenhouse gases (such as the HFCs) can appear unimportant, even though unrestrained growth in emissions could make the gases significant contributors to total forcing. A short horizon would, however, make a less powerful but long-lived gas (N_2O is an example) look unimportant.

In its 1990 assessment the IPCC used 3 periods over which to calculate GWPs, 20, 100 and 500 yr, noting that: 'These 3 different time horizons are presented as candidates for discussion and should not be considered as having any special significance' (IPCC 1990: p 59). Flexibility, adaptability, economy and 'do-ability' are the apparent advantages of GWPs over more complex models—for example in readily matching possible measures to policy objectives by illustrating how emissions of GHGs differ, on a common scale, in their short-, medium- and long-term warming propensities.[1]

This *instrumental* use of GWPs as tools for policy to help implement the comprehensive approach is not the only way to understand their rationale. As one scientist noted, GWPs were developed:

[1]It may be asked why simple, 1-dimensional climate models were not preferred over GWPs. In fact Wigley & Reeves (1991) did apparently provide some such results. That GWPs were preferred is probably accounted for by the fact that it is widely questioned whether such 1-D models could capture the spatially-dependent interaction between atmospheric chemistry and dynamics. Hence their greater complexity might not have been perceived as an advantage over GWPs (in terms of providing reliable additional information). Simple climate models are also only simple relative to GCMs. As a tool for policy, they are still rather complex and require the active involvement of the modelling team

> with a very simple requirement which was to give policy makers an idea of the sorts of gases which could contribute to global warming. It's really as simple as that. To show them that it wasn't just CO_2.
> (interview with S.S., atmospheric chemist, 5 April 1993)

This we term a *symbolic role*. GWPs were additionally advocated by some advisory scientists because they allowed policy makers, especially those from countries with a less well-developed scientific infrastructure, to use this method (whereas use of something more complex would have been confined to just a few countries).

> They've [GWPs] allowed a lot of countries to look at the policy within their own country context than would have been possible if we had been limited to providing people access to, say, leading-edge GCMs, or perhaps to one of these medium level assessment models like IMAGE. ..other countries can't get in even to that level of modelling technology. So, yes, I think GWPs have been very important in allowing policy makers to grab hold of a model that they could use themselves.[2]
> (interview with S.S., atmospheric chemist, 5 April 1993)

Because it relates to the emergence of a research and policy community concerned with climate change issues we call this an *interactional role*. The scientific tool becomes a way of facilitating involvement from scientists and policy makers not otherwise part of that community.

2.2. GWPs in the IPCC 1990 report

GWPs were presented to the policy world by the IPCC in its 1990 report as fairly reliable and resilient tools. Uncertainties in the methodology were acknowledged (though not quantified) and the preliminary status of the quantitative values made clear. For example, lead authors of the relevant IPCC chapter noted that:

> It must be stressed that there is no universally accepted methodology for combining all the relevant factors into a single global warming potential for greenhouse gas emissions. In fact there may be no single approach which will represent the needs of policy makers. . It must be stressed that these indirect effects are highly model dependent and they will need further revision and evaluation.
> (Shine et al. 1990: p 58, 60)

Despite the above provisos, the IPCC provided a table of figures giving the direct and indirect GWPs for a wide range of greenhouse gases (CO_2, a range of CFCs and HCFCs, CH_4, CO, NMHC, NO_x and N_2O) over 3 time horizons—20, 100 and 500 yr. Error bars were not given.

2.3. GWPs in the IPCC 1992 report

In its 1992 report the IPCC refrained from providing quantitative values for indirect GWPs, stating that: 'it is not possible to quantify accurately the indirect GWPs. ..the indirect GWPs reported in IPCC (1990) are likely to be in error and should not be used' (IPCC 1992: p 55). The statement in 1992 that 'we can estimate the sign most likely for [the indirect effects of] some compounds based on current understanding' (ibid.) is a far cry from IPCC90. Furthermore, the table of GWPs in IPCC92 appeared with a number of disconcerting warnings, such as: 'The lifetimes of the various species are not as precisely known as the Table suggests' and 'The indirect GWPs are uncertain but could conceivably be comparable in magnitude to the direct GWPs' (IPCC 1992: Table A2.1, p 56).

One of the most dramatic changes was in the calculation of the GWP for the chlorofluorocarbons (CFCs). In the 1990 assessment these were stated to collectively account for 24% of the current contribution of GHGs to potential global warming. In the 1992 report, the CFCs were considered not to have any warming potential, because of their effect in depleting another GHG, namely ozone in the lower stratosphere, the 2 effects cancelling each other out.

In IPCC92 there was a more complete discussion than in IPCC90 of the methods involved in calculating GWPs and their accompanying uncertainties and assumptions (IPCC 1992: p 54-55). It was stated that GWPs can only be provided for well-mixed, long-lived gases which absorb long-wave radiation, and not for species which absorb in short-wave radiation bands (such as aerosols). Calculation of GWPs cannot take account of latitudinal and seasonal variations, nor of short-lived gases such as CO, non-methane hydrocarbons (NMHCs) or NO_x. In IPCC92 the same time horizons are used as in IPCC90 and the somewhat stronger claim is made that: 'It is believed that these three time horizons provide a practical range for policy applications' (IPCC 1992: p 54).

It was also noted in IPCC92 that GWPs measure surface-troposphere radiative forcing, not surface warming (the response to forcing). Climate models can be used to predict warming from forcing, but such an exercise 'must be approached with caution' (IPCC 1992: p 54). And it was also observed that: 'although

[2]This rationale is also mentioned by one of the developers of an alternative index, the World Resource Institute's Greenhouse Index, who noted that: 'A goal of the index was to make it simple for nations to assess their relative rank and progress in a simple manner without needing elaborate computer models' (pers. comm. 27 November 1995)

the GWP of a well-mixed gas can be regarded as a first-order indicator of the potential global mean temperature change due to that gas relative to CO_2, it is inappropriate for predicting or interpreting regional climate responses' (ibid.). In summary, a shift to scepticism occurred in 1992 given recognition of the complexity of the scientific issues.

There are potential credibility problems for GWPs in this shift of perceptions over just a few years. The repercussions were felt, for example, in hearings of the US Senate Committee on Energy and Natural Resources in May 1992. Senator Wallop questioned whether the IPCC was disingenuous in stating in its 1992 report that: 'Findings of scientific research since 1990 do not affect our fundamental understanding of the science of the greenhouse', given the change in opinion on the role of CFCs (MacCracken 1992). Meanwhile, the press in the United Kingdom picked up on the same issue at a press-briefing. The following headlines appeared in the UK press on the 20th December 1991: 'Has it been a waste of time getting rid of our aerosols?', 'Doomsday is delayed as scientists blow hot and cold on the ozone layer' (*Today* 20/12/91), 'UN environmentalists find silver lining in cloud of CFCs' (*Daily Telegraph* 20/12/91); and 'CFC global warming role in doubt' (*Guardian* 20/12/91). The Chairman of the IPCC, Professor Bert Bolin, reported verbally at an IPCC meeting in Bath (UK) in 1993 that the IPCC92's presentation of GWPs had caused a lot of anxiety amongst policy makers because it implied that GWPs were not very useful.

2.4. GWPs in the IPCC 1994 report

One of the most important issues for Working Group I (WGI) of the IPCC (which is responsible for assessment of scientific processes) following publication of its supplementary report in 1992 was to decide what to do about GWPs. A common opinion at the Bath WGI meeting (coded here WGI 93) was that the 1990 report had oversold the idea of GWPs, but that the 1992 report had gone too far the other way and that the balance now had to be readjusted. The IPCC's report *Radiative Forcing of Climate Change* (IPCC 1995) sought to re-establish the credibility of the GWP. It contains a highly detailed account of GWPs, their assumptions, and of the diverse scientific knowledge behind them, and defines that group of gases for which it is worth calculating direct and indirect GWPs. For example, unlike what was done in 1992, the direct and indirect effects of methane are calculated. The 1992 decision to omit calculating GWPs for NO_x, CO and NMHCs is sustained because of a lack of knowledge: 'This does not imply that they are not significant for radiative forcing' (IPCC 1994: p 224).

Meanwhile, the 1992 opinion that the indirect effects of CFCs would cancel out their direct effects was modified in 1994. The new position was that the GWPs for CFCs, HCFCs, and HFCs could conceivably be positive or negative, and that the uncertainties arising from altitudinal and latitudinal dependence of the indirect effects prevented any more definite calculation. Also, in IPCC94 there is a reasonably lengthy discussion of the role of policy decisions in calculating GWPs.

2.5. Some critical issues surrounding changing presentations of GWPs

2.5.1. Arbitrary time horizons?

IPCC90 suggested that if sea-level rise is the impacts issue of interest then a 100 yr time horizon is appropriate, whilst if it is precipitation then a 20 yr horizon is more suitable. And in 1994, the IPCC noted that: 'GWPs with differing time horizons can aid in establishing such a mix [of emphases given the type of effect with which one is concerned]' (IPCC 1994: p 229). Although not mentioned in IPCC reports, variable time-horizons might also be required for the same category of impact because of local and regional conditions and differential sensitivities, including the effects of natural and social variability and past damage due to climate change and other factors (acidification, other forms of pollution, ozone depletion, and so on).

A policy framework using GWPs is therefore faced with the problem of either using variable 'customised' time horizons or of producing an 'average' time horizon (taking account of the differential impacts upon systems at different times). The use of multiple, customised time-horizons is problematic because it questions the global definition of climate change as a single policy problem, weakening the rationale for a global agreement on GHG emission reductions (seen as necessary given the geographical divorce between sources of GHGs and climate change impacts) (Brown & Adger 1993). And as Fuglestvedt & Skodvin (1996) point out, multiple time-horizons compromise the comparability of different gases, the whole point of the exercise! The apparent flexibility of GWPs in allowing the policy maker to choose the most appropriate time-horizon is then revealed as rather illusory.[3]

[3]How would an average time horizon be chosen? Should it be nationally specific, or a global average? If different national averages were used, this would allow greater opportunity for political manipulation of national analyses. It might also, paradoxically, give more weight to impacts from countries with a disproportionately large share of GHG emissions. Using a globally averaged time-horizon might also risk entering a 'zero sum game', as what one country gained from a chosen time-horizon, another lost (Fuglestvedt & Skodvin 1996)

2.5.2. Discount rates

Some economists have argued that instead of using variable time-horizons GWPs should include a discount rate factor to take account of the extent to which damage in the present is more valued by society than at some point in the future. By contrast, the IPCC's GWPs give equal weight to all included climate effects up to some time horizon, T, and zero weight thereafter. Wallis & Lucas (1994) comment that:

> This is unfortunate because there is no objective way of setting time-horizon T ...there is no way to avoid implicit weighting between gases and between human generations. Implicit in the IPCC choice are certain value judgements that put the GWP function into the ambit of social science.
>
> (Wallis & Lucas 1994, see also Wallis 1994)

In fact, Lashof & Ahuja's original paper of 1990 had used an exponential discount rate with the horizon extended to infinity. This is hardly more convincing to many analysts, however, because it does not take account of the non-linearity between temperature change and climate change impacts and costs. As Eckaus put it: 'it cannot be presumed that the economic evaluations of radiative forcing in successive periods will decline at exactly the discount rate' (1992: p 27) (also, Wuebbles & Edmonds 1991, Reilly 1992, Reilly & Richards 1993). In other words, emissions of a short-lived gas relative to CO_2 might not be so important at time, t_1, as at time t_2, where t_2 falls in a period when the impacts of, and damage from, a given rate of temperature increase are greater than at t_1 because of the non-linear relationship between temperature and climate impacts (Kandlikar 1995, Hammitt et al. 1996). Furthermore, even though there is a well-developed economic literature on discount rates, the choice of a discount rate for the case of future climate change is still arbitrary, and the final result will be very sensitive to the particular rate chosen (Kandlikar 1995).

Hammitt et al. (1996) consider the situation in which climate-induced damages depend only on the maximum global annual-mean surface temperature reached. Again, incremental emissions of CH_4 will have negligible effects compared with emissions from a relatively long-lived gas such as CO_2, if the emissions take place far enough before the year in which the mean temperature peaks. For this reason, Kandlikar, Hammitt et al., and other analysts argue that an index has to incorporate different GHG emission *scenarios*. Kandlikar notes that otherwise there is a danger that GWPs would promote reduction of short-lived GHGs in the near future as a more effective policy response than is in reality the case. Reilly also argues that GHGs have non-greenhouse-related properties which should be counted as credits (e.g. CO_2 fertilisation of crops) or debts (e.g. CFCs depleting O_3) (Reilly 1992), this being the logical extension of the comprehensive approach according to its advocates (Stewart & Wiener 1992, Wiener 1995). Wallis & Lucas (1994) also point out that GWPs do not take account of the rate of change of forcing, even though this is a key policy-relevant variable (cf. Handel 1991). Whilst this limitation is recognised in IPCC94, the IPCC90 and the World Meteorological Organisation (WMO 1992) also suggest that GWPs can be used to explore the rate of change of temperature, sea-level rise, and so on, in the context of providing advice to policy (through the choice of time horizon).

Note that the above analysts refer to the effects and impacts of climate change caused by different GHGs. Hence they convert radiative forcing of GWPs into surface temperature change (by use of a climate model) and then use an algorithm for relating temperature change to damages (of a quadratic, linear, logarithmic form, etc.). The further down-stream effects (see Fig. 1) are also included in some formulations by calculating the economic damages of those impacts with an economic model.

2.6. A typology for understanding debates over GWPs

The perceived stability of GWPs is one of the main points of disagreement in the debates around their usefulness. By perceived stability is meant the degree to which GWPs are perceived as scientifically certain and robust (with respect to the separate data selected and used and the method by which information is aggregated). A second key point of contention is the perceived comprehensiveness of the index, that is the extent to which it includes all the factors and variables held to be relevant in comparing the greenhouse properties of different GHGs (as shown in Fig. 1). A greenhouse index can be made more comprehensive by virtue of including more of the down-stream variables in the chain from physical effects, to effects upon biophysical systems, to impacts upon human systems.

These 2 dimensions are depicted in Fig. 2 in which we have also mapped out the change in relative position of GWPs from 1990 to 1994 as well as the range of opinion on where GWPs should be located in the future. As indicated in Fig. 2, the IPCC has a consistently narrow view of GWPs as based on an up-stream physical formulation (radiative forcing). Not all climate scientists have agreed with the IPCC's judgement that GWPs are stable. A workshop held in 1990 identified many of the key scientific issues, assumptions and uncertainties surrounding GWPs (Workshop 1991). Harvey, for example, concluded that: 'Given the enor-

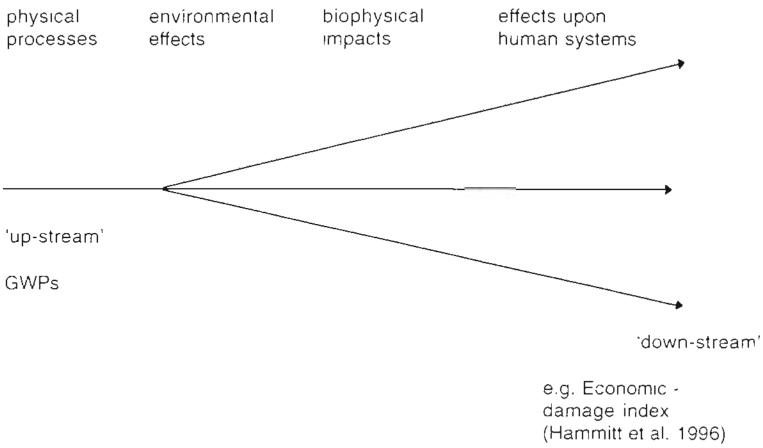

Fig. 1. The chain from physical effects to socio-economic impacts

views see e.g. Enting & Rodhe 1991, Caldeira & Kasting 1993, Wuebbles et al. 1995). The majority of social science and policy analysis commentators also argue that the IPCC's index is currently rather unstable, not because of its natural science component, but rather because it does not include 'down-stream' social and economic variables. A group of economists and climate scientists at the Massachusetts Institute of Technology (MIT) combined forces in preparing a brief note on why GWPs were inadequate in terms of atmospheric chemistry, economics and the needs of policy (Joint Program, no date).

Since the more comprehensive index would indeed seem to be more policy relevant, why has the IPCC not developed the index in that way? When asked about the inclusion of economic factors into GWPs, several IPCC scientists responded that GWPs were already confusing, complicated and

mous uncertainties in the calculation of GWPs and their dependence on future scenarios, it is difficult to see how they could be used in any rigorous way for policy analysis' (Harvey 1993: p 29; for other specialist

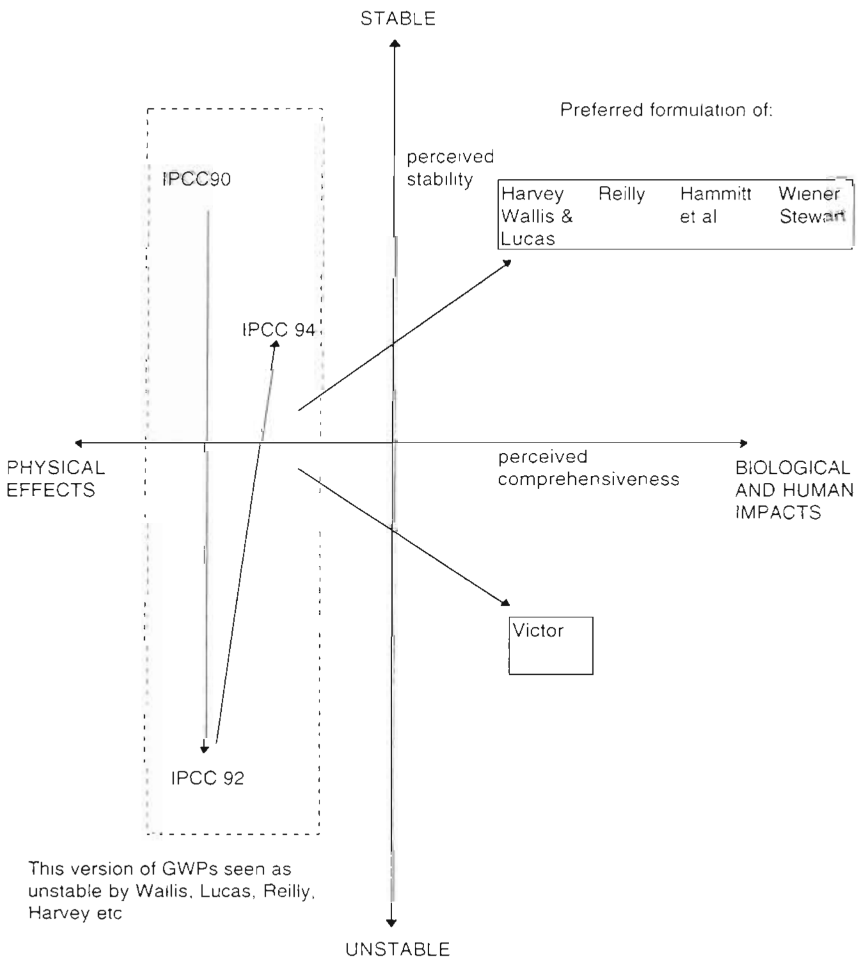

Fig. 2. Two dimensions of the debates surrounding GWPs

uncertain enough without introducing a new level of complexity.[4] One interpretation of this response is that the advisory scientists consider the increased comprehensiveness to come at the cost of greater uncertainty and instability in the index, even if the narrower index is less directly comprehensible or meaningful in a social or economic sense (in terms of Fig. 2, the perceived comprehensiveness scale would slope downwards the further it move to the right). Such instability, and loss of precision (and intellectual control) which would accompany an increase in scope, appears to have been considered by these IPCC scientists to damage the authority of the index in policy contexts. Hence the preference for the more restricted, but also more certain, up-stream physical definition of GWP (i.e. there is an implicit trade-off between potential 'usefulness' in policy contexts and certainty: the more potentially policy useful, the less certain the knowledge). This judgement of scientists has been criticised by Eckaus who notes that: 'There is no easy way out of confronting the cost to society of reducing radiative forcing. Certainly, it would never be suggested that, because of the necessity of 'keeping the argument simple', basic features of atmospheric chemistry should be passed over' (1992: p 34).

In this section we have seen that there is a lively debate amongst specialists concerning the technical construction of a GWP-type index. We have also noted 3 different roles for GWPs as scientific tools for policy. The instrumental role refers to the direct use of the GWP numbers in policy making; the symbolic role to the function of illustrating that more than CO_2 is involved in causing anthropogenic climate change; and the interactional role to the attempt to involve further scientists and policy makers in climate change issues from countries without strong modelling capabilities.

3. AMBIGUITY IN SCIENCE FOR POLICY AND ITS POSSIBLE ROLE

Even amongst natural scientists who accept the IPCC's narrow definition of GWPs, there are a range of views on the precise calculation of GWPs. From surveying the literature we have identified 8 technical issues upon which there are differing opinions amongst climate scientists. We call these cases where there is no single, or clearly 'correct', answer examples of ambiguity. There is:

(1) Ambiguity as concerns the choice of GHGs for which GWPs are calculated (raising questions over the implications of spatial and temporal variability).
(2) Ambiguity as concerns whether, and how, indirect effects are included in the calculation of GWPs.
(3) Ambiguity in the time horizons for which GWPs are calculated. Or ambiguity in the discount rates chosen.
(4) Ambiguity in the parameter of climate change which is being measured in the GWP calculation.
(5) Ambiguity in the atmospheric residence time chosen for CO_2.
(6) Ambiguity in whether the GWPs are calculated using sustained emissions of GHGs or a pulse emission.
(7) Ambiguity over whether GWPs can be used to assess the rate of change in systems affected by climate change.
(8) Ambiguity over whether GWPs can stand alone in policy analysis or require further added-on scientific tools (such as climate models) before they are useful.

3.1. Some evidence of ambiguity

We do not intend to discuss all the above sources of ambiguity in detail. For illustrative purposes only, we will expand on the fourth type of ambiguity. The IPCC has in several places carefully defined GWPs as measuring the radiative forcing of GHGs, not the climate response (such as temperature). Yet, the rationale for GWPs in the Policymakers Summary of IPCC90 stated that: 'To evaluate possible policy options, it is useful to know the relative radiative effect (and, hence, potential climate effect) of equal emissions of each of the greenhouse gases' (IPCC 1990: p xix). The statement in brackets implied that the relative potential climatic effect of GHGs was indicated by GWPs.

One of the earliest research papers to calculate GWPs referred directly to the temperature response (Derwent 1990). The author recalls that the use of response in the calculation did not cause any problems at a WGI meeting at Crowthorne (UK) in preparation of IPCC90 (Derwent pers. comm. July 1996). Several climate modellers involved in IPCC then believed in a simple linear relationship between forcing and temperature rise for the equilibrium case. Soon after that, the first major transient runs of GCMs questioned the realism of equilibrium studies, making the relationship between forcing and temperature unclear (ibid.).

The IPCC 1992 report made clear the distinction between forcing and response, noted that GWPs could be regarded as a first-order indication of global, but

[4]The text in IPCC94 explicitly mentions discounting approaches but then notes: 'The possibility of coupling such factors to the GWP definition requires detailed study of economics and policy implications, together with the requirement for scientific accuracy, and is beyond the scope of the present review' (IPCC 1994: p 216)

not regional, response, and also cautioned against any simple translation of forcing into response. The IPCC attempted to set the record straight in its 1994 report:

> Further, the GWP as defined here is only a measure of relative radiative forcing, not a measure of potential damage resulting from possible climate change that includes economic or other variables. These limitations should be kept in mind in economic or policy analysis.
> (IPCC 1994: p 216)

This quotation is unclear on the extent to which GWPs can legitimately refer to the climatic response (as opposed to the more down-stream measure of potential damage referred to in the quote). The ambiguity over forcing/response reflects uncertainty and changing knowledge amongst the climate change community (for example vis-à-vis equilibrium GCM runs around 1990). That the global mean temperature change at the surface and troposphere is relatively independent of the forcing mechanism (i.e. a constant climate sensitivity) has been a commonly adopted heuristic within the climate modelling community. Fuglestvedt & Skodvin note that: 'This gives support to the application of radiative forcing as an appropriate index that could be used to assess both the absolute and relative climatic impacts of changes in forcing' (1996: p 35). In a study published in 1994 Taylor & Penner used a GCM, coupled to an atmospheric sulphur model, to analyse the effects of including an increase in both sulphate aerosol and carbon dioxide concentration upon radiative forcing (Taylor & Penner 1994). One plausible interpretation of this experiment was that the climate sensitivity may be different for gases which generate different patterns of horizontal and vertical radiative forcing (Wigley 1994). The ambiguity over the precise interpretation of GWPs accommodates the dominant scientific belief in a constant climate sensitivity, as well as the indeterminacy that it may turn out to vary for different forcings.

It is not surprising that users of GWPs have frequently regarded them as indicative of a climate change response. After all, they are termed Global Warming Potentials and it is difficult to see how they could be sensibly advocated for policy use if they did not indicate some first-order response, even if the scientific basis for the relationship is not rigorously established. For example, a US government report from 1991 compared GWPs to model calculations and stated that: 'The differences between the climate model approach and the GWP calculation arise in part because the climate model approach calculated realized temperature change while the *GWP calculated equilibrium temperature change*' (Task Force 1991: p 20; emphasis added), hence claiming that GWPs measure one feature of the response to forcing.

There may have been contingent reasons to do with the US government's desire to establish a system within which permits for greenhouse gas emissions could be traded which help account for that particular interpretation of GWPs, likewise its optimistic views about the ability of the index to cope with uncertainty and a rapidly changing knowledge-base, since any such policy would require at a minimum a robust GWP-type index.[5] Without GWPs, the comprehensive approach would just not be feasible, and a 'carboncentric', command-and-control type regulatory regime would have become more credible, a politically unacceptable alternative for the US government.[6] In this political context, some ambiguity in the precise technical meaning of GWPs serves an important function, since it allows the implication to be made that the GWP is a measure of the response as well as of the forcing. This in turn lends support to that policy response—the comprehensive approach—which is most politically desirable. If GWPs were more strictly defined by technical experts in policy contexts then they would lend less support to the comprehensive approach, and so support for GWPs would be less likely from advocates

[5]We are suggesting that the policy preferences of the US government influenced the technical appraisal of the comprehensive approach—and this spilled over into its representation of GWPs. But this does not mean that the climate policy specialists within the administration deliberately mis-represented GWPs: rather that they used the flexibility in the technical assessment of GWPs in their support. Evidence of the US government's optimistic outlook comes from various government publications. A major report from 1991 stated that: 'Although these uncertainties remain in the GWP values, the consensus of the IPCC was that the scientific method of calculating GWPs is sufficiently sound to permit its use. Similarly, an international workshop on GWP indices organised by NOAA, EPA, NASA, UKDOE, and others in Boulder, Colorado, in November 1990, concluded that though these uncertainties require urgent attention, they do not undermine the scientific fundamentals of the GWP index and do not warrant abandoning it. . A good but imperfect index could serve well and then be amended later when knowledge improves' (Task Force 1991. p 23). This is only one interpretation of the Boulder meeting, however, since the official report can also be read as a detailed list of numerous uncertainties in the calculation and interpretation of GWPs (Workshop 1991)

[6]This is clear from a statement made by John Sununu, President Bush's Chief of Staff from 1989 till 1992, in an interview for *Technology Review*. 'There is an effort to focus only on carbon dioxide emissions, and I think that's because carbon dioxide is virtually a surrogate for economic growth and development. There's opposition to imposing limits on a more comprehensive basis, because you don't slow growth and development down as much by limiting emissions of other greenhouse gases like methane and nitrogen oxides' (Sununu 1992)

of that policy. This political preference serves to illustrate the significance of the flexible definition of GWPs in practical policy contexts. None of this is to suggest deliberate manipulation on the part of scientists or policy makers, however. At least one of the authors of the above-mentioned US government report knew well, for example, the difference between measures of forcing and of response. And yet the ambiguous statement appears in the report, not because of any conspiracy to mislead policy makers, but because it was that scientific interpretation which most nearly dovetailed with the surrounding policy ambitions in the US administration.

The uncertainties and scientific debates surrounding GWPs are, according to Victor, not generally recognised by the policy community and user groups who consider them to be key policy instruments (pers. comm. 23 July 1996), a point confirmed by evidence of how policy analysts from other fields have used GWPs uncritically (e.g. Wade et al. 1993).[7] The lack of knowledge amongst the policy community of the technical ambiguity of GWPs is likely to be important in sustaining their belief in GWPs, and indirectly perhaps also in some of the political programmes GWPs lend support to. In other words, if the ambiguity of GWPs were widely known about amongst the policy community it is likely that scepticism over their anticipated use would be greater and support for the comprehensive approach might be tempered with some reservations as to its practicality. The research and advisory scientists are themselves more aware of the ambiguity but not usually to the extent that is documented here because they tend to be working from a relatively restricted viewpoint (as discussed in the next section). They are also unaware of the role that ambiguity in the science plays in sustaining particular policy options, because they tend to perceive of science and policy as rather sharply distinct and 'stand-alone'.

At a more general level, there is ambiguity concerning whether GWPs are primarily tools for policy of little use to scientists, as Bert Bolin presented them at WGI 93, or whether, as other IPCC contributors have claimed, GWPs have stimulated research, and led to identification of new priorities in, scientific work. Most obviously, calculating GWPs required further development of models (e.g. for cycles of GHGs) which in turn raised questions for more basic research. One participant commented that:

> in a sense requesting a GWP [for a particular gas] is giving a challenge to that particular research community. I mean, they didn't realise how important it was for them to understand the significance of the carbon cycle, and to determine the average lifetime of a CO_2 molecule. . So, for example, when you look at their models it is very clear that they are actually giving a different lifetime to normal CO_2 than they attribute to the radioactive CO_2 produced in the nuclear weapons test. And you say to them, 'well why is this?', and they say, 'well there are very good reasons why this is', but they haven't actually worked them through. The two communities have just gone off, dealing with the same molecule but having different lifetimes, and there was no attempt for the two communities to get together. ...they realised that this meant they had to give a different lifetime to the CO_2 from deforestation than to the man-made CO_2. So they thought at that stage, we really should get to the bottom of this.
> (interview with S.S., atmospheric chemist, 5 April 1993)

Hence GWPs may have unintentionally directed policy for science by presenting new research questions and a concrete basis for interaction between researchers. The inconsistencies between the working assumptions and rules-of-thumb for different scientific sub-disciplines are highlighted by the needs of a further group representing policy makers—the IPCC. We can now add a fourth role for GWPs, that as a *heuristic device* for pursuing further research questions. This multiplicity of roles constitutes further flexibility in the assessment criteria for evaluating GWPs.

3.2. An interpretation of the role of ambiguity

Rather than the 'multivalency' of GWPs being a source of weakness, it may facilitate the involvement of a range of interested parties in their further development and use, including scientists, policy makers and analysts, industry and environmental groups (cf. Singleton & Michael 1993). Several political scientists and sociologists have recently argued that loose coalitions or alliances between a range of policy actors and knowledge-producers around a common understanding of and orientation to, a problem and suitable solutions are highly important in mobilising resources and effective policy actions to address those issues (Sabatier 1987, Haas 1989, 1992, Star & Greisemer 1989, Hajer 1995). In this context, the ambiguity of GWPs is perhaps a *resource* for different scientific and policy actors to draw upon in developing and sustaining scientific and policy agendas. There are after all major questions and uncertainties surrounding how to further the FCCC, as a result of which it is not possible for scientists or policy makers to know just how GWPs will be used in policy, hence exactly what is required of them. In such a situation, an ambiguous, hence flexible, identity is possibly a useful resource since it pro-

[7] GWPs are also sometimes quoted in policy and discussion documents without specifying the time horizon used. Examples include an analysis from the US Department of State (1992) and a book on global environmental policy issues by a well-known political scientist (Skolnikoff 1993: p 182)

vides the opportunity for fulfilling different potential articulations of the relation of science and policy in the climate change domain, and satisfying different agendas. An over-stabilisation of GWPs at this stage, in terms of pinning down its precise meaning and use, could therefore risk it becoming over-brittle and constraining to scientists and policy actors whose agendas and requirements for GWPs subsequently change. Such over-stabilised GWPs would be much less likely to be accepted by policy makers.

The ambiguity also works to the advantage of research scientists, in terms of providing them with a rationale for further research and interesting questions to address. If leading research scientists were not involved in developing GWPs, the scientific credentials of GWPs would surely be questioned. The demands of policy makers go only so far in explaining how and why research scientists undertake original work necessary to the formulation of GWPs (since the research community still has some autonomy, including its own peer-review processes). A further requirement for an ambiguous identity for GWPs is, therefore, that it permits the pursuit of interesting basic research questions. For C-cycle, and other GHG-cycle, modellers, for example, GWPs are an opportunity to pursue interesting research issues (e.g. why are the life-times of ^{12}C, ^{13}C and ^{14}C different?).

The calculation of a new GWP for methane in 1993/4 raised very basic research questions and cutting-edge atmospheric chemistry models were employed. Similarly, experts in radiative forcing and other aspects of atmospheric chemistry, as well as economists and other social scientists, can all pursue major new research questions through their involvement in developing GWPs. Then there are the diverse research communities with an interest in measuring and monitoring greenhouse gas emissions and in developing inventories, and/or who are adapting their research in the light of these new needs; this includes, amongst others, specialists in agricultural, animal husbandry and land-use practices, researchers in the energy field, air pollution specialists, and so on.

Meanwhile for advisory scientists at the IPCC, GWPs are a means of distilling a huge amount of scientific knowledge into a simple 'black-boxed' method for policy makers. Each of the terms in the equation to calculate GWPs is a scientific judgement which draws upon vast areas of research. Chapter 5 of IPCC94 on GWPs is in many senses the summation and integration of the detailed knowledge in the 4 antecedent chapters into more policy-useful knowledge. GWPs therefore also provide some justification for the development and use of highly complex models: in particular, radiative models, carbon-cycle and other GHG-cycle models and atmospheric chemistry models. It is highly important in the present context that science funded for policy reasons is seen to benefit policy makers.

For policy makers, GWPs are seemingly a cheap and accessible tool to devise 'optimal' climate change policies. In principle, they permit involvement of a wider group of national experts than is typically the case when GCMs and carbon-cycle models are the principal sources of knowledge. They promise to be useful tools to 'bridge' the gulf between the complexities of GCMs and policy issues arising from the FCCC, especially the commitment to a comprehensive approach. At the same time, GWPs do not constrain the policy maker to the extent that 'control' is wrested away from them by scientists.

The variable time-horizons for which GWPs can be calculated is also useful for policy makers. That it obscures the focus on a particular time period, system or region is an important way in which a global consensus on the impact or damage from climate change can emerge. At the same time, its potential incorporation of many different time horizons permits scientists to take into account variable impacts on different time-scales. Imprecision here is a key resource, not a hindrance. Variable time horizons in calculating GWPs might also permit greater flexibility for monitoring and presenting progress towards the achievement of seemingly rigid emission reduction targets.[8]

This need for flexibility and ambiguity may also explain why the moves towards making GWPs more comprehensive have not been strongly supported by advisory scientists or indeed policy makers. A more complete index, whilst objectively more 'rational' and policy-relevant, may be less desirable because it is more precisely defined and less flexible as to how it can be interpreted and used (as well as opening up more opportunities for criticism, through the wider set of knowledges and uncertainties entailed in creating a more complete index). Although it may appear curious that 'practical knowledge' is less specific and less useful in an instrumental fashion, it is more understandable when the multiple roles of knowledge in policy are recognised (cf. Stehr 1992). To have an effective interactional and heuristic role, GWPs need to be flexible, whilst the symbolic role can still function as long as there is a low-level common definition. Our analytical approach, therefore, has been to identify what each scientific or policy community involved

[8]A counter-example is ODPs, which were integrated to steady-state. It has been suggested that their lack of varying time horizons was one reason why chlorine-loading potentials (CLPs) replaced ODPs as the predominant comparative policy tool, hence suggesting the policy-significance of some open-endedness over the time-scale of analysis

in GWPs has to 'gain' from that involvement. The diversity of sought-for aims, ambitions and uses—from negotiators, government officials, advisory scientists, research scientists, environmentalists, and so forth—makes a flexible, ambiguous identity of GWPs a requisite feature. That flexibility cannot be infinite, however; there must be a 'lowest common denominator' meaning given to GWPs across all the diverse groups involved in their construction and use if a reasonably coherent community is to emerge around GWPs.

4. IMPLICIT SOCIAL AND POLICY COMMITMENTS INCLUDED IN DISCUSSIONS OVER THE POLICY USE OF GWPs

In this section we explore how discussions between scientists and policy makers frequently include implicit social and policy assumptions, beliefs and commitments. In its 1994 report, the IPCC itself acknowledged the role of policy in constructing GWPs:

> A relative radiative forcing index is not purely a geophysical quantity, such as is a change of temperature. Rather, these indices are user-oriented constructs whose calculation involves not only an understanding of a few relevant Earth-system processes (e.g., radiative transfer and chemical removal), but also some policy-oriented choices (e.g., a selection of the time span of interest). Hence, such indices per se are not subject to observation and testing in the sense of many climate-system predictions, but are best judged by (i) their representativeness of the overall radiative forcing role of the specified trace gas and (ii) their overall usefulness to those who formulate and establish policies regarding the greenhouse gases.
>
> (IPCC 1994: p 212)

The IPCC is referring in the above quote to deliberate choices made by policy actors, whereas here we are additionally alluding to implicit commitments and assumptions, which are not *explicitly* chosen through conscious debate. No one deliberately chose that GWPs would have an ambiguous identity, for example, or that they would have important symbolic and interactional roles. These features arose through social (and political) processes and negotiation, but are nevertheless major elements in understanding the continued resilience of GWPs. We present several illustrative examples of implicit, and sometimes explicit, beliefs and commitments, drawing upon detailed observation by the first author of 3 IPCC Working Group I meetings [a planning meeting in February 1993 (WGI 93), a meeting of the lead authors in July 1994 (WGI 94A), and the Plenary of WGI held in September 1994 (WGI 94B)].

4.1. Time horizons for GWPs: between flexibility and control

Although WGI 93 endorsed the role and relevance of GWPs, there were a few dissenting voices. As one scientist (who we call scientist 1) put it in a note circulated at the meeting:

> We need to decide whether we wish to emphasise the clear and large contribution of CO_2 (and CH_4) to the historical greenhouse forcing or risk a protracted and difficult-to-resolve debate on the technicalities of GWP calculation. . Although we have presented three time horizons to cover these problems, my experience is that they tend to be misused or even abused. Industries tend to pick the horizon that puts their 'product' in the best light.

Evidence to support scientist 1 emerged later that year in the UK following an advertisement, placed by the chemical company ICI, for Klea-134a, an HFC replacement of CFCs, in the House of Parliament's magazine *The House*. It claimed that the direct greenhouse warming of Klea is 90% less than the CFC it replaces (Greenpeace 1993). ICI failed to indicate the time horizon over which the direct GWP for Klea was calculated, this being 500 yr. If a shorter time horizon of 100 years was used Klea has a GWP which is 17% of CFC-12, going up to 44% if the time horizon is reduced to 20 years. The environmental group Greenpeace took the case to the UK's Advertising Standards Authority (ASA), who decided not to uphold this particular complaint, arguing that:

> while the copy would have benefited from an explicit indication of the timescale used, readers would have viewed the claim in the context of long-term rather than short-term global warming and that it was therefore acceptable.
>
> (in Greenpeace 1993)

Greenpeace responded to this by pointing out that the Climate Convention referred to limiting climate change over a time scale of decades rather than hundreds of years; they questioned the policy usefulness of a long time horizon for calculating GWPs, claiming that: '500 years is simply not a timescale that humans instinctively regard as useful' (ibid.). The ASA replied to Greenpeace that: 'the long term would seem to us to be equally important and we remain of the view that an unqualified claim will be interpreted as reflecting the long term situation' (ibid.). Many policy analysts and scientists who quote GWPs, however, now routinely use the value as calculated over a 100 yr timeframe. In discussions at the WGI 93 meeting there was a consensus that the 500 yr horizon was far too long for calculating reliable GWPs—the idea was described by one participant as 'ridiculous'; by contrast: 'we can produce a single set of numbers applicable to anything which might happen in the next 100 years'. The scientists at the IPCC in 1993/4 combined judgements about the scientific feasibility of calculating reliable GWPs with judgements about what were policy-relevant time horizons, coming up with a 100 yr frame as probably most appropriate.

The ICI/Greenpeace example seems to support scientist 1's argument that the variable time horizons for calculating GWPs could become a recipe for endless, irresolvable and politically motivated arguments about what is a policy-useful time frame and what knowledge can be assumed on the part of policy makers. The ability to use GWPs over different time frames and present them to other audiences as the same calculation could be seen as an unwelcome feature of their flexibility which had not been fully appreciated by IPCC scientists when they introduced the time horizons. The 3 time horizons, whilst according to the IPCC without 'special significance', gained credence amongst outsiders as indicatives of the short, medium and long term. For example, 500 yr became, for the ASA, 'the long term'.

One participant at the WGI 93 meeting suggested that the policy use of GWPs would be helped by clearly labelling GWPs according to their time horizons, i.e. GWP_{10} would be a GWP calculated for 10 yr, GWP_{50} for 50 yr and so on. The idea was rapidly taken up by the participants. If users could be persuaded to always label their GWPs in this way, and if that label were widely understood and even required as a matter of course, greater control by the IPCC over the conditions of use of GWPs could thereby be achieved. WGI's solution implied a 'use/abuse' model of science in policy making; abuse which could be tackled by imposing a new mode of control which did not, however, detract from the essential simplicity, hence usefulness, of the concept. However, the idea vanished without comment or explanation at subsequent WGI meetings. A likely explanation is that such a level of control over GWPs would not have been welcomed by policy makers: because it would reduce their flexibility in the uptake and use of GWPs.

4.2. Spatial and temporal variability of forcing

A further issue discussed at WGI 93 was whether GWPs could be calculated for gases which illustrate a high degree of regional variability (such as the CFCs) or for the sulphate aerosols, which have negative forcing as well as spatial and temporal heterogeneity. Scientist 2 argued against including sulphate aerosols because its sources are far from global, being largely concentrated in the industrial zones. The rejoinder to this, from scientist 3, was that the sources of CFCs are about as regional as for sulphate, yet GWPs are calculated for CFCs.

Scientist 4, in response to scientist 2, noted that since GWPs aim to represent global damage, the spatial or temporal variability of forcing was irrelevant. In other words, the forcing might be greater in some parts of the atmosphere than in others, but the climatic consequences would still be globally distributed. Scientist 2 replied to this by pointing out that even if you had the same GWP values for CO_2 and sulphate, they would not necessarily compensate each other because the forcing varies spatially. Thus the compensation would be greater in the North Hemisphere than in the South with consequent differences in damage done, but considered globally such differences would even out, giving a false indication of climatic change in terms of broad regional effects (and, given non-linearities, perhaps in its absolute extent). Scientist 5 then suggested that the word 'damage' should not be used by WGI at all since it 'depends on where you live in the world' He further thought that WGI 'should not get into this at all'.

Discussion of the regional impacts and damages of climate change were directly invoked during WGI 93's debate over GWPs. But these debates did not lead to the conclusion that regional warming potentials should be calculated to assist policymaking in those circumstances where global-scale assessment was not robust. The reason for this appears to have been the strong emphasis placed at WGI 93 by the chairman of the IPCC WGI and Bert Bolin (the overall chairman of the IPCC) on the definition of the enhanced greenhouse effect as a *global-level problem*, which requires global-level analysis and solutions. Rather than regional warming potentials, various solutions were suggested to maintain the global-scale focus of GWPs: for example, defining the spatial heterogeneity of sulphate-aerosol-induced climate change as a policy issue rather than as science (even though heterogeneity on the part of CFCs was not similarly treated as a policy issue); including additional uncertainty bounds because of the regional effects; and ruling out GWPs for short-lived or highly spatially variable gases. We suggest that the social and policy commitment to global-level analysis was a prominent factor in the design and representation of GWPs at WGI of the IPCC, and contributed to the lack of discussion of alternative indices.

4.3. A new GWP for methane

A new GWP for methane was suggested in IPCC94, to take account of the effect of methane on its own lifetime and its indirect effects. Calculation of this new value was performed by 2 or 3 scientists using 3-dimensional atmospheric chemistry models (the only suitable ones available). Since the different models did not produce the same precise values for different direct and indirect effects, and given that there was no obvious way of choosing one model result over another, the final values used, and the associated uncertainty ranges, were agreed through a process of negotiation between the modellers.

At the subsequent Plenary Meeting—WGI 94B—when the Policy Makers Summary was officially endorsed by national representatives, one country's official raised the issue of how to represent the new GWP for methane. This official, who was a scientist, was concerned with the implications of the proposed presentation of the GWP for methane as a single figure (for a particular time horizon) with an uncertainty range of ±35%. The danger, given the new GWP for methane, was that governments would be tempted to trade-off reductions in CH_4 for increases in other greenhouse gases, such as CO_2. The issue is illustrated well by Fuglestvedt & Skodvin (1996) who show that the total GHG emissions for New Zealand (as CO_2 equivalents) increase by 300% when GWPs are calculated using a 20 yr rather than a 500 yr integration, whereas for Norway there is relatively little change (Fuglestvedt & Skodvin 1996: p 75-80). This is because methane is the dominant GHG for New Zealand for the 20 yr time horizon, but if a 500 yr time horizon is used, CO_2 dominates (and the contribution of methane is reduced from 75% to 28%).

The government official at WGI 94B wanted a clearer statement of the wider uncertainties and some statement to the effect that there is too much uncertainty attached to GWPs for them to be used to justify off-setting between greenhouse gases. The involvement at this stage of government scientists from countries with particular greenhouse gas emission patterns introduced new ideas about how uncertainty should be represented, including whether there should be some indication of the (in)appropriate policy use of GWPs. This sort of position is very similar to scientist 1's stance, discussed above, in that it shares a similar perception of how science is typically open to abuse by self-interested parties in policy making, i.e. its uncertainties will be treated as a resource in pursuing a political stance.

Other influential scientists and policy makers at WGI 94B resisted changing the representation of uncertainty. They argued that it was not for the WGI to tell policy makers how to use GWPs and that this would appear as WGI claiming greater knowledge about policy making than that held by the policy makers themselves. Some mentioned the analogy of Ozone Depletion Potentials (ODPs), and in the 1994 report this comparison was developed at some length in a section entitled 'The Insights Gained From Ozone Depleting Potentials'. There it states that: 'The Legal Drafting Group that wrote the final text of the Protocol required that single values be stated for the ODPs, despite the fact that a scientific estimate always has some level of uncertainty and hence a numerical range within which the ODP is likely to lie' (IPCC 1994: p 228).

The WGI's explicit comparison with ODPs is instructive given the considerable overlap between advisory scientists on the WMO's ozone assessment panel and the IPCC WGI. It reveals much about the way in which these advisory scientists conceived of their relationship to policy. For example, that advisory scientists acceded to the policy makers' request for a single ODP value, whilst an understandable response, could nevertheless be seen as misleading from a scientific perspective. The advisory scientists' own extrapolation from the ozone to the climate change case of what policy makers are likely to 'need' by way of knowledge may also come to have a decisive influence on policy makers' *own* perceptions of what knowledge they need and can reasonably expect. That is, policy makers may legitimately conclude from the presentation of a single value by advisory scientists that they do not need to grapple with the issue of scientific uncertainty as expressed in a range of values.

The case of the GWP for methane indicates the fuzzy character of the boundary between science and policy. How policy makers defined science and policy in the related case of ODPs was used by advisory scientists as a guide to distinguish science from policy in the case of GWPs. This is an understandable response, but nevertheless reinforces uncritically the idea that policy makers are unable to cope with more than a modicum of scientific uncertainty, and will not accept a range of figures. Such models of policy are rarely traceable to specific policy makers or policy commitments, but seem more the result of shared assumptions or implicit commitments of the proto-community of climate change policymaking, to which advisory scientists have become wedded.

5. CONCLUSIONS AND IMPLICATIONS

GWPs have a flexible, ambiguous meaning which assists in their continued development through nurturing interactions between research and advisory scientists, policy makers, environmentalists, industrialists and other interested parties. We have identified 4 roles for GWPs—instrumental, symbolic, heuristic and interactional—which contribute to the maintenance of a flexible interpretation and meaning. The way GWPs are discussed tends to incorporate assumptions about the social and policy context of their expected use.[9]

Even the 'lowest common denominator' identity implies belief in analysing and tackling global warming, through GHG emission reductions, at the global level (and despite technical and policy arguments for a regional analysis and policy response). The commitment on the part of many advisory scientists to a global analysis and solution appears to be motivated by 2 considerations: firstly, the perceived tendency for international policy to become reduced to a contest between national interests, and secondly, by the belief that nations will try and avoid their obligations whilst benefiting from the actions of others. (Any one nation stands to gain little, in terms of limiting climate change in its own region, from participating in greenhouse gas emission reductions, whilst gaining much from the actions of other nations.) Only a global solution, entailing global-scale analysis and policy development, will, it is felt, overcome these parochial influences. But the global focus is also founded, we suggest, on the technical judgement that an index at the global scale is more robust and 'do-able' than a regional one. In a sense, the policy and technical definitions of the problem and viable solutions converge at the global-scale locus.

The discussions at IPCC meetings illustrated 2 other substantive beliefs about policy. Firstly, in the ability of the policy system to prevent misuse of the GWP concept from politically driven interest groups. This judgement was arrived at by 'default', as an assumption of the authoritative influence of science. Secondly, that advisory scientists should use the policy makers' *own* distinctions between science and policy when demarcating the limits of their expertise (though we have observed this in only one case). We are not criticising these beliefs about policy *per se*. Our point is more about the processes through which such beliefs emerge and are sustained. They are not judgements which are openly debated amongst a wide section of policy actors, but are instead assumed without much evidence of critical reflection by advisory scientists and some policy makers. (This is not to deny the considerable personal experience the latter groups bring to the IPCC, but rather an acknowledgement that this does not guarantee a sufficiently wide-ranging discussion.) And unexpected consequences flow from these judgements: for example policy makers may take their cue for locating the science/policy boundary from advisory scientists, not realising that the scientists have themselves borrowed the policy makers own perceived distinction between science and policy (as expressed informally and in other policy fora). The scientists may thereby unintentionally reinforce the distinction between science and policy made by policy makers. Because the science/policy boundary is always fuzzy, and subject to negotiation, uncritically reinforcing the prior assumption of policy makers runs the risk of curtailing creative thinking. Other implications in this vein are presented in Box 1.

The focus on GWPs at the science-policy interface has reinforced GHG emission reductions as the prime means of analysing and responding to climate change. As Victor & Salt have put it:

> Options for dealing with multiple gases without using the GWP concept have not been adequately reflected in the international debate because analysts have focused on the easiest measures (i.e. emissions) and then been forced to adopt some sort of conversion index (i.e. the GWP, usually with 100 year integration). With so much now invested in emissions-oriented thinking and policy analysis, it would be painful for many to explore the severe problems with the GWP concept, which would require rethinking of the entire approach to slowing global warming.
>
> (Victor & Salt 1995b: p 34)

To put it another way: (1) GWPs are perceived as more stable and robust by many policy actors than is the specialist scientific perception; (2) partly as a consequence GWPs are increasingly accepted as the most appropriate tool for comparing different GHGs in the context of the FCCC; (3) this approach to GWPs tends to reinforce an emphasis on emissions as the appropriate indicator by which to establish and define policy commitments. A significant influence in this case appears to have been the perceived need of the main actors within the climate policy domain to reach an agreement rather rapidly on how to codify new (i.e. post year 2000) commitments under the FCCC. GWPs are one of the crutches which support the development of the FCCC in the manner preferred by the dominant policy actors, whilst acquiring support themselves from this important policy role.

Alternative definitions of policy responses are available, including: calculating relative radiative forcing and codifying commitments in terms of allowable contributions over a particular period of time to global radiative forcing; producing economic welfare based indices; calculating equal financial shares towards solving a common burden; and according a greater role to deliberate adaptation (Victor pers. comm. 23 July 1996). It could even be argued that a single, standardised metric of global applicability such as the GWP might come to inhibit nationally, regionally or

[9]Victor has analysed in depth the political and administrative conditions which would need to be in place for GWPs to be used effectively in climate policy making. He has found these conditions to be far removed from the current situation (Victor 1990, 1991, Grubb et al. 1991, Victor & Salt 1995a, b). Hence his analysis complements ours by illuminating additional presumptions about the social and policy context in which GWPs will be used which are rarely acknowledged or critically assessed

Box 1. Some implications for climate change science and policy arising from the GWPs case-study

(1) Mutual reinforcement processes between science and policy tend to make certain options look more solidly grounded in scientific analysis than is the case. Vigilance is needed to ensure that premature closure of policy options / modes of scientific analysis does not occur. Recognition and discussion of the ambiguity and multivalency of scientific tools for policy in the public domain is one way to stimulate debate which explores options other than the dominant response.

(2) In some cases, scientific tools for policy cannot become too specific and precise, yet still remain robust in advisory and policy circles, because they would lose much of their ability to interlink different research and policy communities. Arguably, global climate change policy is currently as much about forging new linkages between previously disparate groups, institutions, knowledges and techniques as it as about actual policy actions being decided and acted-upon now (i.e. interactional/symbolic rather than instrumental rationality). Such loose coalitions are critical in facilitating the wider acknowledgement and diffusion of the issue and building-up of trust and appropriate knowledge. Indices or other tools for policy cannot be assessed therefore only in instrumental terms (i.e. concerning whether the particular numerical values are reliable and useful in specific policy contexts). Uncertainty and instability in numerical values, or incompleteness, are then less significant in evaluating the usefulness of such a policy tool than is typically assumed.

(3) For this reason, an index or tool for policy which is more comprehensive in the sense of including more 'down-stream' variables will not necessarily be more acceptable or effective at the science-policy interface. Consensus may be easier to achieve for a scientific policy tool which is less ambitious and leaves more policy choices open to future debate.[10]

(4) As GWPs (and other tools) become used in specific, practical policy-making contexts, greater emphasis will probably be placed on instrumental utility with respect to the policy context of use. At some stage, the ambiguity in identity and interpretation may be insufficient to contain all the versions developed for detailed application, at which point break-away indices or integrated assessments are probable.

locally focused policy actions, or else actions focused on different time horizons than the ones preferred in calculating GWPs. Alternative indices may therefore need to be more specifically tailored to a particular context of policy use.

Amongst research and advisory scientists the ambiguity of GWPs is more widely recognised, though most scientists are familiar with only some of those aspects mentioned in this paper since they are typically interested in only part of the technical knowledge underpinning GWPs. Less familiar to scientists is the notion that science for policy may contain implicit social and policy beliefs, and that the preference for a particular policy option may be founded in part on a misplaced confidence on the part of decision makers in the underpinning science. Some scientists are likely to resist this notion since it may appear (falsely) as a challenge to the autonomy or integrity of science, though all we are attempting to do is to promote a discussion on what are appropriate and effective roles for science in policy. Ambiguity is commonly perceived by scientists as uncertainty which needs to be addressed by further research. They therefore tend to locate ambiguity within their own specific research domain as their 'responsibility'. Ambiguity provides material for further research in the problem-solving mode. For this reason, scientists are unlikely to widely publicise to policy makers the uncertainty and ambiguity over GWPs which emerges in their own specific domain. This allows the key advisory scientists and/or climate policy specialists—who mediate between the research community and policy makers—to connect the perceived needs of policy (themselves uncertain) with that definition of GWPs which seems most relevant to those needs, the result being that the science and policy dovetail snugly into one another. The specialist advisors are, quite reasonably, using the flexibility in the scientific definition of GWPs to find the most appropriate role for science given signals from policy makers and politicians on the characteristics of a desirable policy framework. In doing so, however, policy makers might come to exaggerate the overall instrumental role of science and/or of the feasibility of certain policy approaches (e.g. the comprehensive approach).

GWPs are typically represented in IPCC reports as science-based, objective, stable and value-neutral. Their technical use in generating numbers directly useful for policy is regarded as the end point of success, with little mention of the scientific, policy, political and administrative conditions influencing the usefulness and uptake of GWPs.[11] This presentation does not assist in the development of robust climate change science or policy because it does not reflect the real-world debates between scientists and policy actors concerning the development of a method for comparing greenhouse gases and how this could be used in

[10]Some confirming evidence includes: the preferred use of CLPs rather than ODPs in the policy assessment of ozone depletion, this being a more up-stream measure around which scientific consensus was more readily achieved; and the counter-example of the World Resource Institute's Greenhouse Index which was almost universally regarded negatively because of its needed inclusion of relatively down-stream policy and political judgements about how to allocate responsibility for GHG emissions, though in a less than fully transparent way (Hammond et al. 1990, 1991, Agarwal & Narain 1991, Overview 1991a, b)

implementing the FCCC, nor the non-obvious but important roles that GWPs come to play in policy debates. It is our contention that were the ambiguity, instability, multiple roles, controversy over, and hybrid features of GWPs more widely known, a better overall role for them in climate change policy would emerge. More generally, recognition of the multiple roles of science in policy may encourage reflection by advisory scientists and policy makers on the reasons why particular sorts of knowledge come to be important at the science-policy interface and under what circumstances, and hence permit a better overall assessment, development and application of such knowledge. The next step is to further discuss what alternatives are available or could be developed with respect to scientific tools for policy, policy commitments and ways of thinking. A related point, emerging from the role of science in nurturing new communities, is to consider how the social and policy coalitions centred around climate change might become more socially inclusive and mobilise more political weight.

CODA

As we were revising this paper, we received a draft copy of a paper by Steven Smith and Tom Wigley (dated 16 July 1996) in which the results of GWPs are directly compared with comparable calculations using a 1-D climate model. They find that: ' ..the use of GWPs can result in large and potentially serious errors, and we conclude that GWPs should not be used for policy analysis'. In the view of one of the scientists who developed GWPs, the Smith/Wigley paper 'nicely brings an end to the GWP saga'. As a result, scientific judgement may swing away from GWPs rather dramatically. It is fascinating to note that this rigorous validation task for GWPs has only been conducted in 1996, more than 6 yr after GWPs began to be promoted. Some government departments even requested scientists to conduct similar validation exercises back in 1990. That this was not done is explained, according to one advisory scientist, by the fact that the research scientists were so busy developing and calculating new GWP values that they did not have time to conduct proper validations tests for GWPs. If a correct interpretation, this is a vivid illustration of how perceived policy pressures and needs come to construct scientific tools in a way which closes down reflexive debate and thorough validation. And note how this preoccupation of scientists with developing GWPs, rather than in their validation, could very easily be interpreted by policy makers as evidence that GWPs have *already* been properly validated and hence that climate policy can be developed in the confident knowledge that a robust tool exists for comparing different GHGs. Pending further evidence, this is an excellent and revealing illustration of the mutual reinforcement of climate change science and policy in the case of GWPs, which informs the theoretical component of this paper.

[11]The low-level, singular definition of GWPs is dependent on the existence of multiple, diverse definitions. GWPs would rapidly lose all credibility as scientific or useful for policy were the separate ambitions and work of the range of scientists, advisory scientists and policy makers to be overly constrained by a narrow definition of the GWP. Meanwhile, without the single, reduced version, the range of activities undertaken under the GWPs banner would lose much meaning and there would be no similar currency for international policy and scientific discussions on how to compare GHGs (especially when planning the future trajectory of research and policy). The presentation of certain, quantitative GWPs in formal reports such as the IPCC's, whilst greatly reducing and simplifying the scientific complexities and assumptions, is acceptable to scientists only because of the existence of an informal further level of understanding and negotiation between scientists and policy makers on the interpretation of the way in which scientific knowledge is used for specific policy decisions

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