SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

SPSD II

CLIMATE CHANGE, INTERNATIONAL NEGOTIATIONS "CLIMNEG 2"

S. PROOST, J.P. VAN YPERSELE, T. BRECHET, C. D'ASPREMONT

PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

- GENERAL ISSUES
- AGRO-FOOD
- ENERGY
- TRANSPORT

SPSD II
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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
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Part 1:

Sustainable production and consumption patterns

FINAL REPORT

Climate Change, International Negotiations "CLIMNEG 2"

CP/24

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Introduction

1 CONTEXT AND SUMMARY

The CLIMNEG 2 research project is devoted to the analysis of international and Belgian climate change policy questions in the post-Kyoto era. The research project is an exercise in integrated assessment analysis, i.e. it looks at the problem of climate change from a broad perspective in order to fully appreciate the numerous and complex interactions between the many economic actors (consumers, producers, national governments, supranational organisations) and the complex physical environment they are operating in. This broad perspective is reflected in the extensive geographical coverage (international, European and Belgian perspective), the extensive time horizons considered (several centuries for integrated assessment modelling, several decades for analysis of EU and Belgian climate change policies for the first commitment period 2008-2012 of the Kyoto Protocol), and the variety of policy questions it considers (integrated assessment of both climate change and acidification for the emissions of sulphate aerosols, the interaction of policy instruments like carbon taxes and emission permit trading and so forth).

The CLIMNEG 2 project is organised around three major research themes. In the first major research theme of the proposal, *criteria for sustainable development*, we address the concept of sustainable development in the context of climate change. The analysis will identify minimal requirements a sustainable economic development should satisfy. These conditions will be derived from a theoretical welfare economic analysis of the trade off between the fundamental concepts of (1) economic efficiency, (2) environmental sustainability, (3) intragenerational and intergenerational equity, and (4) implementation and strategic stability of post-Kyoto climate agreements.

The second major research theme will focus on *climate policy instruments* and in particular on the combination of tax instruments and emission trading, the microstructure, initial allocation and trading rules of GHG emission permit markets.

Thirdly, the CLIMNEG 2 project contains an important *integrated assessment modelling* effort. The project will refine, and draw upon several models that are currently available in the network (the integrated assessment model CLIMNEG World Simulation CWS model, the general equilibrium model GEM-WORLD). The project will create "soft links" between the models in order to achieve consistency between the different levels of analysis. For the integrated assessment aspect of the project, an important interdisciplinary contribution from climatology is called upon in order to refine the carbon cycle and regional temperature change module of the existing CWS model by allowing for a multi-gas approach and by paying specific attention to the scientific uncertainty in the climate parameters. The climate team will also contribute to the analysis of the Brazilian proposal concerning industrialised countries' historic responsibility.

1.1 Objectives

The aim of the CLIMNEG 2 project is to characterize theoretically and to simulate numerically the economic and climate change consequences of different GHG emission reduction policies on the global, European and Belgian level. This characterisation and simulation exercise requires using different types of models of which some must have a simplified but reliable representation of the climate system. The purpose of this multidisciplinary research is to build a consistent interaction between the economic variables and climate change consequences. The results of this short and long term analysis will be used as input for recommendations for short term climate change policies and for the international climate negotiations.

The principal role envisaged for climatologists (ASTR) in Climneg-2 was to improve the climatic part of a model created by economists (CWS), to investigate stabilisation scenarios, and to explore coupling of more complex climatic and economic models.

Since any chain of integrated assessment is only as strong as its weakest link, we therefore started by looking for the factors to which the results may be most sensitive, and focussed more effort on these. Essentially the purpose of a climate module in a model such as CWS is not for predicting global average temperatures, but for allowing combining abatement and impact costs in an optimisation framework. Reviews of relevant literature and models suggested that the results were likely be more sensitive to factors which had not been included in the original workplan, particularly the step from global average temperature to impacts and impact-costs, and the (lack of) inclusion of uncertainty along several steps of the cause-effect chain. Factors such as the socioeconomic baseline (without policy) and the abatement cost formulae may also make a larger difference than the steps between emissions and global temperature (at least for a best-guess model). Therefore it was considered appropriate to extend the original workplan, and to examine further the sensitivity to all of these factors, using the interactive Java Climate Model (JCM), developed by Ben Matthews in UCL-ASTR (and earlier in KUP Bern, UNEP-GRID Arendal and DEA Copenhagen), as described further below.

1.2 Expected outcomes

Numerical simulation models are the main ingredients of the CLIMNEG 2 project. These models provide scientific tools that can be used to analyse many different policy questions. The models used in the CLIMNEG 2 project are the following.

1. CLIMNEG World Simulation CWS model. The CLIMNEG 2 research project will update and extend the existing integrated assessment CWS model in the following way: increasing the number of regions from 6 to 18, constructing new BAU scenarios, abatement cost and climate change damage estimates and so forth. CWS model is particularly suited for analysing long term (up to a century and beyond) climate change policy issues like post-Kyoto burden sharing, GHG concentration stabilisation policies and game theoretic stability analysis of international climate agreements.

2. GEM-E3-WORLD is a computable general equilibrium model of the world economy. It describes in much more detail than CWS the economic production process (18 sectors) and trade flows between 18 world regions. However, it is not coupled to a carbon cycle/temperature model and it considers a time horizon of only a few decades. The CLIMNEG 2 project will extend the GEM-E3-WORLD model with non-CO2 GHG emissions originating from agricultural production.

3. Mac-GEM and MacBank. The CLIMNEG 2 project will develop a new, simple and portable simulation tool for GHG emission trading markets and flexible mechanisms. It is based upon GHG marginal abatement cost functions that are estimated using simulations results of GEM-E3-WORLD.

4. JCM, the Java Climate Model, is an interactive climate model, with a fast and rapid responding interface. It is a very flexible tool, which is designed in such a way that users can easily investigate the effects of the different modelling assumptions. As such it is a perfect

instrument to examine the impact of the simplified physical assumptions taken in economic models. In the CLIMNEG 2 project, the model will be used to look at uncertainty and a new optimisation module will be added.

Encountered Problems

1 PERSONNEL PROBLEMS

Several people left the CLIMNEG 2-project during its operation.

During the first year of the CLIMNEG 2 project, an important change has occurred in the composition of the research network. In September 2002, Jutta Roosen (UcL-ECRU) has left the Université catholique de Louvain to take up a position at the university of Kiel in Germany. Given that there was no other specialist in the field of agricultural economics in the UcL-ECRU department to take over the part of the CLIMNEG 2 project, the original project was adapted. CES took over some of the work of ECRU, and TASK I-C, environmental taxation, public finance and intergenerational distribution was added. (See report of 2002).

The study of intergenerational equity has faced setbacks due to the limited availability of researcher Luc Van Liedekerke (CES-ETE).

The researchers Johan Eyckmans and Greta Coenen left the CES in September 2003. As a result the ambitions of the CES program for the integrated CWS-model have been curtailed.

2 DELAY IN INTEGRATED ASSESSMENT

The integration of the physical models and the economic models had some delay due to a several factors: First there was the problem of the lack of researchers in the CES. Second, the optimization programs which are used in the economic models are hard to combine with the physical models with a simple interface program. This is certainly the case when one wants to take into account the nonlinearities of the physical system. It was therefore decided to transfer most of the integrated assessment modelling to the Java Climate Model (JCM), which was extended with an optimization module.

Task I: Criteria for Sustainable Development

1 HISTORICAL RESPONSIBILITY AND THE GREENHOUSE PROBLEM

In the first part of Task I, the Climneg II consortium concentrated on the issue of historical responsibility for Greenhouse emissions. The international discussion on the Greenhouse problem is constantly confronted with arguments about historic responsibility. The topic became even more central to the discussion when in 1997 in the context of the Kyoto negotiations; Brazil launched a proposal in which it used cumulative emissions from 1840 onwards till today as the point of reference for defining the abatement targets for the countries taking part in the negotiations. The obvious effect was that the entire economic burden connected to the greenhouse problem was shifted to the industrialized countries. The Brazilian proposal remains one of the strong arguments used by non-industrialized countries to claim that the Greenhouse problem is essentially a problem of the rich countries.

The question of historical responsibility is rooted in the philosophical discussion on what we owe to future generations. There are two defining moments in this discussion: the first was the appearance of John Rawls *Theory of Justice*, in which the topic of what to do for future generations was explicitly tackled;[1] the second was the publication of Derek Parfit's *Reasons and Persons* in 1984. The fourth chapter of this important book is dedicated entirely to the problem of future generations. In the light of this we organized a multidisciplinary workshop where we invited two internationally renowned experts with respect to the philosophical discussion on our relation to future generations, Lukas Meyer and Axel Gosseries, and combined them with economists and climatologists working on the Climneg project (Leuven, 28 May, 2003). Contributions to this workshop were later on edited in a special volume of *Ethical Perspectives*.[2] The topic was further discussed in a workshop on economic growth and distributive justice in UCL (Louvan-La-Neuve, 6 May, 2004). This discussion resulted in the participation by Luc Van Liedekerke in cooperation with Luc Lauwers on a volume dedicated to theories of intergenerational justice, to be published by Oxford University Press in 2006. This book will be a reference book worldwide; contributors and proofreaders involve the best experts currently active in the philosophical field of our responsibilities towards future generations. Although the greenhouse problem is not the central topic of the book, this practical application will play a considerable role not only in our contribution, but also in those of others.

The discussion on historical responsibility for Greenhouse emissions is a difficult one and is certainly not finished. Let me briefly spell out the conclusion that we reached so far after going through the Climneg project.

Economists tend to reject the notion of historical responsibility. Dismissal of the notion of historical responsibility is often linked to the classical economic presupposition that costs made in the past are sunk cost and should therefore play no role when planning for the future. However, one need not argue that historical responsibility does not exist, one can also argue as Schokkaert and Eyckmans do in their contribution to the special volume of *Ethical*

[1] Crucial in this respect is chapter 5 and more specifically paragraphs 44 and 45.

[2] *Ethical Perspectives*, vol.11, 1, January 2004.

Perspectives, that arguments from historical responsibility are dominated by distributive justice arguments. This can be demonstrated by the following example. Suppose that the consumption of a commodity in the past (called cassava), concentrated in the poor part of the world, was unknowingly to its consumers responsible for a huge environmental problem for everybody today, shall we now argue that it is the poor countries that have to pay for the damage, since it is their consumption profile that caused the damage? Welfare economists believe the answer to this question is clearly negative; it is the rich countries that should mitigate the pollution problem, since they have the power and the means to do so. At the back lies the strong conviction that the present distribution of resources is grossly unjust, and that this injustice validates the conclusion that even if the rich did not cause the problem, they still have to solve it. What happened in the past seems to be irrelevant here, or at least it is strongly dominated by the present unjust distribution of resources which implies that you can not ask the poor descendants of the cassava eaters to rectify the past.

A second conviction that is common to welfare economists and many (though not all) philosophers alike is that they refuse to consider global justice questions at the level of the state. Arguments like 'Bangladesh should be helped because its income per capita is so small', or even worse 'the poor South should not be punished by past actions of the rich but irresponsible North' are bogus. Amartya Sen (1981) describes this approach of anthropomorphizing nations as "fantasy", as the "fiction of all nations throbbing as symbolic individuals in existence".[3] The problem is that it is very hard to see how national identity (that does not necessarily square with cultural identity), can be a meaningful ethical variable in order to judge responsibilities of persons. This argument jeopardizes the present negation process on greenhouse gasses that is taking place on a national basis.

Thirdly, we should point out that contrary to welfare economists, philosophers tend to accept the notion of historical responsibility. There is however a serious problem involved. If you believe that harm and responsibility are ultimately connected to persons (rather then groups, states or institutions); you can be confronted with Derek Parfits non-identity problem. In a nutshell this problem points out that when we consider our relation with non-contempories and certainly with far away generations, our decisions now might affect which persons and how many persons come into existence. Can these persons, whose existence is contingent upon present actions ever be harmed by these actions? Had the actions not taken place, they would simply not have existed at all. And from the other side, can present persons, in making decisions that affect the precise identity and number of people in the future, ever be guided by the interests of future persons? These are the questions that underlie Parfit's so-called 'Non-Identity' problem, a puzzle that has preoccupied philosophers for some time.

Under a person-affecting view of ethics Parfits problem is a real challenge if we believe that attributing interests to future people requires us to make reference to individual persons. But when we consider which environmental policy to adopt, we cannot possibly be guided by obligations to concrete (genetically identifiable) people living in the remote future. From this however, it does not follow that we have no obligations to future persons. Rather, such obligations would be grounded in the fact that future persons are human being; that is they share those properties of being human that permit and require us to relate morally to them as fellow human beings. We find here the nucleus of the moral discussion, the ultimate basis for moral concern with respect to past as well as future people is the fact that we consider them to be part of one big moral community stretching over time, which might be labeled mankind. If

[3] One should off course keep in mind that this is an ideal theory, the authors are quite aware that at present and for the foreseeable future nations will continue to be the main actors in arguments about distributive justice

we accept the above, that is that personhood is immediately connected to a moral framework which includes certain duties, responsibilities or just claims, the contingency argument evaporates. When we ask ourselves if we have harmed someone, the answer will no longer depend on a comparison of the state of the harmed person, with a counterfactual state of that person, had the harm not taken place- which would be impossible if the existence of that person depended upon the harm taking place. Instead the conception of harm could refer to a certain decency threshold, a baseline, below which we feel no human person, whoever she might be, should ever sink. This gives rise to the so-called subjunctive threshold view of harm. According to this view an action harms someone if we can indicate that this action was causally connected to the well being of the (exact) future person; or if it is impossible to make this causal connection, that action can still be considered harmful if it caused future people (whatever their identity) to fall below the threshold. At that moment we can conclude that this was a harmful act for which compensation is warranted. It remains however unclear how we could ever indicate a just amount of compensation to be paid, precisely because of the uncertainties surrounding the correct specification of the threshold. That does not imply however, that certain duties can not be specified. It is for instance clear that drastic environmental degradation will drive many future people below even the most basic threshold and should therefore be avoided.

2 SUSTAINABLE COOPERATION IN INTERNATIONAL ENVIRONMENTAL AGREEMENTS

2.1 Efficiency versus equity in international permit trading schemes

An effective solution for the problem of global climate change requires an international agreement characterized by three properties: (1) efficiency, (2) justice and (3) ecological sustainability. In the framework of her master paper, Greta Coenen (K.U.Leuven-CES-ETE) has developed a theoretical framework for analyzing the trade off between justice and efficiency for a specific policy instrument, namely tradable emission permits as foreseen in the Kyoto Protocol.

In this set up, efficiency refers both to *cost efficiency* (i.e. producing greenhouse gas emission reduction at the lowest possible overall cost implying that cheap reducers should bear more of the reduction burden than expensive reducers) and to *ecological sustainability* (i.e. the appropriate level of global emission reduction). Justice is interpreted in a consequentialist manner, i.e. outcomes are judged on their impact on the global distribution of consumption possibilities.

One of the attractive features of tradable emission permits is that in principle, this policy instrument allows for separating efficiency from equity considerations. On the one hand, international trade in GHG emission rights will lead to an equalization of marginal emission reduction costs in all countries making the final allocation of reduction efforts cost efficient. This result crucially depends on the assumption that permit traders are profit maximizing and that the permit market is perfectly competitive, i.e. no market party can exercise market power to drive up the permit price and its trade revenues. These assumptions are reasonable in the context of the Kyoto Protocol if trade is organized on firm level as it is currently the case in the European Emissions Trading Scheme covering the pre-Kyoto period 2005-2007.

On the other hand, the initial allocation of emission rights can be used to pursue equity and/or political feasibility objectives without jeopardizing the cost efficiency of the allocation because in a perfectly competitive permits market, the final allocation of emission reduction efforts (after trading) is independent of the initial allocation of permits.

When no limitations are imposed on the initial allocation of emission rights (when negative allocations of rights and "hot air" are possible), it is possible to implement the first-best solution maximizing global welfare. This is basically the Second Fundamental Theorem of Welfare Economics (see for instance Mas-Colell et al, 1995) that any Pareto efficient allocation can be implemented by means of a competitive market mechanism, provided initial endowments can be freely reallocated in a lump sum fashion. However, when constraints like "no hot air" or "no negative allocations of permits" prevail (because of political feasibility or resistance in public opinion), then the first-best allocation might no longer be implemented via a permit trading scheme.

In working paper Eyckmans and Coenen (2005), Efficiency versus equity in tradable emission permit systems (CLIMNEG Working Paper 77), the question whether the total number of permits issued should be higher or lower compared to first-best levels, is analyzed in a context with binding constraints on the set of permissible initial permit allocations. The main determinants of the direction of deviation from the first-best allocation include (1) the correlation between income per capita and (marginal) climate change damages, and (2) the correlation between income and net permit trade revenues/expenses.

Theoretically, no general conclusions can be drawn (except under very restrictive assumptions) and therefore, the results were tested by means of numerical simulations with a simple 15-region abatement cost-benefit model for the World's GHG emissions. Figure 1 shows how the welfare maximizing total amount of permits (expressed as a percentage of Business-As-Usual emissions) depends on equity preferences expressed as the "inequality aversion" parameter. The inequality aversion parameter equals zero for a pure utilitarian welfare function that simply adds all per capita consumption levels without weighting. Increasing inequality aversion reflects more concern for global income distribution. For very high inequality aversion parameter values, the underlying social welfare function converges to the so-called Rawlsian maximin welfare function (maximizing the well-being of the worst off). The constraints that are imposed on the initial allocation of permits are threefold: (1) no hot air (i.e. emission allocations should be less than projected BAU emissions), (2) no negative allocation, and (3) individual rationality (i.e. every country should be better off with the trading scheme compared to the laissez-faire situation without any international climate agreement).

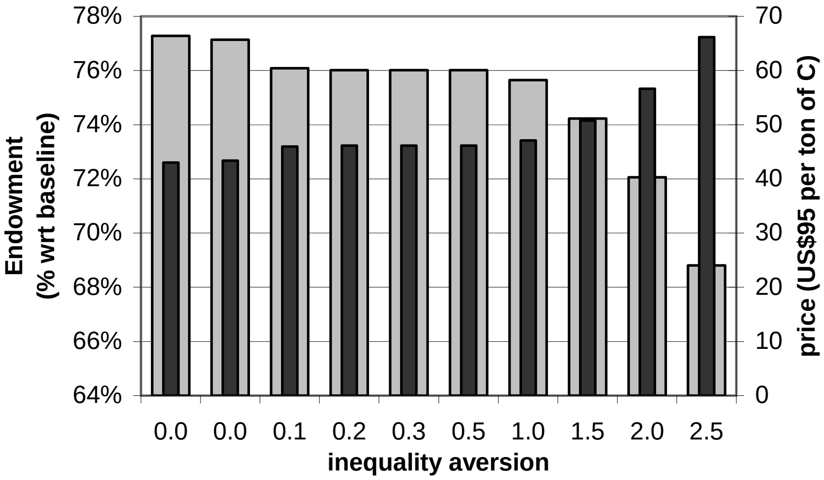

Figure 1: How the global emission ceiling depends on inequality aversion under binding constraints on the initial permit allocation

The simulations show that for increasing inequality concern, the welfare maximizing overall GHG emission ceiling is gradually lowered from about 77% of BAU emissions to about 69%. Hence, more emission reduction is required for higher inequality aversion. This tendency reflects in a gradually increasing equilibrium permit price: from about 43 to about 67 US$/ton C.

In the paper and in additional research work, the analysis is complemented with an analysis of incomplete global climate agreements when only a subset of countries cooperates. Although the analysis becomes technically more complicated because of "leakage effects" (i.e. every additional effort by the coalition members is matched by a reduction in effort by the outsiders and vice versa), the qualitative results remain the same as in the complete agreement case.

2.2 Endogenous coalition formation in international climate agreements

2.2.1 The design of international climate agreements and the role of transfers

Johan Eyckmans has continued working on the theme of endogenous coalition formation and international environment agreements. This research was performed in close cooperation with Michael Finus (Fernuniversität Hagen, Germany) who visited the department of economics of the K.U.Leuven in March (2 weeks) and July 2004 (4 weeks) in the framework of the CLIMNEG 2 project. This cooperation has resulted in several joint research papers that have been presented at international scientific meetings and that were submitted to international scientific journals.

1. Eyckmans, J., and Finus, M. 2003, Coalition Formation in a Global Warming Game: How the Design of Protocols Affects the Success of Environmental Treaty-Making, CLIMNEG Working Paper 56 (forthcoming in: *Natural Resource Modeling*).
2. Eyckmans, J., and Finus, M. 2003, New Roads to International Environmental Agreements: The Case of Global Warming, CLIMNEG Working Paper 57.
3. Eyckmans, J. and Finus , M., 2004, An Empirical Assessment of Measures to Enhance the Success of Global Climate Treaties CLIMNEG Working Paper 61.
4. Eyckmans, J. and Finus , M., 2004, An Almost Ideal Sharing Scheme for Coalition Games with Externalities, CLIMNEG Working Paper 62.

5. Carraro, C., Eyckmans, J. and Finus, M., 2005, Exploring the Full Potential of Transfers for the Success of International Environmental Agreements, CLIMNEG Working Paper 78.

Papers 1, 2, 3 and 5 make use of the dataset of the CWS model (previous CLIMNEG project 1996-2000) to compute recent game theoretical solution concepts for international climate negotiations. The purpose of this investigation is to test alternative architectures for an international environmental treaty on their game theoretical stability and ecological performance. From this work, the following general conclusions can be drawn:

- Single versus multiple coalitions: instead of one large climate agreement, it is often better to have several partial subagreements. These multiple coalitions structures are often more stable, lead to more ambitious environmental objectives and higher global welfare.
- Open versus exclusive membership: currently most international environmental agreements are characterized by open membership meaning that each country can join the agreement without preceding permission of the original members. We show however that the stability of an agreement can be improved considerably by making accession dependent on the consent of the original members. The larger the extent of consensus required to approve accession (unanimity versus 50% majority rule), the more stable the agreements become.
- Financial transfers are often capable of promoting stability of international environmental agreements.

The latter point on transfers deserves some more attention since it has been one of the major focuses and achievements of the CLIMNEG research up to now. The following description is based largely on Eyckmans and Tulkens (2005).

Winners and losers from cooperation without transfers

Although total global welfare in the World optimum is higher than in the laissez-faire optimum, it need not necessarily be the case that every individual country gains from an optimal global climate agreement. In order to illustrate this point, we use some numerical results obtained from the CLIMNEG World Simulation (CWS in the sequel) model. This model was built by the authors in the framework of the Belgian CLIMNEG research network and has been used extensively for game theoretic analysis of climate agreements. More details on this model are provided in Eyckmans and Tulkens (2003).

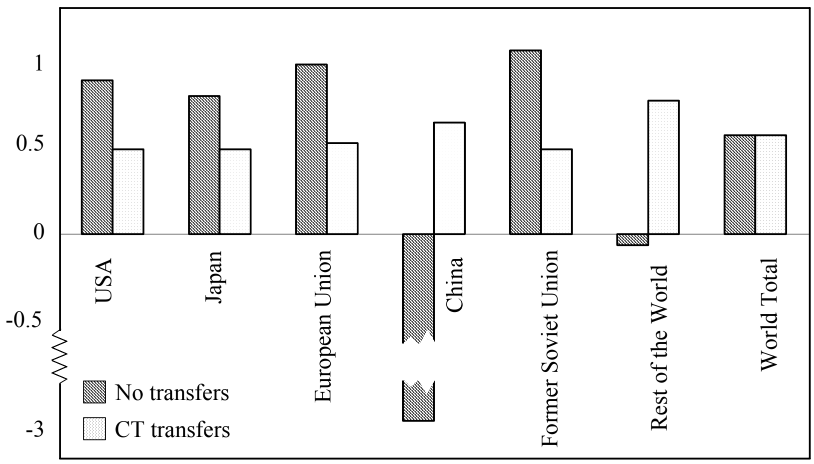

Figure 2: Winners and Losers in World optimum with and without transfers compared to laissez-faire

The striped bars in Figure 2 show the percentage difference between the individual regions' welfare levels at the World optimum and Laissez-Faire situation. Welfare is measured as the discounted value of the lifetime consumption flow over a horizon of several centuries.

On the right of the figure note first the positive gain of cooperation for the World as a whole. Individually, however, China suffers significant losses. The intuitive explanation for this is as follows. It is generally assumed that GHG emission abatement costs in China are low because of its obsolete industrial infrastructure and energy plants. Replacing old coal-fired power plants by new more efficient gas-fired power plants would be a relatively cheap way to save emissions in China. On the other hand, it is believed that China does not value much the potential climate change damages to its economy. Hence, in the national optimum, China would choose for a relatively high emission level, or equivalently, low emission abatement effort. However, in a cost efficient global emission arrangement, China would be required to reduce emissions significantly because its reduction costs are so low.

Also RoW (Rest of the World) is slightly worse off in the grand climate agreement compared to the national optimum. From Figure 2 it is clearly not surprising that China and RoW (which includes Brazil and India) did not want to adopt quantified emission ceilings for the First Commitment Period of the U.N.F.C.C.C., i.e. the Kyoto Protocol. These countries are bound to lose in a cost efficient international climate agreement since they have to perform a lot of abatement effort and the resulting costs are only partially compensated for by lower climate change damages.

Transfers to stabilize international climate agreements

In the discussion thus far we have argued that countries will be willing to sign (and comply with) an international climate agreement only it they feel it is in their best interest to do so. Turning this around, we consider that the design of the agreement should take into account that countries are not always altruistic when it comes to bearing the costs of providing a better environment, especially if the benefits are enjoyed (partly) by other countries and other generations. In the remainder we discuss other aspects of future climate agreements relating to their stability, which is endangered by various forms of free riding behaviour. In particular, we consider whether resource transfers between the signatories can enhance stability. Note that we will only use transfers to mitigate free riding incentives and not to pursue any normative or ethical objective. Hence we focus on the incentive problem only.

Chander-Tulkens transfers

Consider a proposed global climate treaty that would implement the overall emission level and distribution of effort implied by the World optimum. Without any additional monetary transfers, this agreement would yield a positive global surplus of cooperation but some individual countries might be worse off compared to the national optimum, as we have seen (e.g. China in Figure 2).

Chander and Tulkens (1995, 1997) have suggested a transfer scheme to mitigate this problem. The Chander-Tulkens transfer scheme ensures that each country enjoys at least its Laissez-Faire welfare level, and on top of that lower bound, each one receives a positive share of the global surplus from cooperation. Hence, all will be better off than in the Laissez-Faire situation. This property is called *individually rationality*.

Chander and Tulkens (1995, 1997) have shown a remarkable property of a particular version of this transfer formula. If one chooses the surplus sharing weight that reflect the share of the country in the total marginal climate change damages, the resulting allocation is not only individually rational but also *coalitionally rational*. This last property means that no subgroup of countries can suggest a *partial* or incomplete climate agreement making all of its members better off than under the global agreement with the above transfers[4]. In this sense, the Chander-Tulkens transfer formula provides stability to a global climate agreement comprising all countries of the world.

Returning to Figure 2, the spotted bars show the welfare differences after applying the Chander-Tulkens transfer formula to the grand coalition. As can be seen, all countries are now receiving more than their Laissez-Faire welfare level (there are the positive spotted bars). Moreover, we can see who is paying and who is receiving transfers by comparing the striped and the spotted bars: the developed countries United States, Japan, European Union and Former Soviet Union are paying to China and Rest of the World. However, no one country is paying so much that it would be driven below its Laissez-Faire welfare level. For the numbers underlying Figure 2, Eyckmans and Tulkens (2003) have shown that the transfer allocation is not only individually, but also coalitionally rational.

Eyckmans-Finus transfers

Parallel to the stability result just discussed, other authors are challenging the stability concept underlying the proposed sharing rule. Indeed the stability notion involved rests on the assumption that, if a country or a group of countries objects to the proposed global climate agreement and moves to partial agreement, the other countries abandon the proposed agreement too and return to their national optimum position[5].

An alternative assumption is that it might be in the best interest of the remaining signatories to continue cooperating but with one or two members less. It is in this spirit that authors like Barrett (1994) and Carraro and Siniscalco (1993) advocate that climate agreements should be both *internally stable*, i.e. none of the members should have an incentive to leave, and *externally stable*, i.e. no outsider should have an incentive to join.

The concept of internal stability better captures the idea of free riding incentives. Intuitively, one sees that these free riding incentives are typically very high in the context of non-excludable public goods. It then comes at no surprise that the literature initiated by Carraro and Siniscalco (1993) and Barrett (1994) finds international environmental agreements stable in this sense only for very small groups of countries. Finus (2001) offers an excellent survey of the different stability concepts and results to be found in the literature.

Recently, Eyckmans and Finus (2005) have presented a new transfer scheme which is designed to counter these free riding incentives: the *Almost Ideal Sharing Scheme*. In order to explain what this means, considers an international climate agreement comprising only a subset S of all countries in the World as is the case in the 1997 Kyoto Protocol. The idea behind AISS is simple: give every member of S at least its free rider payoff, and distribute the remaining surplus, if any, proportionally to the members. The free riding payoff refers to the scenario where a country has left its coalition S and the remaining members of S minus i continue to cooperate[6]. The surplus sharing weights may be any value, as long as they are all positive and sum up to one.

[4] Technically, the allocation after transfers belongs to the "gamma-core" of the global greenhouse gas emission game, as formulated in Chander and Tulkens (1995, 1997).

[5] Chander (2003) shows that if players are farsighted, it is in their self-interest to leave a suboptimal coalition after deviation by a free rider. Each remaining coalition member has this incentive and hence, the agreement would dissolve completely.

[6] The emission allocation under such a partial cooperation scenario is modelled as a Partial Agreement Nash Agreement as in Chander and Tulkens (1995, 1997).

A remarkable property of AISS is that, given any potentially internally stable agreement, it can be shown to stabilize the coalition of members, not only internally (by construction), but also externally. Potentially internally stable agreements are coalitions that generate sufficient cooperation surplus to cover the free riding claims of all of its members. In other words, AISS maximizes global welfare under the constraint that climate policies are to be implemented by an internally and externally stable agreement.

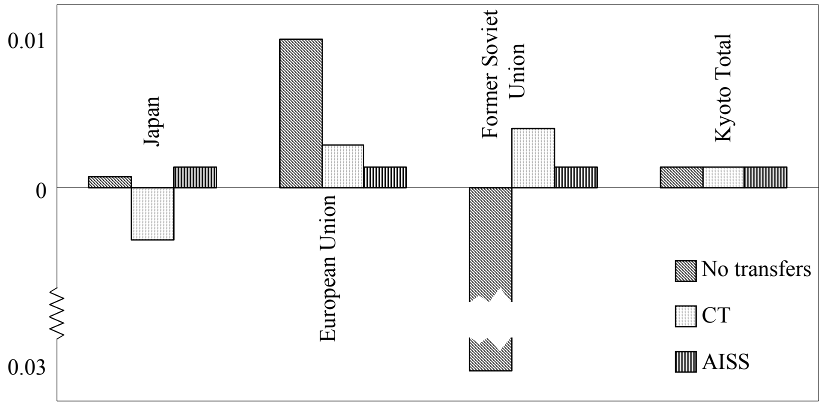

Figure 3: Winners and losers in different transfer scenarios compared to free riding payoffs

Figure 3 is similar in spirit to Figure 2 but it compares welfare levels of the ratifying members of the Kyoto Protocol under different transfer schemes: No Transfers, Chander-Tulkens transfers (CT) and Almost Ideal Sharing Scheme transfers (AISS), with the free riding payoffs of the same signatories. By ratifying members of the Kyoto Protocol we mean the coalition consisting of Japan, European Union and Former Soviet Union. For the six region aggregation of the CWS model, this coalition is closest to the actual Kyoto Protocol since USA has decided not to ratify. The welfare levels computed with the CWS model are the results of an intertemporal optimization, assuming that the Kyoto coalition continues for ever and implements emission strategies that maximize their group welfare. This is obviously a more comprehensive treaty than the actual protocol, which only specifies emission targets for the First Commitment period 2008-2012.

The striped bars denote the percentage difference between the Kyoto welfare levels without transfers (No transfers) and the free riding payoffs. It turns out that Japan and EU are better off with the treaty compared to their free riding position. However, the Former Soviet Union faces a strong free riding incentive. It is worse off joining the protocol compared to a free riding scenario.

The spotted bars (CT) show the percentage differences between Kyoto welfare levels, including Chander-Tulkens transfers applied to the Kyoto coalition, and free riding payoffs. Recall that the Chander-Tulkens rule guarantees every signatory its Laissez-Faire outcome (i.e. complete absence of cooperation) and a positive share of the cooperation surplus. The Chander-Tulkens transfer scheme induces internal stability for the Former Soviet Union. However, it creates a new free riding incentive for Japan. In order to keep FSU on board, Japan and EU have to pay heavily in the Chander-Tulkens transfer—so much so that Japan is driven below its free riding payoff.

The vertically striped bars (AISS) show the payoff differences for the AISS transfers. Note that all signatories are better off in the agreement compared to their free riding payoffs. Hence, no insider wants to deviate under AISS. Note that this is possible because the Kyoto coalition creates enough group surplus to compensate for the members' free riding claims: see the bar labelled "Kyoto Total" at the right in Figure 3. Jointly, there is enough surplus to stabilize, in the internal sense, this Kyoto coalition.

Finally, it should be stressed that the AISS transfer scheme is also cable of stabilizing other coalitions, in particular the four-player coalition consisting of United States, European Union, China, and Rest of the World. This coalition achieves a global World welfare level that closes the gap between the World optimum and the national optimum by 94.5% (versus only 2.9% for the Kyoto coalition in Figure 3!). Using the data of the CWS model, it is not possible to achieve an internally and externally stable climate agreement that performs better. More details on this simulation exercise comparing AISS to other transfer schemes are to be found in Carraro, Eyckmans and Finus (2005).

2.2.2 The co-operative game theory approach and Maskin's (2003) contribution

George Zhang and Bert Willems have studied the formation of international environmental agreements using co-operative game theory. This study is important in order to understand the current and future international agreements.

Classical co-operative game theory assumes that all countries in the world will work together and will form a so-called grand-coalition: They jointly will take these decisions which are optimal from a World viewpoint. Classical co-operative game theory then deals with the question how the efforts should be distributed among the different countries in the grand coalition, i.e. who should pay for the reduction of CO_2 emissions. The classical approach is hence focused at the issue of fairness, starting from the assumption that the grand coalition will form.

In practice, we see that the grand coalition does not always form. The Kyoto agreement was, for instance, not ratified by the U.S., and developing countries did not commit to reduce their CO_2 emissions. Also future global international environmental agreements seem to be hard to achieve. The assumption that all countries will achieve an agreement is clearly not valid. Why is it so hard to sign an international agreement?

The reason for this difficulty lays in the existence of so-called "positive externalities". This means that if a number of countries sign a coalition agreement and commit to reduce their CO_2 emissions, that also other countries will enjoy the benefits of a lower CO_2 concentration, but will not incur the costs for reducing CO_2 emissions. Hence, for a single country it would be optimal that the rest of the world signs an international agreement and reduce their CO_2 emissions, and that the country itself stays outside the coalition and does not pay for emission reductions. Such a country is said to "free-ride" on the efforts of other countries. Hence, countries have an incentive not to join a coalition if they know that other countries will sign an international environmental agreement. Coalitions break down, and co-operation is not achieved.

Maskin (2003) has developed an extension to the classical co-operative game-theory for games with positive externalities. He proposes a new axiomatic approach to predict which coalitions will form in equilibrium and how efforts will be shared within these coalitions. His method to derive the equilibrium is elegant and in the case that there are no externalities, the proposed equilibrium gives identical results as classical co-operative game theory.

Maskin's theory is an axiomatic approach, defining the equilibrium outcomes by a set of rules, but the intuition of his approach is best understood in a non co-operative model. The main underpinning of Maskin's theory consists of two assumptions (1) countries can sign binding contracts, and (2) contracting occurs sequential. More in particular, he assumes that countries arrive in a pre-determined order, and that the countries who arrive first give a take-it or leave-it offer to the countries arriving later to join one of the existing coalitions. The countries who arrive later, decide whether they will join one of the existing coalitions, or whether they will stay on their own.

The key axioms in Maskin's model deal with determination of the outcome of the bidding game, where the existing coalitions bid for the new arrivals to join their coalition. Knowing the solution of the bidding game, one can then define the outcome of the full game by backward induction. We will know discuss this bidding game in more detail.

In the bidding game, the existing coalitions (let's say the countries who ratified the Kyoto agreement) will make an offer to a newly arriving country (let's say the U.S.). They make a take-it or leave-it offer to the U.S. about joining the coalition. The U.S. then decides what it will do: join the coalition, and getting paid by the other members to reduce emissions, or stay outside the coalition, and free ride on the effort of the existing members of the coalition.

The coalition bidding game can be considered as an auction for a good which externalities. In an auction with externalities, the pay-off of the bidders does not only depend on whether bidders obtain an object or not, but also on who would obtain the good if they do not obtain it. For instance, a sports club might be willing to hire a player in order to weaken one of its competitors. Even if this player would not be actively playing, the team might still be willing to pay a lot to obtain the player. The willingness to pay for such a player will be higher when the selling team is a direct competitor. The same is true in the coalition formation process in international environmental agreements, the willingness to pay for having an entrant to join your coalition, will depend on to which coalition the player would go otherwise.

One way to solve the auction with externalities is to look for a standard non-cooperative Nash equilibrium: all coalitions bid simultaneously for the entrant to join their coalition, and the entrant joins the coalition with the highest bid. The problem with this approach is that in a game with externalities, such equilibria only exist in mixed strategies.

Maskin takes an alternative approach and looks only at pair-wise stability: an entrant will join a coalition A, if there is no other coalition who could pay the entrant more to leave coalition A. In sports terms: a player will remain with team A, if there is no other team B that would pay the player a higher wage to lure him away from team A to team B. With pair-wise stability we mean that we do not look to the willingness of team C to pay the player to make sure he would not go to team B.

Using pair-wise stability equilibria can be calculated rather simple and the outcomes are straightforward. There is, however, a problem with Maskin's equilibrium concept: The existence of equilibria not always guaranteed.

Maskin argues that if the pay-off function of the coalitions are super-additive, i.e. that if two coalitions join, the joint coalition obtains a higher pay-off, that then equilbria always exist. We have shown with a counter-example that this does not hold if there are more than three countries. Maskin's theory is therefore not applicable to all games with super-additive pay-off functions.

In order to test whether the non-existence of equilbria would be an issue in practice, or whether it would only occur in some specially designed examples, we have used data from the CWS model to test Maskin's theory. We have shown that for International Climate Negotiations, Maskin's extension of co-operative game theory cannot be used. The equilibrium concept of Maskin should thus be refined in order to be useful tool to discuss the current international agreements.

2.3 CLIMNEG Workshop on International Environmental Agreements

Finally, we mention the organization on 14 March 2003 of an international workshop CLIMNEG Workshop on International Environmental Agreements in Leuven with the financial support of the CLIMNEG 2 project. This successful workshop has brought together someof the most renowned experts (Michael Finus, Charles Kolstad, Santiago Rubio, Ekko of Ireland) in the field of environmental economics and international environmental agreements. This workshop was particularly interesting for the CLIMNEG 2 researchers because it offered them an occasion to confront their most recent research work in the area of international environmental agreements with the international experts in the field.

3 ENVIRONMENTAL TAXATION, PUBLIC FINANCE AND INTERGENERATIONAL DISTRIBUTION

In the third part of Task I, the Climneg consortium studied environmental taxation, public finance and intergenerational distribution. This task was re-oriented towards an alternative kind of policy design. Instead of studying the impact of environmental taxes, we studied the policy consisting in selling pollution permits to productive firms. This allowed us to place ourselves inside the current debate on the pollution permits. At the same time, when pollution permits are sold by the regulator to the firms, the model is worked out in a similar way as the model with environmental taxes. In the system of taxes on emissions, the level of the taxes is set by the regulator and the volume of regulated emission is determined endogenously by the firm's demand for emissions. In a system of sold pollution permits, the volume of emissions is set by the regulator and the equilibrating price of these emissions is endogenously determined.

In a framework without uncertainty like ours, these two systems are formally equivalent. From the point of view of the firms, each unit of emissions is subject to a payment to the public authorities. As a result, taxes or sold pollution permits result in additional revenues for the government, with the issue of recycling these revenues in the economy.

We will first describe the methodology used to address the issues of environmental policy with sales of pollution permits and intergenerational equity. Then we will present our results.

3.1 Methodology

One of the major points on which we insisted was the question of the tool to be used to study generational issues in environmental economics.

First of all, we only used in this task intertemporal general equilibrium models. This is the only way to capture the macroeconomic effects of environmental policies aiming at fighting climate change. We think partial analyses are not able to give qualitative results at the macroeconomic level.

Second and most importantly, for this task, we used throughout the project the overlapping-generation model (OLG) and not the infinitely-lived agent framework (ILA). The opinion according to which the ILA framework is as satisfactory as the OLG framework to study intergenerational equity in environmental issues rests on the assumption that OLG households have an operative dynastic bequest motive (Barro (1974)). This is questionable in two respects:

- First, the contribution of Weil (1987) is too often neglected: in its important paper, he studies the conditions under which the bequest motive is operative. The degree of altruism must be sufficiently strong for households to leave a positive bequest. Why is this crucial? Because when altruism is inoperative, the formal equivalence between the ILA framework and the OLG framework simply breaks down. So the question of the equivalence between these two frameworks is not as unconditional and obvious as it seems at first sight;
- Second, the substance of dynastic altruism is also questionable, especially to study intergenerational equity. If the bequest motive is operative, the whole dynasty behaves as a single decision unit. So the diversity of the "selves and egos", which characterizes the OLG framework and which is central to the analysis of intergenerational equity, is diluted into a complete harmony between generations. Becker (1991) itself cast doubt on the realism of dynastic altruism by simply stressing that the individuals' ability to foresee the indefinite future, as it is assumed in the dynastic model, is something which outreaches the skills of the most prescient. Other forms of intergenerational bequest motive exist which do not imply an infinite horizon of decision: the joy-of-giving bequest motive (Andreoni (1989), the family altruism bequest motive (Lambrecht, Michel, Vidal (2005) and Michel, Thibault, Vidal (2005)). At odd with the dynastic model, they do not allow to say that households which are linked by transfers form a single decision unit, and thus the equivalence between the ILA and the OLG also breaks down even if transfers are operative.

In the overlapping generations model, when each generation cares for itself, the problem of intergenerational equity can be raised. In the Lerner-Samuelson debate on this matter, the solution proposed by Samuelson (1958) seems to be more appropriate (in the spirit of Rawls) since it represents a way to combine intergenerational equity with intertemporal efficiency. The Samuelson's proposal is to require stationary individual consumption, including both young- and old-age consumption, and this is compatible with the maximization of a representative lifetime utility but not with the utilitarian criterion proposed by Lerner (1959). Of course, the recent developments on endogenous growth have inspired other intergenerational equity criteria, allowing for a positive per capita growth rate, but only for particular cases.

3.2 The results

We will now present the results following the order of the sub-tasks of Task 1C.

3.2.1 Constructing the basic model

This task has first led to the Climneg Working paper n°59 (Lambrecht, 2004) and, in a second version to the CORE Discussion paper n°2005/74 (Lambrecht, 2005). This last version has been submitted to an international scientific journal. It is representative of our general approach to Task 1C and, as such, can be considered as the "template" of our approach.. The paper moreover can be seen as an essay to analyze the ins and outs of US sky Trust initiative; a proposal to auction pollution permits and recycle the proceeds to the households.

The question addressed is the following: Is there always a tradeoff between growth and environmental quality, especially when global pollution is regulated through the sales of pollution permits to firms and the proceeds of the sale is rebated to those agents who save in the economy? What are the redistributive effects of the introduction of such a system in a business-as-usual economy?

The paper we developped (Lambrecht 2005) models an overlapping generations economy in which young individuals choose between investing in physical capital or in environmental maintenance. Each period, firms must buy non-tradable permits of emissions to the government, which sells them inelastically. The proceeds are redistributed to the young households. The issue dealt with in this paper is the following: do we always have to choose between growth and environmental quality? Are there policies which solves this tradeoff? In equilibrium, environmental maintenance may be positive or zero. Consequently, the transition path may experience switches from equilibria with maintenance to equilibria without maintenance, or the reverse. In the business-as-usual economy, the higher capital accumulation, the lower environmental quality. In equilibria with permits sales and no maintenance, the dynamics of capital and those of the environment are independent. If maintenance is also operative, capital and environmental quality move together, i.e. the economy may become both wealthier and cleaner. We study the effect of the introduction of both instruments - permits and maintenance - when the economy lies initially at the business-as-usual steady state. There always appears an immediate gain in environmental quality. However, the magnitude of this gain is not necessarily maintained in the long run. It may partially vanish if capital accumulation is strongly evicted by the policy.

3.2.2 Enriching the basic model: the hypothesis of family altruism

This task has been carried out with two minor modifications with respect to the initial plan. We were to model family altruism between generations but finally chose the hypothesis of the joy-of-giving bequest motive. This change simplifies the analysis and constitutes a first step, the second of which is now being under construction. The second minor change is that we adopted a framework with a privately-owned renewable resource, instead of a standard model with a global pollutant. This was to follow some remarks of the panel of experts. We developed a paper (Bréchet and Lambrecht, 2005) which has been through several revisions and is now submitted to an international journal.

The question addressed by this task is the following: Can the intergenerational links based on descendant altruism help the economy to follows a sustainable path of growth? Are there condition under which a renewable resource is preserved by the operation of a private resource bequest motive? Does this bequest motive necessarily leads to the highest consumption possibilities?

In this paper we model an overlapping generations economy in which individuals are endowed with a renewable resource. This resource can be exploited at no cost by the young households and provided to production. A joy-of-giving bequest motive motivates the transfer of the unexploited resource to the heirs. The study of intertemporal equilibrium reveals two puzzles neglected by the literature on sustainability. First, the existence of a bequest motive does not automatically guarantee a sustainable future. Second, human exploitation may preserve the resource in equilibrium but at a sub-optimal rate; in this case, both those who exploit too much and those who do not exploit enough should run a capital stock lower than the golden rule level.

3.2.3 Environmental taxation and public finance

This task has been conducted with the model initial model in which pollution permits are sold to firms. It elaborates the basic model in two directions.

The first direction was to study the effect of a policy combining sales of pollution permits and a pay-as-you go pensions system. The question addressed is the following: Can a negative demographic shock have a positive impact on the households' welfare when global pollution is regulated and households mandate a fund to sell their pollution rights to the firms? To answer this question we use an OLG model in which retirees have three sources of income:

their savings in capital, their pension benefit and a share of the sale of pollution permits? Therefore a corollary of the above question is the following: can pollution rights be used an auxiliary instrument to sustain the retirees benefit, together with pension benefits?

To answer these questions, we first analyze an economy in which there are no institutions to carry out environmental policy. We refer to this economy as the business-as-usual (BAU) economy. In the long run, a negative demographic shock increases the households' welfare through higher environmental quality, while lifetime consumptions are unchanged. On the transition, a negative demographic shock permanently and monotonically increases the environmental quality. It temporarily sets the individual lifetime income, and thus consumptions, on an inverted-U path. In a second step we introduce policy instruments like property rights on the environment. We assume the existence of a fund which is responsible of selling to the firms the property rights of the households each period. In the long run, a negative demographic shock increases the households' welfare through higher lifetime consumptions while environmental quality is unchanged. On the transition, environmental quality remains unchanged while capital intensity first falls below the pre-shock level and then increase until it reaches a higher post-shock level of capital intensity.

The second direction of extension of the basic assumes two new features. First It assumes the possibility for inefficiencies to arise in the conduct of environmental policy by an environmental administrative department: pressure from lobbies, bureaucratic inertia, environmental dumping,… Second it looks for the possibility for the government to make intertemporal transfers of property rights on the environment in order to reach the optimal solution, in spite of the institutional rigidities .

So the question addressed is the following: Can we imagine a mechanism of transfer of pollution rights across time such that the government does not proceed to a net creation or a net destruction of pollution rights and nonetheless re-establish the optimal growth path of the economy?

The paper we developed assumes the existence of rigidities in the conduct of environmental policy. An administrative agency receives the delegation to conduct environmental policy but sets an unoptimal emission ceiling because of the above-mentioned rigidities. The government is mandated to sell, each period, to the firms the volume of the households' pollution rights set by the agency and to redistribute the proceeds to the households. Depending on the agency's mistake in setting the volume of the property rights ceiling, the government transfers pollution rights from the current period to the next period or from the next period to the current period. Over two periods of time, there is no net creation or destruction of the two-period volume of rights. By observing the transfers of the government, the agency partially adapt its ceiling. We show that the action of the government leads to optimal growth. In the long run, the agency's emissions ceiling corresponds to the optimal emissions and the government issues and repay a constant debt of property rights on the environment.

TASK II: Instruments

1 INITIAL ALLOCATIONS AND TRADING RULES

This part of the project is devoted to the analysis of the impact on compliance costs and permits prices of alternative allocations rules and trading rules for the forthcoming international markets of greenhouse gases emission permits. The analysis is divided into two parts: (a) the near and middle terms, that is the Kyoto commitment period (2008-2012) and susbsequent ones up to 2030 and (b) the long term (up to 2100).

1.1 Near and middle terms

A first aim has been to evaluate compliance costs and the permits price in 2008-2012 for all regions of the world and to quantify the repercussions of the US withdrawal from the Kyoto Protocol. To that purpose, the MacGEM model has been built. It consists of a set of marginal abatement cost functions for carbon emissions originating from fossil fuel use. The approach is similar to Ellerman and Decaux (1998) and Criqui et al. (1999). Emission trading equilibria are computed by seeking a price for which total market excess permit supply is zero. The marginal abatement cost functions are estimated on data generated with the GEM-E3-World general equilibrium model (for detailed descriptions of GEM-E3-World, see Capros et al. (1997 and 1999). MacGEM also allows for the introduction of trading restrictions like for instance a Commitment Period Reserve, transaction costs and limited accessibility of the Kyoto flexible mechanisms like Joint Implementation (JI) and Clean Development Mechanism.

The detailed results are presented in the CLIMNEG WP 48. Our findings are that, while in the absence of an agreement on CO_2 emission reductions, world carbon emissions would increase by about 30.1% compared to 1990, the ‘original’ 1997 Kyoto Protocol would have limited this increase to 15.5%. However, non participation by the USA causes world emissions to increase by 25.5% in 2010. The equilibrium carbon permit price and Annex-B* (EU15, OEU, AUZ, JAP and CAN) total costs fall by 50%. Moreover, our results show that accounting for carbon sinks enhancement activities will lead to a further decrease of Annex-B* total costs by more than 45%.

However, the MacGEM model does not explicitly take into account the possibility to bank emission permits from one commitment period to the other. This important limitation must be addressed in conjunction with the issues of future commitments and participation of USA and non-Annex B countries. The purpose here is to explore these questions by setting up a simple dynamic partial equilibrium model based on a set of marginal abatement cost curves for CO2 fossil fuel energy, called **MacBank**. The MacBank model thus extends the MacGEM model. The simplicity of the model is motivated by the requirement of flexible participation structures and by the willingness to model all the main characteristics of the permits market like, for instance, the use the Clean Development Mechanism, possible restrictions on permits' trades and inclusion of carbon sinks. One can also use the permits allocation rules the most often referred to in the literature. The robustness of our results is tested by sensitivity analyses.

The results of the analysis are presented in CLIMNEG WP 51. We find that, provided ambitiuous post-Kyoto commitments are negotiated: (i) in 2008-2012, the amount of banked permits will largely exceed the amount of hot air and permits prices will be much higher than predicted by most other studies, (ii) the banking provision significantly reduces world total costs but increases total costs for all permit-importing Annex B countries (i.e. all Annex B countries except countries of eastern Europe) via a rise in the permits price in 2008-2017 and (iii) the issue of market power on hot air is not likely to be a relevant one.

Moreover, the MacGEM and MacBank models are limited to CO2 emissions (from fossil fuels). Such a limitation is likely to overestimate the compliance costs and the permits price. It is therefore important to include non-CO2 gases in the analysis. The introduction of such gases in the models highlights their very important impact in reducing the world market price for emission permits. Table 1 shows the price of the emission permits (in $1995/ton of CO2) for a given possible scenario in the Kyoto commitment period (i.e., around 2010) when (i) only CO2 gases are included and (ii) all the other greenhouse gases are also included. For each of these cases, we consider the situation with banking and the situation without banking. These results, which are based on a 'base-case' scenario, characterized by the commitment of USA in a second commitment period (2013-2017) and the commitment of all developing countries in a third period (2018-2022), suggest that the inclusion of non-CO2 gases drastically lowers the price of the permits.

		CO2	All	Diff (%)
Price (2010)	Banking	24,0	14,7	-39
	No banking	6,5	4,6	-30

Table 1: Permits prices in the first commitment period ($1995/ton of CO2)

As far as total costs are concerned, we obtain results of the same magnitude. The following table shows the relative difference in total costs (abatement costs + costs of net purchase of permits) due to the inclusion of non-CO2 gases.

Period	EU15	OEU	JPN	AUZ	CAN	USA	FSU	CHI
2010	-30	-15	-29	-28	-28	NaN	-33	-40
2015	-30	-11	-28	-26	-27	-30	-33	-38
2020	-35	-25	-34	-32	-34	-33	-48	-57
2025	-36	-26	-35	-31	-34	-33	-51	-52
2030	-36	-28	-35	-30	-34	-34	-55	-27

Table 2: Variation in total costs due to the inclusion of non-CO2 gases (%)

1.2 Long term allocations of GHG emission permits

This part of the project focuses on seeking for long term allocations of GHG emission permits which are equitable while leading to stability (in the sense of the core of cooperative game) of the global agreement. It extends the analysis by Germain and van Steenberghe (2003) –who only account for individual rationality— to coalitional rationality. The purpose is to analyze the welfare implications of different rules to allocate tradable CO2 emissions quotas among the regions of the world by using a long term dynamic (closed loop) model. The total amount of quotas to be distributed at a each period of time corresponds to the world optimal amount of emissions to be realized during that period. Since coalitional rationality is a necessary condition for the stability of an agreement, we develop a method consisting in finding an allocation of quotas which guarantees coalitional rationality for every country along the entire time path and which is as close as possible to any given equitable allocation rule. Hence, the priority is given to satisfying participation constraints and the degree of freedom that is left is devoted to satisfying equity in the allocation of the quotas.

The results of the analysis are presented in CLIMNEG WP 64. The constrained allocations are such that the members of any coalition of countries for which an equitable allocation-based rule is not acceptable, receive more quotas in order to compensate the coalition so as to make it indifferent between signing and not signing the global agreement. The countries belonging to unconstrained coalitions receive then fewer quotas than the others. However, the equitable rule is preserved among them. These simulations highlight two results of particular interest. First, introducing core constraints instead of individual rationality constraints only may signifcantly affect the amount of permits to be allocated under a constrained allocation rule. However, the magnitude of this effect differs very much from rule to rule. Second, the degree of freedom for allocating emission permits while satisfying at each period core participation constraints is still signiffcantly large. For instance, under a global agreement, the United States of America receive 23% more permits with the constrained grandfathering rule than with the ability-to-pay one at the end of this century. This figure goes up to 193% for Japan, 83% for the European Union, 21% for former Soviet Union and -13% for China.

2 FUNCTIONING OF EMISSION PERMITS' MARKETS

2.1 Speculation on markets for emission permits

After having devoted some time to the analysis of the literature on financial markets microstructure, we have set up a model aimed at illustrating (i) how the presence of speculators might lead to a lasting change in permits prices and (ii) how the agency in charge of the environmental policy must adapt this policy due to their presence. This analysis has benefited from the collaboration of a financial economist visiting CORE (Paolo Colla).

The results of the analysis are presented in CLIMNEG WP 81 (also available as CORE DP 2005/66) entitled "Environmental policy and speculation on markets for emission permits". We show how the presence of speculators on a market for emission permits affects the price of these permits when firms face risk aversion. As such, the presence of speculators has an impact on the market through an increase in the market risk bearing capacity. Overall, speculators help firms hedging the production risk they face when choosing capital under uncertainty about the future productivity shock. Given a certain level of quotas, the entry of speculators in the emission permits market (1) rises the first period equilibrium price, (2) decreases expected returns and reduces volatility and (3) increases aggregate capital as well as production.

The agency in charge of the optimal environmental policy should account for the presence of speculators when determining the total amount of permits to issue. We focus on two polar cases. In the first case, the agency's risk tolerance is directly related to the preferences of the agents active in the market, i.e. firms and speculators. Then welfare is a monotonous increasing function of the risk bearing capacity of the market and the price of permits reflects social marginal damage. The agency should allow speculators and take all measures that increase their activity on the permits market. In the second case, the agency's risk tolerance is exogenous. Then welfare is no more a monotonous increasing function of the risk bearing capacity of the market. The agency should only accept speculators as far as its risk tolerance is higher than the firms' risk tolerance, and under the condition that the speculators do not increase the risk bearing capacity of the market too much.

2.2 Taxes, tradable permits and innovation

A survey of the literature entitled « Comparaison des propriétés des taxes et des permis négociables. Revue de la littérature. » has been published as CLIMNEG WP 70. In this survey, taxes and permits are firstly compared in a static basic framework, i.e. without pollution accumulation. Several extensions to the basic model are then reviewed : (i) combination of instruments, (ii) dynamic context (stock pollution), (iii) technical innovation, (iv) models with entry/exit of polluting firms.

An important element which must be accounted for in the comparison of the two instruments is the level of innovation they induce. The literature on the impact of economic instruments (typically taxes and tradable permits) on the level of innovation is usually based on the assumption that innovation reduces the slope of the marginal abatement cost curve. This assumption, which usually leads to the conclusion that taxes induce higher levels of innovation than tradable permits, is however never motivated. In CLIMNEG WP 80 (also available as CORE DP 2005/76), entitled "Innovation under taxes vs permits : How a commonly made assumption leads to misleading policy recommendation", we analyse the assumption by introducing innovation in the production function of a polluting firm and by showing how it affects the corresponding marginal abatement cost curve. We show that the slope of the marginal abatement cost curve does not necessarily decrease with the level of innovation. As a consequence, previous analyses lead to misleading policy recommendations.

Finally, we were concerned by the comparison of taxes and permits in a dynamic setting. Different papers (a.o. Hoel and Karp (2002), Newell and Pizer (2003)) have shown that taxation would be a better instrument to mitigate climate change. Nevertheless they rely on the assumption that the choice of the instrument is made once and for all at the beginning of the planning period. Only the level of the instrument (taxation rate or quantity of permits) is endogenous through time. In CLIMNEG WP 82 (also available as CORE DP 2005/64) entitled "Prices vs quantities : stock pollution control with repeated choice of the instrument", one examines strategies of pollution control through choices between taxes and tradable permits, supposed to be decided at several time periods. The regulatory authority and the polluters have asymmetric information about abatement costs, and environmental damages are due to a pollutant that accumulates. At each period of time, the regulator chooses the type and the level of the instrument that maximizes a welfare functional depending on the expected flow of production minus damage costs, taking in account the expected answer of the polluters to the chosen environmental policy. We depart from the literature by allowing the possibility of switching between instruments at each period, by considering finite as well as infinite horizon frameworks, and by considering a more general formulation of the regulator's objective and of the pollutant accumulation. We do not restrict ourselves to the infinite horizon case studied in the above mentioned literature where the choice of the instrument appears to be constant through time, and we show in the finite horizon case that permits are decided for a while, followed by decisions of taxes for all the remaining periods.

3 INDUSTRIAL ACTIVITY EFFECTS OF CLIMATE CHANGE POLICY INSTRUMENTS

The effects of different climate change policies on industrial activity and on welfare in the EU countries are examined with the general equilibrium model GEM-E3. The policy instruments considered are domestic permits, EU wide permits and carbon taxes recycled via higher transfers or via lower social security contributions. The impact of exempting the energy intensive industry in Belgium is also considered.

3.1 The baseline emission scenario

The total emission reduction effort that is necessary in 2010 will depend on two elements: the burden sharing among EU countries and the autonomous "baseline" development of emissions. The burden sharing has been agreed in 1998 and specifies that emissions have to be reduced in each member country by a given percentage compared to emission levels of the year 1990.

The baseline scenario is obtained by running GEM-E3 without carbon abatement policies and with assumptions on expected economic growth and on energy price and energy efficiency developments. It generates an expected carbon emission level for 2010 for each member country. Comparing this baseline emission level with the politically agreed maximum emission level (1990 level minus the percentage specified in the burden sharing agreement) gives the percentage reduction that is needed in 2010 to comply with the Kyoto target. This is the percentage in the first line of Table 1.

3.2 Comparing national tradable permits with EU-wide permits

We analyse the effects of two harmonised policies: national tradable permits and an EU-wide permit system. The results are given in Table 1 In the domestic permit system permits are grandfathered proportionally to emissions in the past. For the EU permit the allocation between countries follows the burden sharing agreement. In the welfare costs we disregard any environmental benefits.

A domestic permit system will lead to different equilibrium permit prices in the member states: in the different scenarios CO_2 permit prices vary between more than 100 Euro/ton to less than 1 Euro per ton. As the marginal production costs of all firms will contain an abatement cost term and a permit cost term the marginal costs of energy-intensive sectors is also increased unequally and this will affect their output levels. The effect on industrial activity for the energy supplying sectors (except electricity) will be driven by the overall decrease in demand for energy products (domestic as well as foreign and by industry as well as other sectors like transport and households). For products such as coal, the overall demand effect is strongly negative in all member countries because substitution of coal by gas and oil is one of the cheapest options to reduce CO_2 emissions. The demand effect will also be dominant for the other energy sectors but will be less pronounced because some sectors may benefit by moving away from coal.

The EU Commission has proposed[7] a restricted EU-wide trading scheme for CO_2 permits. It is clear that the difference in emission reduction costs between member countries calls for an EU-wide trading scheme. We discuss here the effects of an EU-wide permit scheme for all sectors[8]. We restrict the trade in emission rights to the EU. In fact, the Kyoto-agreement allows trade within a much wider group of countries. Our results are therefore to be

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[7] See COM (2001) 581 final. The trade in emissions started in 2005. We present model results for 2010 when the scheme is supposed to be working at full regime.

[8] The differences between the schemes we discuss and the restricted scheme cannot be very large because a combination of a domestic permit trade for all sectors and an EU-wide scheme restricted to some sectors would, in the absence of transaction costs, generate end results that are close.

considered as an upper bound estimate of costs and effects because they neglect interesting low cost abatement possibilities in other Annex B countries.

An EU-wide permit trading will equalize the permit prices and will smooth the effects on the marginal production costs across the EU. This will in principle result in smaller variations of activity levels across the EU member states for every sector. Table 1 reports the results per sector.

% differerence with reference	*Domestic permits*		*EU-wide permits*		*Domestic permits with exemptions in Belgium*	
	EU	Belgium	EU	Belgium	EU	Belgium
CO_2 emission	**-12.6**	**-19.2**	**-12.6**	**-19.2**	**-12.6**	**-19.2**
Coal	-16.2	-31.8	-22.6	-32.1	-16.6	-16.6
Oil	-9.3	-6.4	-5.7	-6.1	-21.0	-21.0
Gas	-4.6	-1.2	-2.8	-1.2	-6.2	-6.2
Electricity	-2.4	-2.1	-2.5	-2.1	-2.5	-2.8
Ferrous & non-ferrous metals	-1.7	-2.3	-1.5	-2.4	-1.6	-1.3
Chemical	-0.9	-0.9	-0.6	-0.9	-0.9	-0.9
Consumer goods	-0.7	-0.4	-0.4	-0.5	-0.8	-3.0
Welfare	**-0.26**	**-0.11**	**-0.11**	**-0.04**	**-0.3**	**-0.4**

Table 1. Effects of a domestic permit system, an EU-wide emission permit market system and a domestic permit system with exemptions

With this policy instrument, emissions of CO_2 can be reduced at relatively low cost: for the EU the reduction of welfare would be limited to -0.11 (before taking into account the benefits of lower climate change damage). With the EU-wide permit system, Belgium would reduce emissions more than other EU 15 countries mainly through a contraction of its energy intensive industries. The ultimate economic welfare effect on Belgium remains small.

3.3 Effects of industrial exemptions in one member state (Belgium)

Several industries and in particular the energy–intensive industries want an exemption from emission reduction obligations. It is clear from the outset that a general exemption at the EU level is not very cost-effective as total efforts will then be concentrated in a much smaller group of polluters. Here we test what would be the effect if the industrial lobby within one country gets such an exemption for its sector. We analyse the case where Belgium exempts its energy intensive industries[9] from greenhouse gas emission obligations. The exemption can very well take the form of a policy instrument like a voluntary agreement that is less strictly enforced. We focus on domestic permit systems, since these offer more scope for unilateral policies. Moreover, compared to EU permit trading, domestic permit policies will show more extreme results as there is no dampening of domestic permit prices in a wider market. In the case of an exemption of these sectors in Belgium, the non- exempted sectors receive less domestic permits and consequently have to make larger abatement efforts.

[9] Among others, this includes electricity, ferrous and non-ferrous metals, and chemical products.

In Table 1, we see that some energy–intensive sectors (ferrous and non-ferrous metals) have a smaller loss in activity with exemptions than without exemptions (compare second column with sixth column in Table 1). The reason is that a small country is much more geared to export markets so that their gain on export markets is only partly balanced by their loss on the home market (due to overall effect of lower economic activity of other sectors). Although there may be a gain in activity for some sectors, the welfare effects of exemptions are particularly negative in Belgium: welfare decreases by 0.4% rather than by 0.11% in the no exemption domestic permit case. Also for the EU as a whole, there is now a negative welfare effect associated with this exemption within Belgium. Belgium has indeed managed to shift part of the burden to the rest of the EU.

Task III Integrated Assessment Modelling

1 INTRODUCTION

In the task description of the Climneg 2 project, it was foreseen that economists and climatologists would work on a further integration of the existing economic and physical models, in the form of soft links between the CWS-model and a physical climate model such as the Mobidic model.

During the Climneg 2-project the strategy was changed. Instead of looking for a soft integration of economic and physical models, we opted for a fully integrated model based on the JCM model. Previous versions of the JCM model looked at the physical aspects of climate change, now a new economic module would be added. As a result, the consortium decided to stop the work on the CWS-model.

Moreover, as Johan Eyckmans and Greta Coenen both left the CES-group, some of the expertise on the CWS-model had left the CES and it was unclear whether the CWS-model would have a future when the Climneg 2 project would be finished.

Next to extending the JCM-model, the consortium also updated GEM-E3 model, a General Equilibrium Model of the world economy. The output of this model was used to calibrate the economic cost functions of the JCM-model and to look some more specific analysis of different burden sharing agreements.

The emphasis of the third task was on the following topics:

- To study different stabilization scenarios and the impact of uncertainty
- The analysis of different burden sharing agreements
- Optimal emissions paths when there is uncertainty

2 EXTENSION OF THE JCM MODEL

2.1 Context within the Climneg-2 workplan

The principal role envisaged for climatologists (ASTR) in Climneg-2 was to investigate stabilisation scenarios, and to explore coupling of more complex climatic and economic models.

Since any chain of integrated assessment is only as strong as its weakest link, we therefore started by looking for the factors to which the results may be most sensitive, and focussed more effort on these. Essentially the purpose of a climate module in a model such as CWS is not for predicting global average temperatures, but for allowing combining abatement and impact costs in an optimisation framework. Reviews of relevant literature and models suggested that the results were likely be more sensitive to factors which had not been included in the original workplan, particularly the step from global average temperature to impacts and impact-costs, and the (lack of) inclusion of uncertainty along several steps of the cause-effect chain. Factors such as the socioeconomic baseline (without policy) and the abatement cost formulae may also make a larger difference than the steps between emissions and global temperature (at least for a best-guess model). Therefore it was considered appropriate to extend the original workplan, and to examine further the sensitivity to all of these factors, using the interactive Java Climate Model (JCM), developed by Ben Matthews in UCL-ASTR (and earlier in KUP Bern, UNEP-GRID Arendal and DEA Copenhagen), as described further below.

2.2 Making risk analysis more transparently

There are many uncertain factors in the climate system from emissions to impacts, including biogeochemical cycles and feedbacks, aerosol forcing, climate sensitivity including cloud and ice processes, and inertia in ocean-mixing and ice-melting. Better understanding of some processes reveals others which add to the system complexity. As the problem will not disappear, we must develop strategies for coping with this cascade of uncertainty in integrated assessment (IA) of climate change.

Recognising that one "best-guess" model is insufficient, IPCC Third assessment report (TAR, IPCC, 2001) presented projections based on a range of models and scenarios (for example 7 general circulation models (GCMs) and 6 scenarios from the IPCC Special Report on Emission scenarios (SRES, IPCC, 2000), a range which is much wider than the shift of the average scenario between the IPCC second assessment report (SAR) and the TAR. New science evolving towards the fourth IPCC assessment (AR4), is increasingly adopting a probabilistic approach, in which each model variant is given a weighting, often derived from the correlation between model calculations and historical datasets. Reviewing such methodology in the scoping papers for IPCC-AR4 cross-cutting themes ("Article 2 and Key Vulnerabilities", "Risk and Uncertainty", and "Integrated Assessment of Mitigation and Adaptation") has naturally influenced our ideas for future work in Climneg.

So the "state of the art" of IA has become a risk analysis approach, in which we integrate the product "impact x probability" (e.g. Leggett, *et al., 2004*). This accounts both for low-probability high-risk 'catastrophes' which may be the greatest cause for concern about climate change, and also for the effect of skewed probability distributions of key parameters such as climate sensitivity which, combined with nonlinear impacts functions, may lead to a greater expected impact than an equivalent best guess model. On the other hand, the increased complexity as IA moves to risk analysis is likely to exacerbate the problem of lack of transparency, especially regarding the effect of controversial valuation and aggregation assumptions. Thus we have a challenge to make IA simultaneously more complex and more transparent.

The Java Climate Model is particularly suited to this task, since it was designed to be interactive, hence rapidly responding and easily adjustable, whilst at the same time implementing the core scientific formulae behind the IPCC-TAR projections. The complexity of JCM's biogeochemical and global climate system modules is much greater than that of typical economic IA models. Another particular feature of JCM are its flexible scenarios for stabilising any indicator, which may be combined with formulae for distributing emissions between regions, in an inverse calculation.

In the framework of CLIMNEG-2, the carbon cycle and climate components of JCM were extended to allow a probabilistic approach (section 3.3), and combined with new socioeconomic costs and optimisation modules. This enabled an original discussion of stabilisation scenarios (section 4), preliminary experiments regarding optimisation under uncertainty (section 6), and investigation of regional responsibility for climate change (section 7). Recent model improvements (section 9) also paved the way for a better representation of regional climate impacts and their aggregation over sectors, regions, generations, and probability, which is arguably the weakest link in the chain of IA.

Impact valuation and aggregation to a single monetary index may hide controversial risk and value judgements, which has led to much criticism of the cost-benefit (or welfare) optimisation paradigm (e.g. Schneider, 1997) which is central to many economic models. Although using an interactive model helps in this regard, by allowing the user to explore the sensitivity to key assumptions, we should also consider some alternative integrating paradigms.

Another approach is to create tools for multi-criteria analysis to inform stakeholder dialogue, assuming that the ultimate "integrated assessment model" remains the global network of human heads. However, global climate change is so complex that we need ways of reducing the dimensionality of the problem. One suggestion was the "tolerable windows" or "guardrail" approach developed at PIK (Potsdam)(e.g. Bruckner *et al.,* 2003), in which the stakeholder dialogue focuses on identifying some critical thresholds beyond which climate change impacts become unacceptable, and models are used to calculate the range of pathways which meet these requirements. However, when the cascade of uncertainty is taken into account, we find we cannot be 100% certain to avoid any serious impact thresholds, so it becomes necessary to attach acceptable probability levels to each impact ("fuzzy guardrails"). These arbitrary probabilities effectively weight different impacts, similarly to the monetary valuation of the cost-benefit approach and thus it seems that as the analyses become more complex, the guardrail and risk-analysis approaches would converge and have similar modelling requirements.

3 JCM METHODOLOGY

3.1 JCM core science

JCM implements models and formulae very similar to those used by IPCC for the core TAR projections, including an efficient implementation of the upwelling diffusion-energy balance (UDEB) climate model fitted to a range of seven GCMs, as described in IPCC-TAR (Chapter 9 Appendix 1 of WG1) (see also Raper *et al.* 2001).

JCM's carbon cycle copies the Bern model (Joos *et al*, 2001 and 1996), combining the HILDA ocean including non-linear carbonate chemistry with a temperature feedback (exactly as in IPCC-TAR), plus a 4-box biosphere responding to carbon fertilisation. The changing carbon contents of the boxes are shown in Figure 4 (top left). An extra feedback from temperature on soil respiration was added by adapting a simple "Q10" formula proposed by Jones *et al.*, 2003 (whereas Bern-TAR used the complex but slow LPJ model for climate-vegetation feedback).

JCM also includes many other greenhouse gases: CH_4, N_2O, 9xHFCs, 2xPFCs, SF_6, 14x CFCs, stratospheric ozone, and tropospheric ozone (affected by emissions of CO, VOC, and NO_x). To derive concentrations and radiative forcing, atmospheric chemistry formulae are used as in IPCC-TAR, including the feedback on the lifetime of CH_4, HFCs, CFCs etc. due to changing atmospheric OH concentration.

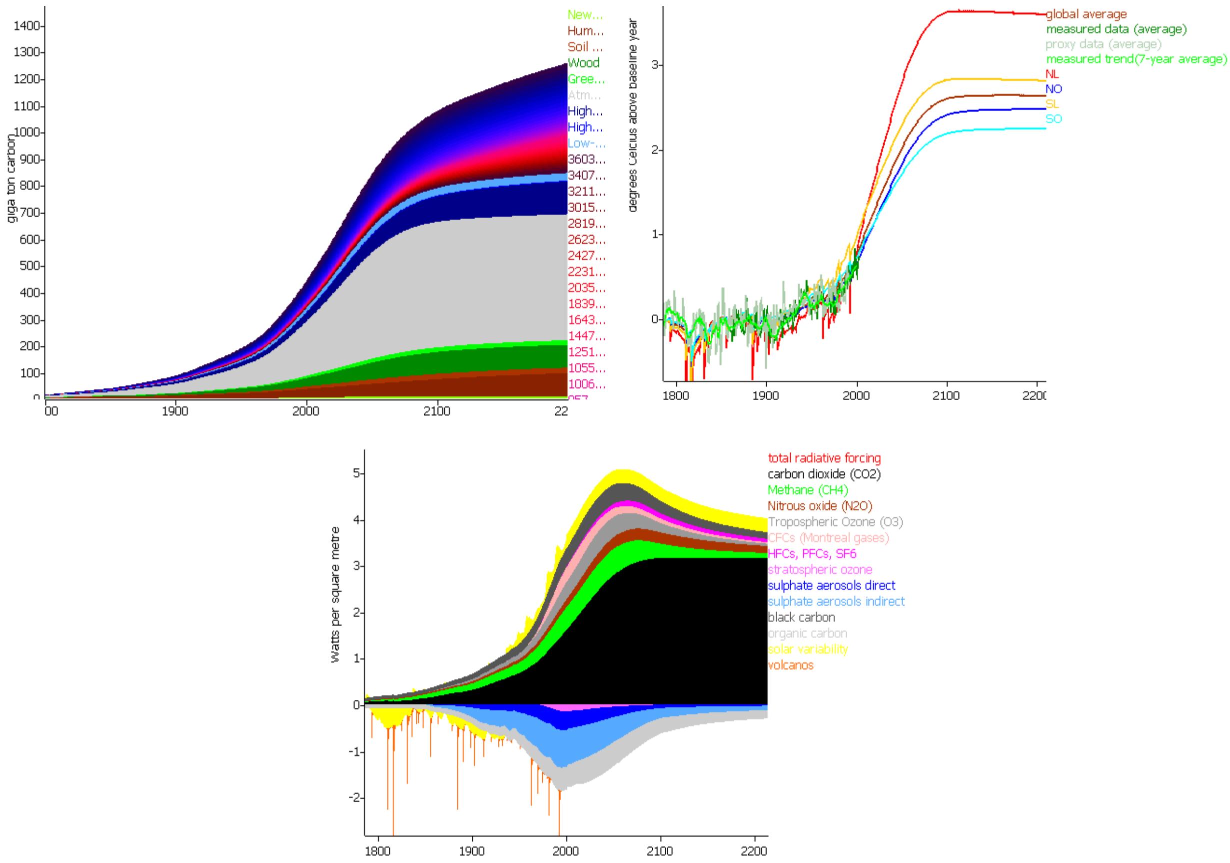


Figure 4: JCM core science.

Top-left: storage of anthropogenic carbon in the ocean (blue <=> red, many layers), atmosphere (grey), and biosphere (green/brown). Bottom: radiative forcing from all gases and aerosols. Top-right: global average temperature rise (brown), plus historical data (green). Averages for north-land, south-land, north-ocean, south-ocean are also shown. All plots show a scenario where CO2 is stabilised at 500ppm.

JCM also includes radiative forcing due to solar variability and cooling by sulphate aerosols (including their indirect effect on clouds). Figure 4 (bottom) shows the radiative forcing from all of these sources, whose combined effect gives a good fit to the historical temperature measurents (top-right).

3.2 Baseline Scenario Extension

The baseline emissions and socioeconomic driving forces are taken from the six IPCC-SRES “no climate policy”marker scenarios, using data from IMAGE model (Eickhout *et al.*, 2004) for the breakdown to 12 regions. To calculate an optimal mitigation pathway (discussed later), it is necessary to extend these scenarios over a longer time horizon. Therefore, these scenarios were extended from 2100 to 2300, by extrapolating regional trends of population, GDP/capita, and emissions/GDP, using exponential fits to the data from IMAGE (from 2050-2100; Eickhout *et al.*, 2004). The resulting functions are presented in Figure 5. Beyond 2200 population and emissions start declining even in the most extreme scenario (A2), whilst for SRES scenarios B1 and A1T the CO2 concentration also declines. Steps from emissions to concentration, radiative forcing and temperature are calculated as above.

The blue curve B2 was the default case used in most later figures, because it is the closest to current trends, especially considering the relatively slow growth of emissions between the creation of SRES and 2003. Minimising the gap between the actual emissions and the start of scenarios is important to avoid "hot air" mitigation costs. It is instructive to compare with equivalent no-policy baselines from CWS. For example, in Climneg WP57 (Eyckmans and Finus, 2003), global CO_2 emissions are 40 and 62 GtC in 2100 and 2200 respectively, higher than all curves in Figure 5 (note even the optimum policy scenario ("SOCIAL"), with 24 and 21 GtC for these years, is higher than 4 out of 6 SRES baselines)[10] . On the other hand, the GDP of CWS is in the middle of the SRES range, so it seems that a much lower reduction in emissions intensity (due to technological change) than SRES has been assumed in CWS. This single factor may explain a large part of the lower optimal concentrations / temperatures in JCM compared to CWS (as discussed later).

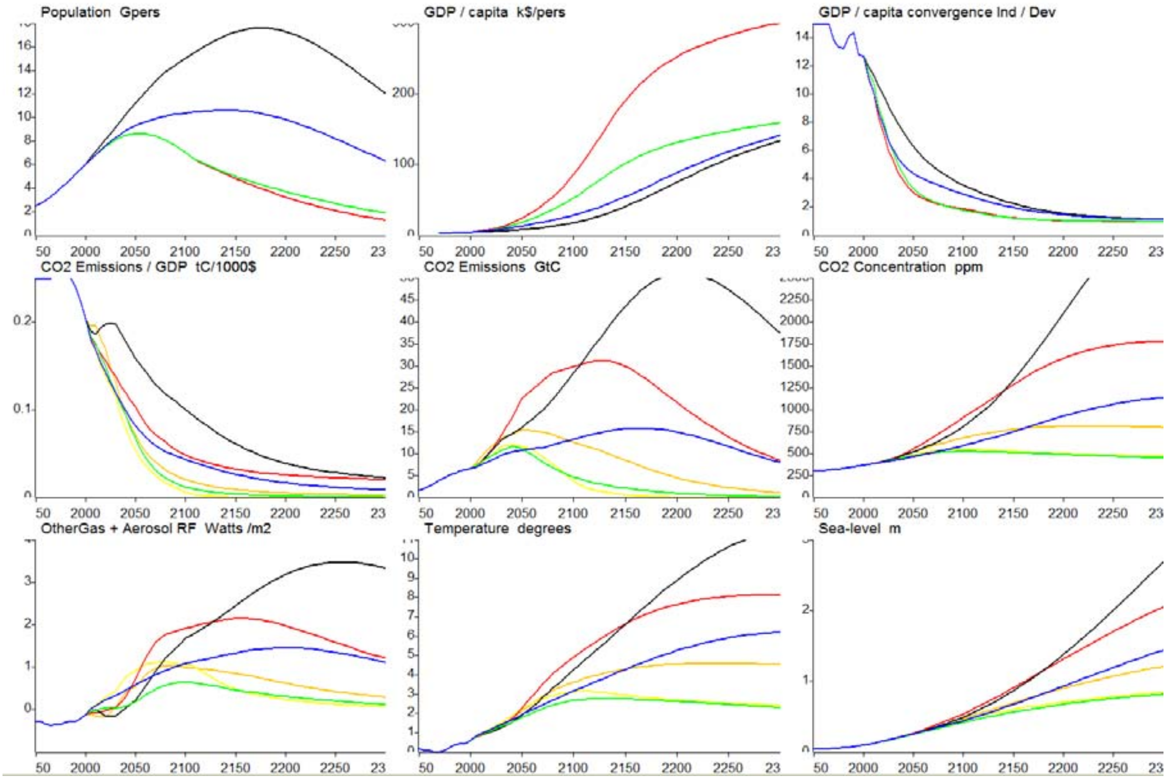


Figure 5: IPCC SRES baseline scenarios, extended by JCM beyond 2100

Black=A2, Blue=B2, Red=A1F, Orange=A1B, Yellow=A1T, Green=B1.
Top row: socioeconomic driving forces (note A1F=A1B=A1T), population, GDP/capita, and convergence of the ratio of industrialised /developing country GDP/capita. Centre row: CO2 emissions and concentrations. Bottom row the radiative forcing from other gases, temperature and sea-level rise.

3.3 Probabilistic methodology

The general principle is to calculate a relative probability for coherent sets of parameter values, based on the fit of model calculations to historical measurements, and then to apply these in future projections to calculate a probability distribution from the ensemble of sets. More details were given in previous CLIMNEG-2 reports.

[10] It should be noted that Eyckmans and Finus (2003) main purpose is not to determine a quantitative optimum, but to study how transfer schemes can facilitate stable coalition structures generating high global welfare.

3.3.1 Carbon cycle and other greenhouse gases

Parameters of carbon cycle models may be constrained by inverse analysis to fit historical measurements and current flux calculations. The change in the atmospheric concentration of CO_2 can be measured precisely. Historical emissions of CO_2 from fossil fuel burning are relatively well known, although those from land-use change are highly uncertain. Net fluxes into the ocean and terrestrial biosphere are difficult to measure directly due to high spatial and temporal variability, however over the longer term the ocean sink may be constrained by physical mixing and chemical buffering processes. However, the *breakdown* of the net terrestrial flux into gross fluxes of land-use emissions, additional photosynthesis due to "carbon fertilisation", and additional respiration due to climatic feedbacks, remains poorly constrained. The respiration source also lags behind the photosynthesis sink, since temperature rise lags behind CO_2 rise due to inertia in ocean heat uptake, and so the net balance of these two feedback effects changes over time, and is the greatest source of uncertainty in future CO_2 projections.

Thus the probability distributions for each factor are not independent, and so it makes sense to analyse *coherent sets* of parameters. In the stabilisation study (next section) 81 variants of the carbon cycle were considered, combining three variants of each of the following four parameters: historical land-use changes, CO_2 fertilisation, temperature/soil respiration feedback, eddy diffusivity in the ocean.

For each combination, a relative probability was derived from the inverse of the sum of root-mean square differences between the model calculations and historical CO_2 concentrations (with a greater weighting since 1950 when direct measurements began at Mauna Loa). For example, a relatively higher score would be given to combinations in which a high fertilisation factor (more sink) is offset by either a slower ocean (less sink). Historical land-use emissions do evidently not have a direct effect on the future, but they also affect the probability of each variant, including for the future.

For the other greenhouse gases (CH_4, N_20, etc., see above), emissions were taken either from SRES baselines or, in the case of stabilisation scenarios, mitigated by the same proportion as CO_2 with respect to one of these scenarios. As their principle sink is by chemical reaction in the atmosphere, the relationship between emissions and concentrations is simpler than for CO_2. The lifetime of these greenhouse gases also involve uncertainties, but their impact on future climate projections is considnered to be small compared to that of carbon cycle uncertainties, and so in this analysis the corresponding parameters have not been varied.

The relationships between concentrations and radiative forcing of greenhouse gases are relatively well known, as radiative transfer is an instantaneous process. These formulae are taken directly from IPCC-TAR, and uncertainties are not considered.

3.3.2 Sulphate/solar forcing and climate response

Sulphate aerosols reflect sunlight, both directly and via an indirect influence on cloud formation, and thereby contribute a large (but short-lived and regional) cooling effect. The magnitude of this negative forcing is not well constrained by measurements, and is a major source of uncertainty in both historical attribution and future projections. The other major uncertainty in historical radiative forcing is from solar variability. Although the variation in energy received from the sun is itself very small, various feedback mechanisms have been postulated which may amplify this effect.

For the probabilistic assessments, the climate model sensitivity (i.e. temperature elevation corresponding to a given forcing change) must be constrained according to its likelihood with comparison to historical data. The uncertainties in historical aerosol and solar forcings complicate the application of historical temperature data to compute probabilities. It is necessary to seek coherent sets of parameters, varying sulphate and solar forcing alongside the climate model response.

In the stabilisation study, 84 variants of the forcing-climate system were considered, combining: 7 sets of climate model parameters (UDEB model, climate sensitivity and ocean mixing/upwelling rates), 4 variants of sulphate forcing, and 3 variants of solar forcing.

For each combination, a relative probability is derived from the inverse of the sum of root-mean square differences between the model calculations and measured temperature changes (post 1865, from Jones *et al.,* 1999 or proxy data (prior to 1865, from Mann, *et al.*, 1999), with weights reflecting the changing uncertainty in the measurements.

For example, a relatively higher probability is associated to sets where high climate-sensitivity is offset by high sulphate cooling, or vice versa. The resulting distribution is narrower than if parameters were varied independently. However, the distribution is not smooth due to the 7 sets of GCM parameters - without this constraint the range of sensitivities consistent with measured temperatures could be much wider, (e.g. Knutti, *et al.* 2002, Meinshausen, *et al.,* 2005). A recent study varying many parameters in a GCM (Stainforth, *et al.,* 2005) found that sensitivities as high as 8°C are physically plausible.

Carbon aerosols also contribute a significant and highly uncertain forcing (although at present the warming from black-carbon and cooling from organic-carbon largely offset each other). These effects are included in the model, but not yet varied. Forcing from volcanic dust, which caused a significant but temporary cooling following each major eruption, is also included.

The sets of parameters derived from GCMs also affect the sea-level rise, due both to thermal expansion and ice-melt processes, and are consistent with IPCC-TAR projections to 2100. However, the contribution from melting polar ice-caps over longer time horizons is especially uncertain, and this is still an area for further model development.

3.3.3 Combination of probabilities

Carbon-cycle variants (section 3.3.1) are combined with forcing-climate variants (section 3.3.2), by multiplying their relative probabilities. Combinations with probability below a threshold level are rejected (this is inevitable because we cannot sample over an infinite parameter space). The remainder (468 out of 6804 variants) were used for analysis of future projections.

Note that in principle the relative probabilities of carbon-cycle and climate-system parameter sets are not independent, since there are feedbacks between the temperature and the ocean chemistry and soil respiration. However, treating them as independent saves considerable calculation time, and the effect of this slight incoherency is judged to be small.

4 STABILISATION SCENARIOS UNDER UNCERTAINTY

The long term aim of the UNFCCC convention, specified in its article 2, is to "stabilise concentrations of greenhouse gases in the atmosphere at a level which will prevent dangerous anthropogenic interference with the climate system". Analysis of stabilisation scenarios was specified in Task 3A2 of Climneg.

4.1 Generic stabilisation curve

A simple yet flexible formula was developed for defining stabilisation scenarios for either CO2 concentration, radiative forcing (including all gases), or temperature. Curves are a ratio of two polynomials constrained by both initial and final concentrations, their gradients and second derivatives, thereby ensuring a smooth emissions profile. This extends the formula used by Enting *et al.* (1994) for the IPCC "S" scenarios (later evolving to the WRE scenarios), by allowing the final concentration gradient to take any value, in order to achieve constant forcing or temperature. Beyond the "stabilisation year" curves were extended using an extra quadratic curve. To achieve stabilisation of either forcing or temperature, an iterative algorithm was used to find the best concentration profile, and from there the carbon cycle was inverted to find corresponding emissions pathways, by guessing that the ocean and biosphere sinks will change by the same amount as in the previous year (any error being corrected in the next year). This algorithm is efficient as only three parameters are adjusted, whereas optimising a curve defined along timesteps is much slower. It is therefore convenient for both an interactive tool, and a systematic probabilistic analysis.

4.2 The EU 2°C target and "Shifting the Burden of Uncertainty"

In 1996 the European Union Council of Ministers interpreted Article 2 by stating that global average temperatures should not exceed 2 degrees Celsius above pre-industrial level. This objective remains central to policymakers discussion of long-term climate policy. In response, JCM was used to investigate the relationship between the temperature and concentration, and the implications for emissions. Thousands of model variants, as described above, were applied to each of four sets of stabilisation scenarios defined either by emissions, CO2 concentration, radiative forcing or temperature.

The result is shown in Figure 6. The transitions between columns illustrate the effect of model uncertainties in (going from left to right) the carbon cycle, forcing of other gases/aerosols, climate sensitivity, and ocean mixing/ice-melting. The four scenarios (rows of plots) were chosen such that the average temperature in 2150 is almost the same for each set; these are:

- an emissions scenario (TGCIA450, Swart, *et a,,*. 2002)
- stabilisation of CO2 concentration at 475 ppm
- stabilisation of radiative forcing (all gases) at 3.5 W/m2
- stabilisation of temperature at 2°C above preindustrial level.

The choice of stabilisation indicator makes a big difference to the uncertainty ranges. It is evident, that choosing a temperature target rather than a concentration target reduces the uncertainty regarding impacts / adaptation, but increases the uncertainty regarding emissions mitigation pathways (assuming we commit to adjust emissions to stay below the limit, as the science evolves). Which uncertainty is preferable is a value judgement, which would also be expected to vary by region.

Versions of this figure illustrating the shifting burden of uncertainty were presented by Ben Matthews and Jean-Pascal van Ypersele to policy makers at several occasions in 2003 (e.g., World Climate Conference in Moscow, "Climate Policy after 2012" conference in Ghent, European Climate Strategy meeting in Firenze).

According to our results (Matthews and van Ypersele, 2003), having at least 50% chance of staying below the EU's 2°C limit requires a stabilization of CO_2 concentration below 450 ppmv, whilst the level of 550 ppm CO_2 specified in the original policy statement (based on older IPCC-SAR science) now seems extremely optimistic, giving a 90% chance that the 2°C limit would be exceeded. This conclusion is consistent with other recent analyses such as those of Grassl et al. (2003; WBGU, Germany), Meinhausen (2005), Jones (20004, Australia), MIES (2004, France).

Note that a stable CO_2 concentration corresponds to a slightly declining radiative forcing (or "CO_2 equivalent" concentration), but an almost stable temperature. This is due to the decline in CH_4 and O_3 (due to their short lifetimes), offset (coincidentally) by the inertia in ocean heat uptake. The latter is much more apparent in the sea-level rise.

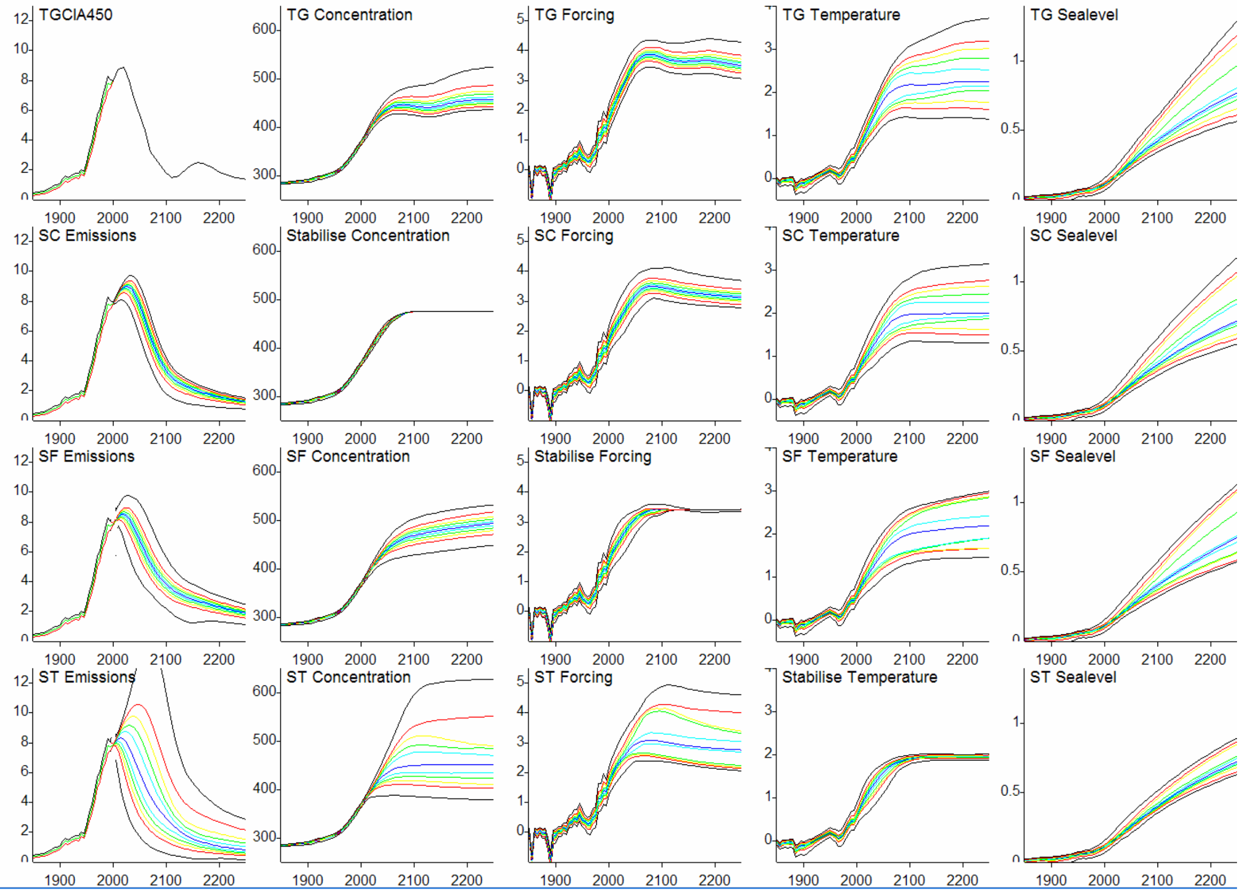


Figure 6: Stabilisation under Uncertainty

The plots show (from left to right) CO_2 emissions (GtC, including land use change), CO_2 concentration (ppm), radiative forcing (Wm^{-2}, including all gases, aerosols, solar and volcanos), temperature (°C), and sea-level rise (m).
Four sets of scenarios (from top to bottom) show the "TGCIA450" emissions scenario (Swart, *et al.*, 2002), stabilisation of CO_2 Concentration at 475 ppm, of radiative forcing at 3.4 Wm^{-2}, and of temperature at 2°C above pre-industrial (the EU's proposed limit for future warming). The mean temperature is the same for each set, but the uncertainty ranges are very different. The curves show bands of 10% cumulative frequency, for example we have an 80% chance to be below the third curve from the top. Probabilities where calculated for 40824 variants on the basis of the consistency between the model and historical records of temperature and atmospheric CO_2.

5 ECONOMIC THEORY: OPTIMAL EMISSION PATHS UNDER UNCERTAINTY

Johan Eyckmans, Jean-Pascal van Ypersele and Bert Willems wrote an introductory article on the optimal emission path in a world with uncertainty and learning. (Eyckmans *et al*. 2005).

The aim of the article is to demonstrate how integrated assessment models, which combine stylized representations of the physics and economics of the problem, can be used to design long-term climate policy. The main questions addressed are: (i) What is the optimal, global emission ceiling? (ii) What is the optimal timing of emission abatement efforts in order to achieve this global ceiling? And (iii) how does uncertainty affect the answers to these questions?

Designing optimal long-term climate policy is complicated because of the very nature of the problem. A first complication is that the climate change problem is characterized by major *irreversibilities*. Some of the greenhouse gasses which we emit today will remain in the atmosphere for several hundreds of years. Their natural decay rate is small, and once emitted, it is very costly to reduce their concentrations in the atmosphere in the future. Also with regard to the economics, irreversibility is an important issue. Committing resources today to developing new, low-carbon energy technologies implies that these resources cannot be used for other purposes. The article shows that both irreversibilities play an important role in designing climate policy.

A second complication is that there are a lot of physical and economic *uncertainties* concerning key parameters of the climate change process and future economic development. On the physical side, climate sensitivity to changes in atmospheric greenhouse gas concentration and the regional distribution of climate change impacts are subject to considerable uncertainty. On the economic side, costs of emission abatement, and the damages for society of a changing climate, are only known within wide bounds.

A third issue is that uncertainty is not constant. As time passes, we will gain new insights into the physical processes of climate change; we will have better estimates of the costs of new technologies to reduce emissions, and of the cost of protecting ourselves against damages caused by a changing climate. Therefore, this *learning* process will have to be taken into account in an integrated assessment model.

The article shows that uncertainty affects the optimal emission path in two ways. First, because people are risk averse, more ambitious reduction targets should be set today in order to prevent catastrophic events in the future. Secondly, the design of current climate policies should take into account that future generations will have learned about the crucial parameters and will therefore be able to make decisions with less uncertainty than current generations. According to most numerical simulations presented in the literature, this learning effect allows generation 1 to emit more compared to a best-guess approach without learning. It is clear that these results depend on the assumptions one takes. Under different assumptions, the results will be different as well.

6 OPTIMISATION UNDER UNCERTAINTY: JCM

The objective of optimisation is to maximise a global welfare function, or in practice to minimise the total welfare change due to costs of emission abatement and impacts. First steps towards an implemention of a cost optimisation methodology have been included in JCM as a contribution to Climneg-2 (see introduction). Our principal aim was not to duplicate complex economic models inside JCM, but to bring the insight of JCM regarding the consequences of uncertainties in the carbon/climate components to economic studies. The results shown here are similar to those reported at an integrated assessment workshop in Trieste (Matthews, 2004).

6.1 Methodology

Welfare changes due to both climate change impacts and emissions abatement efforts are computed over a set of regions (eg 12 or 25 -this can vary) and integrated over time and over probability (in some cases). As a first step, climate impacts functions were taken from RICE99 (Nordhaus and Boyer, 2000), and marginal abatement curves were taken from MACGEM (provided by our partners in KULeuven). We are aware of the limitations of such functions, and intend to make disaggregated impact functions later, as discussed in section 6.

Regarding the abatement costs, during 2003-4 Ben Matthews has participated in three meetings of the Innovation Modelling Comparison Project (IMCP), contributing to the project design regarding the definition of scenarios with non-CO_2 gases, and the consideration of uncertainty. From this we have learned the importance of a disequilbrium approach with endogenous and induced technological change, taking into account "learning by doing". Initial results show that this may reduce mitigation costs very substantially, particularly for low stabilisation levels. In order to explore the sensitivity to this factor, cost functions in JCM were tuned by a simple statistical fit to the results from the 10 models summarised by Edenhofer and Lessman (forthcoming) as shown in figure 8d.

Welfare changes are defined as a nonlinear function of consumption, using an elasticity of marginal utility of income equal to 1. This approach, sometimes referred to as "equity weighting", is becoming generally accepted for this type of analysis, as discussed, for example, in a recent European Commission report (Watkiss, *et al.,* 2005). Without equity weighting, contingent valuation of impacts would effectively imply "one-dollar-one-vote", thus reducing the relative importance of poor countries, while setting this parameter to one corrects this to "one person-one-vote". Since this analysis with JCM considers only the point of view of a global decision-maker aggregating in a consistent way over space, time and probability, the elasticity of marginal utility of income is effectively the same as both "inequity aversion" and "risk aversion". It also affects the integration over time, such that the effective discount rate (or social rate of time preference) is a combination of the inequity aversion, the growth rate, and the pure rate of time preference (by default 1.5%). This allows discount rates to be higher in regions with high growth, and declining as economies approach stabilisation, which reflects reality. As these aggregation parameters are inherently value judgements, it is useful that the interactive model enables users to explore the sensitivity to such assumptions, which is also illustrated by plots 8p and 8q below. The integration of welfare is illustrated by the plots in figure 7. From these it is evident that while moving from a no-policy to a policy scenario shifts the bulk of the welfare loss from the future towards the present, the integrated welfare loss is still greater in the no-policy scenario. Note that the effect of climate change on welfare is greatest in the poorer countries, especially India and Africa – this is a consequence both of assumptions in the cost functions and of using equity weighting (which applies to both climate impact and mitigation costs).

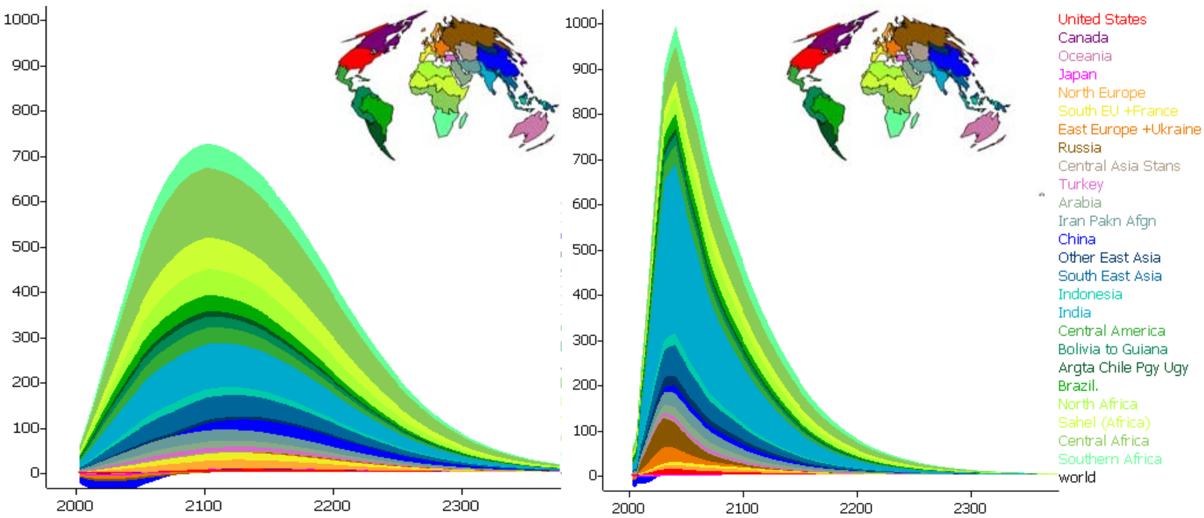


Figure 7: Integrating net welfare change over space and time

Net welfare loss taking into account both climate impacts and abatement costs, adjusted to present value, for 25 regions as in the map, for a no-policy scenario SRES B2 (left) and a scenario stabilising temperature at 2°C (above 1850) with per-capita convergence by 2050 (right) . The pure rate of time preference (PRTP) is 1.5% and the elasticity of utility of marginal income (equity aversion) is 1.0, giving a global average discount rate of 2.86% in 2000. Model parameters here are the same as the default cases shown in figure 5 (except for the 2°C scenario and its convergence). It is the integral under such curves (or its expected value integrated over uncertainty) that is minimised by optimisation in JCM, as in the examples shown in figure 5.

A general optimiser tool was developed in java using a well-known simplex algorithm (Nelder-Meald-O'Neill). Various ways of defining the scenario to be optimised were explored, adapting the flexible polynomial formulae introduced earlier for stabilisation scenarios analysis. The difference in present-value welfare between an optimal emissions trajectory (not constrained to reach stabilisation) and the closest optimal stabilisation scenario was usually small, as long as the timing of stabilisation was flexible. Although stabilisation scenarios are too simple to be optimal, it is convenient to focus on one dimension, such as a concentration or temperature level, both because this facilitates calculation and comparison of many variants in a probabilistic risk analysis, and because this is the focus of the policy discussion around UNFCCC Article 2. Accepting this approximation to the optimal scenario permits us to explore greater complexity in the representation of the world, which may lead to a more accurate solution to the real problem.

6.2 Sensitivity of Optimal Scenario to Uncertainty

Figure 8 shows the results of a sensitivity analysis exploring how an optimal stabilisation scenario depends on various model parameters. Plots (p) and (q) in the top row show the effect of parameters which affect the aggregation over time and between regions: the pure rate of time preference (p.r.t.p) and the elasticity of marginal utility of income (equity aversion). In plot (q) the p.r.t.p. was been adjusted to maintain a constant global discount rate (social rate of time preference) in 2000.

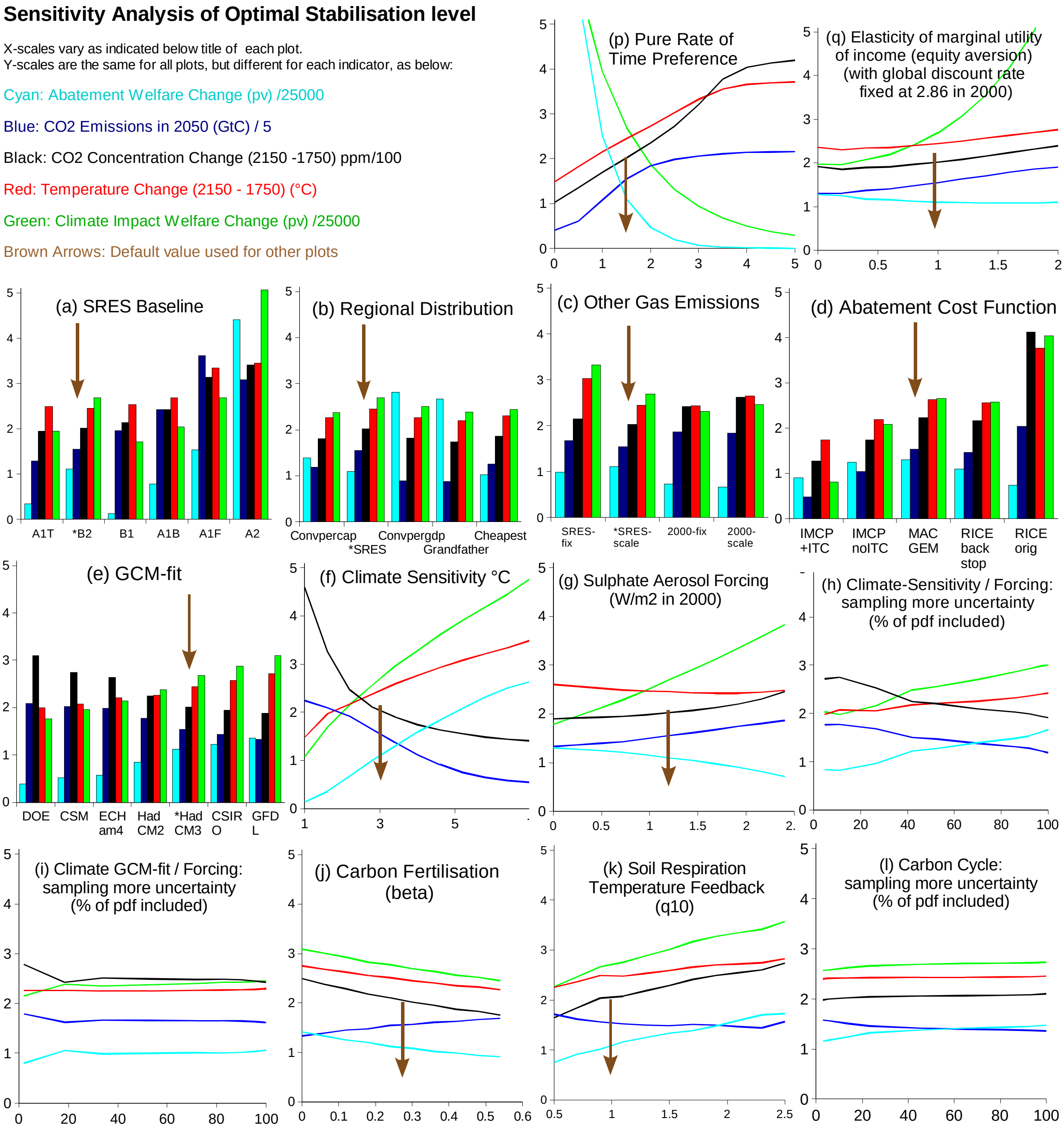


Figure 8: Sensitivity Analysis of Optimal Stabilisation Level. (see legend on top left of the figure and text).

The second row illustrates factors affecting the abatement cost – note the importance of the baseline SRES scenario (a) as discussed above. The effect of changing the distribution of abatement between regions (b) and gases (c) is smaller, although significant, for example the optimal temperature seems much higher when there is no mitigation of other gases (variant "SRES-fix", as IPCC-TAR SYR). The difference between the abatement cost formulae (d) is very large – when the fit to IMCP with induced technical change (ITC) is used, stabilisation levels well below the EU 2°C limit can be optimal, on the other hand using the old formula of the original RICE model (not RICE99, but the earlier version from which CWS originated) makes the optimum little lower than the no-policy scenario.

The third row shows the effect of climate model parameters. Changing the GCM-fit (plot e) adjusts several parameters together (as defined in IPCC TAR WG1 appx 9.1), but the result is still dominated by the climate sensitivity (the models are arranged by increasing sensitivity). Increasing aerosol forcing (cooling) (plot g) seems to increase the optimal emissions (as carbon and sulphur emissions are linked), although in reality this might be offset by a higher implied climate sensitivity (explored in the probabilistic analysis accounting for intercorrelation between parameters) as well as by local aerosol impacts. Regarding the carbon cycle parameters, decreasing the carbon fertilisation (plot j) (a negative feedback) or increasing the soil respiration (plot k) (a positive feedback) both tend to decrease the optimal emissions but *increase* the optimal concentration – illustrating why it is important to consider more than one indicator. Sensitivities to some other physical parameters, including the eddy diffusivity (mixing rate) for both carbon and heat in the ocean, were also investigated, but found to be smaller than those illustrated in this figure.

It may be observed that the optimal concentrations / temperatures are generally much lower than those projected by CWS in early Climneg working papers (e.g. WP57). Some key reasons for this are the different baseline emissions (as discussed in section 3.2 following figure 5), and that the RICE99 impacts functions used in this analysis include a large low-probability-high-risk "surprise". Additionally the default GCM-fit in JCM is to HadCM3 (sensitivity 3°C, not 2.5°C), and the carbon cycle includes nonlinear feedbacks. Three plots (h) (i) (l) illustrate the effect of integration over probability, calculating the expected values by applying weights based on the fit to historical data, derived as for the analysis of stabilisation under uncertainty described earlier. It is apparent that taking into account uncertainty in the climate sensitivity coupled with the aerosol forcing (plot h), significantly decreases the optimal concentration (by about 80ppm, compared to the best-guess case), whilst the expected climate-impact rise by about 50%. On the other hand, this effect is much smaller when the analysis is constrained to the set of seven TAR GCMs (plot i). For the carbon cycle (plot l), integrating over probability increases the optimal concentration slightly but still decreases the optimal emissions in 2050 (by about 15%). Although this analysis was limited to parameters of the carbon and climate modules already well developed in JCM, it demonstrates that the difference between integration over uncertainty and a best-guess model can be important, so this approach should be extended to the socioeconomic driving forces and impacts.

7 RELATIVE RESPONSIBILITY AND VULNERABILITY

Investigation of regional attribution (responsibility) for climate change was inspired by the "Brazilian proposal" to UNFCCC COP2. This topic was included in the original Climneg-2 proposal but later cut from the workplan due to budget constraints. Shortly after our project began, an international model intercomparison on Attribution of Contributions to Climate Change (ACCC, later evolving to become MATCH) was set up in response to a request from UNFCCC-SBSTA for further study of "scientific and methodological aspects of the Brazilian proposal". Seeing this as a good opportunity for comparing relatively simple models applied to a complex question related to the climate negotiations, Ben Matthews developed a module in JCM to explore this problem, contributed results to the intercomparison, and participated in a sequence of workshops from 2002-2005 (Bracknell, Berlin, Köln, Rio (by teleconference), and Reading). Figure 9a shows some typical results. On the responsibility per-capita histogram it is evident that, while all Kyoto Annex-I countries are on the right, the range among them is very high, and much greater than the difference with the higher developing countries (although it may be debated, whether current population is an appropriate divisor).

This work also led to a peer-reviewed paper (den Elzen *et al.*, 2005), including contributions from seven institutes. Results from JCM focused on the effect of varying the carbon cycle, as shown in figure 9b. It is clear that while carbon cycle uncertainties and feedbacks make a lot of difference to the *absolute* attributed temperatures, they make very little difference to the *relative* contributions of the regions. Similar conclusions applied to other steps in the cause-effect chain, suggesting that relative contributions may be calculated quite accurately despite model uncertainties. Results were, however, particularly dependent on uncertainty regarding historical land use emissions. To pursue this topic further, another co-author of this paper, Christiano Pires de Campos, came to work with us in UCL-ASTR during 2005 (see example in figure 10).

Figure 9: Relative Contributions to Climate Change

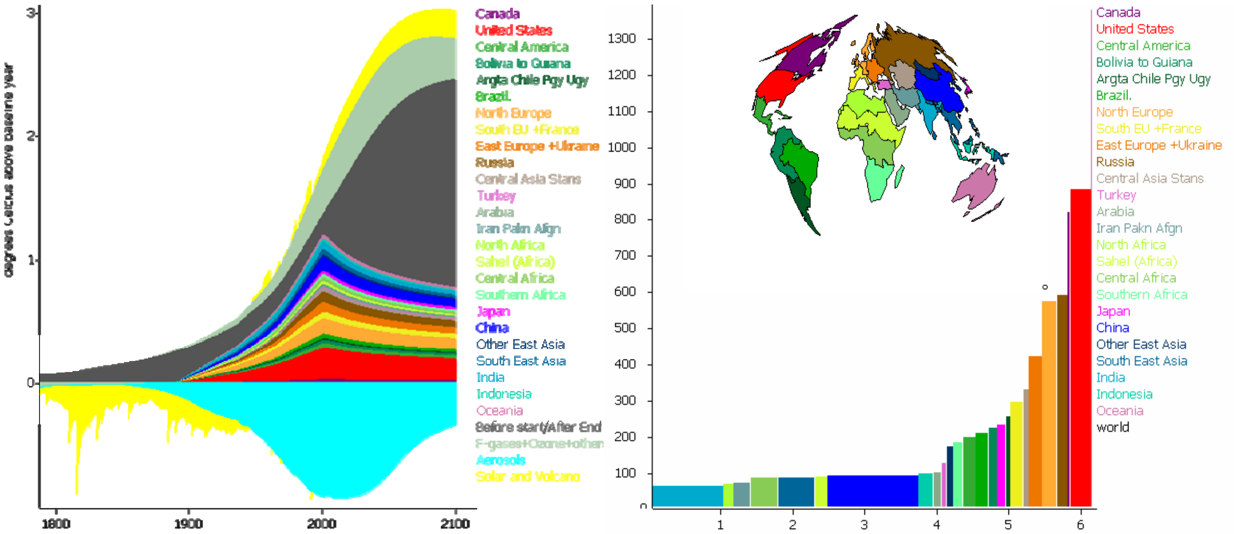


Figure 9a: Global temperature rise attributed to regional emissions from CO2 (fossil + land-use from IVIG), CH4 and N2O (from EDGAR) from 1890 to 2000. Left: stacked contributions as a function of time, combining history with a future scenario stabilising CO2 at 500ppm. Emissions before 1890 and after 2000, emissions from other gases and aerosols, and solar and volcano forcing, are all included in the total temperature but not attributed regionally. Right: histogram showing attributed warming per capita (°C x 10^{12}, Y-axis) in 2002, plotted as a function of population (billions, X-axis). Note the thin pink line on the far right is for Australia.

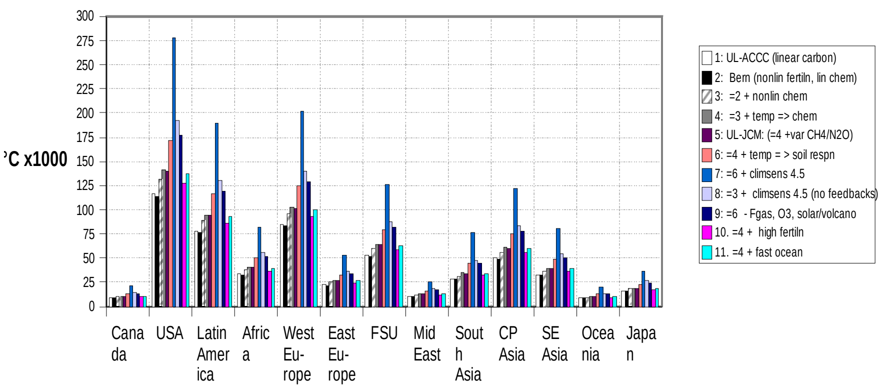
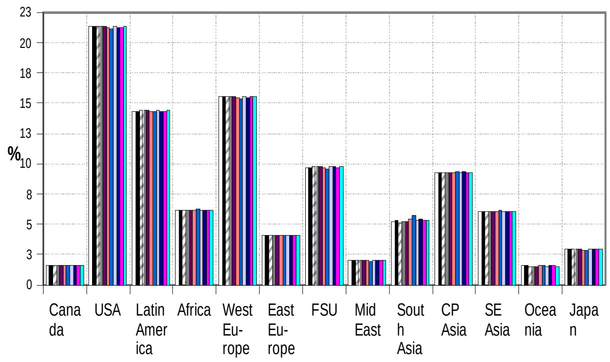


Figure 9b: Absolute (left, °C x1000) and relative (right, %) regional attribution of temperature rise in 2100 due to emissions of CO2 (inc. land use), CH4 and N2O from 1890 to 2100 (scenario A2), for different carbon-cycle model variants: data from JCM, as used in Fig17 of MATCH paper #1,. The model variants are



The concept of applying the "polluter pays principle" to the climate negotiations has considerable political support particularly among developing countries. However economists within Climneg have questioned the relevance of historical responsibility, as this approach does not try to maximise future welfare, and does not provide sufficient incentive for the polluters to reduce their emissions. Instead, transfer systems to stabilise coalitions such as those discussed in several Climneg papers, (e.g. Germain and van Ypersele, 1999) effectively imply that the countries anticipating to suffer the most damage from climate change impacts should pay others to encourage them to reduce emissions. This has been described by some other economists as a "victim pays principle", although this is not necessarily less ethical, as several dimensions of equity, including responsibility, vulnerability, need, capacity and effort, must all be balanced in the real climate negotiations.

Before a global agreement could be based on any such principles, it would also be essential to have some consensus about the calculation of the underlying data. The ACCC/MATCH group was created to assess this for relative responsibility, but assessing relative vulnerability may be even more controversial (recalling for example the debate about aggregation and evaluation of non-market climate impacts in IPCC SAR WG3 1995). Thus, at a recent MATCH workshop (Reading, October 2005), it was proposed that when SBSTA next meets (May 2006) to consider the continuation of this intercomparison process, its scope might be broadened to assess "scientific and methodological aspects" of calculating relative vulnerability as well as responsibility. One obvious connection could be applying the "polluter pays principle" to the funding of adaptation and response to extreme climatic events, but such information would also be valuable for more accurate assessment of transfer schemes of the type considered in Climneg.

8 EMISSION ALLOCATION AND WELFARE

The previous sections described how the JCM model can be used to define different stabilization scenarios under a large set of assumptions and discussed how one can define historical responsibility.

In this section we will analyse the economic impact of different emission allocations using the general equilibrium model GEM-E3. The first subsection describes updates of the GEM-E3 model with non-CO2 emissions, and the second subsection looks at the actual analysis with the model.

8.1 Adding non-CO2 GHG emissions in GEM-E3-World

Due to the leaving of Prof. Dr. Jutta Roosen (UcL-ECRU) during the summer of 2002, this part of the project has faced some difficulties. The data collected by the UcL-ECRU team are not sufficient in order to be able to complete the task. Therefore, the CLIMNEG 2 research contract has been adapted such that K.U.Leuven-CES could take over this task.

Denise Van Regemorter (CES-ETE) has estimated the marginal reduction cost curves for non-CO_2 GHGs in the course of 2003 based on the data obtained in a European research project. With these cost curves implemented in GEM-E3 World, the abatement cost curves for the MACGEM model were derived through the simulation of GEM-E3 World.

8.1.1 Sources of non CO2 GHG

The main activities through which each greenhouse gas is generated are given in the next table.

Sector	Activity	Greenhouse Gasses					
		CO_2	CH_4	N_2O	SF_6	HFC	PFC
Agriculture:			■	■			
	Dairy livestock producing milk.		■	■			
	Non-dairy livestock producing beef.		■	■			
	Rice production.		■				
	Cereals productions			■			
	Pulses and oilseeds production.			■			
	Roots and tubers production.			■			
Energy:		■	■	■	■		
	Oil industries: production, venting and flaring of the associated gas in oil extraction and production.	■	■				
	Gas production and gas transportation.		■				
	Coal production and handling (underground and surface coal production).		■				
	Transport: vehicles equipped with catalyst.			■			
	Stationary combustion (in particular clean coal technologies).			■			
	Electricity transmissions and distribution: leakages from high and medium voltage switchgear.				■		
Industry:		■		■	■	■	■
	Cement production: during the production of clinker	■					
	Aerosols.					■	
	Solvents cleaning.					■	
	Refrigeration and Air Conditioning equipment.					■	
	Foam production.					■	
	Fire Extinguishing.					■	
	Aluminium Production.						■

	Semiconductors.					■	■
	Production of adipic and nitric acid			■			
	Magnesium production & casting industry				■		
	Gas insulator in electric equipment				■		
Other:			■				
	Landfills and Wastewater management.		■				

Table 2: Activities with GHG emissions

The relative contribution of the different sectors to the non CO2 GHG emissions is given in the table below.

Agriculture and waste	61%
Energy	25%
Industry	14%
CO2 non energy	59%
N2O	19%
HFC	11%
PFC	7%
SF6	4%

Table 3: Sectoral contribution to World non CO2energy greenhouse gases in 1995 (%)

8.1.2 Link to GEM-E3 activities

For the implementation in GEM-E3, the non CO2 greenhouse emissions are linked with each GEM-E3 activity according to the scheme:

Emission Sources		GEM-E3 Activities
CH4 : Rice production, livestock waste, enteric fermentation, land fill waste, natural gas venting and distribution losses.	→	Production of coal,gas,oil,crude oil,agriculture and non market services.
N2O Fertilized soils, Adipic and nitric acid production, catalytic converters in vehicles, biomass burning.	→	Production of chemicals,agriculture and transport.
SF6 High voltage switch gears, magnesium production and semiconductor production, other.	→	Production of electricity, ferrous non ferrous metals and other equipment goods.
PFCs Aluminum and semiconductors production, solvent use.	→	Production of ferrous non ferrous metals and electrical equipment goods.
HFCs Refrigeration and air conditioning, solvent and foaming agent use, by-product of HCFC production.	→	Production of chemical products and electrical equipment goods.

Figure 10: Sources and GEM-E3 Activities Links.

Based on the GECS reference scenario, an emission factor was derived linking the emission of a pollutant with the corresponding GEM-E3 activity.

8.1.3 The marginal abatement cost function for non CO2 GHG

Within the GECS project, a bottom-up approach of detailed cost analysis has been applied to construct marginal abatement curves (MAC) from the available abatement options, using engineering information technologies/measures on abatement or for agriculture, a specific model AGRIPOL.

The MAC is presented as a ranking – or merit-order – of emission reductions options that could be implemented at increasing level of cost/emission penalties. The analysis considers the cost of emission reductions represented in $/tCO$_2$, plotted against the amount or percentage of emissions abated. The full documentation on the data can be found in the GECS final report.

Based on these data MAC curve for GEM-E3 were estimated. Two types of function were tested:

$$m\tilde{c}^{ab}_{p,i}(a_{p,i}) = \beta_{p,i} \cdot (1 - a_{p,i})^{\gamma_{p,i}},$$

and

$$m\tilde{c}^{ab}_{p,i}(a_{p,i}) = \beta_{p,i} \cdot \ln(1 - a_{p,i})$$

The second function was implemented in GEM-E3 as the marginal cost is zero when the degree of abatement is zero.

An abatement cost function is derived for each pollutant and each country and each specific sector based on the GEM-E3 classification. The results, though statistically not very significant for some pollutants, reflect the broad picture:

- mitigation measures for N_2O emissions will be much more effective in the industrial and agricultural sectors than for mobile source emissions.
- there are no particular abatement options to reduce CO_2 emissions from cement production, the main bulk of non-energy related emissions from industry.
- the major potential of emission reduction lies in the HFCs from other industry, mostly in the developed countries due to their large share of HFC emissions from industry.
- the SF6 emissions from other industry can be reduced significantly at a very low cost.
- the abatement possibilities in the agriculture sectors remain limited even with high carbon value. Factors such as land availability and consequent limited technical substitution can explain these responses

8.2 Emission Allocation and Welfare in Post-Kyoto Scenarios, an analysis with GEM-E3 World

In this task the effects of the alternative burden sharing rules are computed with the GEM-E3 WORLD model, a general equilibrium model that represents the world by 18 regions that have each their economic activity, their trade with the rest of the world (including GHG permits) and their emission and abatement costs.

A long term (2030-2050) emission target for the world that prevent global mean temperatures rising by more than 2°C over pre-industrial levels is assumed. The target is reached by allocating tradable emission rights to the different regions in the world. The amount of permits a region receives will determine the abatement efforts, the purchase or sales of emission permits and therefore the welfare impact on a region. We test the welfare impact of three rules for the initial allocation of permits. The three emission allocation rules used vary between pure cost efficiency (lower abatement cost country receives less permits), ability to pay (poorer countries receive more emission rights) and converging per capita emission rights (the same number of emission rights per capita for all countries).

8.2.1 Alternative burden sharing mechanisms

There exists a long tradition in economics to structure discussions on equity and efficiency (Kolm, 1996; Sen, 2000). In the case of climate change, it is useful to distinguish (Rose et al. (1998)) between criteria based on the initial allocation of emission rights ('allocation-based') and criteria based on traditional welfare economics ('outcome-based').

Allocation-based equity criteria

'Allocation-based' rules are related directly to the distribution of emission rights. The equity criterion is translated in terms of emission rights endowment. Some examples are:

- equal right to the use of the atmosphere, translated into allocating the same level of emission permits per head to each region;
- historic responsibility, translated into a greater effort of reduction now for big polluters in the past;
- in function of the ability to pay, translated into an allocation of emission permits inversely proportional to GDP per capita.

In terms of modelling these rules correspond to the allocation of an initial endowment of emission rights to each country.

Outcome-based equity criteria

In contrast to allocation-based rules, outcome-based rules take into account the incidence of costs and benefits, i.e. the net welfare change due to global warming policy, including the reduction in damage. There is not always a perfect correspondence between an allocation based equity criterion and an outcome based criterion because the ultimate welfare effect ("outcome") of initial permit allocations depends on the trade interactions (of GHG permits and other goods) between regions.

The outcome based criteria are derived from the social welfare approach. In this approach, total social welfare of the world is defined as a weighted sum of the regional utilities. Different weights can be used for the aggregation of the regional utilities into social welfare. We will use in this chapter two criteria[11]:

- A simple sum (all weights=1) of the utilities (expressed in equivalent income terms). This will be called the efficiency criterion as there is no attention given to equity: one unit of income given to the poor is as important for social welfare as one unit of income given to the rich.
- A weighted sum where the logarithm of the individual utilities is used as weight. This implies that a gain of one unit of income for the poor contributes much more to social welfare than a gain of one unit of income to the rich.

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[11] More formally social welfare is defined as $SW = \sum_{r=1}^{R} \frac{U_r^{(1-\varepsilon)}}{1-\varepsilon}$ where ε represents the degree of inequality aversion, U_i represents the utility of an individual (or a representative individual of a country expressed in internationally comparable money terms). If $\varepsilon = 0$, SW becomes a simple sum of individual utilities, if $\varepsilon = 1$, one uses the sum of the logarithms.

The definition of social welfare incorporates therefore three effects: effects on the total value of private goods consumed, the environmental benefits and the equity effects (which depend on the weighting system used).

In practice, a mix of several equity concepts (namely the proportionality to current emissions, historical responsibilities and ability-to-pay approach) was chosen in the Framework Convention on Climate Change. The same is supposed to hold for the burden sharing proposal of the EC-Council of Ministers given in March 1997 and in more recent proposals.

8.2.2 Analyses of Allocation rules with GEM-E3 World

GHG target and allocation rules

In order to explore the impact of some of the equity criteria described above, various simulations have been made with the GEM-E3 World general equilibrium model (Capros et al;, 1997). We evaluate the impact of different allocation of emission rights on social welfare. The target year for the GEM-E3 simulations is 2030.

The emission target

The global emission target is derived from the GRP study (Criqui et al, 2003). The target allows satisfying the long-term objective of the European Union to prevent global mean temperature rising by more than 2°C over pre-industrial levels. It assumes a global emission profile stabilising the total greenhouse gas concentration at the level of 550 ppmv in CO2 equivalent. The implied abatement effort corresponds to a global reduction of the anthropogenic GHG emissions of 44 % in 2030 and of 70% in 2050 compared to the GEM-E3 baseline and respectively of 12% and 40% compared to the emission level in 2005.

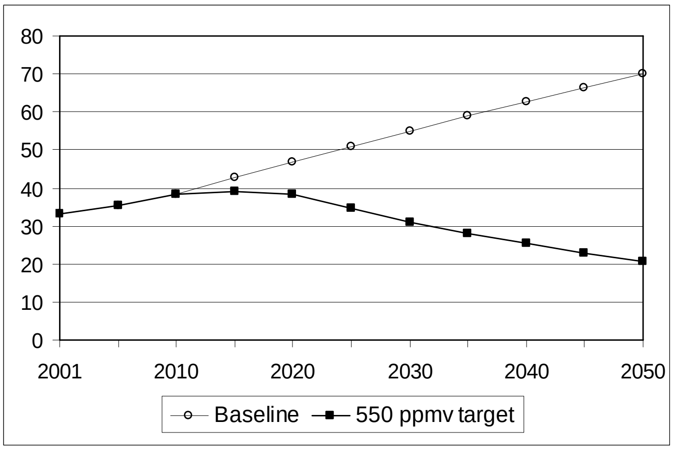

Figure 11: World GHG emission reduction target (Gtons CO2eq)

The allocation rules

There have been numerous proposals for the burden sharing of the emission reduction target (Ringius et al, 2000, Welsch, 1993). Three allocation rules are considered here:

- Efficiency only: the abatement burden is distributed so as to minimize the total abatement cost. The regions with the lowest abatement costs receive the lowest amount of permits, and the inverse for the regions with the highest abatement cost. This allocation rule serves as benchmark, in which the initial allocation of permits does not contain an implicit income transfers between the different regions.

- Per Capita Convergence (derived from the Global Commons Institute (GCI) Contraction and Convergence proposal), in which the target is to converge to an equal per capita emission at a certain period in the future, here 2050. Starting from the current situation and the commitments made in the Kyoto protocol, the target is gradually reached over the period 2010-2050.
- A combination of an ability to pay criterion (measured by the GDP per capita) and the per capita convergence criteria. Starting form the current situation, the allocation will eventually also converge to an equal per capita emission in the long term, as poor regions are slowly catching up.

Each of the allocation rules generates a scenario for future economic development, emissions level, and trade in goods and in emission permits.

As the developed countries are the main responsible for the GHG emissions in the past, the per capita criterion takes implicitly into account both the historical responsibility and the equity aspect. This is reinforced with the ability to pay criterion. The "efficient" allocation of the emission rights serves mainly as benchmark because it excludes redistribution effect from the allocation of emissions.

The figure below illustrates what the different allocation rules imply for the European Union, inclusive Romania and Bulgaria.

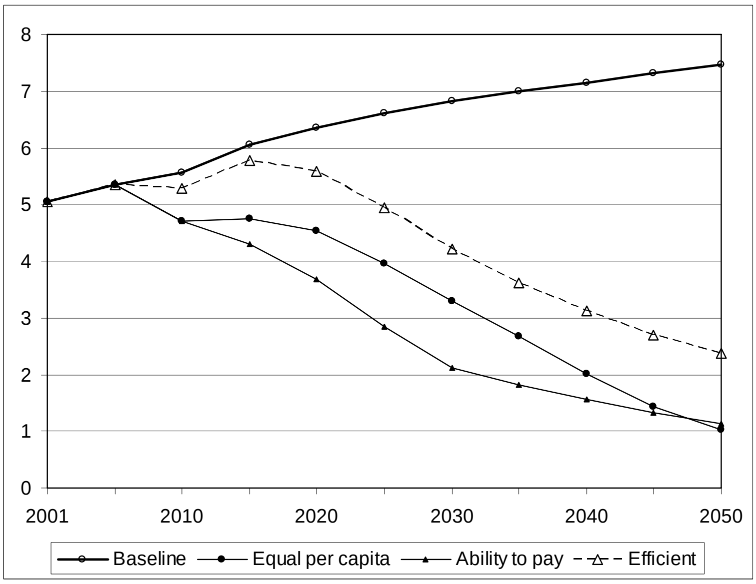

Figure 12: EU27 GHG emission reduction target (Gtons CO2eq)

Model simulations indicate that the speed of transition from the actual situation to an allocation according to an internationally accepted equity rule, e.g. equal per capita emission rights, has significant influences on the international distribution of costs. This aspect is not considered here but has been explored in the study GRP for DG Environment (Criqui et al, 2003) and in Cazorla and Toman, 2000.

More specific assumptions

The simulation results with GEM-E3 cover the period 2005-2030. The greenhouse gasses considered are the six gasses covered by the Kyoto protocol. The policy instrument used in the GEM-E3 simulations is a World wide emission trading system where the initial allocation of GHG emissions rights is based on the allocation rule defined above. Moreover all flexibility mechanisms foreseen in the Kyoto protocol are used assuming zero transaction costs. If 'Hot Air' is generated through the allocation (e.g. for the Former Soviet Union in the Kyoto protocol, or for some developing countries with the allocation rules in 2030), it amounts to a transfer to these countries through the international permit system and in GEM-E3 it is assumed that half of these transfers are given to the households and the other half is part of the public revenue in the country benefiting from these transfers. This assumption matters to determine the general equilibrium outcome.

For the first commitment period 2008-2012, it is assumed that the Kyoto protocol is applied except for the USA and Australia. For these countries an efficiency improvement combined with the average growth rate for GDP is used for the computation of their emission target for that period. An emission trading system is implemented in GEM-E3 covering the Annex I countries having ratified the Kyoto protocol. CDM with the non Annex I countries is not considered.

8.2.3 Model results

Overall results

The global and regional welfare changes in 2030 are reproduced in Table 4. It gives also the emission reduction and the assigned reduction target as an indication for the trade in permits. When a region has a reduction target larger than the emission reduction in absolute value, then it is a buyer of permits. This is mostly the case for developed regions. When a region has a positive reduction target[12] it can sell permits without abatement effort. This surplus of permits is called 'Hot Air'.

Though the reduction efforts per region depend on their baseline emissions, comparing the three scenarios allows focussing on the impact of the allocation rules. The welfare results reported here do not include the environmental benefits from the reduced GHG emissions. However, this is not important for the comparison of the three scenarios as the total level of GHG emissions is held constant over the three scenarios.

Reducing the GHG emissions to allow for a 550 ppmv concentration in the future implies a global reduction of 44% in 2030 compared to the reference. The global welfare loss is around 3% without equity weights and goes from -0.8% to +0.4% when equity weights are used. Though this reduction is important, it represents only a reduction of 0.12% of the World GDP annual growth rate over the period 2005-2030[13].

[12] A positive reduction target means that the region receives more permits than its emission level in the baseline.

[13] With a 70% reduction in 2050 it would imply a reduction in the annual GDP growth rate of 1.1% for the period 2030-2050.

	Per capita convergence			Ability to pay			Efficiency criterion		
	welfare	Emission	emission target	welfare	emission	emission target	welfare	emission	emission target
USA	-4	-50	-61	-6	-51	-84	-3	-50	-50
Canada	-8	-45	-73	-9	-45	-81	-3	-45	-45
EU27	-9	-38	-57	-11	-38	-71	-5	-38	-38
Europe Other	-6	-26	-51	-6	-26	-54	-3	-26	-26
Former Soviet Union	10	-58	-26	0	-59	-54	-38	-59	-59
Australia & New Zealand	-7	-44	-61	-8	-44	-76	-3	-45	-45
Japan	-3	-64	-43	-5	-64	-59	-4	-64	-64
Brazil	-12	-41	-47	-11	-41	-42	-10	-40	-40
Mexico & Venezuela	-6	-28	-57	-7	-28	-56	-3	-27	-27
Latin America Other	-8	-29	-47	-8	-29	-42	-4	-29	-29
South & East Mediterranean Countries	-4	-35	-29	-2	-35	-13	-5	-35	-35
Middle East	-11	-37	-45	-12	-37	-50	-9	-37	-37
India	-11	-39	-39	-9	-38	-19	-11	-38	-38
China	-4	-47	-38	-8	-48	-40	-7	-47	-47
East South East Asia	-7	-36	-46	-9	-36	-52	-4	-36	-36
Rest of Asia	4	-29	18	11	-28	111	-7	-32	-32
South Africa	-27	-62	-65	-20	-62	-65	-24	-62	-62
Rest of Africa	22	-18	183	45	-16	499	-3	-21	-21
Global welfare									
No equity weights		-2.8			-3.0			-2.9	
With equity weights		-0.8			0.4			-2.7	
Global GHG emissions		-44			-44			-44	
GHG permit price (US$2001 per ton CO2eq)		117			118			116	

Table 4: The regional and global welfare in 2030 under the different allocation rules

(% difference compared to baseline without GHG reductions)

The redistribution effects over regions

The per capita convergence scenario and the ability to pay scenario imply a long term target of equal per capita emissions and are thus favourable towards the less developed regions in terms of reduction target. This is reflected in the global social welfare which is less reduced with equity weights than without equity weights in the two scenarios. Including the ability to pay favours still more the equity dimension. This clearly indicates a certain consistency between the allocation based criteria and the outcome based criteria.

The 'ability to pay' allocation rule shifts, compared to the per capita convergence scenario, more private consumption to the poorest regions. The greater loss of consumption and activity in the richer regions is not enough to annihilate this gain through bilateral trade flows, at least at the aggregation level of GEM-E3 World. The presence of 'hot air' is important for the regions benefiting from it, such as Africa and the Rest of Asia as they represent a net transfer of resources to the poorest regions without associated emission reduction[14]. The changes in

[14] The baseline emissions determine also partly the level of 'hot air'.

the assigned reduction targets are the largest for the rich and poor regions. The welfare loss is reduced (increased) for the regions receiving more (less) emission rights.

9 RECENT PROGRESS, CAPACITY AND FURTHER WORK

9.1 JCM5, increasing complexity in an interactive model

For the reasons explained in the introduction ("making risk analysis more transparently"), it was considered indispensable to continue to develop a tool which can be on the one hand fast and flexible enough for interactive analysis and integration over several dimensions of uncertainty, whilst at the same time sufficiently complex to include important feedbacks, keep up with state-of-the art knowledge, and explore sensitivity to a wide range of factors. Balancing such requirements is not trivial.

JCM evolved first as an interactive tool available for everybody in a web browser, and so was designed to work with an early version of the programming language Java (1.1) and to be extremely efficient in terms of both calculation speed and package size. Whilst this made it convenient and flexible for end-users, it increased complexity for the developer adding capabality for new analyses. Two key factors behind JCM's speed were efficient but complex algorithms for resolving the multilayer oceans in carbon and climate modules (developed with Jesper Gunderman at DEA-CCAT, Copenhagen), and an interactions system ensuring that only modules both needed for plots and changed by user interaction are recalculated, in a sequence depending on the application (eg top-down or bottom up scenarios).

During this project many new capabilities were added to JCM, extending beyond its original basis on IPCC-TAR, including extra scenarios, higher regional resolution, more socioeconomic dimensions, more detailed land use change and carbon feedbacks, and algorithms for stabilisation, optimisation, regional attribution, and integrating over uncertainty. Adapting the model structure to cope with the increasing complexity has required considerable effort.

An interactive multipurpose model available online also has to respond sensibily to every possible combination of end-user choices, whose number increases with the factorial of the number of user-adjustable parameters (112 at "expert" level by the end of 2005). The interactions system must remain robust and be checked for all these cases. Varying the region-sets, depending on input sources (historical data and future scenarios), output requirements (such as for the ACCC/MATCH intercomparion or anticipated linkages with CWS), and scientific questions (as climatic and sociopolitical regions are very different), is another source of complexity. In addition, graphical interface components must be added and explained for each new scientific feature. Thus, compared with a typical model whose only public output is in static scientific papers, for which the code structure may be adjusted for each new question and only has to work for selected parameter sets, creating a robust interactive tool is much more challenging.

Anticipating further increase in complexity, particularly to handle disaggregated impact funtions, in early 2005 it was decided that a new model structure was needed, taking advantage of the new language features of Java5 which simplify scientific programming. This new version "JCM5" focuses more on convenience for new scientific analysis, whilst retaining the interactivity which is useful for testing sensitivity to new parameters and tracing cause and effect through the system. JCM5 is an standalone application, which can still be launched from the web-browser, whilst escaping its constraints. It is now easier to concentrate on scientific code since new curves and parameters are automatically added to the graphical interface. Data input and output is made more convenient (in response to requests from student groups using JCM). Replacing fixed-size data arrays by flexible collections makes it much easier to change region-sets and interpolate between them, enabling any quantity (climatic or socioeconomic) to be calculated for any individual country, or bigger regions as required. A new "parallel worlds" structure allows several different copies of each module to run simultaneously, making it easy to compare different variants.

Historical data in JCM5 (population and GDP, emissions, concentrations, forcings, temperature etc) were also updated using the latest available data combining diverse sources, thereby enabling the model start date to move to 2003, and using national rather than regionally-aggregated data where available to improve potential resolution.

9.2 Recent applications of JCM5, links in integrated assessment chain

JCM5 has proved robust and more efficient for further scientific development, enabling expansion beyond earlier complexity constraints. In particular, since June 2005 JCM5 has been used by Christiano Pires de Campos (a doctoral student from IVIG, Rio, working with us in UCL-ASTR for 15 months) for developing a complex module of historical land-use change by country. This experience also showed that modules for JCM5 can be developed in parallel by other researchers (essential if its capacity is to be exploited further). Some results are illustrated by figure 13.

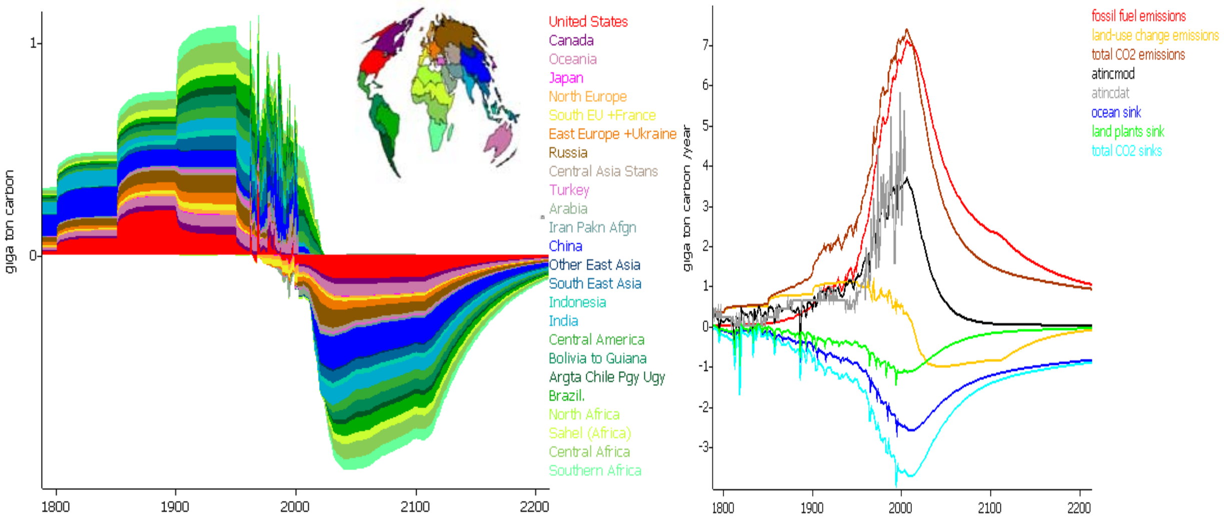

Figure 13: Land Use Change and Carbon Cycle:

Regional CO2 emissions from land use change (left), and corresponding global carbon sources and sinks (right), from 1800-2200, for a scenario stabilising temperature at 2°C (>1850).

Historical emissions are based on biome change estimates from HYDE, coupled with national data from FAO (after 1961). The anticipated application was assessing regional contributions to climate change (within the ACCC/MATCH process, as discussed earlier), but this module might also be applied to the problem of balancing the historical carbon cycle, and thereby deriving better probabilities for weighting coherent parameter sets. The right hand plot shows the corresponding global carbon cycle fluxes, the black curve which shows the difference between emissions and sinks may be compared with the grey curve showing the measured increase in the atmosphere - note that the latter contains much noise, but the model also shows spikes traceable to the feedback from volcanos, through temperature, to ocean chemistry and soil respiration. Beyond 2003, the regional emissions projections combine information from the SRES baseline scenario B2, an estimate of the maximum "potential" land-use sink (based on reconversion to original biomes), and the total mitigation required to reach the inverse stabilisation target.

Such regional projections might also be useful for assessing future scenarios including economic impacts of both mitigation and adaptation, although we have not yet incorporated related cost functions. For such purposes an extension of the landuse module to project CH4 and N2O emissions under mitigation scenarios would also be necessary. Whilst a cost-effective distribution of effort between gases is desirable, we are not convinced that currently available abatement cost functions include sufficient potential mitigation in agriculture (particularly in developing countries), meanwhile the simple scaling to SRES projections used in the the multi-gas stabilisation / optimisation scenarios discussed earlier remains a reasonable guess.

JCM5 has also been used recently to make new regional seasonal climate analyses, as in figure 7. Viewing GCM data in this way illustrates the importance of taking into account the seasonal cycle as well as the inter-regional variation, and taking into account variables other than temperature. For example, the plot of incident solar radiation (right) shows that sunlight in northern europe (including Belgium) would decrease by about 20-30% in midwinter due to increased cloudiness, although in the annual average this would be more than offset by an increase in summer. This also illustrates that warmer does not necessarily imply sunnier, a misconception which lies behind the substantial "amenity" (= leisure activities) benefit of global warming included in the cost functions of RICE1999. Meanwhile, whilst southern Europe generally gets much sunnier, it also gets much drier (see the left plot), which could also reduce amenity. A better amenity function should be based on a combination of several climate variables.

Figure 14: Regional Climate Change

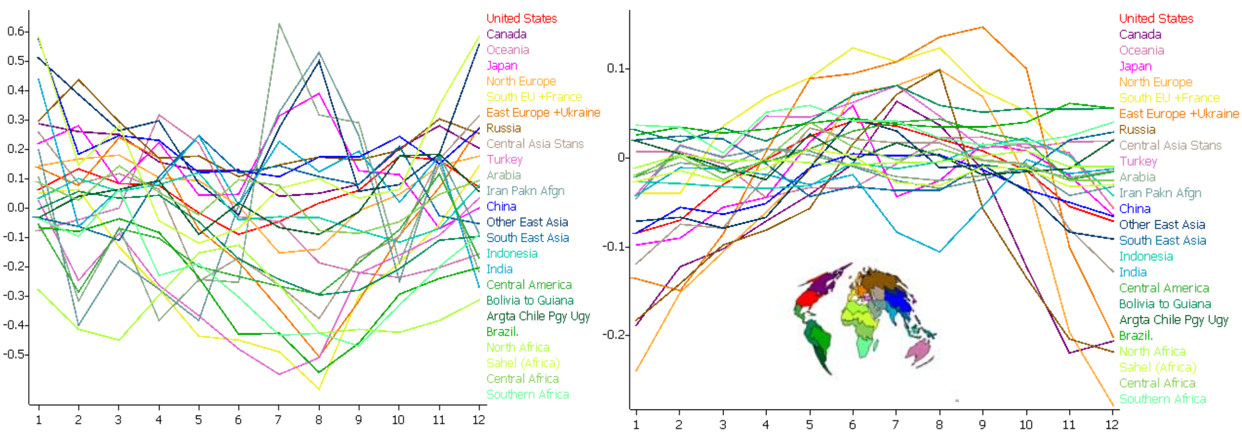

Figure 14a: Seasonal cycle of regional change in precipitation (left) and incident solar radiation (right) in 2071-2100 (for no-policy scenario SRES A2) compared to 1961-1990. X-axis: month, Y-axis: ratio [future – current] / current (for sum over region). Data from HadCM3 imported from IPCC-DDC into JCM. Region colours as map.

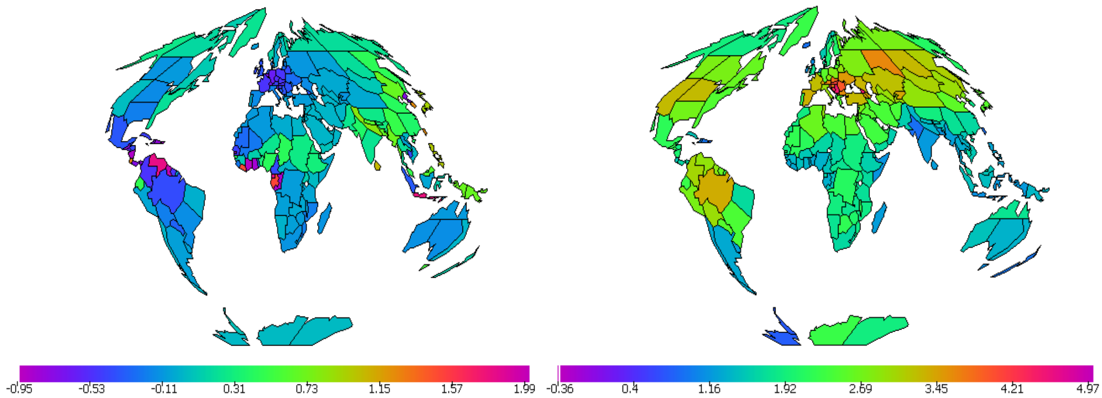

Figure 14b: Regional change in Temperature (left) and Precipitation (right) in August, scaled to a global average temperature rise of 2°C (note, average includes ocean). Data from HadCM3 imported from IPCC-DDC into JCM.

Figure 14b shows temperature and precipitation change averaged for countries (of which the largest are subdivided). This was also developed in anticipation of connection with socioeconomic data, which JCM5 can also generate for individual countries, for analysis of impacts in for integrated assessment. As GCMs give widely differing projections, especially for clouds and precipitation, ensembles should be considered using a methodology such as proposed by Giorgi and Mearns (2002), to take uncertainty in regional climate projections into account.

Some oceanic impacts which may be studied using JCM5 are also shown in figure 15. The decline in dissolved CO_3^{2-} , due more to the acidification effect of CO_2 itself than to temperature, is important for all calcifying organisms including coral reefs (as highlighted during the Stabilisation2005 conference in Exeter). Regarding the sea-level rise, it should be noted that whilst JCM's functions are consistent with IPCC-TAR, recent observations and newer models suggest that the contribution from Greenland may be much higher than this, so even a 2°C (global) temperature limit may not be low enough to prevent substantial melting.

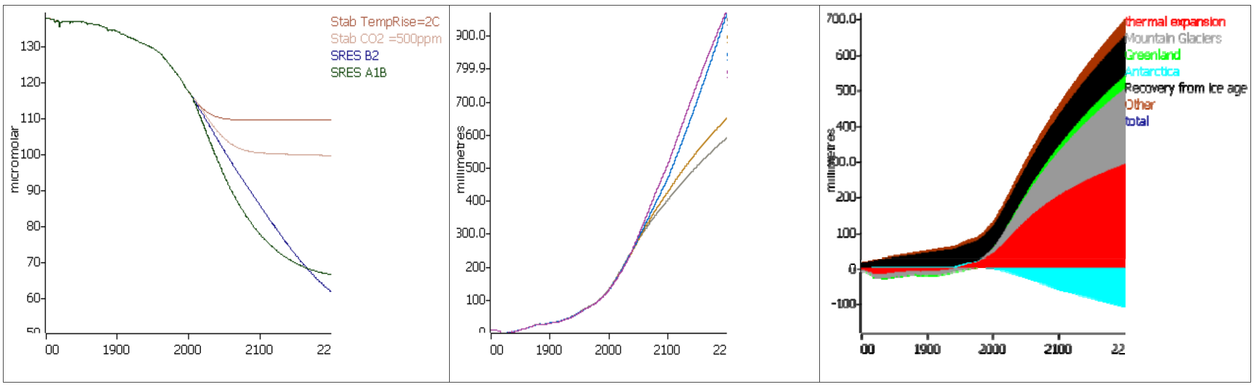

Figure 15: Oceanic Impacts in JCM

Left: Decline in dissolved carbonate in the surface ocean (CO32- , needed for calicification by corals, shellfish and plankton), for four scenarios, from JCM implementing Bern model (note the pH decreases from 8.18 to 7.69, for B2 by 2200). Center: Sea-level rise for same 4 scenarios. Right: contributions to sea-level rise, for the lowest scenario (stabilisation at 2°C >1860).

Some other recent applications of JCM5 include attribution calculations for individual countries (instead of regions) and exploration of the sensitivity of optimisation to abatement costs including from the IMCP.

9.3 Further work using capacity developed

Whilst the examples illustrate steps towards developing JCM5 as a better system for integrated assessment, or "making climate risk analysis more transparently" (as proposed by Matthews, 2004), some work remains be done. In particular, the disaggregated regional impact costs module, envisaged to tackle one of the weakest links in the integrated assessment chain is not ready in time for contribution to this report. However the development of the first stage of such a module is not so far away, building on JCM5's existing capacity to calculate regional changes of several climate variables from different GCM datasets, and to project socioeconomic data for the same regions over long time horizons for diverse scenarios. The aim is to combine diverse impacts functions from diverse sources such as the ICLIPs database (Füssel, *et al.,* 2003), the OECD study (Corfee Morlot, 2003), estimates of high-impact low probability impacts (Kellet, *et al.*, 2005), or observations of agricultural impacts (Peng, *et al., 2004*), giving the user an opportunity to explore the sensitivity to different assumptions.

Regarding the abatement costs side of the problem, it is also intended to make further calibrations based on IMCP results, and to add costs for other gases and landuse change. These modules could be linked together by the existing tools to aggregate and optimise present-value welfare changes, exploring effects such as equity weighting. Of course we recognise that to do all this more comprehensively, including many impact sectors and extreme events, and covering several dimensions of uncertainty, to really make climate risk analysis more transparently, is a much larger task worthy of another project in itself.

To study the risk of impacts we also need more more probabilistic information in scenarios, specifying intercorrelations between socioeconomic driving forces and associated climatic consequences. To discuss further steps towards this end, we attended a recent IPCC workshop (June 2005) on scenarios beyond AR4, and expect to participate further in this process.

Further work is also anticipated on the documentation of JCM5, both online (interactive and multilingual as for JCM4) and through scientific papers, both explaining the core methodology and its application to stabilisation and optimisation as discussed in this report. As soon as the documentation for JCM5 is complete, we then intend to make further effort on valorisation activities, so that it becomes more useful for a wider user group. We intend to continue JCM5 documentation, development, and application to several research questions.

As an interactive model is most useful together with people who understand and can explain it, we invite the Belgian Science-Policy Office to make use of this human+model capacity developed within this project, particularly for any stakeholder dialogue or valorisation activities in Belgium. It is anticipated that this capacity will be retained in UCL-ASTR through further projects.

Specifically, JCM5 is expected to contribute to a new SDD project "Aviation in the Belgian Climate, Integration Options and Impacts", comparing different ways of calculating the relative climate impacts of different aviation emissions, and providing an interactive interface to visualise model analysis within a multi-criteria stakeholder analysis. This will provide an welcome opportunity to continue to develop JCM5 at both ends of the cause-effect chain, i.e. regional impacts and sectoral emissions, both calibrated from more complex regional climate and socioeconomic models.

The MATCH processes on regional attribution of responsibility, and related work with JCM in ASTR on land-use change, also continues and is anticipated to lead to further papers, we also hope that its scope may be expanded to cover relative vulnerability as discussed above.

In the longer term, we aim to update the core science of JCM to be consistent with new results emerging for the IPCC 4th Assessment Report (AR4), drawing on literature cited therein and GCM datasets from IPCC-DDC etc., building on earlier experience matching JCM to IPCC-TAR in Denmark, Norway and Switzerland (prior to Climneg-2). The principle aim that the interactive model may contribute to outreach work after publication of the AR4, helping people to understand some key conclusions and their sensitivity to model and scenario variants. Additionally, this may help to us comment on ways to synthesise cross-cutting issues within the AR4 process, and on future scenarios beyond AR4.

10 CONCLUSIONS

Within the duration of this project the global scientific community has made progress in quantifying uncertainties in the climate system, but has not reduced that uncertainty as fast as might be preferred, by policymakers and modellers alike. Meanwhile integrated assessment tools for studying the interface between science and policy have to be adapted to fit the changing nature of the problem, always seeking to identify and focus on the weakest links of the chain. As explained in the first section, consideration of uncertainty may even lead to some convergence between the optimisation/risk-analysis and threshold/guardrail paradigms, however increased complexity poses an additional challenge of transparency. Within this project, the Java Climate Model has been significantly improved in UCL-ASTR for this purpose, and contacts with economists in the Climneg-2 network have helped to understand the value of complementary approaches. The carbon cycle and climate components of JCM where extended to allow a probabilistic approach. New modules were added on several topics including historical land-use changes, future socioeconomic scenarios, costs and welfare optimisation, attribution of responsibility, regional seasonal climate changes. This enabled an original discussion of stabilisation scenarios under uncertainty, with a quantitative evaluation of the consequences of the choice of stabilisation indicator .

Recent studies have increased the plausible range for some factors such as climate sensitivity and the strength of climate-carbon cycle feedbacks. Although increased sensitivity implies greater need for mitigation action, it also makes it more challenging to achieve fixed targets such as the EU policy to limit global warming below 2°C above pre-industrial, as shown by our study of stabilisation under uncertainty using JCM. Some economists question the economic optimality of such targets. Our sensitivity analysis using JCM has illustrated that there is no simple answer to such questions – indeed by varying parameters representing both scientific uncertainties and risk/value judgements, one can demonstrate that almost any level can be optimal. With lower discount rates and baseline scenarios together with induced technical change, it is plausible that the optimum level may be lower than the EU limit. However the weakest link of such calculations remains, arguably, on the climate impacts side of the problem, further augmenting the cascade of uncertainty illustrated in figure 3. We have little confidence in simple aggregated functions which have been used for such analyses, and intend to work further on this topic, building on capacity already developed in JCM during Climneg-2, and elsewhere.

Meanwhile it remains our opinion (in UCL-ASTR), that no integrated assessment model in the world is yet capable of making a sufficiently high-quality analysis of global climate risk, for cost-benefit optimisation to provide a meaningful guide to interpreting UNFCCC Article 2 quantitatively. The results of integrated assessment models depend much on the precise parameterizations used. Even without scientific uncertainties, the results would still be sensitive to value judgements regarding aggregation over regions (equity weighting), generations (discount rate), probability (risk aversion), and different types of impacts. Nevertheless questions posed by the risk-analysis approach remain highly policy-relevant, and such models do provide a useful tool for exploring the relative sensitivity to different parameters, which may help to guide further research activities.

Climatologists have also learned from our interaction with economists during this Climneg-2 project. For example, many climatologists start from the concept that our primary task is to project the possible range of future climate change (rather than what we can do to change this), wheras from an economist's viewpoint it is more obvious that what really matters is to quantify the marginal difference we can make through different types of policy. As the relative sensitivity of marginal changes to various uncertain factors is rather different from that of absolute projections, this may influence our priorities even for research on the physical climate system. Regarding the climate negotations, we learned that international cooperation is not so easy as a natural scientist might assume, and may be strongly influenced by, e.g., different perceptions of relative vulnerability to climate change. It is thus important to generate more accurate information regarding the marginal regional impacts. Moreover, although disagreements exist about the relevance of historical responsibility, we also discovered in the course of support work made for the UN Framework Convention on Climate Change (MATCH process) that the technical methodology for calculating historical attribution is rather similar to that used by economists for estimating marginal "social costs" of future emissions.

Through wider contacts at international conferences and workshops we also learned that there are many differing types of economic models, and that it is possible to develop disequilibrium economic models including learning effects which may be more appropriate for coupling with climate models on long timescales.

Instead of coupling models which are structurally very different, which was part of the original work plan, but was particularly difficult to do, we developed a completely new version of our model (JCM5) as a tool for more transparent integrated assessment at an intermediate complexity level. It offers increased flexibility in the computation of climate-relevant variables for different regions and will allow a better representation of regional climate impacts and their aggregation over sectors, regions, generations, and probability. The capacity developed in JCM5 within this project is a good step, but further dedication is needed and anticipated.

VALORIZATION OF PROJECT

1 CLIMATE CHANGE POLICY CONFERENCE

The Climneg consortium organized on October 21, 2005 a climate change policy conference. The aim of the conference was to present an up-to-date overview of the policy aspects of climate change.

Academics from KULeuven and UCL, policy makers and stakeholders were invited to present their views on the longterm and shortterm policy issues of Climate Change. Ample time for discussions was scheduled.

The conference was a success. More than 90 people attended, results of the conference have been reported in national media. The program and the presentations of the conference can be downloaded from the website.

2 BOOK ON CLIMATE CHANGE POLICY

In order to present the results of the CLIMNEG 1 and CLIMNEG 2 consortia, a book on the economics of Climate Change Policy was published. The edited volume contains eleven contributions to the economics of climate change with special emphasis on the European and Belgian perspective.

In Part One, the book starts off at the global level looking for answers to questions such as the following. What emission pathway would be optimal from a global perspective? How should efforts be divided over generations and countries? How can international agreements be made more acceptable and sustainable to their signatories?

We then turn in Part Two to the so-called flexible mechanisms available under the Kyoto Protocol. Emissions Trading (ET) and the Clean Development Mechanism (CDM) are analyzed in detail. Some of the questions that we will address in this section are: What is the impact of carbon sinks on expected equilibrium permit prices? Will the banking of permits give incentives to undertake emission reduction projects earlier? What can the clean development mechanism contribute to Belgian climate policy?

Part Three starts with a general appraisal of the impact of the Kyoto Protocol on industrial activity in Europe in general and in Belgium in particular. What is the expected impact on industrial activity in Europe if other regions in the World do not limit their emissions? Is it a good idea to exempt carbon-intensive industries from, say, a tradable permit scheme? Part Three also reviews the internal burden sharing question within the federal state of Belgium; in doing so, it compares and evaluates the major existing studies of this question. The last chapters focus on transport, land use and energy policies, and assess the potential contribution of each of these sectors to an efficient Belgian climate policy.

3 JCM ONLINE, DOCUMENTATION AND EDUCATIONAL APPLICATIONS

One of the objectives of the JCM model is to deliver an easily accessible and open-source program, which can be used not only for scientific applications but also for educational purposes. Two versions of JCM are currently available: JCM4 and JCM5. Both JCM5 and the older version JCM4 are now available from the website of UCL-ASTR, and linked from the Climneg 2 website, at:

www.climate.be/jcm

The new JCM5 is now working and usable for scientific analysis, however at present it is only recommended for expert use as online documentation is not yet updated.

The older web-browser version JCM4 contains about 50,000 words of online documention, which is automatically adjusted to reflect the changing state of the model. This documentation system is also internationalised - with the model labels translated in nine languages, and some key documentation pages were also translated into french. Creating this online documentation took considerable time during 2003, however it has proved useful particularly for educational applications – for example JCM has been used for teaching not only in Louvain-la-Neuve but also Bern, Waterloo (Canada), Turino, Norwich, and the Open University (UK – a substantial distance-learning course involving several hundred students online).

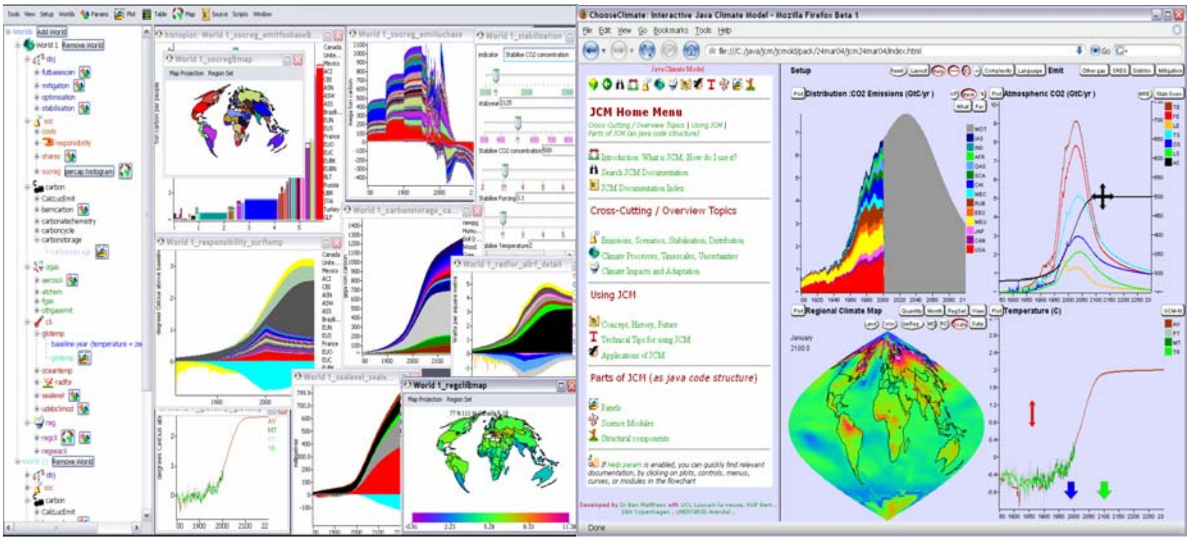

Figure 16: JCM on the web Snapshots from (older) JCM4 (left) and new JCM5 (right)

One application of JCM here in Louvain la Neuve was to inform a "role-play" climate negotiation game (autumn 2002) initiated by J.P. van Ypersele in the framework of the course SPED3300, which was so successful that it led a group of the students to participate in the Belgian delegation to UNFCCC-COP9 in Milano the following year, and present there a side event (right) demonstrating their work together with JCM.

Our experience from this role-play experiment in the first year of Climneg-2 also helped to identify key scientific questions addressed during the following years.

4 CONTRIBUTIONS TO THE UNFCCC

Jean-Pascal van Ypersele, Ben Matthews and Phillipe Marbaix have been actively involved in the decision making process of the UNFCCC. The results of the CLIMNEG consortium have certainly contributed to the discussions on different stabilization scenarios taking into account uncertainty and the discussion of the Art. 2 and the definition of dangerous climate change.

Publications by the CLIMNEG 2 consortium

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3 CHAPTERS IN BOOKS

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