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Improving Information for Policy Makers

Developments in integrated assessment: the co-productive approach

by

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FOREWORD

This paper was prepared for an OECD Workshop on the *Benefits of Climate Policy: Improving Information for Policy Makers*, held 12-13 December 2002. The aim of the Workshop and the underlying Project is to outline a conceptual framework to estimate the benefits of climate change policies, and to help organise information on this topic for policy makers. The Workshop covered both adaptation and mitigation policies, and related to different spatial and temporal scales for decision-making. However, particular emphasis was placed on understanding global benefits at different levels of mitigation -- in other words, on the incremental benefit of going from one level of climate change to another. Participants were also asked to identify gaps in existing information and to recommend areas for improvement, including topics requiring further policy-related research and testing. The Workshop brought representatives from governments together with researchers from a range of disciplines to address these issues. Further background on the workshop, its agenda and participants, can be found on the internet at: www.oecd.org/env/cc

The overall Project is overseen by the OECD Working Party on Global and Structural Policy (Environment Policy Committee). The Secretariat would like to thank the governments of Canada, Germany and the United States for providing extra-budgetary financial support for the work.

This paper is issued as an authored "working paper" -- one of a series emerging from the Project. The ideas expressed in the paper are those of the author alone and do not necessarily represent the views of the OECD or its Member Countries.

As a working paper, this document has received only limited peer review. Some authors will be further refining their papers, either to eventually appear in the peer-reviewed academic literature, or to become part of a forthcoming OECD publication on this Project. The objective of placing these papers on the internet at this stage is to widely disseminate the ideas contained in them, with a view toward facilitating the review process.

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1. INTRODUCTION

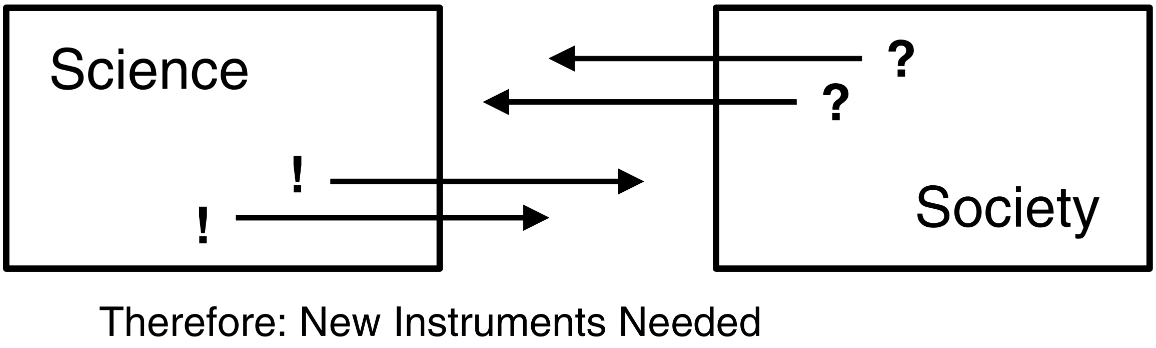
Initial concerns about climate change in the 1980's highlighted the potentially enormous and damaging impacts on humans and natural ecosystems, which have iteratively been estimated scientifically by the IPCC (IPCC 1996, IPCC 2001). The perceived need to act resulted in a focus on estimates of mitigation costs under present socioeconomic conditions (Grubb et al. 1993, Peck and Teisberg 1995, Richels and Edmonds 1995, Schneider and Thompson 2000, Tol 2000). The majority of studies predict high mitigation costs, which has engendered considerable doubt as to whether we can afford climate protection. Other studies predict that lower costs can be achieved through endogenous technical change and judicious application of carbon taxes, or even that costs are not high when viewed in the context of a slight delay in economic growth (Azar and Schneider, 2002). However, the widespread concern about the costs of climate policy (which are reflected in the outcome of the Kyoto process) means there is an urgent need to assess the benefits of decarbonization including: (i) avoided damages, (ii) ancillary advantages, and (iii) role models for participatory action and global partnership in facilitating holistic assessments involving both key users and our best scientists.

This is not a simple task. There is a difficulty in properly assessing these genuinely complex benefits: even factual damage costs of recent climate-related disasters like the August 2002 flood in Central Europe are hard to calculate. Further dimensions of complexity are added if: (1) mankind's potential to adapt to climate change is taken into account; (2) the climate issue is embedded in a sustainability context; (3) the assessment is carried out at multiple spatial scales; (4) the assessment allows for the use of different paradigms; (5) the assessment simulates the behaviour of various interacting actors.

Integrated assessment (IA) is, in principle, the only mode of scientific analysis that can cope with this complexity. However existing knowledge production systems based on IA (Alcamo 1984, Dowlatabadi 1993, Dowlatabadi 1995, Hulme et al. 1995, Kainuma et al. 2003, Matsuoka et al. 1995, Morgan and Dowlatabadi 1996, Plambeck et al. 1997, Prinn et al. 1999, Rotmans 1990, Rotmans et al. 1994,) rapidly approach their inherent limits, namely (i) the impossibility of building monolithic all-purpose models that assemble a comprehensive array of components at a single site, and (ii) the impossibility of providing responses to policy-relevant questions with a turn-around time that is acceptable to policy-makers.

Figure 1 represents the traditional mismatch between questions raised by policy makers and society (represented by question marks) and information available from scientists (represented by exclamation marks). It has often been pointed out that involvement of non-scientists in integrated assessment is necessary in order to ensure the relevance and later acceptance of the analytical modelling (Hordijk 1991); and a variety of participatory modelling approaches have been used in attempts to resolve this mismatch (Rotmans 1998, van Asselt and Rijkens-Komp 2002). Relatively simple approaches include the use of scientist-user workshops, as employed in the MacKenzie Basin Impact Study (Cohen et al. 1997), and projects which aim to map diversity of opinion as in the COOL project (Berk et al. 1999).

Figure 1. Traditional Mismatch between Cognitive Demand and Supply Side



Rotmans (1998) classes existing participatory-based integrated assessment into three categories : Mutual Learning, Policy Exercises (gaming), and a Dialogue Method:

- In *Mutual Learning*, scientists and users are co-producers of knowledge, and an early example of this is the ULYSSES project (Jaeger and Chadwick 1995, Kasemir et al. 1997, Kasemir et al. 2000) in which focus groups made use of a global integrated assessment model, here the IMAGE model (Alcamo 1984, Rotmans 1990) to facilitate discussions on the impacts of policy decisions and lifestyles. Another example is that of the VISIONS project (Rotmans et al. 2001) which produced consistent scenarios for the future which were approved by both scientists and users.

- *Policy Exercises* involve gaming, in which a complex system is often represented by a very simple model, as in the climate policy exercises (Parson, 1996).

- The *Dialogue Method* has typically had two phases. In the first, users form a test group to determine how the results of the assessment will be brought to the fore, and this has been pioneered by the DELFT Dialogue Process (van Daalen et al. 1997). This involves users in the use of, and with the ability to provide input to, integrated assessment models. In the second phase, intended users contribute to the design principles by making their needs known (Rotmans 1998). This most advanced example of the dialogue method has been realised by the RAINS modelling approach (Alcamo et al. 1990, Gough and Castells 1998) in which a community of scientists and policy makers formed the knowledge space, and involved users became co-designers in suggesting ways of answering a set of related policy questions.

The solution posed in this paper is a radically new system. It can be considered as a hybrid approach that combines and extends the mutual learning method with an advanced version of a dialogue method. It is a radical step beyond previous IA projects, because here users are involved at a fundamental level in *conceiving and prioritising, the policy questions which should be addressed*, before the integrated model has been constructed, and iteratively influencing the direction of model design as it evolves. This is particularly useful for the highly controversial area of climate change where a wide array of users pose a multitude of different questions. Note that the word “involved” rather than “dictate” is used, since prioritisation of questions must also take into account the feasibility of answering them in realistic timescales, and also the fact that CIAS staff must try to anticipate the future needs of users as well as those which they are currently making known. Users are also involved in assisting modellers by providing data and other knowledge for the model, and in advising on the most relevant or immediately comprehensible manner of presenting model results. Hence the approach also holds a strong component of mutual learning.

Society has yet to find a solution to the climate change problem, owing (in part) to the large number of different user views involved, and the complexity and multi-disciplinary nature of the problem. Thus climate change is *the* issue for which a structured participatory approach is vital. This paper outlines a formal structure for a co-production of climate change wisdom through an interactive- distributed-modular IA system (Community – or Co-productive - Integrated Assessment System = CIAS). The term "co-production" is used to illustrate (a) how the scientific and the user communities contribute to evolving design of the CIAS, and (b) how different parts of the scientific community, resident at different institutions, contribute to the construction of the CIAS system. The resultant matching of demand and supply (of our understanding of the climate change issue) is represented as a non-linear medium (i.e. one which transforms or changes that which crosses it) in Figure 2. Section 2 describes the proposed system in some detail, and section 3 goes on to describe how this might be applied to assess the benefits of climate policy.

2. A BLUEPRINT FOR A CO-PRODUCTIVE ASSESSMENT SYSTEM

The challenges for a next-generation IA system, able to maintain an ongoing societal relevance and state-of-the-art scientific capability, may be characterized by following questions:

- Which issues is society really concerned with?
- What scientific evidence is either available or producible on demand?
- How can the pertinent fragments of our knowledge base be assembled and linked?
- What is the best way to communicate and implement the analytic conclusions?

We propose a systematic way of unifying these activities within a coherent operational framework based on the concept of a Community Integrated Assessment System (CIAS) which is built by a set of participating institutions. Thus, components and data will originate from a set of different institutions, and the composer is required to link them. This requires that the integrated model be distributed across a range of participating institutions: and hence that the model is co-produced by the community of institutions: hence our acronym CIAS: Community (or Co-produced) Integrated Assessment System. This allows understanding of different approaches taken by different institutions (e.g. through component inter-comparisons). If a field is identified in which controversy exists about modelling methods, or if alternative approaches exist based on different paradigms, the system can be used to understand the assumptions behind, and the implications of the use of, the use of these different paradigms or modules.

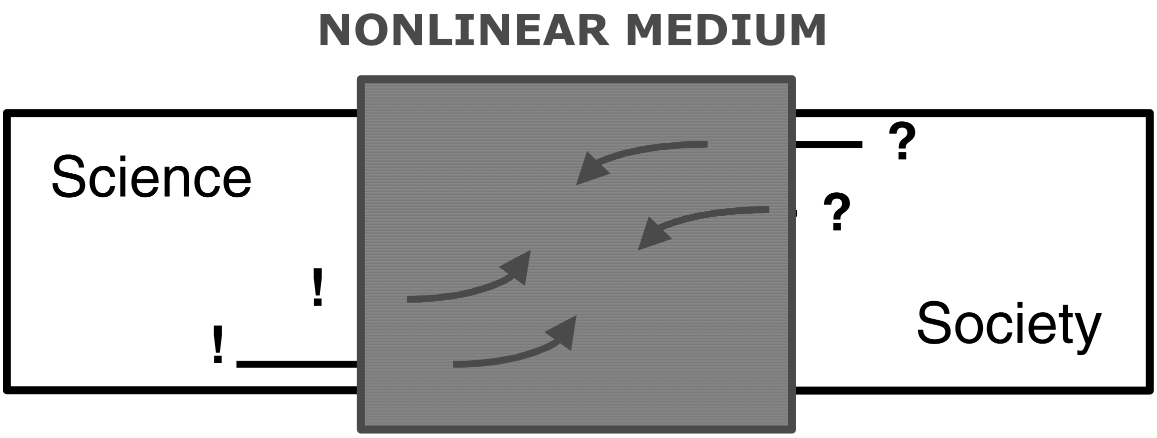
Thus, it facilitates a pluralistic approach to policy analysis, internalising competition between different approaches.

2.1 The CIAS framework

The CIAS framework is designed to avoid the traditional mismatch between cognitive demand of users (including policy makers) and the supply of information from scientists. It makes possible the iterative interaction of the needs of society and the knowledge of scientists via four sub-operators: a Demander, a Surveyor, a Composer, and a Responder, overseen by a set CIAS operators located at participating institutions. The (sub)-operators are not users, but act as the mechanism for linking the knowledge held by the scientific community to the needs of (and information provided by) users such as the policy community.

CIAS is based on a refinement of the structure sketched in Figure 2. The medium combining science and society has to connect cognitive demand and supply across *two* interfaces: a societal one and a scientific one. This is visualized in Figure 3, where the concept of the "CIAS Wheel" is introduced. Compare with Figure 2, where only one interface is shown.

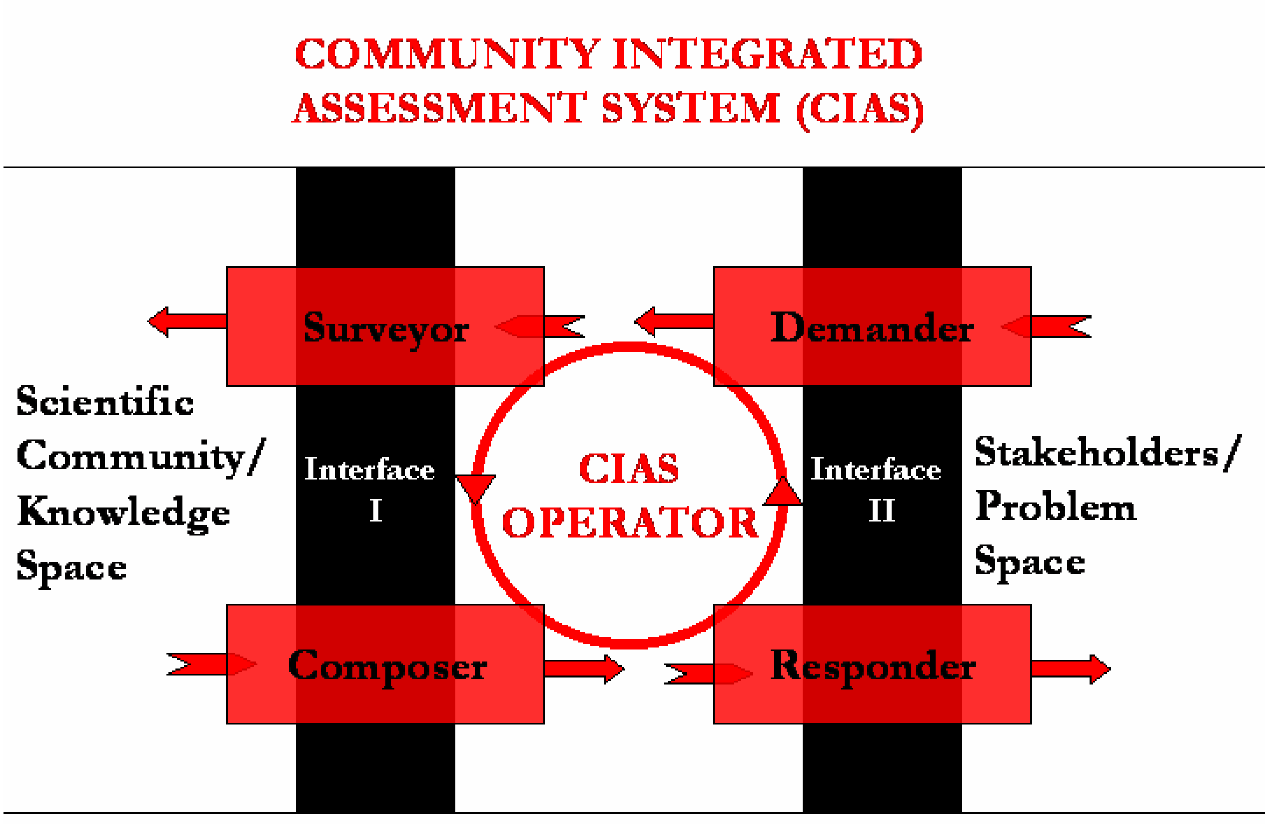
Figure 2. Non-linear Medium



One interface forms a linkage to the *knowledge space*, that is, the scientific community, and in particular the single-discipline scientists with whom a pair of sub-operators, the *surveyor* and the *composer*, communicate. These sub-operators comprise what we call the *scientific interface*. The complementary interface forms a linkage to the *problem space*, that is, the policy community, industry, NGOs and the general public. We call this the *societal interface*. A second pair of sub-operators, the *demander* and the *responder*, comprise this second interface.

There are thus seven components of the system (see Figure 3.): the knowledge space, the problem space, the four sub-operators, and overall operators located at participating institutions who together ensure system-wide efficiency and coordination. Through an iterative interaction of these elements it is possible to maintain a consistent policy-relevance for the integrated assessment of climate change. Crucially, this framework emphasises the necessary *co-production* of knowledge between scientists and users, and between the modelling system and the demands of, and information provided by, users.

Figure 3. The Community Integrated Assessment System (CIAS)



2.2 Example of CIAS in operation: use of an integrated assessment model

Initially the Demander highlights that there is a problem, climate change, which is global in extent, and multi-disciplinary in nature; and formulates some initial questions that should be answered (see Figure 3.). The wheel now turns to the Surveyor, who then contacts experts in the relevant disciplines at participating institutions and collects the best peer-reviewed information (data), models (theories), and expert judgement available to address the climate change problem and which could help answer these questions. The wheel rotates again, reaching the composer, who identifies which models may be linked together in a scientifically consistent way, and then creates a Community Integrated Assessment System model (CIAS model). At this stage the Composer can also indicate which policy questions can be answered by the model, which can be answered through other existing single- or multi-disciplinary approaches at participating institutions, and which cannot be answered with any degree of confidence. The composer may also suggest further, or alternative questions to be addressed, thus trying anticipate users' future needs and taking into account the limitations of available knowledge.

The wheel now advances further, reaching the Responder, who can now begin disseminating information to the original demander, for example about the potential impacts of climate change, about the costs and benefits of mitigation and adaptation options in different world regions, and the uncertainties in these estimates. The Responder also provides information about which policy questions have been answered, which cannot be answered, and in the latter case, lists the related questions which *can* be answered by the CIAS system. The Demander now holds a dialogue with users to assess whether the information provided has been useful, and whether the proposed alternative questions (which *can* be answered by the system) would be of interest to the Demander.

The CIAS wheel has now made one complete revolution. The cycle can now begin again with the demander suggesting new policy-relevant questions to be addressed (through a continued interaction with actors in the problem space). The surveyor may then need to collect new information; the composer will re-configure the modelling system to address the new request, and the responder will again disseminate the results.

In this way (i) timely answers to climate-change policy questions required by users can be provided in a transparent manner, and presented in an appropriate format (ii) where necessary, compromise can be reached between user needs and available information. We refer to the collective ongoing development and application of the seven components of CIAS as an Interactive Integrated Assessment Process (IIAP). We will now describe in more detail each of the seven building blocks.

2.2.1 The problem space

The problem space represents a conceptualization and mapping of the societal and institutional context in which the CIAS model should operate to co-produce knowledge relevant to policy and decision-making on climate change and sustainable development.

The way in which the problem space is empirically mapped and understood conceptually is of crucial importance to the sub-operators that interact with this interface: the "demander" and "responder" sub-operators. Together these three components form an interactive process that allows the integrated assessment modelling system and other relevant knowledge, data and tools (obtained from the knowledge space) to be applied to help find a solution to pertinent real-world problems.

It is important that this problem space is not conceived of with an overly narrow or instrumental focus on climate change policy: it is not assumed that we are aiming at a single decision maker who is envisaged to make a decision on the level of investment appropriate for climate policy using a single global welfare function, for example. Rather the conceptualization of the problem space must include the embedding of climate change within a broad agenda of futures debates. These will include, for instance, debates about appropriate stabilisation levels, scenario analysis, and economic cost-benefit analyses. These debates will be related to issues such as the development of new technologies, modern governance, quality of life issues, differential vulnerability of regions, societal strata, etc. Ultimately, the aim of this work is to improve the quality of the debate which underpins what may well be a somewhat "messy" negotiation process at the global scale. However, it will also underpin decision making at national and local scales, which will hopefully be more structured.

The challenge for the researchers involved in developing the CIAS model is that, on the one hand, the dimensions of this space are potentially limitless. Thus the problem space as conceptualized in the research process must be a radical simplification of the actual domain spanned by the climate change and sustainable development issues. On the other hand, the problem space must not be allowed to remain a cosmetic backdrop to the problem-solving machinery of the research process. Ultimately, the ability of the machinery of the CIAS model to respond proactively and effectively to societal needs for knowledge on climate change and sustainable development depends crucially on the quality and sophistication of the mapping and conceptualization of the problem space.

It is also important to ensure a high degree of reflexivity in this mapping and conceptualization of the problem space. This involves questioning how our own "worldview" colours our mapping of the problem space and interaction with it. Reflexivity must also be incorporated in another sense, by reflecting back to the user and user community our understanding of the problem space (through working papers, workshops, etc) the research process may have a direct effect on improving the way that policy-makers and decision-makers understand their role.

Of course such a conceptualization of the "problem space" is something that any researcher engaged in policy-relevant research will always have to deal with to some extent. The hypothesis here is that: by making this an explicit, reflexive and significant part of the research process we can greatly enhance the ultimate "effectiveness" of the research. By "effectiveness" we imply the ability to identify and interact with a small subset of all possible users to address a small subset of all possible research problems and communicate the results of the research to a small subset of all possible users in such a way as to result in an effective contribution to particular societal goals (such as climate protection in the context of sustainable development).

In practise the application of these ideas requires a dual approach of both empirically mapping the problem space through e.g. conducting user surveys of the policy and research questions that users would like to see addressed combined with a conceptual framework capable of structuring this information and providing operational answers to questions such as the following:

- Who are the most appropriate users to interact with?
- Which research questions should be selected?
- How, and to whom, should results be communicated?

It is also important to consider how the users should be selected. For global studies, it would be particularly important to include those from developing countries, where there is the largest gap between scientific understanding and the needs of policy makers. Efforts have been made to bridge this gap through a number of initiatives, for example the AIACC project[1]

(www.start.org/Projects/AIACC_Project/aiacc.html) which has been designed to increase the skills of developing country scientists in studies of climate change impacts, vulnerabilities and adaptation. A great deal more needs to be done, and CIAS provides an ideal opportunity.

2.2.2 The knowledge space

A key letter in the acronym "CIAS" is "C" for "Community" or "Co-production". The community of participating institutions pools their knowledge, creating a diverse knowledge space from which information may be selected. In addition, the users also contribute to this pool of knowledge, by providing data, information, and qualitative insights. However the knowledge space extends beyond the immediate community involved in producing a CIAS model– for example through dissemination of scientific information in the literature and at international conferences. The full scientific knowledge space is potentially vast, although it should be restricted to the peer-reviewed publications. In practise the knowledge space must span all the relevant disciplines which need to be involved, and therefore must be explored and defined by the surveyor. It may contain crucial information about topics such as mitigation, geo-engineering or effects on human health and ecosystems. However, it should be borne in mind that some of this information may be qualitative, perhaps resulting from expert judgement, rather than quantitative as in a computer module. For example, information concerning the public acceptability of various decarbonisation options, including carbon sequestration, has been assessed using multi-criteria anlaysis (Gough et al. 2002).

2.2.3 The demander

The role of the demander is to identify pertinent policy-relevant research questions to be addressed by the CIAS model. This involves several stages as follows (i) *relevant potential users and users need to be identified* (ii) *research questions need to be co-produced with them* and (iii) *the questions need to supplied to the main problem-solving parts* of the research process (the composer and the overall CIAS operators). In many cases this requires a substantive dialogue with users (informed by the mapping and conceptualization of the problem space) to identify the real questions to which they require answers, and to identify where there is a potential for the assessment process to provide useful answers to these questions. However, the demander must also work with the composer to try to anticipate what questions users may need to ask in the future in the light of two possibilities, firstly that users' horizons are often short and they may not be able to anticipate this well themselves, and secondly that users may sometimes withhold information for commercial or political reasons. The Demander must also (iv) *ensure an ongoing empirical mapping of the problem space* (as described above under the description of the problem space), and must not lose sight of the fact that integrated assessment is a research process, and the ultimate aim should be to gain an understanding of the climate change issue.

2.2.4 Surveyor

The role of the surveyor is to (i) to identify the individual scientists/institutions who can answer the question posed by the demander (ii) obtain the concepts and components necessary to address the questions posed by the demander (iii) to accumulate relevant scientific information from peer-reviewed

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[1] The AIACC project is implemented by the United Nations Environment Programme (UNEP) and co-executed by the Global Change System for Analysis Research and Training (START) and the Third World Academy of Sciences (TWAS), and funded by the Global Environment Facility (GEF), the Intergovernmental Panel on Climate Change (IPCC), and the Canadian International Development Agency (CIDA).

journals and ongoing research projects in institutions (iv) if necessary, to request further data from users. Ideally, institutions will form a consortium, all members of which contribute to the development of the CIAS, allowing the surveyor to construct an inventory of pooled consortium information. This ultimately can be accessed by a knowledge browser (similar to that used on the world wide web) which can then facilitate the process by providing a first port of call in trawling for information.

In this way the surveyor can rapidly ascertain whether (a) the information requested by the demander already exists in the knowledge space, in which case the response can be provided immediately to the responder (b) the information requested requires further work to carried out by the scientific community.

2.2.5 The composer

The role of the composer is to assemble information from the knowledge space, in order to answer the question posed by the demander. However, pertinent research questions may also be posed by a scientific team, particularly as questions posed by users do not cover key issues where integrated assessment could contribute to an increasing understanding of major climate change policy issues. The composer might answer these questions constructing an integrated assessment model, whose design is therefore directly influenced by the needs of the user (although a variety of other integrative tools might also be used, for example, a multi-criteria analysis or a scenario-based approach). Important tasks for the composer are (i) *to select the most appropriate components* from the information the surveyor has provided, and (ii) *to assemble, amalgamate and harmonise them* together to answer the question provided by the demander in a scientifically valid and optimal fashion. This is a highly non-trivial task, and would be so even if all the elements were located at a single institution. Before modules/components are incorporated into the CIAS model, the composer needs to work with the institution(s) from which the components to be linked originate in order to create a suitable component application and a scientifically valid linkage between modules. It should be emphasised that the composer's role involves a high degree of collaborative work between the participating institutions.

In constructing the model the composer must ensure that (iii) *the most important processes are taken into account* in the model, and that (iv) *the control flow matches the question being asked by the demander*. However, it is also necessary (v) for the composer to *optimise the degree of complexity of the model*. It is intuitively easy to understand that an overly-complex model may produce a situation of "not seeing the wood for the trees", or that it may result in an incompatibility between the timescales on which a solution to the problem is required, and those over which a computational solution can be produced. In practise, the composer will use robustness studies to identify the correct level of complexity. Complexity increases as (a) the number of modules increases (b) the level of detail included in modules increases and (c) as the number of feedbacks between modules increases. Increased complexity may be associated with increased uncertainty, owing to the larger number of parameters involved. However, it may not necessarily be the case that robustness decreases as complexity increases, since a small number of key factors may control model output. However, if this is so then much of the detail may be redundant. The relationship between complexity and robustness depends on the particular modules and feedbacks that are present in the system, and also the particular answers which the composer is attempting to supply to the responder.

The composer must also determine whether the question under consideration actually *can* be answered by running an existing, or an adapted/extended, version of the CIAS model, or indeed by using any kind of formal quantitative model. If not, the composer must return to the surveyor to determine whether other approaches such as formal qualitative methods (e.g. surveys of expert judgement analysed within a multi-criteria framework) can provide a response, or whether in fact the demander's question cannot be answered, in which case the composer can suggest alternative, related questions that could be answered instead.

As the CIAS wheel operates the composer has to constantly revise the integrated modelling system to ensure its continued usefulness to a wide range of users. This calls for a highly flexible model design. To achieve this, firstly, a modular system is necessary, in which individual disciplines, databases and sub-disciplines are clearly represented by different computer modules. Secondly, the integration system must be flexible enough to allow "plug and play" use of modules. This can only be achieved by (i) rigorous scientific examination of the module coupling methodologies (ii) the construction of a set of interfaces between modules which conform to certain standard protocols. Both are by no means trivial tasks, but together, (i) and (ii) produce a highly adaptable system, which allows the integrated model to be altered by the composer to adopt new configurations in order to answer new questions. This adaptability also ensures the life of the model beyond the date by which original software developers of a component leave a particular institution within the consortium.

In parallel to the development of a knowledge-database by the surveyor, the composer develops a database containing all the quantitative information contained within modules. This facilitates module consistency within the CIAS model.

Finally, an additional task for both surveyor and composer is to highlight areas of scientific information that may be available unbeknownst to the demander. The responder can than ascertain whether or not such expertise is relevant to the demander.

2.2.6 The responder

The role of the responder is to communicate the results and insights generated in the assessment process back to the users who are the problem-owners, but also to any other groups identified as having an interest in those particular results, and to society as a whole. So at the most basic level this can involve communicating the results to the problem owner through meetings, workshops, reports, etc. However, an optimal communication of insights back into society requires a well-defined communication strategy that takes into account issues such as: (i) *identification of multiplicators*, e.g. umbrella organisations which can disseminate results and insights to a specialized audience through their own communication channels (ii) *the holding of Agenda Setting symposia* aimed at using the insights gained in the assessment process to inform or catalyse debate of key climate change issues within the context of sustainable development (iii) *ensuring that the "institutional credibility level" is appropriate* to the type of results being communicated (iv) *harmonization of the communication strategy* with the communication strategies of all institutes involved in the research process – this is vital to avoid the increasingly serious problem of "user fatigue".

The responder must also make use of a conceptual framework and mapping of the problem space to inform the communication process. This should include an operational understanding of the factors which can optimise the potential for users to actually incorporate results into their decision-making processes. At a most basic level this involves issues such as working with the CIAS operators to (v) ensure that the delivery of results is timely in terms of the decision-making or policy process and (vi) ensure that the results are communicated to the right people within an organisation and through channels which are appropriate in terms of the political ecology of the organisation. At a more sophisticated level it involves e.g. the mapping of optimal implementation options so as to provide decision-makers with results that can be directly used within the policy process.

2.2.7 The CIAS operators

CIAS operators will comprise of key people at the participating institutions, each advised by their IA teams. The operators must take overall responsibility for the functioning of the CIAS wheel. Different operators may take responsibility for different CIAS modelling tasks[2]. In particular they must:

i. ensure that there is a balance between the societal and scientific interfaces and between the knowledge space and the problem space. The interfaces must operate efficiently, in particular to maintain strong linkages between demander and surveyor, and between composer and responder. Thus they must ensure that the material provided by the demander IS addressed by the surveyor and composer; and that new information identified by surveyor and composer is passed to the responder, where its value to society can be assessed. The operators must be aware of how much particular problems have been discussed by users.

ii. determine the configuration in which the elements of the wheel are used. The operators must be responsible for determining the implementation prescription of the system. In some cases, such as the one mentioned previously, iterative revolutions of the wheel may be necessary in order to address certain problems. In other cases, a single revolution of the wheel may suffice. However, in other cases still, the wheel need not be used in this fashion, for example the order of "play" might proceed from demander to surveyor direct to responder, if answers already exist to a user's question. Responses may come directly from the results of already completed projects, existing data-sets or through polls of expert judgement carried out by the surveyor, rather than via an integrated assessment model. This is obvious, given that it will never be possible to quantify all details of the system through mathematical modelling. A number of other configurations of operation may be envisaged in which "play" proceeds ping-pong-ball like between the different sub-operators.

iii. control the timescale upon which the wheel operates, balancing user needs and scientific capability.

iv. recognise when a particular question requires an answer ahead of appropriate modelling results being available. In cases where this occurs, e.g. in the early stages of a CIAS building project when the model is not yet mature, the operator(s) must work with the surveyor to draw on other scientific knowledge/theories/results from single-disciplinary or existing studies. As such the CIAS can greatly improve the communication between scientists and users about existing knowledge

v. ensure that a valid uncertainty analysis is carried out for each operation of the CIAS system, in collaboration with the composer. A method for doing so is mentioned in the following section.

vi. supervise the optimisation the configuration of the IA model, in collaboration with the composer.

[2] It should be emphasised that these operators are merely ensuring efficient operation of the project. The operators do not define the decision structure that policy makers might subsequently go on to use, neither do they make policy decisions.

3. APPLICATION TO THE ASSESSMENT OF BENEFITS OF CLIMATE POLICY

A fully-fledged CIAS system, treating impacts and feedbacks holistically, could ultimately be applied to answer a wide range of policy questions, such as:

- What is an appropriate division of investment between mitigation, adaptation and sequestration?
- What is efficacy of the application of carbon taxes and investment in technological innovation?
- Which economic pathways lead to which stabilisation scenarios and what are the implications for climate change damage and for adaptation?
- How do the impacts of climate change feed back on the economy?
- How will climate change, the demand for food, and land use change interact through the Carbon and Nitrogen cycles and what the implications of these feedbacks?
- How robust are our conclusions given the uncertainties in the system?

A full list of the kinds of problems that could be addressed is beyond the scope of this paper. The major application that will be focused on here, owing to the context in which this paper is presented, is the question of how CIAS can be used to provide a holistic assessment of damages due to climate change across different sectors and spatial scales. Such an analysis is relevant both for the case of forward simulation from climate policies to impacts, and for the case of analysis of stabilisation scenarios. This relates to the deeper policy question of identifying an appropriate stabilisation level that excludes “dangerous anthropogenic interference with the climate system”.

3.1 Holistic assessment of damages due to climate change

We propose two approaches to the holistic assessment of the benefits of climate policy. By “climate policy” we mean the decision to apply economic and other instruments/incentives designed to reduce emissions of greenhouse gases, i.e. that which is commonly known as “mitigation”. Since these decisions are not the only drivers of future socioeconomic pathways and hence emissions, analysis of climate policies needs to take into account a range of socioeconomic futures such as those encompassed by the IPCC SRES scenarios. (Population, for example, is a strong driver of emissions). For each socioeconomic future, climate policies will lead to a particular emission trajectory for greenhouse gases and thence a particular scenario for global climate change over a particular number of years. In order for a policy maker to assess the different climate policies, it is necessary to provide a holistic assessment of the damages due to climate change associated with the combination of each climate policy under different socioeconomic futures. It is this latter problem that we address here.

Two potential methods are proposed:

- A state-of-the-art integration of damages in a holistic manner across the globe for as many regions, sectors and stocks at risk covered in the CIAS model.

- A theory-based approach, aimed at the more fundamental question of assisting policy makers in defining dangerous climate change.

3.1.1 State of the art integration collection

A CIAS modelling framework eventually creates a knowledge pool large enough to generate a holistic, global, and yet regionally specific, impact assessment for a range of climate scenarios. This provides the basis on which consistent estimates of damages can be made. At early stages of development, incomplete assessments may be made covering key sectors or regions, particularly those where either (a) vulnerability is high or (b) stock at risk is high or extremely valuable in economic, ecological or societal terms. Either of these situations is likely to lead to high damages. Where appropriate, such damages may also be monetised. The CIAS system could also be used to implement holistic assessment schemes such as that recommended by Schneider (this volume) in which five numeraires are put forward as useful indicators of climate impacts, including monetary losses, loss of life, extinction rates, and reduced quality of life.

Ideally, such a framework should also include within it estimates of the impacts resulting from changes in the frequency of extreme weather events such as that outlined by Milly et al (2002). Initial work at the University of East Anglia and elsewhere is allowing IA models to address this, and the increasing intensity of such events, for the first time (Goodess et al. in press). Omission of this would lead to large underestimates in climate change damages. Schneider (this volume) also highlights the necessity to incorporate these considerations. Similarly, the framework should include within it an estimate of the impacts results from abrupt climate changes such as the break down of the thermo-haline circulation (Mastrandea and Schneider 2001).

Such assessment requires three major challenges in integrated assessment to be addressed:

- The existence of multiple scales in time and space
- The problem of uncertainty
- How to include qualitative assessments

Taking first the issue of scaling, the problem is that no theory exists which can describe and explain dynamic behaviour at various scales of social, economic and ecological activity (Rotmans 2003). The approach that the CIAS modelling system plans to take is that of a nested hierarchy of models, linked together with appropriate boundary conditions. Such an approach has been applied in the past at the national level, as exemplified by the “Environment Explorer” decision-making tool created for the Netherlands. The system allows integration of physical, environmental and economic/institutional variables at these different scales (Engelen 2003). In that system, GIS based applications are used to nest models operating at local, regional and national scales. In CIAS, it is planned to employ peer-reviewed up-scaling and down-scaling techniques such as those reviewed by Wilby and Wigley (1997) to statistically downscale climate output from a GCM to a finer regional scale (e.g. to 0.5 x 0.5 degrees of latitude and longitude). These scaling techniques often assume homogeneity and linearity, and problems exist because the range of GCMs do not produce sufficiently converged large-scale information to be processed through downscaling (IPCC 2001).

The question arises as to how to manage that, which brings us to the second point, that of how to handle uncertainty in damage estimates, whether that uncertainty arises from estimates of the shapes and magnitudes of dose-response curves linking local climate to local damage, of whether it arises from the availability of a range of possible local climatic conditions matching the same level of global climate change.

In the CIAS modelling system uncertainty can be analysed using Bayesian statistics techniques developed for analysing computer experiments (Craig et al. 2001). In the Bayesian approach all uncertain quantities are treated as random variables described by a joint probability distribution, and data such as field observations are used to modify beliefs about the system that is being modelled. The precise methods used depend on the complexity of the relevant module component. For simple modules (i.e. modules with small input spaces and rapid execution times) samples can be constructed from the full probability distribution of the system variables. For more complex modules, and for the CIAS modelling system as a whole, a linear Bayes approach can be applied, in which uncertainty about the system is summarised by a mean vector and a variance matrix. In the latter approach the module is represented as a numerical "black box" of uncertain functional form. Module evaluations are used to construct a statistical emulator which is then used within the inferential process to evaluate the system mean and variance. The statistical emulator can also be used off-line to provide information such as a good choice of parameter values at which next to evaluate the module, and an estimate of the benefit (e.g. in terms of the reduction in predictive uncertainty) of further evaluations. These inferential calculations can be expensive, and for very complex modules it is likely that only selected subsets of the module inputs and outputs can be considered. The approach can also be applied to modules which provide spatially varying output on a fine grid.

The results of such a robustness study could be presented to policy makers in the form of a risk management approach, which is a common method of handling decision making under uncertainty.

The question of incorporation of qualitative assessments into a CIAS system is most easily addressed by using the CIAS wheel in a mode not incorporating the CIAS model. However, it is recommended that intensive work be carried out on approaches such as the use of fuzzy sets to build the capability to combine qualitative and quantitative assessments.

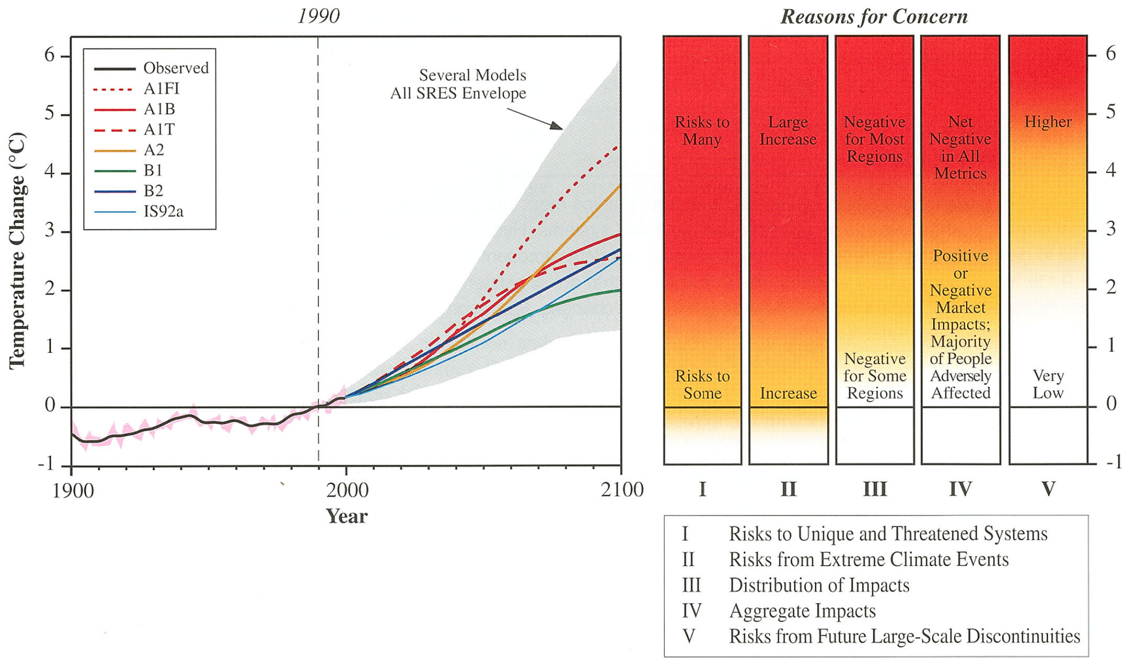
3.1.2 A theory-based approach to the definition of dangerous climate change

Although most discussions about “dangerous interference with the climate system” and “safe stabilization targets” have been plagued by concerns over intellectual and political consistency, there is no way to escape consideration of the ultimate reason for trans-national climate policy, and the post-Kyoto deliberations starting 2003 will have to face this difficult challenge. In attempting to define dangerous climate change within a formal, analytic framework designed for decision making, there are two types of thresholds that can be employed for setting long-term emissions reduction targets, namely *normative* and *systemic* ones.

In the first case (normative), multiple value judgements by pertinent users are condensed into definitions of tolerable ranges of acceptable outcomes. In the second case (systemic), major phase transitions (i.e. points at which the behaviour and properties of the entire system suddenly alters very drastically, completely transforming it so that essential characteristics of the functioning of the system are lost) in the systems involved provide criteria for identifying completely unacceptable outcomes.

The CIAS modelling system can be used to address the question of “dangerous” anthropogenic climate excursions using the first (normative) approach, in particular by consolidating the IPCC TAR (IPCC 2001) approach, from which Figure 4 is reproduced**.** However, very different threshold levels of global warming can be envisaged for different sectors of society, and for each natural ecosystem, in each region, depending on the functionality of the relationship between climate changes and impacts, and upon value judgements made by those defining these normative thresholds. Numerous examples of attempts to quantify dangerous climate change exist (Parry et al. 2001, O-Neill and Oppenheimer 2002, Vaughan and Spouge 2002). There is clearly a need to develop a more holistic approach to the problem.

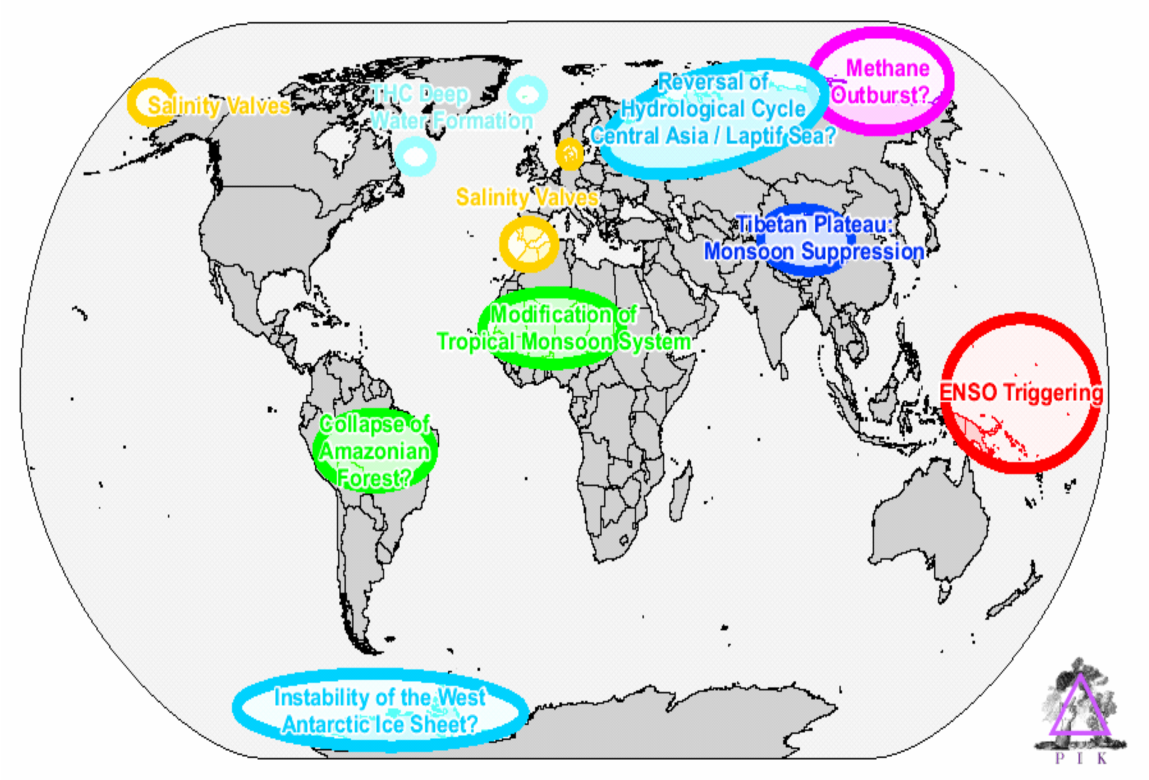
Figure 4. Reasons for concern about climate change



Source: taken from IPCC (2001)

A systemic approach to the problem of dangerous climate change was used by the ICLIPS network (see below). The aim was to track down the systemic thresholds in planetary dynamics potentially transgressed in the course of unabated global warming. Figure 5 (taken from Schellnhuber, 2002) provides an overview of switch and choke elements in the Earth System that might be (de-)activated by human interference. The most prominent example of a switch element is the North Atlantic Deep Water Formation (Rahmstorf 1995) off Greenland and Iceland, which acts as a driving force for the thermohaline circulation generating the Gulf Stream. Obviously, any human alteration of such first-order modes of operation of the ecosphere would have severe impacts and should be avoided by all reasonable means available. It has to be emphasized though that the pertinent criticality analysis is still in its infancy and will have to be considerably advanced by earth system modelling as part of co-productive assessment systems.

Figure 5. Potentially critical elements for ecosphere operation



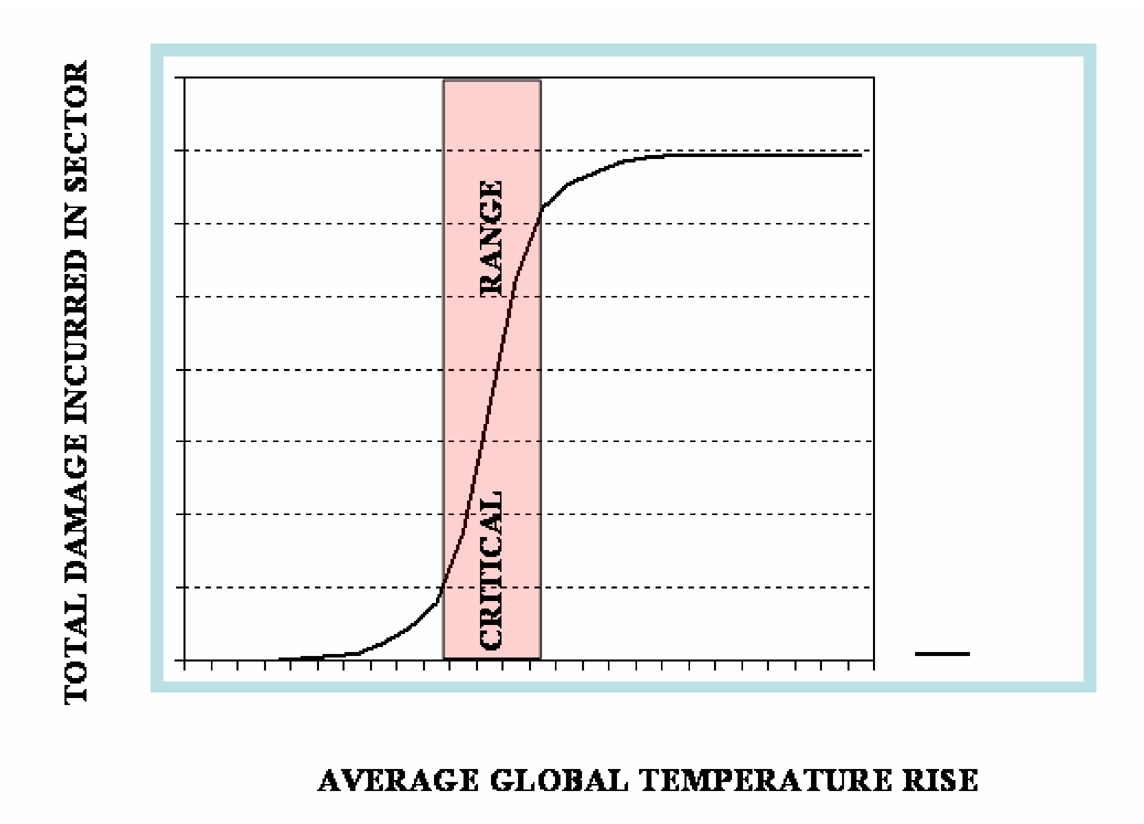
Source: after Schellnhuber (2001)

Our second illustration of the application of CIAS to this problem is the adoption of an *intermediate* approach which combines aspects of the normative and systemic. In this a series of (normative) damage functions may be constructed for each vulnerable nation/stock at risk/function/sector. Each damage function is sigmoidal in shape, showing how damage accrues as a function of global average temperature rise. Damage first accrues slowly, and then rapidly rises as climate changes; and then accrues more slowly, reaching a plateau when the entire sector has been permanently damaged or lost, as shown in Figure 6. Such damage functions can be drawn from existing information held at participating institutions, from users, from the peer-reviewed literature, including reports on case studies of valuable or vulnerable sectors. For each damage function, a band of global temperatures at which climate change is considered "dangerous"for the sector in question is identified, by identifying the critical range of temperatures for which the gradient of the sigmoidal damage function exceeds a certain threshold, as shown in the Figure. For example, for coral reefs, such a band might match a 0.5 to 1.5 degree C rise in sea surface temperature[3], or, it might match the range of sea level rises which would cause significant additional inundation of a low-lying small island state, or the range of average global temperature changes over which significant losses in the agricultural economy of a particular area. Thus, each damage function would show a "critical range" of average global temperature over which dangerous climate change occurs (shown in red in Figure 6). Within CIAS, the spans of these critical ranges could then be plotted on a single graph, to create a probability distribution function showing the number of critical ranges occupied for each average global temperature rise. Such a plot would thus determine whether there is a clustering in these critical ranges at a certain average global temperature rise. Whether or not this proves to be the case, the

[3] Global sea-surface temperature maps show that mass coral-reef bleaching episodes between 1983 and 1991 followed positive anomalies more than 1 degree C above long-term monthly averages (Goreau et al. 1994)

CIAS system could be used to plot how dangerous climate change accrues in various sectors as temperature rises – which gives a systemic picture. The policy decision would then be in which sectors/countries/stocks can we prevent a dangerous level of change. (We have already reached dangerous climate change in the small island states).

Figure 6. Illustrative sigmoidal damage function



3.2 Mitigation, adaptation and sequestration policy

Although a major use of CIAS will ultimately be to inform policy makers about the consequences, costs and benefits of different levels of investment in mitigation, adaptation and sequestration, (M, A and S), this is not the focus of this paper.

We have made suggestions as to how CIAS can be used to assess holistically climate change damages under different climate and socio-economic futures, and the potential for human systems to adapt to climate change is not included specifically[4]. CIAS does provide a way of doing this, however. The potential to adapt may be included in each of the individual components used in the holistic assessment (case A) or for case B, revised "damage functions under adaptation" may be considered. Owing to the inherent uncertainties of making such calculations, it is important to retain the capability within CIAS to investigate the situation with and without the adaptive options included. If adaptation is to be considered holistically, then assessments of the vulnerability and adaptive capacity of all sectors/regions must be drawn upon, which is a massive task for which the data is not currently available. A practical suggestion

[4] However, it should be noted that some policies designed to reduce emissions are also policies which could be regarded as adaptive. For example, improved building design could both reduce the energy consumed by the occupants of a building and better insulate them against an adverse and rising outside temperature.

given the state of current knowledge (and the likely impossibility of building up a comprehensive library of information on adaptive capacity) is to incorporate indicators of adaptive capacity in the CIAS system through ongoing work on the development of a theory of adaptive capacity. Such research is ongoing at the Tyndall Centre for example. The detailed treatment of adaptation would be a very difficult task, and for this reason the modelling of adaptation policies was not considered directly under (a).

The presentation of results as a risk assessment (as suggested under (a) above) provides a useful vehicle through which policy makers can view their decisions about levels of investment in M, A and S. The problem can be presented as a risk management situation, with different combinations of policies leading to varying levels of risk (of reaching certain levels of damage that may be considered dangerous) in a diverse range of sectors.

3.3 Ancillary benefits of climate protection

Mitigation of greenhouse gas emissions has a number of ancillary benefits. For example, climate change mitigation policies also reduce the concentration of many harmful air pollutants in the atmosphere atmosphere that could lead, *inter alia*, to human health and eco-system benefits (Jochem and Madlener 2003). Energy security issues will be significantly reduced if dependence on oil is reduced. Other environmental impacts such as oil spills would also be reduced if dependence on oil were reduced. Davis et al. (2000) review some of the ancilliary benefits of greenhouse has mitigation. Some of these will be mentioned below.

3.3.1 Ancillary benefits in terms of air pollution

Greenhouse gases share many common drivers and methods of mitigation with air pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NOx), volatile organic compounds (VOC) and primary particulate matter (PM10). Thus climate mitigation and air pollution mitigation can be achieved by employing many of the same strategies, such as switching to low-carbon or non-fossil fuels, or by increasing energy efficiency. Any process that reduces fossil fuel will have beneficial effects in terms of mitigation of both climate change and regional scale/large scale air pollution. Carbon sequestration of exhaust gases often requires the removal of other pollutants from the waste gas stream, whilst in contrast, end-of-pipe technologies commonly used to abate air pollutants (e.g. flue gas desulphurisation for SO_2 or fabric filters for the removal of PM10 emissions) do not remove CO_2, and hence there may be negative synergies among these conventional pollution policies and mitigation of climate change (for example, SO_2 removal technology increases energy use for combustion facilities increasing CO_2 intensity of production processes; also in the transport area, NOx control technologies/policies have led to an increase in N_2O).

Air pollution and climate changes also impact on a similar set of “receptors”, for example human health (e.g. Kunzli et al. 2000), natural and semi-natural ecosystems, agricultural practices, and the built environment, and so with combined policy benefits accrue for human health, agriculture, and natural ecosystems, where synergistic effects between the two are also reduced[5].

The causal commonalities between climate change and air pollution, as well as the similar nature of the stock at rik from both, created the potential for considerable synergy in policy terms. The CIAS system is an ideal one in which to explore the complex relationships between the two subject areas, including the feedbacks resulting from the different radiative properties of air pollutants. For example, the black carbon component of primary PM has a positive forcing, acting to warm the atmosphere, whilst NOx

[5] We are now at the 50th anniversary of the infamous London smog of 1952, where the burning of coal in the domestic sector, combined with anticyclonic conditions, led to the deaths of some 4000 people owing to the dense concentrations of SO_2 and PM.

and VOCs are the precursors of tropospheric ozone, which itself a greenhouse gas. Conversely, secondary particulate aerosols (sulphate and nitrate) formed from SO_2 and NOx have a negative radiative forcing acting to cool the atmosphere. Existing work in this area has already highlighted potential synergies and pitfalls (Alcamo et al. 2002, T. van Harmelen et al., 2002, Krupnick et al. 2003).

3.3.2 Climate policy and security

An important emerging issue is the question of how climate policy may or may not increase security. There are a number of dimensions to this issue ranging including:

- the fact that a climate policy involving a diversification in energy sources would result in a reduction in societal and economic sensitivity to disruptions of the oil supply to

- the potential for prevention of security problems through reduction of climate change damages.

Climate change would render parts of the world uninhabitable/agriculturally unproductive, creating potentially large movements of refugees across national borders and placing pressure on remaining food supplies. This could in turn lead to violent conflict. Environmental refugees have already been created in at least three areas. In small island states, sea level rise threatens the existence of small states. In parts of Central America, desertification and increasing demand for water is rendering land unsuitable for agriculture. Thirdly in Bangladesh, extreme weather events (cyclones, storm surges and floods) have affected 3 million people in the year 2000 alone, as a result of which emigrants are leaving the country in droves (Tanzler et al. 2002). Ensuing violence has already occurred in Bangladesh where clashes between emigrating Bangladeshi and tribal people in Northern India have led to the deaths of several thousand people. Tanzler analyses the conflict dimension of the societal and political implications of climate change in interaction with 6 other factors (soil erosion, hydrological cycle, water-scarcity, population growth, urbanisation, and agriculture) and concludes that there is a major gap between "the primarily natural science and economic work of the IPCC and the social science orientation of the environmental security debate", and suggests possible linkage points between the two. A CIAS approach has a high potential to make contributions in this area. Similarly, Brauch (2003) examines the links between environmental stress, climate-induced extreme weather events, and potential humanitarian crises which can in turn lead to political crises. Tanzler et al. note that environmentally induced stress within a single country can have implications beyond its borders, with violent conflict becoming a possibility at the regional or international levels as well as the national. Therefore, climate policy would reduce potential humanitarian crises (e.g. food supply issues) and ensuing political security problems that would otherwise be likely to develop. The integrated assessment system described here could be used to indicate the potential benefits of climate policy in terms of security. This has to be placed in the context of recent security developments in the context of the potential for terrorist attacks to energy installations and other infrastructure which is of increasing importance.

3.3.3 Avoiding considerable costs of fossil fuel transports like tanker accident damages

Secondly, climate mitigation that reduces dependence on fossil fuels for energy would avoid the costs associated with the transport of fossil fuels about the globe. For example oil pollution incidents such as the recent Prestige disaster close to the N Iberian coast would be avoided. This has caused a marine ecological disaster on an unprecedented scale, the costs of which are likely to run in to the billions. Over the past 20 years, the total damage costs of such incidents run into tens of billions. For example, the use of the contingent valuation method following the Exxon Valdez incident in Alaska found damage costs of $10 billion[6] (Marine Conservation Society, pers. comm.).

[6] In court, Exxon managed to argue that these be reduced to $4 billion.

3.4 Embryonic realizations of concept

Box 1. An interactive integrated assessment process

The Tyndall Centre and the Potsdam Institute for Climate Research are pioneering the development of a CIAS system (including the development of a CIAS model), through a flagship project at the Tyndall Centre on developing an Interactive Integrated Assessment Process (IIAP). A core group of institutions are involved in the initial phase of the project, with the expectation that many more will participate in due course. Two interlinked parallel activities are developing this IIAP, one to support a functioning societal interface (demander and responder), and one to support a functioning scientific interface (composer and surveyor) (Warren 2002). Operators of the system will consist of expert groups from a range of European research institutes assisted by advanced decision-support computer software tools.

The IIAP contains an ongoing mapping and conceptualization of the problem space. This is being developed through (1) a dual approach of carrying out a major scoping study of user needs for research on climate change, and (2) the development of a conceptual framework of the problem space based on a co-evolutionary systems approach. The conceptual framework has provided an initial mapping of the climate change policy network with which the research must interact. The scoping study consisted of a series of some 60 structured interviews with key potential users across industry, the public sector and NGOs in the UK. The results are being analysed in the context of the conceptual framework and provide a further mapping of the major research questions that users identify as important on the timescale of the next 1-10 years, and insights into the opportunities and challenges for research on the integrated assessment of climate change to interface with these potential users (Haxeltine et al., in prep).

Work is underway to develop a variety of communication and dialogue tools for use in the application of the Demander and Responder roles. These include a scenario construction methodology for use in co-developing questions with users and communicating research results.

The Composer and Surveyor team are currently developing a modular, flexible and distributed integrated modelling system (as described in section 2 of this paper). This will be achieved through four key design features: (1) the use of the self-describing computer language XML to create interfaces between modules; (2) use of a framework generator to automatically generate control code; (3) use of simple "put" and "get" commands to exchange data; (4) use of "Grid" technologies such as Globus (Foster et al. 2001). The "Grid" is a distributed computing infrastructure which allows the efficient, reliable and secure communication between a set of different computer modules written in different computer languages and operating upon different platforms in different participating institutions. The first three of these assets allows the creation of a modular and flexible system. When there is a requirement to add a new module to the system, verification of scientific compatibility between modules is first addressed; then standard XML interfaces are constructed to allow modules to be added/removed in a "plug and play" fashion.

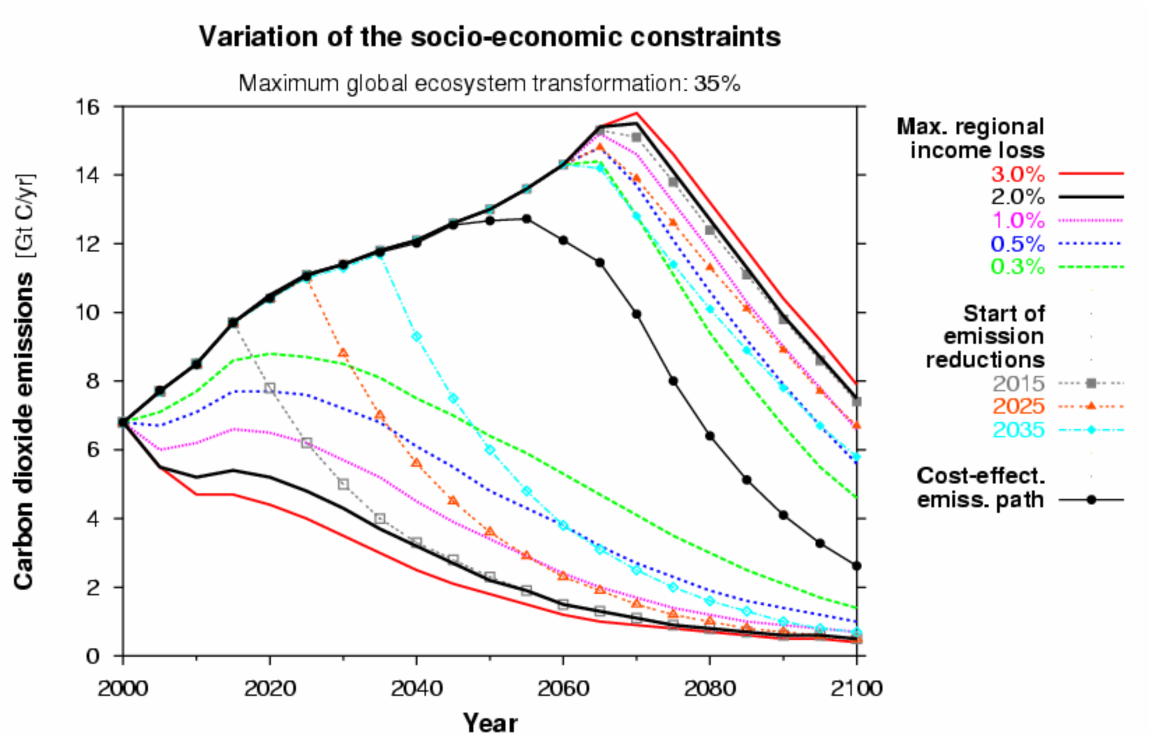
The Surveyor has accumulated a range of modules for potential use in the CIAS model, together with information from the literature and completed projects. Model design will evolve over time, being co-produced by the surveyor and composer in reaction to the demander's requirements.

Box 2. The ICLIPS project

A proto-version of a CIAS-type system has been assembled a few years ago for addressing the issue of a definition of dangerous climate change. The ICLIPS project, initiated and coordinated by the Potsdam Institute in 1995, gave birth to an international and interdisciplinary network of eminent experts on relevant climate-change aspects for an inverse analysis of climate management strategies using the "Tolerable Windows Approach" (Toth et al. 2002, Leimbach 2000, Schneider and Toth 2003). The basic idea was to identify/define *intolerable* global (or regional) impacts of anthropogenic planetary warming and to calculate, via causal-backwards modelling, the admissible GHG emissions corridors for different macro-actors (like the Annex-I countries) over the next centuries. The ICLIPS community model calculates many crucial entities such as ecosystem impacts, regional costs of mitigation measures and timing of emissions reductions. It acts in a semi-co-productive way already: generating and sharing a common pool of model source codes and data sets to provide the crucial building blocks for (inverse) integrated assessment.

A recent publication emerging from the ICLIPS project (Toth et al., 2002) illustrates the use of normative thresholds described in section 3 above. Here the percentage of the world's macro-ecosystems (biomes) transformed by anthropogenic climate change is used to provide a normative threshold. The ICLIPS community model actually calculates many crucial entities beyond ecosystem impacts, like the regional costs of mitigation measures and the timing of emissions reductions. Figure 7 presents, as an example, the admissible emissions corridors for various boundary assumptions *if the outcomes must achieve a 65% conservation/preservation criterion (this equivalent to the statement that more that 35% biome transformation is considered unacceptable).* In fact, this constitutes a rather unambitious climate protection target. The study shows, however, that a 75% conservation/preservation objective already seems impossible to achieve. The study by Leemans and Eickhout (this volume) also links the percentage of ecosystems that will be preserved to the magnitude of temperature changes over the coming century using the IMAGE integrated assessment model.

Figure 7. Admissible corridors for energy-related CO2 emissions for different levels of regional income loss if at least 65 % of the world's ecosystems are to be preserved under climate change



Source: after Toth et al. (2002)

Box 3. The "Coastal Simulator" project at the Tyndall Centre

As a proof-of-concept exercise, the "Coastal Simulator" flagship project of the Tyndall Centre will test the co-productive approach for a limited geographic area (North Norfolk coast, UK) and contribute to the advancement of the science of integration (www.tyndall.ac.uk/research/theme4.html). It is being designed as an innovative decision-support tool which will allow assessment of various climate response policies on this scale. This will be made possible through the integration of climate change scenarios and policy response options with information on sediment transport, biodiversity, sea defences and socio-economic activities. Typical policy responses considered include managed retreat, sea wall construction, etc. Thus, demands from society to assess the impact of various climate change scenarios, socio-economic scenarios and policy responses on the likely coastal future will be addressed using an integration tool composed specifically to address them. For each coastal future generated by the model, the probable effects on biodiversity, sediment dynamics, landform characteristics and socio-economics will be estimated. The outputs of the model will be linked to a Geographic Information Systems (GIS) framework that will display biodiversity data and socio-economic information, allowing detailed case studies to be visualised using cutting-edge virtual reality GIS techniques. This provides the responder with a sophisticated and attractive method of replying to user demands.

The model is being developed by a composer using a fuzzy logic, expert system approach where the probabilities of a range of different coastal futures can be estimated for a given section of coast. This approach is preferable to a more mechanistic, black-box model design as both qualitative and quantitative data can readily be incorporated into the model while the model can be continually informed and modified by user involvement. Moreover, this technique allows the model to be flexible, as probabilities of future change can be readily updated by the composer as climate model estimates are refined. These qualities of a fuzzy logic approach allow the model to be readily used in a policy-relevant context, where the trade-offs and benefits of different coastal futures can be evaluated. The long-term aim for the simulator will be a quantitative modelling approach – as such, the simulator is an evolving entity where expert opinions will be gradually confirmed, refuted or replaced by quantitative models, as our scientific understanding improves. For example, the results of recent research will be used to provide an index of vulnerability, generating estimates of changes in wave height and storm frequency associated with NAO index variations and future climate change predictions.

4. CONCLUSIONS

4.1 A way forward for the assessment of the benefits of climate policy

This paper describes how a Community Integrated Assessment System (CIAS), can be used to develop a next-generation integrated assessment system to address climate change problems. As described here, a CIAS contains 7 elements: a problem space (consisting of user needs); a knowledge space (consisting of scientific knowledge and information from users); and four sub-operators (scientists at participating institutions) and CIAS operators (also scientists at participating institutions).

Key challenges for today's integrated assessment community (particularly the climate change IA community) include:

- ensuring a continued policy relevance of information provided by scientists, i.e. how to avoid the traditional mismatch between IA science and user demand;
- understanding why different modelling systems constructed at different institutions produce different results, and to present useful messages to policy makers in spite of this;
- distilling robust policy conclusions in the face of large uncertainties;
- integrating across scales;
- holistically estimating global climate change damages under differing climate futures;
- using Integrated Assessment to help define dangerous climate change.

The paper explains how the proposed CIAS system has the ability to make progress on all these points: through bringing scientists and users together in a co-production of solutions to problems; through allowing multi-institutional model comparison exercises; through rigorous uncertainty analysis; through an ability to answer questions on different time scales and on different spatial scales by using a nested hierarchy of models; and finally through application to the assessment of dangerous climate change, and the holistic assessment of the benefits of global climate policy.

We illustrate the construction and use of CIAS models with embryonic examples taken from projects under way at the Tyndall Centre for Climate Change and the Potsdam Institute for Climate Impacts Research.

The principal advantages of a world with CIAS (as opposed to one without) are that:

- The "Community" aspect of CIAS highlights how it facilitates collaboration amongst a variety of currently disparate IA modelling groups in Europe. This will bring forward IA in a European research community/policy community context on a major scale.

- CIAS is firmly based on a concept of mutual learning and advanced user dialogue which will ensure policy relevance of IA which has hitherto been difficult to achieve. This will have the greatest advantage in the developing world.

- The flexibility of the CIAS integrated model allows it to rapidly address new policy questions as they arise without entailing the construction of a new IA model.

- This adaptable system has as long life, and has a structure which ensures continued relevance in the real world

- CIAS enhances the communication between scientists and users allowing more widespread and appropriate use of existing knowledge to inform any decisions which need to be made before IA results are available to underpin it

- CIAS helps the IA community address the 7 challenges mentioned above.

In order for a CIAS-system to become accepted as a "useful" way of addressing the assessment of climate change it must be tested and then evaluated. We suggest the following priorities for the research community in testing such a proposed CIAS "solution": Firstly, collaborations should be set up to link integrated model components from different institutions. Secondly, these distributed models should be used to answer straightforward policy questions such as forward simulation of SRES scenarios to ensure their validity. Thirdly, the system should be used to facilitate module/paradigm inter-comparison studies in cases where different institutions have adopted different approaches to the study of economics, climate, etc. Fourthly, robustness studies should be carried out to understand the robustness of results to paradigm shifts, parameter and data uncertainties. These are in fact the immediate plans for the system described in Box 1.

Having achieved this level of competence, the community will then be ready to address the priorities of the policy community at the international/European scale. Through the development of appropriate operational (and ongoing) dialogues in the *Demander* and *Responder* parts of the CIAS system, the research community should be equipped with a sophisticated and accurate understanding of the current needs of decision-makers in the policy system and elsewhere. Based on this information, the community might then, for example, pool its resources through CIAS to provide policy makers with holistic estimates of the (non-monetised) climate change damages associated with different climate futures; where appropriate, monetisation might be carried out and linked back to economic models to analyse cost-benefit issues. Damages could be summarised using, for example, the set of numeraires proposed by Schneider (this volume). Stabilisation scenarios could be analysed in a similar way.

4.2 CIAS in the context of the science of integration

If the co-productive approach discussed in this paper is pursued, new dimensions of complexity will be added to the task of integrated assessment modelling, since a host of subtle orchestration problems need to be solved for operating the integrated system. This is a reminiscent of the challenge created for IT research by the transition from vector to (massively) parallel computers some time ago, although novel hardware /software issues represent just one of the issues which must be addressed for effective, valid, co-productive integrated assessment to succeed. In order to do the latter in the appropriate (if not optimal) way, its very realization has to become itself an object for scientific investigation.

Operations research, dynamical systems theory and artificial intelligence programmes can provide useful insights about how to extract crucial knowledge from a set of imperfect components. An interesting illustration, although more concerned with the construction of high-tech gadgets, was recently presented by Challet and Johnson (2002). They demonstrate how perfect, or near-perfect, devices can be assembled from imperfect components. This "defect combination approach" may indicate one of the ways towards generating integrated assessment systems according to well-defined and efficient scientific principles. This, in turn, can be an important contribution to the emerging "science of integration", which has to develop and consolidate the methodologies or "arts" for the following tasks.

- Exploration (e.g. of problem and knowledge spaces);
- Communication (e.g. of risk through user dialogues);
- Recognition (e.g. of causal patterns);
- Contextualization (e.g. of specific societal demands);
- Accounting (e.g. of available data sets);
- Caricature (e.g. of complicated processes through reduced-form models);
- Guessing (e.g. of best management under uncertainty employing Bayesian techniques);
- Valuation (e.g. of systems consisting of non-convertible components); and
- Comparison (e.g. of models based on distinct paradigms).

4.3 Related initiatives

It should be noted that in the US a similar approach is under way in the form of the US Climate Change Research Initiative (www.Climatescience.gov). It began with a workshop for scientists and users with more than 1,200 scheduled to attend from a wide range of interests in academia, government and economic and environmental organizations, from more than 30 countries and almost every state in the United States. A main goal is to advance science-based decision support systems for policy. The approach is in some ways similar to the one described here, but would appear to be aimed at short-term (2-4 year) decision support (Henry Jacoby pers. comm.).

In the medium term, the development of such CIAS-type systems will require not only the development of new computing infrastructures but also entirely novel institutional arrangements. A new European initiative being facilitated by the Tyndall Centre is underway to develop a Virtual Institute for Sustainability Assessment. This ambitious initiative aims to develop a European Network of Excellence focused around the multi-institutional development and application of the sort of Integrated Assessment System described here. The term Virtual Institute refers to the idea that existing institutes will collaborate over the long-term to develop: common computing infrastructures; common research strategies; common training programs; and harmonized engagement with users and users. The use of the term Sustainability Assessment implies that the problem space would be expanded to include assessments such as: energy for the future, re-inventing the rural landscape, or blueprints for a sustainable city. Such an initiative has the potential to provide an emerging institutional infrastructure to support the development of a CIAS-type framework at the European level and beyond.

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