ESF-CIAM^{n} WORKSHOP ON COMMUNITY INTEGRATED ASSESSMENT MODELLING OF CLIMATE POLICY

CLARE COLLEGE, CAMBRIDGE

24-26 MARCH 2004

Convenor: Rachel Warren, Tyndall Centre

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***With apologies from* Graham Riley (UK), Jean-Charles Hourcade (FRA)**

*replacement for Graham Riley + attended technical session only ++ attended session 2 only

Acknowledgements

I would like to express my sincere thanks for the enthusiasm and support of the attendees of this workshop. This made it a very rewarding and enjoyable experience for me. I am very grateful to the ESF for funding this event, and for their efficient handling of administrative matters, and also to Vanessa McGregor of the Tyndall Centre for her assistance in the UK.

CONTENTS

1. EXECUTIVE SUMMARY

This ESF Exploratory Workshop brought together the "n" joint owners of a novel Community Integrated Assessment Model "CIAM-n". The purpose of this model is to assess society's potential responses to the climate change problem – now a crucial European and global public policy issue. The "n" owners currently include the UK's Tyndall Centre, the Potsdam Institute for Climate Change (PIK) in Germany, the National Institute of Public Health in the Netherlands (RIVM), the Institute for Integrative Studies (ICIS) in the Netherlands, the Centre International de Recherche sur l'Environnement et le Développement (CIRED) in France, and will in future include any institution that wishes to contribute to the project.

Integrated assessment modelling (IAM) is one of the most promising forms of scientific analysis that can cope with the complexity of, and linkages between, the physical and social science inherent to the climate policy issue. IAM is a problem-solving exercise requiring the linking of a number of key pieces of scientific information from different disciplines. Although the principles of IAM are agreed, implementation is generally rather simplistic, involving an inflexible linkage of a small number of models at a given institution, commonly written in the same computer language and run upon the same platform (Alcamo 1984, Dowlatabadi 1995, Hulme et al. 1995, Kainuma et al. 2003, Rotmans 1990). These systems have inherent limits, namely (i) the impossibility of building large all-purpose models that assemble a comprehensive array of modules at a single site, and (ii) the impossibility of providing responses to policy-relevant questions sufficiently rapidly. Thus, it has become widely recognised that a new co-operative approach to integrated assessment is required (Jaeger et al. 2002). A group of institutions are at a preliminary stage in developing an ambitious, innovative Community Integrated Assessment Model "CIAM^n" (Warren 2002).

CIAM^n is a multi-disciplinary model. It will ultimately bring together models of climate, economy, technological change, transport, social behaviour, hydrology, agriculture, and climate change impacts on humans and ecosystems. Uniquely, it will

- link together modules written at several *different* European institutions
- link together modules written in *different* computer languages supported by *different* platforms
- will have a modular, flexible design in which modules are linked in a "plug and play" fashion, hence its development is being supported by a new application of the latest e-science technologies
- will take a participatory approach to integrated assessment.

Currently, CIAM-n is at a preliminary stage, with pilot models containing a small number of modules (contributed by some of the n owners) in existence at the Tyndall Centre and at PIK. Both pilot models are flexible and modular, and are based on a technology which provides an ability to link modules written in different computer languages and upon different platforms. Tyndall and PIK have plans to merge these systems technically allowing interchange of models. However, this is only a first step in what ultimately should be a suite of institutions exchanging modules and knowledge to address society's possible responses to the climate change problem according to the needs of a diverse range of stakeholders.

The purpose of this workshop was to allow the CIAM^n owners to meet to decide how the integrated modelling system should be developed from its prototype stage into a fully fledged, policy-relevant operational system.

The over-arching goal of the workshop was to decide to what extent the known stakeholder (user) needs can be satisfied through use of CIAM^n, to decide which model experiments should be set up to satisfy those needs, and upon what timescales.

The main output is an action plan for future development of CIAM^n, in a form suitable for use as a basis for participants to submit high quality research proposals to obtain new funding from the ESF or the EU 6th Framework Programme, or to other European or international funding organizations.

At the beginning of the workshop RW updated the participants on the current state of development of CIAS, CIAM^n and its prototypes at Tyndall and PIK. In session 1 RW outlined the policy questions which a future CIAM^n could potentially address and these were discussed. Session 2 focused on new modules or control flows which could be developed for future CIAM^n prototypes or extensions of existing prototypes. Session 3 addressed numerics and feedback analysis, whilst Session 4 focused on the enhancement of the software technologies underlying existing CIAM^n prototypes. Session 5 considered methodologies for uncertainty analysis in CIAM. In each session participants were given the opportunity to present recent relevant work which they had carried out, which is detailed in section 3, whilst the Appendix contains abstracts of these contributions.

On the final day, five break out groups devised detailed action plans in five key areas which the group had identified as important.

Specifically, attendees selected 5 sub-action plan leaders to research in the following areas:

(1) ***Linking Land Use Change in CIAM^n*** (lead Tom Kram, RIVM, NL)

This group will bring to CIAMn the combined expertise of PIK and RIVM in the land use change and biogeochemical schemes, using LUC scenario from IMAGE as input to PIK LPJ module. Expertise on population dynamics and soil respiration will also be combined.

(2***) Economic Dynamics*** (lead Jonathan Kohler, Tyndall Centre, UK)

This group will explore a major gap in economic modelling, specifically the linkage between short and long-term processes, particularly with respect to financial markets and international financial flows.

(3) ***Technology for CIAM^n*** (lead Ciaron Linstead, PIK, Germany)

Tyndall and PIK have already performed linkages between their coupling technologies softIAM and TDT; this group seeks to extend the application of both TDT and softIAM to a third institution, RIVM.

(4) ***Uncertainty Analysis*** (lead Peter Challenor, Tyndall, UK)

This group seeks to further develop Bayesian tools for uncertainty analysis for application in CIAM^n, increasing the level of automation and including modules of high dimensionality.

(5) ***Feedbacks*** (lead Jean-Yves Granpeix, LMD, FR).

This group seeks to further develop feedback analysis techniques developed at LMD and CIRED through simplification and use of the Tangent Linear System and adjoint models.

In addition, the group as whole made plans to explore the following topics:

(6) an economic analysis of material flows

(7) assessing the economic damages of climate impacts (lead?)

(8) a demographic module for CIAM^n (lead RIVM)

(9) a lean biosphere module for CIAM^n (lead PIK)

(8) use of a coastal package DINAS-COAST in CIAM^n (lead PIK)

(10) water modules for CIAM^n (Tyndall, Wageningen UR)

(11) lifestyle change module for CIAM^n

(12) agent based modelling in CIAM^n (lead KH)

(13) adaptation module in CIAM^n (lead Tyndall, UK)

(14) impact modules and damage functions for CIAM^n in relation to article 2 (lead RW)

Interest was also expressed in areas such as modelling geo-engineering, macro-adaptation, and societally relevant quantities other than GDP – for example equity gaps.

These plans were then assimilated into a grand action plan in our concluding session 6, which is presented in section 4 below.

2. DECISIONS ON ORGANISATIONAL MATTERS

Acronym: The use of acronym CIAM^n for the computer modelling system had been previously agreed by RK and RW, and it was agreed to retain this. However, it was also agreed that our overall project should be referred to as CIAS, Community Integrated Assessment System. This decision reflects the group's principle of pursuing two goals

(i) *maintaining a two-way interaction with stakeholders* to identify scientifically valid and answerable questions which are relevant for policy makers (as emphasised by HJS) and which influences the design of CIAM^n

(ii) *the building of an integrated assessment modelling capacity, CIAM ^{n}*, which is flexible enough to answer new, unforeseen policy questions at short notice (as emphasised by TK).

Involvement of Institutions: The following institutions participated in the workshop and all wish to remain involved in the CIAS project : CIRED (France), the GENIE project, ICIS (Netherlands) LMD (France), Max Planck Institute Hamburg (Germany), PIK (Germany), RIVM (Netherlands), Tyndall (UK), University of Bern (Switzerland), University of Oldenburg (Germany), Wageningen University and Research Centre (Netherlands). In particular, PIK and Tyndall are officially collaborating on CIAS whilst the arrangement with the other institutions is that of unofficial collaboration with individuals. The group identified four institutes who should be invited to participate in the future : the International Institute of Applied Systems Analysis (IIASA, Austria), who had been unable to attend this workshop owing to practical circumstances, and with whom JK and RW had already initiated discussions; the Joint Research Centre at ISPRA (Spain) with whom RW had commenced discussion concerning work on ancilliary benefits of climate policy in terms of air pollution; the Paul Scherrer Institute (CH), with whom NE has good contacts; and Fondazione Eri Enrico Matthei (FEEM, Italy).

Organisation

The full multi-institutional CIAM^n is to be a jointly owned system. At the moment, prototype models exist at Tyndall and PIK. No single institution is organising the assembly of the much larger, multi-institutional CIAM^n which is envisaged. Rather, sub-groups have agreed to assemble key new components which they will contribute to the whole, and/or to the Tyndall or PIK prototypes as agreed. Other institutions may also want to build new CIAM^n prototypes as and when they deem appropriate. Ultimately, cross-linkages and exchanges between these prototypes may allow the development of the fully fledged system.

3. SCIENTIFIC CONTENT

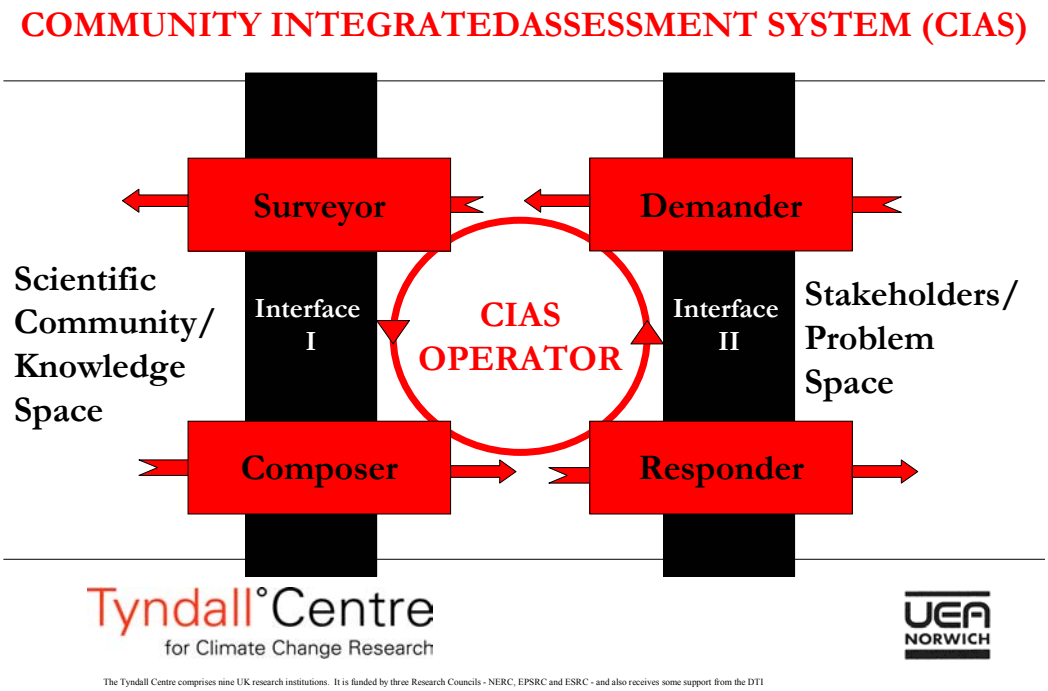
In this section the scientific content of the presentations is summarised. Most of the sessions evolved rapidly into a discussion of points contained in the action plan (section 4) and so details of these discussions will not be repeated here. Abstracts of presentations are presented in Appendix 1.

RW welcomed the attendees and then presented the workshop aims as given in the Executive Summary above. There now follows a summary of the work presented in sessions 1 to 5 in the Workshop Programme and detailed in the Appendix.

Session 1 Policy Questions

RW presented the synergy between modelling and stakeholders envisaged through the operation of the Community Integrated Assessment System (CIAS) (Figure 1):

Figure 1.



RW then highlighted

a. the policy questions that the Tyndall centre plans to address with its prototype CIAM^n in 2004 (see Appendix 1)

2. a list of policy questions which could be addressed with a more advanced version: (see Appendix 1)
3. a list of policy questions arising from a brainstorming meeting held between DEFRA, Hadley Centre and Tyndall in the UK on the topic of climate stabilisation. (see Appendix 1)

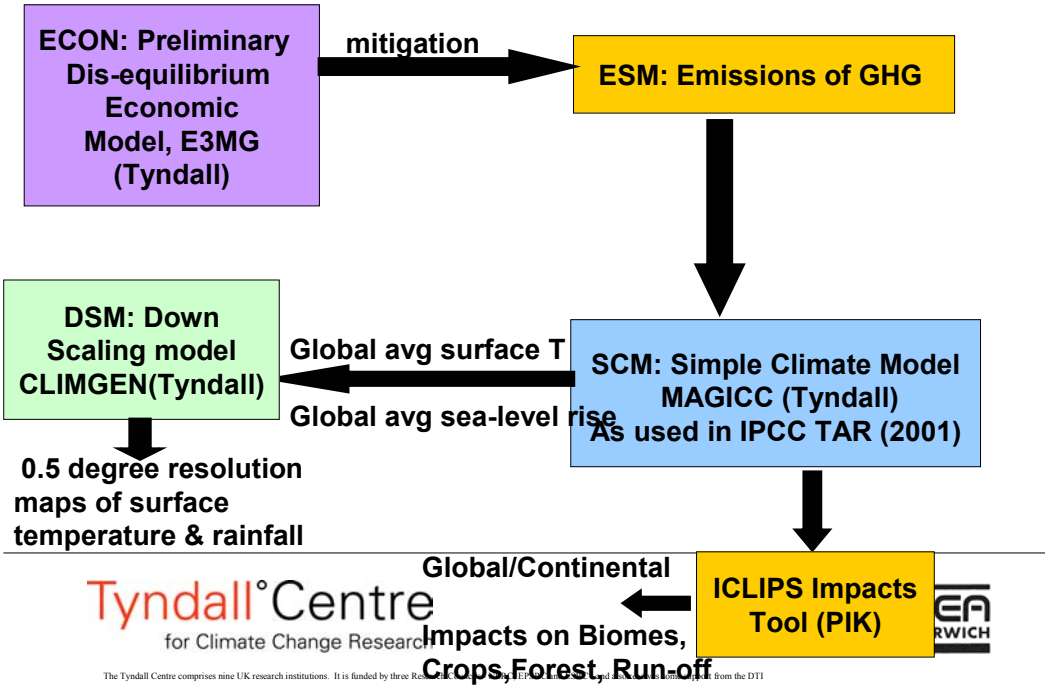
Attendees found it difficult to prioritise policy questions, and this led to proposals for a set of actions detailed in section 4.2

Session 2 Design of CIAM^n model experiments to address the policy questions.

Presentation 1. CIAM^n model experiments, initial and planned
RW, Tyndall Centre, UK

RW presented an update on the status of the prototype CIAM^n at the Tyndall Centre

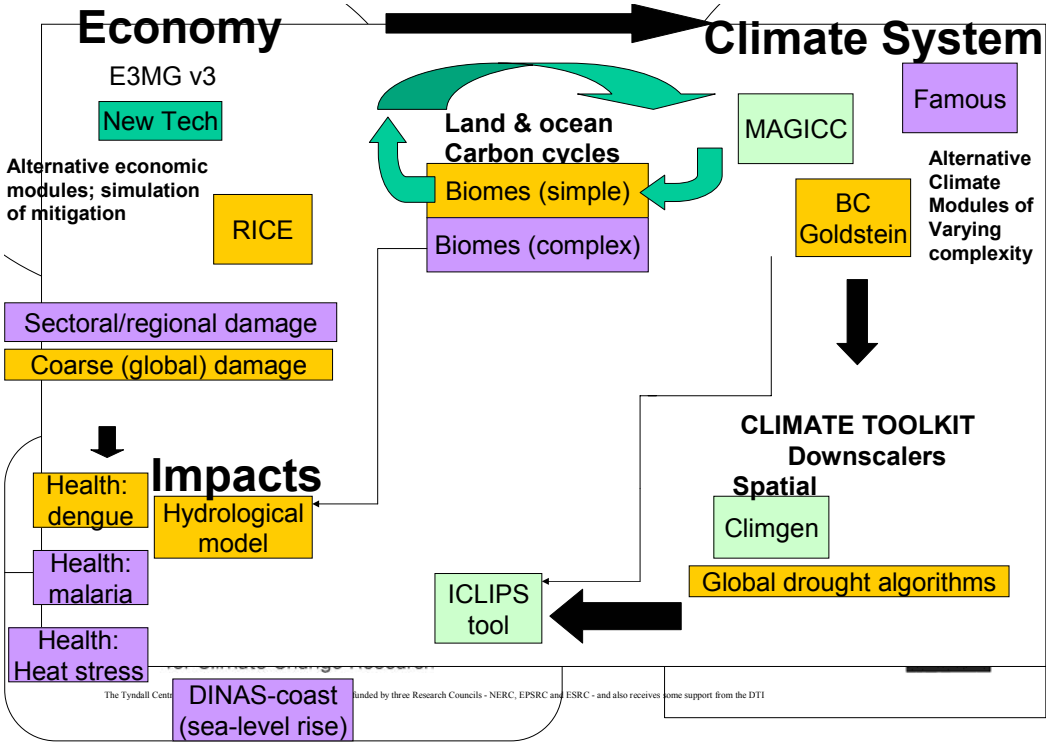
Figure 2. Status of a Prototype CIAM^n showing origin of component modules



(Figure 2), including a description of the novel approaches to economic modelling, and the

immediate plans for model expansion (Figure 3). A summary of the software system (softIAM) providing the capacity for flexible modular multi-institutional modelling was also given.

Figure 3. Some immediate plans for extension of CIAM^n Prototype in 2004/5



The following plans for CIAM^n extension were suggested by RW:

- Build capacity to explore **robustness** of integrated assessment results to
    - (a) use of modules based on different modelling paradigms
    - (b) use of modules of different complexity
- Build capacity to explore **feedbacks** between
    - (a) impacts of climate change and climate
    - (b) impacts of climate change and the economy
    - (c) interactions between sectors which are impacted by climate change
    - Maintain **uncertainty analysis** throughout

Note that the PIK CIAM^n prototype is up and running, applications of this are presented in presentation 5 of session 2.

BE and TK (RIVM) then highlighted the important contribution that the IMAGE model can make to CIAM^n in simultaneously exploring changing in climate and land use, which is of particular use when modelling C cycle feedbacks or the political importance of land use change in mitigation options.

WL also put climate change in the context of other global changes through presentation of (i) PIK's BIOS-X scenarios created through linkage of models of biomes, agricultural practise and trade (ii) the land use manager MagPIE. Illustrative results from the LPJ biome model were produced, focusing on (i) natural vegetation distribution and soil carbon at equilibrium (ii) the carbon balance to 2100 (iii) the impact of agriculture on carbon and water. The role of soil carbon was emphasised.

Discussions following these presentations led to the setting up of sub-group A to develop an action plan on the linkage of land-use change into CIAM^n.
KH presented a multi-actor dynamic model MADIAM of the coupled climate-socioeconomic system which bridges the gap between CGE models and growth models, and is based upon a nonlinear impulse-response for greenhouse forcing.

RM presented GENIE, a grid-based, modular distributed and scaleable Earth System Model for long-term and palaeo-climate studies. Its intermediate complexity fills important gaps in the spectrum of Earth System Models. This system can be used to explore centennial timescales and is already linked to CIAM^n, with which it has many common ideas.

ML/OE presented their experiences from module coupling experiments, in particular through the CIAM^n pilot system at PIK, which contains a coupled economic (optimisation) module and a climate module. Applications include identification of emission reduction policies that meet a normatively given climate guard-rail to lowest macroeconomic costs.

Appendix 1 includes an important output from this session: methodologies or modules which were identified as gaps in the group's current modelling capability.

It also reviews useful cross-cutting discussions which were held on (a) the necessary degree of complexity to include a process in IA (b) coupling between modules of differing complexity (c) scale.

Session 3 Model Coupling: Scientific Issues

JYG presented the partitioning and coupling methodology. The general problem of model coupling and of coupled model analysis was first addressed in a formal way, within the more general framework of model partitioning and coupling. Then a particular approach (the TEF, Transfer Evolution Formalism) was introduced and various methods of linear analysis were presented (sensitivity analysis, coupling analysis, feedback analysis).

AL presented an introduction to feedback gain, showing how feedback functions may be objectively determined in numerical models, and introducing the Tangent Linear System as the key to deriving a formal approach to the determination of dynamic feedbacks.

SH presented (i) an application of the TLS feedback concept to climate-economy interactions, considering three levels of climate impact on the economy (slow, moderate, strong) (ii) a study of the interaction between long term process in climate & economy with short term processes in impacts.

NE presented a consistent 2-way coupling between C-GOLDSTEIN, a 3D ocean climate model, and a simple economic growth model based on DICE99. His solution procedure identifies that emissions path which optimises global utility subject to a constraint such as a damage function calculated by a climate model.

RK showed how the dynamics of ageing capital stocks can be represented mathematically by a set of hyperbolic conservation laws. A simple first economic optimization was shown to be feasible in the CIAM^n framework.

SW presented the Global Unified Meta-model of the Biosphere (GUMBO model) and it simulation of the IPCC scenarios and their effects on the earth system. GUMBO synthesises the key concepts and results of existing dynamic models in natural and social science. It models the dynamic feedbacks between global change & land use change, technology, pollution, economic production, welfare, and ecosystem goods & services.
GUMBO is written in STELLA and could be used to represent the processes contained within CIAM^n rather than to be included within it.

Session 4 Model Coupling: Technical Issues

CB presented an overview of GCF/BFG, a general approach to coupled modelling which is used in the Tyndall version of the prototype CIAM^n.

CL presented recent developments in the TDT library at PIK, which has been used to run a distributed coupled model.

It was noted that considerable success has been had with the creation of a linkage between these two systems, with models being successfully deployed between PIK and Tyndall using both systems.
Potential extension of systems to other institutions, and limitations, were discussed.

JH presented methodologies for modular integrated assessment as used in PIK's DINAS-COAST project, highlighting the provision of a common language and an intuitive interface to allow modellers to code their knowledge in the form of modules. An iterative model development process occurs, rather than the upfront definition of module interfaces.

Sub-group C was set up to explore how technical aspects of model coupling could be taken forward in the action plan.

Session 5 Uncertainty Analysis

PC presented a method to study the propagation of uncertainty through complex computer models of the climate and related socio-economic systems. Such models are often highly non-linear and may take many hours to run. PC demonstrated his use of Bayesian statistical methods. To address the problem of long run-times a statistical approximation to the computer model, called an emulator, is built, which includes an estimate of its own uncertainty. This emulator allows use of Monte Carlo methods to establish uncertainty (order 10000 or more runs). Statistical inferences on the original intractable model can be made.

NE discussed uncertainty propagation in coupled climate – economy modelling systems in the context of (i) propagation of uncertainty from climate data to climate model parameters (ii) from climate model parameters to integrated assessments. An ensemble Kalman Filter is shown to be a highly efficient tool for tuning model parameters. Uncertainty in model parameters has a large impact on energy policy choices.

An extensive discussion of appropriate methods for applying uncertainty analysis techniques to CIAM^n was held, so sub-group D was set up to produce an action plan on this topic.

Presentation from the ESF: Martina Hildebrandt

Martina gave a very useful overview of the ESF's structure and function, highlighting the schemes which are currently running which could provide opportunities for a European community of scientists to continue to liaise, assemble at workshops and hold conferences. She also listed the ESF participating countries.

4. ACTION PLAN

This work plan has been produced on the basis of the discussions held at the workshop. It was considered better to produce a synthesis of the whole workshop rather than reporting on the outcome of individual sessions. Outputs from all sessions 1 to 6 have been taken into account.

Overall goals remain as in the proposal for this workshop, namely
(i) the assembly of a multi-institutional, modular and flexible IA system, CIAM^n
(ii) the embedding of this in an interaction with stakeholders to encourage policy-relevance. It is envisaged that the system will ultimately be able to provide a wide range of policy relevant advice.

4.1 ADVANTAGES AND USES OF CIAM^n

The group agreed that CIAM^n was an advance on previous modelling systems because it could harness the expertise of many institutions to provide a more comprehensive capability than was possible for any single institution and would facilitate collaboration and model comparison.

The group agreed that the CIAM^n system should be used to (i) *explore the robustness of different IA results to the use of modules based on different paradigms* and written at different institutes, provided that it was scientifically meaningful to substitute the modules (ii) to *explore the robustness of IA results to the use of modules of different complexity*. It was also emphasised that the system should be used to (iii) ***identify those questions to which a robust answer exists***. For example, this might be the prioritisation of alternative policies in terms of cost-effectiveness (OE). Fourthly, the group agreed that CIAM^n should be used to *identify the robustness of IA results to the strength of feedbacks in the system*, which could help prioritise research into the various feedback mechanisms. (WL)

4.2 POLICY-RELEVANCE OF CIAM^n: THE CIAS PROCESS

RW had presented an extensive set of policy questions which the CIAM^n model could potentially address. Whilst it was considered difficult to prioritise these questions, AL suggested a survey of institutional drivers for integrated modelling, and this proved illuminating. Some institutions, such as RIVM, were interested in capacity building rather than designing models to specifically address stakeholder need. AL's suggestion enabled the identification of some key questions that the group wished to address:

1. What are the mitigation costs of even very ambitious climate policy goals (OE)
2. Can we devise robust policies in the face of the uncertainties in the climate and economic modelling systems (OE, RH)
3. What are the costs and benefits of stabilisation of greenhouse gases? (RW)
4. How is such a calculation affected by the potential for carbon sequestration in geological formations (OE, RW)
5. Can we model non-CO2 GHGs accurately (OE)
6. What are the most important feedbacks in the earth system/economy? (WL)

The group also agreed to provide for (i) *research into the optimum form of stakeholder interaction for CIAS* and (ii) *a form of stakeholder interaction, at least in the form of collating the results of previous stakeholder surveys and interactions to inform model development*. In particular, OE mentioned that a majority of questions coming from stakeholders were not scientifically well-posed, a view that was held by many of the scientists present. CIRED/LMD (AL, JG and SH) and the Tyndall Centre are keen to explore how and why this is the case. As explained above, some groups (e.g. TK) were not policy-driven but instead wished to build the capacity to answer a wide range of policy questions.

4.3 DETAILED ACTION PLANS

In particular the break-out groups identified five avenues of study which would be pursued by sub-group members. The next section presents the workplans for each of the five avenues. A lead scientist was agreed for each avenue.

4.3.1 Sub-group A. Linking Land Use Change (LUC) into CIAM^n

Lead Tom Kram, RIVM

Members: Wolfgang Lucht, Bas Eickhout, Heike Zimmermann, Rupert Klein, Saskia Werners, Ottmar Edenhofer, Jacquelyn Harman, Neil Edwards

The main partners in this workplan are RIVM and PIK. The drivers for this research are the many linkages between land use change and climate change – for example, the impacts of climate change upon soil quality and hence agricultural potential, linking with the demand for food and the well-being of poor people particularly in developing countries. Further important linkages include the effect of LUC on the earth's albedo, which is an important feedback on the climate system. The option of biofuels as a renewable energy source has large implications for land use. The demand for land for agriculture and biofuels impacts on the remaining area left to preserve natural ecosystems and biodiversity, and soil liquidation leads to poor land quality and poverty.

Two components form a basis for the planned work, firstly the RIVM's IMAGE land allocation model based on SRES scenarios, and secondly the Lund-Potsdam-Jena (LPJ) model, of which PIK is a partner organisation. PIK's detailed biogeochemical model which has already been coupled to climate models. Specifically four actions were planned:
1.*RIVM and PIK can contribute simple models to the CIAM^n pool* over the next few months. Examples include (a) from RIVM, the population model from IMAGE (b) from PIK, the soil respiration scheme from the LPJ module.
2. *RIVM and PIK plan to discuss together how best to include agricultural (land) economy in the models*, through the design of a land use manager. For example, the MagPIE scheme from LPJ would form a basis for this work. This would contribute results to CIAM^n on a longer timescale.
3. The subgroup will *investigate the impacts of LUC scenarios from IMAGE if used as input to the LPJ* module. In particular LPJ's biogeochemical schemes will be used to examine the effects on productivity and the consequences for climate. The will complete an important loop in CIAM^n from the land system to climate. Currently, only the linkage between the energy system and climate exists in CIAM^n. 4. The subgroup agreed to follow a two track approach: (i) a simple approach to look at the system dynamics and (ii) a complex one, which would require the building of module interfaces to CIAM^n, for example for LPJ.5.

The GENIE project, closely allied to the Tyndall Centre, is also producing a land surface scheme and has an interest in the interaction between land use change and climate. In line with the CIAM^n emphasis on robustness to paradigm shifts, CIAM^n will ultimately incorporate land schemes from both PIK (LPJ-based) and GENIE (Triffid based) allowing robustness studies to be carried out.

4.3.2 Sub-group B. Economic Dynamics

Lead: Jonathan Kohler, DAE, Cambridge/Tyndall Centre.

Members: Klaus Hasslemann, Marian Leimbach, Ottmar Edenhofer, Stephane Hallegate

This sub-group identified a major gap in economic modelling, specifically the linkage between short & long-term processes. In economics, long time steps typically 5 years in climate macroeconomic models are not adequqate if short term impacts influence long term changes. This applies with endogenous technical change, learning and spillover effects with increasing returns to scale and the modelling of investment. This can lead to multiple equilibria, so one finds local minima; then the question is how to escape the local pull. Short term changes can be used to select local equilibria.

Four gaps were identified:

(i) Financial markets: some economic models include business cycles, but most models have a poor or missing representation of stock markets.

(ii) International financial flows and their relationship to technological development.

(iii) Representation of insurance policies & risk aversion.

(iv) Economic impacts of climate-change induced extreme weather events.

(v) Effects of propagations, interactions and aggregations (both regionally and sectorally) (see also section 4.5, point 2)

Rather than building a "super-economic-model" including all these aspects, the group agreed to develop models in parallel in different study groups, whilst selecting case studies for model inter-comparison purposes and/or model calibration. The application of these models to provide policy advice should be furthered.

The emphasis here is on comparison and communication rather than module exchange. However, once complete it was anticipated the modules would be open source and can be released to the public. The group agreed to meet in August for 2 to3 days.

It was emphasized that the envisaged models will be simple compared to the climate models. To code the relevant processes and solve the differential equations within a simulation type model is not anticipated to be time consuming. However, solving optimization models as well as data collection and calibration can consume much time. Some economic modules would be written in FORTRAN and other in GAMS.

It was emphasised that this is a new field in which everyone is doing very different things in their models. At this preliminary stage, participants will focus on making a comparison of what different theoretical ideas can give you. Bottom-up models would also be desirable in this area.

4.3.3. Sub-group C. Technology for CIAM^n.

Lead : Ciaron Linstead, PIK

Members: Arthur Beusen (RIVM), Chris Barton*, Murtaza Gulamali*
Since PIK and Tyndall have already linked the bfg and tdt systems in a coupled model (namely the CIAMn prototype), the group explored the involvement of other institutions in the use of these systems. The interfacing of modules written in the language M, used by RIVM and ICIS, in the IMAGE model and others, to both the tdt and bfg systems was deemed feasible. This is a major step forward for CIAM^n.

1. A set of test models was selected with which to prototype the modularisation of the IMAGE model with tdt. Over the next few months the test programs will be worked upon to check that tdt will deliver what is required – using shared memory.

2. The use of bfg will be tested through the incorporation of the ICIS module MIASMA-Dengue into the Tyndall CIAM^n prototype. Further linkages will be made with modules from the IMAGE system as appropriate.

3. Linkage of bfg to the GENIE web portal is already being explored through the close linkage between the Tyndall and GENIE groups.

*CB and MG participated in technical discussions on Thursday 25, prior to the break-out session.

Outside of the breakout group it was agreed (JH, CL, RW) that the following principles should be upheld concerning technical development (i) there should be a rigorous version control system (ii) modules to be included in CIAM^n should be well documented and validated (iii) protocols need to be agreed for modellers wishing to link their modules to the CIAM^n system

4.3.4 Sub-group D. Uncertainty Analysis

Lead: Peter Challenor, Tyndall

Members: Jonathan Rougier, Robin Hankin, Neil Edwards

This group is already applying Bayesian methods to the modules in the Tyndall CIAM^n prototype, and has constructed emulators for a number of key modules. These methods are quite different from traditional approaches. Many research groups and practitioners, particularly in the oil industry, have moved beyond the notion that a model (or a module) should be calibrated to system data by an optimisation method that attempts to identify the `correct' set of parameter values. Probabilistic inferential methods, often termed Bayesian methods, generalise the notion of a correct input to consider the behaviour of a model across a collection of 'not implausible' values, and this collection then feeds through to predictive uncertainty. We believe that climate research should embrace these probabilistic methods for model calibration and prediction.

These probabilistic methods are computer intensive, and will remain so for the foreseeable future. For this reason we approximate the models (or model modules) with statistical approximations, called emulators. These are extremely fast to run and can be used for statistical inference. In order to create these emulators, and more importantly for the specification of prior knowledge, we need extra information about the model/modules. At the very least this should include reasonable ranges for the uncertain model parameters. More detailed information, for example identifying the key inputs for different types of module output, should be possible, and would be welcome. Some measure of the `quality' of the module, in terms of its ability to replicate the underlying system behaviour, would also be useful and should be provided, if available. A key requirement the group identified right at the start is to preserve every evaluation of every module, in order that we can build up, over many individual usages, a database of module behaviour over a range of parameter values. This information can be used to construct an emulator of an individual module, or of a collection of modules connected together in a given configuration. The database of evaluations will be a resource for for all CIAM^n users: for example it could provide good starting points for non-probabilistic calibration approaches.

The group discussed the possibility of constructing emulators on a module-by-module basis, rather than making a single emulator for a specific collection of modules. Constructing the emulators is relatively easy, but building a framework in which an arbitrary collection can be joined together, including possible feedbacks, is a very difficult problem. It is related to the concept of dynamic emulators, where you emulate a time step at a time)This is an active research area and although not feasible at present should be an aspiration for the future. Our first emulators, and uncertainty calculations, will be for the most popular configuration of modules, and that, for the time being, a detailed analysis of uncertainty will only be possible for a limited number of configurations.

Outside the breakout group it was agreed to attempt to implement probabilistic uncertainty calculations within the CIAM^n project. While it will be difficult to construct a generic "uncertainty module", it should be possible, once sufficient evaluations are available, to provide a case study which can act as a template to roll out the uncertainty analysis over other configurations of modules, and to be updated as more and more evaluations become available. At this point the key features of the uncertainty analysis could be integrated into the module functionality, to improve efficiency. It is to be hoped that other methods of uncertainty analysis will be `templated' in the same way. The purpose would not be to compare methods, since this is difficult within a subjective inferential framework, but rather to allow stakeholders to identify different ways of presenting uncertain information, and selecting that which they feel most appropriate.

Three major avenues of research were recommended for the long term

(a) the investigation of dimensional reduction of simulator outputs, focussing on the needs of stakeholders
(b) the development of uncertainty methods capable of dealing with arbitrary collections of modules
(c) the development of a more automated procedure to calculate module/integrated model uncertainties, for example the creation of an “uncertainty wrapper” which would automatically attach to any given module or modular system.

Discussions were also held about procedures for dealing with expert judgements. These will be particularly important in assessment of the likelihood of events which are not modelled, for example the likelihood of “climate surprises” such as the melting of Greenland ice or the release of methane from clathrates. Policy makers will be interested in strategies which are “robust” to climate surprises. NE at the University of Bern will continue to collaborate with

PC and JR on uncertainty analysis. In particular the Kalman filter approach which he presented here is being extended to the GENIE model, and further application to CIAM^n is a possibility. The possible use of tangent linear systems and derivative information from the methods being developed by group E should be investigated.

4.3.5 Sub-group E. Feedbacks

Lead: Jean-Yves Grandpeix, LMD

1. Continue efforts to make feedback analysis simpler using a 1D version of a GCM to do feedback analysis. This is a good proxy for study of an integrated assessment system. Such studies throw important light on uncertainties in modelling. The interest shown recently by the Hadley Centre in coupling impact modules directly to GCM adds an interesting dimension to the possibility of future work, since it is likely that modules will be exchanged with the Tyndall Centre

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2. Use of the Tangent Linear System to assist understanding of error propagation in feedback loops. This will be applied small economic or climate models. The approach requires a closed system and would not be suitable for analysis of a complex modelling system.
3. Explore use of adjoint models for feedback analysis in non-linear systems. Initially, work will focus on the modules of SH at CIRED. Adjoint methods and data assimilation can be used to match historical data
4. Develop an automated approach to adjoint model generation.

The latter points are related to a wider discussion held by the group as a whole, which considered how to link optimisation and simulation approaches in CIAM^n.
Sub-group B considered this not to be a problem in principle (since, for example, such a linkage has already been carried out at PIK (see presentation of ML/OE) and at the University of Bern (see presentation of NE)). Sub-group B expressed an interest in developing or obtain adjoint model compilers for CIAM-n to allow for more efficient optimisation. It was noted that such compilers can take any fortran code with several thousand input parameters and calculate the gradient of the model, in contrast to the GAMS-style optimisers frequently used by economists. However, it was deemed that the applicability of adjoint models to some particular modules needs to be explored. KH can investigate the availability/affordability of existing adjoint compilers

4.4 PRE- EXISTING PLANS FOR CIAM^n MODEL EXPERIMENTS

It is useful to document here pre-existing plans for CIAM^n prototypes that were already funded by individual institutions or collaborations prior to the meeting.

1. The plans for expansion of the Tyndall prototype CIAM^n will continue as envisaged by RW. The prototype currently consists of a coupled economic module, E3MG, a climate module, MAGICC, a simple downscaler, CLIMGEN (all supplied by Tyndall) and an impacts tool ICLIPS (provided by PIK). RW is currently incorporating the PIK simple vegetation scheme VECODE into the system, and also the GENIE intermediate climate model, BCl-GOLDSTEIN, which contains a simple land scheme. Tyndall has identified a series of policy questions which the CIAM^n prototype will address in its first year of operation, primarily to address the policy needs of DEFRA. First results are expected in late 2004. The system is coupled together with the "softIAM" technology referred to as bfg later in this document.
2. The linkage between the PIK and Tyndall CIAM^n prototypes is being enhanced technically. Thus the bfg and tdt technologies have been successfully coupled together and a distributed CIAM^n model has been run between Tyndall, Manchester and Germany using both technologies.
3. Several institutes had already planned to compare a series of coupled climate-economy models (Tyndall, University of Bern, PIK, GENIE) and this work will continue within the two CIAM^n prototypes (RW, JK, OE, NE).
4. The Tyndall Centre is creating a module for the prediction of extreme precipitation events (flood and drought) (lead Nigel Arnell, University of Southampton, who was not present at the workshop). Rather than relying on the direct output of GCMs and RCMs, a statistical approach is being developed. Subject to a scholarship being obtained, the Tyndall Centre has recruited a graduate student to contribute to this work. Current models do not generally give distributions of extreme events and therefore cannot model changes in distributions of extreme events.

The remaining sections list ways forward proposed during some of the whole-group sessions. It is important to document all these ideas, but it is recognised that there is a need to focus rather than to move forward on all fronts.

4.5 NEW METHDOLOGIES FOR CIAM^n

A. An Economic Analysis of Material Flows

In the final discussion, WL and OE proposed a radical new modelling approach, namely the re-formulation of economic theory to take into account how the economy is linked with the biosphere. The purpose of this would be to model society's dependence on material stocks and flows, focusing on water, carbonaceous fuels, minerals. This would require a new theory of valuation to be constructed reflecting our use of the earth's finite resources, taking into account the value of ecosystem services. Both energy flows and spatially resolved material flows for the planet would be included. Such an approach would throw light on the remaining reserves of earth's resources and is therefore likely to be relevant for a variety of stakeholders.

B. Assessing the economic damages of climate impacts

It was proposed to use four approaches to this:

(a) OE proposed a radical approach to address the problem that arises when climate damages are discounted into the future: namely the modelling of climate impact upon capital stock

(b) to assemble a library of impact modules from participating institutions for incorporation into the CIAM^n system. The Hadley Centre's interest in impact modules may lead to an availability of additional modules.

(c) Rather than using global aggregate damage functions, an approach providing differentiated impacts was recommended. This could be achieved through the assembly of a series of damage functions and a series of thresholds for climate damages. RIVM is carrying out an analysis of impacts on ecosystems and biodiversity related to their land use studies. A method of assessing impacts of extreme events needs to be included (lead RW, members RIVM, PIK). Linear or continuous systems can give threshold crossing behaviour and can therefore be used to identify thresholds.

(d) There is a need to create linkages from climate impacts to economic damage. Hence the development of economic models to assess sectoral impacts of climate damage (lead JK, as part of the work of sub-group B, point (v))

The group also discussed whether it could provide a holistic assessment of the economic and physical, direct and indirect, impacts of the heatwave of 2003.
(Please sign here is there is interest in contributing to this). HJS emphasised the particular relevance this could have for the upcoming US presidential election.

An alternative suggestion (NE) is for an EU proposal to investigate the integrated impact of ice sheet and shelf melting over the next several hundred years, whilst restricting socioeconomic aspects of the study to the next 200 years.

4.6 NEW MODULES FOR CIAM^n

(i) Demographic Module for CIAM^n

The IMAGE team will supply a regional demographic module (covering the 17 IMAGE regions) and capable of simulating growth processes by Dec 2004.

(ii) Economic Modules for CIAM^n

Among the economic modules that CIAM^n will draw upon is PIK's MIND model, developed by OE. MIND is an optimisation model including a reduced form energy model embedded in a macro-economic environment.

(iii) Lean biosphere module for CIAM^n

A simplified version of LPJ would comprise an important new contribution to CIAM^n.

(iv) DINAS-COAST for CIAM^n

It has already been planned to link the DINAS-COAST modular system from PIK to the Tyndall CIAM^n prototype from spring 2005.

(v) Water Modules for CIAM^n

Tyndall and the University of Wageningen agreed to commence discussions on modules for water availability and quality for CIAM^n.

(vi) Lifestyle Change Module for CIAM^n

JH offered the use of his lifestyle change module in CIAM^n.

(vii) MADIAM

The MADIAM approach contributed by KH will be added to the CIAM^n pool.

(viii) Adaptation for CIAM ^{n}

The Tyndall Centre agreed to lead on the development of an adaptation module for CIAM^n. Links should be made with **sub-group A** since land use change, agriculture and adaptation are so strongly linked. It will be important to address the costs of adaptation in developing countries. The approach may be based on the Tyndall Centre's existing work by Nick Brooks (not present) which provides a set of preliminary national vulnerability indicators.

(ix) Impact modules for CIAM^n

It was noted that the Hadley centre has an interest in coupling impact modules to GCMs: and that they are interested in an exchange of impact modules with the Tyndall Centre.

The desirability of developing a number of other capabilities in CIAM^n was also highlighted (see Appendix 2). However, in all cases substantial model development would be required.

4.7 Way forward : Funding

Martina Hildebrandt gave a very useful summary of the ESF as an organisation, and the opportunities that it can provide for a community of scientists working between the ESF participating countries. As a result of this presentation, it to proposed to:

1. Make an Application for an ESF Programme

A successful application for an ESF Programme would finance the group and its sub-groups to meet on future occasions over a period of several years. This would be highly beneficial for this group, since it would not have been possible to bring all CIAS partners together in the absence of ESF funding. It would be useful to involve additional institutions from some the ESF participating countries not so far represented at the present workshop.

2. Refine the Action Plan for use as a Case for Support in a proposal to a European funding agency such as an FP6 call. Either the entire action plan, or portions of it, could be used as a basis for an FP6 integrated project.

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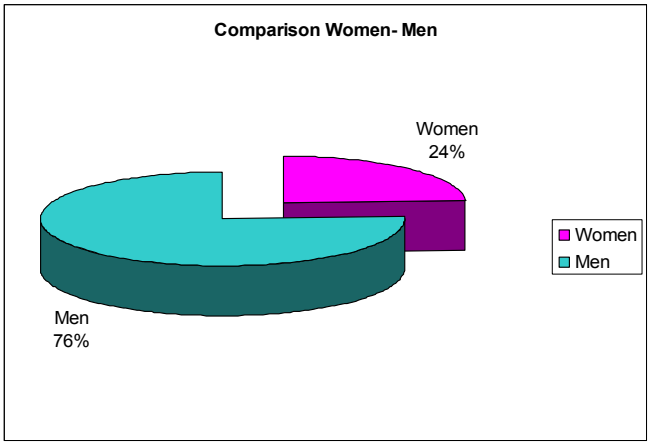
Statistics

There was a total of **29 participants**.

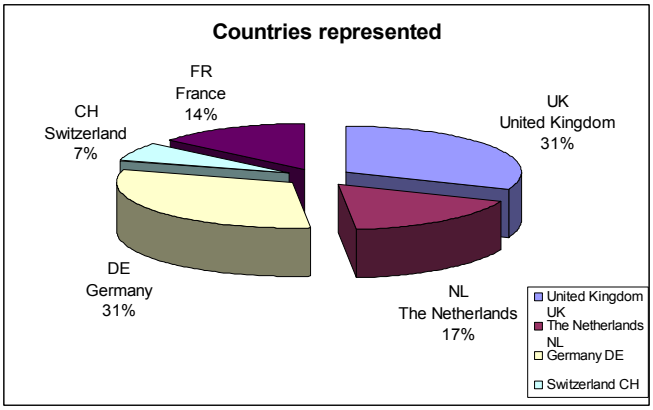
Male – Female Ratio:

Women	7
Men	22



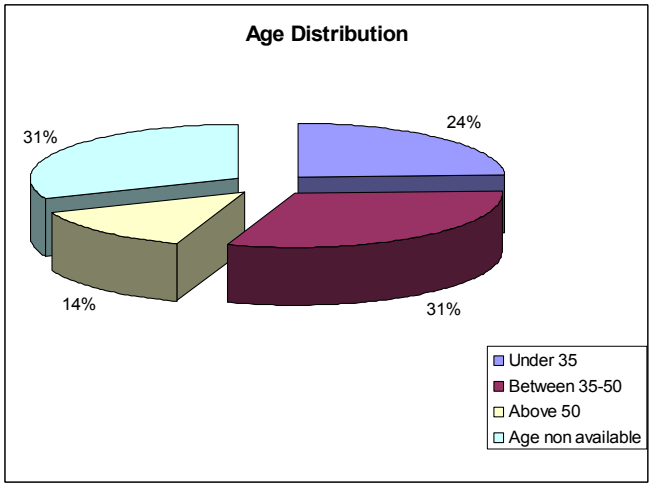
Representation by country:

United Kingdom	UK	9
The Netherlands	NL	5
Germany	DE	9
Switzerland	CH	2
France	FR	4



Age Distribution

Under 35	7
Between 35-50	9
Above 50	4
Age non available	9



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