GREENHOUSE GAS EMISSION CONTROL STRATEGIES

GECS – Research Project N° EVK2-CT-1999-00010
Thematic Programme : Environment and Sustainable Development
DG Research Fifth Framework Programme

GECS FINAL REPORT
SECTION 6: DETAILED REPORT

Prepared by P. Criqui, CNRS-IEPE (France)

from contributions of:

P. Tulkens, TFSD-FPB (Belgium)

D. Vanregemorter, CES-KUL (Belgium)

A. Kitous and Nguyen Anh Tuan, CNRS-IEPE (France)

N. Kouvaritakis, L. Paroussos, N. Stroblos and S. Tsallas, ICCS-NTUA (Greece)

C. Graveland, A.F. Bouwman, B. de Vries, B. Eickhout and B.J. Stengers, RIVM (Holland)

F. Eckermann and A. Löschel, ZEW (Germany)

P. Russ, JRC-IPTS (Spain)

D. Deybe and A. Fallot, CIRAD-amis Ecopol (France)

November 2002

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1 GECS: A GENERAL INTRODUCTION

The GECS project has been implemented in order to enhance the European capabilities for the economic analyses of long term (2030) Multi-Gas abatement strategies in the perspective of future climate negotiations. These analyses were only possible provided substantial improvements and enlargement in the modelling tools, of which the energy sector model POLES and the General Equilibrium model GEM-E3 that have already been extensively used by the Commission services. In order to provide the convenient analytical framework, it has been necessary to:

i Identify global cap and international emission permit endowment schemes that had to be consistent with the development in the on-going scientific assessment of climate change and international climate negotiation **(GECS Work Package 1.)**.

ii Develop a reference projections for non energy-related GHGs, bottom-up assessments of the different technological options to reduce these gases, and finally Marginal Abatement Cost curves for the different world region and time horizons **(GECS Work Package 2a.)**.

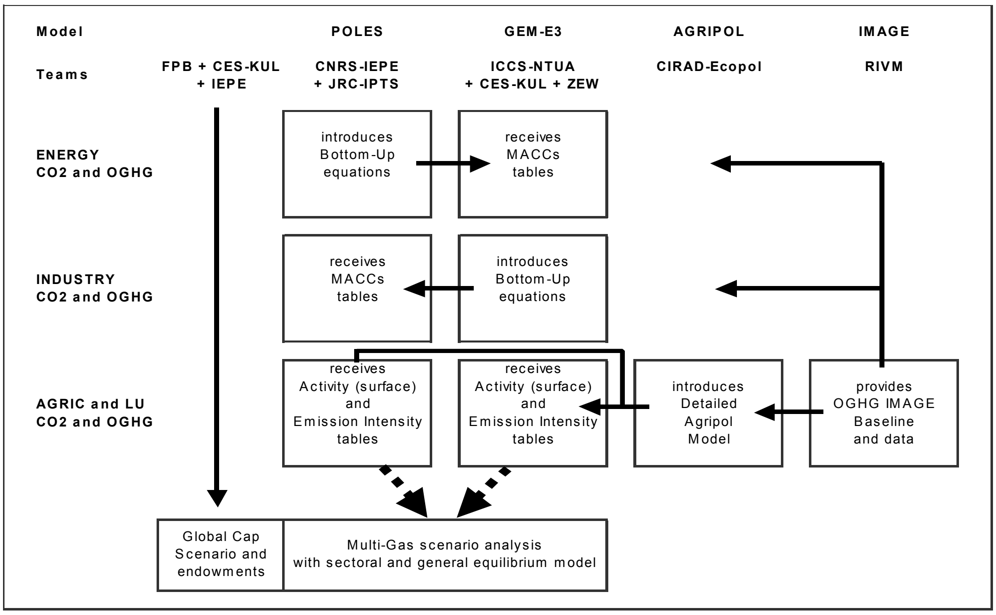
iii Build a new modelling framework for the simulation of the impacts of the introduction of a carbon value (CO_2 equivalent) in agricultural activities at the world regional level. This is based on the IMAGE model for the reference projections of agricultural activities and on the AGRIPOL model for the associated MAC curves **(GECS Work Package 2b.)**.

iv Improve and extend the POLES and GEM-E3 models in order to include all abatement options and MAC curves describing the potential abatement for the 6 Kyoto GHGs **(GECS Work Package 3.)**.

v Develop a full economic assessment of common global cap and endowment scenarios both with the POLES and with the GEM-E3 model, highlight the complementarity between the two modelling tools and explain – on the basis of sound economic analysis – the differences in results when they appear **(GECS Work Package 4.)**.

While Diagram 1 below illustrates the structure of the project and the circulation of information among the different teams/models, this Synthesis Report strictly follows the logic described above. *Section 2.* is dedicated to the analysis of global GHG emission trajectories and international permit endowment schemes. *Section 3.* presents the key technological information that has been gathered in order to prepare for the 6 GHG reference projection and MAC curves for energy, industry and wastes, while *Section 4.* concentrates on the modelling of the reference and MAC curves for agriculture. *Section 5.* briefly presents, without entering in full technical details, the improvements and extensions introduced in the POLES and GEM-E3 model in the framework of the GECS project. Finally *Section 6.* presents and analyses the detailed results of the Multi-Gas Emission Control Strategies, before *Section 7.* summarises the key findings of the project.

Diagram 1: Structure of the GECS project and corresponding information flows



2 THE INTERNATIONAL CLIMATE NEGOTIATION AND THE LONG TERM GHG CONSTRAINTS (GECS WORKPACKAGE 1.)

This section presents a review of the recent outcomes of the international climate negotiation, before turning to an examination of the key principles that may be used in the future for the definition of international emission permit endowment schemes. Finally it presents the global emission profile and contrasted endowment schemes that have been selected for economic assessment of the multi-gas abatement scenarios in GECS.

2.1 Greenhouse Gas emission reduction policies: the international negotiation process (TFSD-FPB)

2.1.1 From Rio to Kyoto: from qualitative objectives, to quantitative targets

The ultimate objective, expressed in the Article 2. of the UNFCCC is to achieve the *"stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system"*. The Convention does not define what levels might be "dangerous", although it does state that ecosystems should be allowed to adapt naturally, food supply should not be threatened and economic development should be able to proceed in a sustainable manner. No concentration target is thus defined but a recommendation for a stabilisation by 2000 of the greenhouse gas emissions in the industrialised countries was adopted.

In December 1997 the Kyoto Protocol to UNFCCC was adopted. The most striking element of this Protocol was that most industrialised countries accepted that the average emissions over the 2008-2012 period for a country should not exceed a reduction commitment defined as a percentage of the country greenhouse gases emissions in the base year, i.e. 1990 for most countries. The emission limitation covers a basket of six different types of greenhouse gases, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

In meeting their commitments, countries that adopted targets may use several policy options. The most straightforward option is to reduce domestically the greenhouse gas emissions. However, the Protocol contains other options that allow countries domestic emissions to exceed the reduction target if equivalent reductions are achieved elsewhere or if corresponding and additional carbon capture by the biosphere has been demonstrated. This option is also referred to as 'sinks' activities. Additional carbon capture in the biosphere could indeed be less expensive than domestic emission reduction, however the temporary nature of the capture increases the risk of this option from both the economic and environmental point of view.

At the time of its adoption, the Kyoto Protocol (December 1997) left a number of implementation matters undecided. The flexible mechanisms, sinks and compliance provisions were agreed upon in principle but their operational guidelines still needed to be defined. The modalities of the monitoring, reporting and verification systems necessary to assure compliance and the banking provisions for different types of emission allowances also remained to be discussed. The principle of sinks enhancement was accepted but the list of eligible sinks activities and the extent of their use was still undecided.

2.1.2 From Buenos Aires to Marrakech

All these unresolved issues led to continued negotiations. They have filled the international environmental agenda in the recent years and it took the negotiating countries nearly four years to decide upon these extended guidelines and to make the text on the different instruments of the Kyoto Protocol operational. After failing to reaching an agreement at the 6th Conference of the Parties to the UNFCCC in The Hague, Netherlands, in November 2000 and the official rejection of the Kyoto Protocol by the United Stated of America in early 2002, the negotiations resumed nevertheless in Bonn in July 2001 and Parties reached a political agreement. At the 7th Conference of the Parties in November 2001 in Marrakech. There the Parties succeeded in translating the Bonn political agreement into legal texts and to finalise the rulebook that is referred to as the Marrakech Accords. The main outcomes of the Marrakech accord can be summarised as follows:

- *Sinks or Land use, Land use change and Forestry*

The Marrakech Accords define which types of human-induced sinks activities generate emission allowances (RMUs) under the Kyoto Protocol. These activities are limited to afforestation, reforestation, deforestation, revegetation, forest management, cropland management, and grazing land management. But large uncertainties remain on the measurement of biosphere carbon sequestration and some technical items remain unclear for the implementation regarding sinks activities. For instance, the negotiation process has defined ceilings on the quantities of carbon sequestered that could be accounted for, but the rules for the monitoring, reporting and verification of the sinks activities still need to be determined.

- *Flexible Mechanisms*

Concerning the flexible mechanisms, it was decided that no quantitative restrictions should apply to the amount of emission allowances that a country may buy to demonstrate compliance with its targets. Participation in these flexible mechanisms is conditioned upon a list of eligibility requirements. The most important criteria are that a country should have ratified the Kyoto Protocol and that its monitoring and reporting system for its greenhouse gases emissions meets certain quality standards.

- *Joint Implementation (JI), a second track*

Some Parties where concerned that the eligibility requirement that demands an elaborated monitoring and reporting system could be difficult to reach for some countries. Indeed, if some host countries receive investments for JI projects but fail to comply with the monitoring eligibility requirement, the investing country would be prevented from the delivery of the expected emission allowances generated by these JI projects. In order to alleviate this concern, provisions were introduced and allow investing countries to obtain the allowances even if the monitoring and reporting system of the host country does not meet the required standards. Under this procedure, external verifications on each project assess the amount of emission reductions carried out.

- *The Clean Development Mechanism (CDM) and the sinks in the CDM*

A comprehensive project life cycle was elaborated for projects under the CDM in order to guarantee the compliance with the two objectives of this mechanism. CDM projects help industrialised countries in meeting their commitments by performing emission reductions in the developing countries that are additional to a baseline but CDM projects should also assist developing countries in achieving their sustainable development objectives. It was also decided that afforestation and reforestation are eligible as projects under the CDM. However, the amount of emission allowances generated through these sinks activities is limited.

- *The Commitment Period Reserve*

As described above, no quantitative restrictions were put on the amount of emission allowances that may be bought by countries to demonstrate compliance with its reduction targets. On the seller side, a temporary limit is put on the amount of emission allowances that may be sold by countries. Under the Commitment Period Reserve provision, countries may not sell emission allowances if that would lower the country's total holdings of emission allowances under a certain limit[1]. This provision is only a temporary limit in order to prevent Parties from selling all their emission allowances at once and then leave the Kyoto Protocol as a rogue trader.

- *Limitations on banking, with no 'real' consequences*

Some provisions have been adopted to limit the amount of emission allowances that countries could bank for subsequent use in future commitment periods. Quantitative limits are put on the emission allowances generated through JI and CDM (ERUs and CERs) and emission allowances generated through sinks activities (RMUs) may not be banked at all. These provisions will have no effect in

[1] 90% of the country's reduction commitment or five times the amount of the most recent reported annual emissions.

practice as no rules have been adopted to define the type of emission allowances that should be used to demonstrate compliance and those which can be left over to bank to subsequent periods.

- *The restoration rate*

Countries that hold less emission allowances than the quantity of greenhouse gases released at the end of the commitment period are non-compliant. A 30 % penalty applies to the reduction target that is transmitted to the subsequent period. The amount of reductions to accomplish is increased with 1.3 times the amount of tons that the country failed to reduce or buy in the preceding period.

2.1.3 Political perspectives

The Kyoto Protocol will enter into force only if 55 countries ratify the treaty and if these countries account for at least 55 % of the 1990 CO_2 emissions of those industrialised countries listed in the Annex I of the UNFCCC. The limit of 55 ratifications, including ratification from the EU and Japan, has been attained but the second necessary condition is more difficult to fulfil since the United State of America, despite their ratification of the Convention, have officially declared in February 2001 that they have no intention to ratify the Kyoto Protocol.

Without the US and Australian ratification, which account respectively for 36 % and 2 % of Annex I Parties CO_2 emissions of the year 1990, reaching the 55 % CO_2 emissions threshold will require ratification from the Russian Federation. Although Russia has indicated officially its intention to ratify, the process remains at an early stage and might not be finalised before spring 2003. But this date seems a realistic deadline for the agreement to enter into force. The fundamentals of the Kyoto Protocol as it may be implemented are the following:

- The overall emissions reductions, particularly with the US withdrawal and the decisions on sinks, will no longer lead to a 5% reduction of Annex B Parties emissions from 1990 level. Estimates differ on the quantitative impact of these decisions. However, if the Kyoto Protocol is fulfilled as decided in Marrakech, one should not expect more reductions than a stabilisation around 1990 level for the Annex I group as a whole by 2012.
- The impact of the US withdrawal of the KP is indeed considerable in terms of emissions reductions as the climate Plan from the Bush administration does not differ significantly from the business-as-usual trends. However, a growing number of States do adopt climate policies at the State level. This fact should be kept in mind and could have some influence on the national emissions but also on the political process relevant to climate at the federal level.
- About the international emissions trading scheme as from 2008, the amount of allocations banked by the Russian federation and Ukraine will be fundamental elements for the evolution of the international prices of the carbon credits. Moreover, the low quality of the inventories in these Parties could create some significant uncertainty on the international market as, in today’s situation, the fulfilment of the eligibility criteria to access the market mechanisms is not certain.

2.2 Emission targets and international equity: a preliminary assessment (CES-KUL)

Given the public good nature of climate and the level of GHG emission reduction needed to arrive at the stabilisation level as advised by the scientists, an international agreement where countries commit themselves to emission reductions on a more or less voluntary basis is required. Because of the great differences between countries in terms of population, wealth, GHG emissions and abatement possibilities, vulnerability to climate change, preferences and priorities regarding climate change… the international equity issue is the most difficult element in the set-up of such an agreement.

Although long term scenarios suggest that some developing countries could become main contributors to the GHG emissions, these countries will not accept to participate if they feel the agreement is unfair. Moreover, because of the public good nature of climate, countries can also benefit from free-riding. Finally, the choice of the equity rule will have significant consequences for the distribution of the costs of environmental protection amongst countries.

2.2.1 A review of the equity issue in international abatement scenarios

As long as the theoretical conditions for an efficient allocation prevail, economic efficiency – defined in terms of Pareto-optimality – is neutral with respect to distributional issues. The economic efficient allocation of emission reductions is independent of how the total costs of these reductions are shared between countries, or which equity rule is applied respectively.

Generally, empirical analyses support the theoretical finding of the independency of the Pareto-optimal emissions trajectory from the initial allocation of emission rights. Conflicts between efficiency and equity principles in global warming policy arise only in the absence of international lump-sum transfers. Each policy that is supposed to address both efficiency and equity needs two policy instruments: one instrument for dealing with allocative objectives, e.g. a tax or permit system, and a second for implementing equity issues, e.g. compensation payments or transfers.

Introducing an international permit system allows, through the allocation of permits, to compensate countries, i.e. to take into account the “equity” dimension in climate change policy. Auctioning permits and using the income for redistribution allows also to take this dimension into account but may be still more difficult to implement at an international level. Therefore in all GECS studies an international permit system has been supposed, where the initial allocation is used for ensuring an ‘equitable’ burden sharing. The GECS overview of the equity concepts brought up in the climate change policy debate and specifically linked to distributive justice can be summarised as follows:

- *Utilitarianism and the Welfarist approach*

The utilities of individuals are the main concern, these utilities are then added (utilitarianism) or aggregated in a social welfare function so as to evaluate the global welfare at the society level. Though this approach has been much criticised (as the basic needs are not considered), it has been widely applied in welfare economics but without trying to give a more precise definition of utility and its link to the observable characteristics used in the evaluation. These theories concentrate on the ends and do not consider individual rights.

- *Libertarian theories of justice*

These theories give the priority to rights and liberties. There is a kind of egalitarianism in these theories, in terms of equality in rights/liberty, however other concerns are absent.

- *Rawlsian theory of justice*

This theory invokes two principles: equal liberty for each (but a narrow set of liberties, concerning basic personal and political liberties) and equal holding of "primary goods" with the least well-off having to be made as well-off as possible (maximin formulation). It concentrates on the means.

2.2.2 Emission permit allocation systems

The above mentioned theories can translate into equity criteria that can are defined in terms of the initial allocation of emission rights (‘allocation-based’) or in terms of traditional welfare economics (‘outcome-based’). Allocation-based rules are related directly to the distribution of emission rights. In terms of modelling, this corresponds to each country’s initial endowment of emission rights. In contrast, outcome-based rules take into account the incidence of costs and benefits, i.e. the net welfare change due to global warming policy.

- *Allocation based criteria*

They generally refer to an egalitarian or libertarian approach in terms of initial rights:

  - equal right to the use of the atmosphere, can be translated into allocating a same level of emissions per head to each region;
  - because of historic responsibility, greater effort of reduction for big polluters;
  - welfare approach, or egalitarian in terms of needs or capacities;

- in function of the ability to pay, translated into an allocation inversely proportional to GDP per capita;
- in function of abatement cost and benefits;
- maximin, i.e. maximise the net benefits to the poorest and therefore most of abatement cost on the richest countries.

- *Outcome based criteria*

The outcome based criteria are mainly based on the welfare approach and can be expressed as:

- equalise net welfare change across nations;
- net welfare change proportional to GDP per capita;
- maximisation of the welfare of the worst-off nations.

2.2.3 A preliminary analysis of equity criteria with GEM-E3

In order to explore some of the equity criteria described above, a preliminary comparison has been made with the GEM-E3 model in order to evaluate the impact in terms of social welfare of different allocation of endowments with a global emission target derived from the IPCC scenario B1 for the period 2000-2030. It implies a global reduction of emissions of 23 % compared to the GEM-E3 baseline and only CO2 is considered at this stage.

The allocation rules that are considered here are three:

vi Per capita Convergence (derived from the Global Common Institute), in which the target is to converge to an equal per capita emission at a certain period in the future, here 2050.

vii Global Compromise, in which the allocation is based on a weighted average of two criteria, grandfathering/past emissions (1/4) and equal emission per capita (3/4).

viii Ability To Pay, in which a third criteria is added compared to Global Compromise: the ability to pay measured by the GDP per capita (2/3), with one third for the two other criteria.

Though the results per region are dependant on their baseline emissions, comparing the three scenarios allows to focus on the impact of the allocation rules. The 'Per capita Convergence' and 'Global Compromise' allocation rules, as applied in this exercise, give rather close results, because they are both based on the grandfathering and emission per capita criteria, the weight attached to each criteria differing slightly in both scenarios. In the 'Ability To Pay' scenario, the aversion to inequality plays a dominant role and this is reflected in the outcome for the regions favoured by this allocation rule and also in the global welfare evaluation.

The 'ability to pay' allocation rule, by allocating more permits to the poorest regions, shifts the demand to these regions. The greater loss in the richer regions is not enough to annihilate this gain by the interconnection through bilateral trade flows, at least at the level of aggregation of GEM-E3 World. The presence of 'hot air' is important for these results as they represent a net transfer of resources to the poorest regions without associated emission reduction[2].

Considering only allocation based criteria, leaves out of consideration the interconnection of countries through bilateral trade. If big countries (i.e. countries that are powerful in terms of economic activity), are affected considerably, the interconnection of countries through bilateral trade might make the underlying burden sharing rule less attractive even for those countries which are favoured by the particular equity rule in terms of the initial allocation. Therefore, the analysis has to be complemented with outcome-based criteria. However the preliminary results with GEM-E3 show that this element is rather less important compared to the initial allocation rule for the regional effect of emission reduction.

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

2.3 The reference scenario for the GECS projections and Multi-Gas Assessment (TFSD-FPB and CNRS-IEPE)

The GECS project aims at performing economic modelling projections for GHG emissions to 2030, i.e. in a post-Kyoto time frame. It has thus been necessary to select from existing long-term scenarios, an emission path for the period 2010-2030 that may satisfy a clearly identified GHG concentration target and related global temperature evolution, and in that way represent a useful basis for the comparison of the different scenarios computed in the GECS project.

The IPCC 2001 scenarios, published in the Working Group I & III reports, follow an integrated approach between geophysics and economics and provide modelling results that link the emission paths to the GHG concentration and global temperature change. The IPCC special report on emissions scenarios (SRES) and the IPCC third assessment report (TAR) are therefore a consistent set of references that analyse together the emission scenarios and their consequences on GHG concentrations and global temperature on a century time scale.

In order to identify in the TAR and SRES reports the emission paths that are relevant to the work within GECS, it has been considered that the emission path should be compatible with CO_2 concentration stabilisation around 550 ppm before 2150 and the global temperature increase relative to 1990 should not exceed 2°C.

From the four main “storylines” in the IPCC scenarios, the B1 category has been selected for the GECS study as it best responds to the above criteria. The B1 storyline and scenario family describes a convergent world with a global population that peaks by mid-century and declines thereafter, and with rapid changes in economic structures toward a service and information economy, reductions in material intensity, and the introduction of clean and resource-efficient technologies.

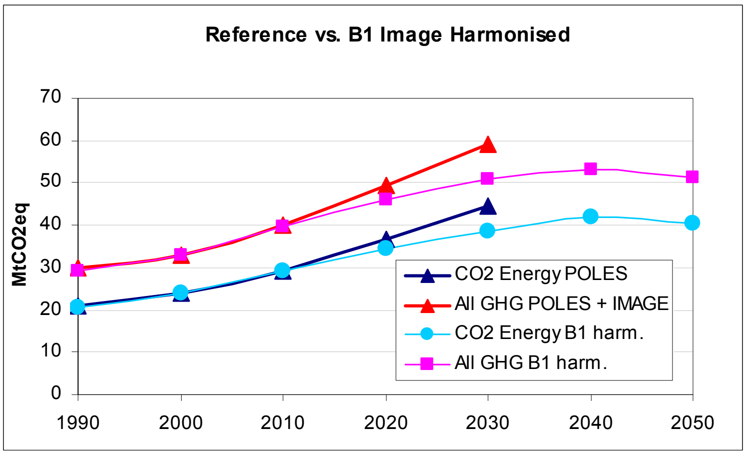
The B1 category of scenarios shows emission paths that allow a stabilisation around 550 ppm of CO_2 and a global temperature increase of no more than 2°C relative to 1990 observations. These paths are more compatible with sustainable development goals, but imply earlier action to curb current emission trends. As the projections for the GECS project concentrate on the 2000-2030 period, comparing with the results from the B1 storyline appears then as the most appropriate choice.

2.3.1 GECS global constraint profiles, endowment schemes and scenarios

- *The global profile and four GECS scenarios*

The total amount of emissions that are considered as compatible with long-term climate objectives, have thus been taken from the B1 scenario, after some adjustments have been introduced in order to account for the GECS models’ structure and reference projections. The international distribution rules have been selected after the analysis of the literature on international and intergenerational equity principles. Then the allocation rules have been applied in order to define the regional endowments in the POLES model’s 38 regions nomenclature.

Figure 1: The GECS POLES Reference and the Global Emission Constraint from IMAGE B1



The process of development of the international endowment schemes in GECS has thus been based on a three-stages process, resulting in a total of 2+2 scenarios:

i The selection of a global emission profile, the B1-IMAGE IPCC-SRES scenario.

ii The identification of two contrasted international emission endowment schemes, one aiming at a relatively progressive introduction of the emission constraint – Soft Landing, SL –, the other based on an a principle of international equity – the Per capita Convergence in emissions, PC.

iii Finally in the SL case, the definition of two "CO_2-only" variants, the CO_2-only "only", COO and the CO_2-only proportional case, COP.

Table 1: The four abatement scenarios assessed in the GECS study

		Type of GHG considered	
		6 GHG (Multi-Gas)	CO2
Endowment Scheme	Soft Landing	SL-MG	COO (CO2 only) COP (CO2 proportional)
	Per Capita Convergence	PC-MG	-

- *The Soft Landing scenarios (SL-MG)*

In the SL-MG scenario, the 38 POLES countries/regions are split in two groups: Annex B and non-Annex B countries.

The formers (or "Category 1") have "Kyoto-like" targets up to 2030. It is supposed that: for all OECD countries (as of the 1990 OECD definition) the emissions in 2030 should be 15% lower than the corresponding level in 2010; for the Eastern Europe and Former Soviet Union that emissions in 2030 should be stabilised to the corresponding 2010 level.

The non-Annex B countries are due to stabilise their emissions at a certain date in the future, depending on their level of per capita GDP in 2010 (this methodology is very close to the one used in Blanchard et al., 2002, except that we have not included here the emissions per capita criterion and used the GDP per capita criterion as the only criterion for categories definition):

- regions with a per capita GDP above 60% of the 2010 OECD90 per capita GDP have to stabilise their emissions in 2030 to the 2015 level: "Category 2"; South Korea is the only country entering into this category;
- regions with a per capita GDP between 15% and 60% of the 2010 OECD90 have to stabilise their emissions in 2030 to the 2030 level. This creates the "Category 3", to which pertain non-Annex B parts of Eastern Europe and Former Soviet Union, Mexico, South America, Turkey, North Africa non-OPEC, Middle-East (including the Gulf countries) and China; *the joint 2+3 Category is hereafter referred to as "Developing Countries" (DCs);*
- regions with a per capita GDP lower than 15% the 2010 OECD90 stabilise their emissions in 2045. This is the "Category 4" that encompasses the Sub-Saharan Africa, India and the Rest of South Asia, the Rest of South-East Asia (South-East Asia without China and South Korea), Egypt and North Africa OPEC and the Rest of Central America; *the Category 4 is hereafter referred to as "Least Developed Countries" (LDCs).*

The analyses concerning the "CO_2-only" cases are carried out simply by reporting:

- the whole volume of reductions from the *SL-MG* scenario to the energy related CO_2 emissions for the SL CO_2-only "only" scenario (COO);
- and by applying the same percentage reduction to CO_2 than to all gases in the SL CO_2-only "proportional" scenario (COP).

- *The Per capita Convergence scenario (*PC-MG*)*

The Per capita Convergence scenario is fully defined by the global emissions path and an equation with three key parameters. For the sake of comparison, it has been decided to apply to this endowment scheme the same emission profile than for the *SL-MG* scenario. This will indeed allow illustrating and analysing the consequences of two strongly differentiated distributions of endowments within a single global envelope.

In the PC case[3], the convergence scheme is non-linear, meaning that the share of emissions evolves non-linearly from the 2010 level towards the population share at *the convergence year*. The equation governing this convergence scheme depends on a *convergence parameter* that basically defines when the greatest part of the convergence effort takes place i.e. at the beginning, the middle or the end of the convergence period. No *cap year* for the calculation of the regions' population share is include in this scenario which means that the regions share of emissions at the convergence year will be equal to their population share at the convergence year.

The convergence year is arbitrarily chosen as 2050. No cap year applies to the population for the endowments calculations, and the chosen convergence coefficient is 4, which means roughly that most of the convergence effort takes place in the middle of the convergence period from 2010-2050.

2.3.2 Resulting endowments by main regions

In all scenarios and up to 2010 all constrained Annex B countries - with the exception of the USA - follow their Kyoto targets (reached in 2010), while non-Annex B countries follow their baselines. The USA follows a path close to the so-called "Bush plan[4]". It is assumed that, from 2011 onwards, all countries participate to the global allocation schemes described below. This constitutes only a rough estimation of the possible emission trajectories as it corresponds to a "linearisation" of the more complex system of the 5-year Commitment Period in the Protocol. The Annex B countries, which are in effect not constrained because of their hot air, the Eastern European Economies (EEE) and the Former Soviet Union (FSU), follow their baseline emissions: there is no use of the hot air up to 2010. The SL and PC endowment schemes are then applied for the 2010-2030 time-frame.

- *The Multi-Gas scenarios*

Figure 2. *SL-MG* scenario, total endowments

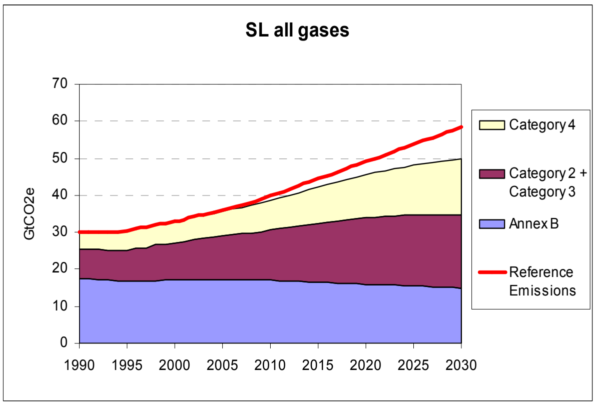
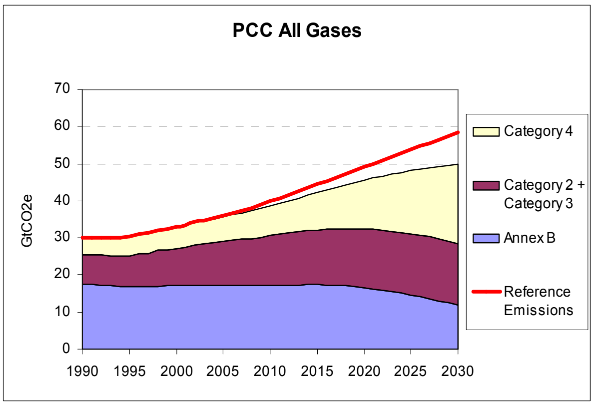


Figure 3. *PC-MG* scenario, total endowments



In the SL case, the Developing Countries' endowments are the most important in volume (about 20 $GtCO_2e$), while Annex B and Least Developed Countries benefit from similar total endowments (15 $GtCO_2e$). The PC case is, as expected, much more stringent for the Annex B countries, which receive only about 12 $GtCO_2e$. On the contrary, LDCs benefit the most of this case, as their endowments

[3] This approach is inspired from the key features of the "Contraction and Convergence" scheme, defined by the GCI, however it doesn't follow the exact principles and rules of the C&C approach.

[4] This plan calls for a -18% of reduction of the emissions intensity in the USA over the 2002-2012 period. In this study we have applied a -15% reduction over 2002-2010.

reach more than 21 $GtCO_2e$ in 2030, i.e. 6 $GtCO_2e$ more than in the SL case. DCs get a smaller volume of allowed emissions than in the previous case, with 17 $GtCO_2e$. One can notice a strong inflexion in the Annex B endowments around 2020, compensated by a strong increase in allocated emissions rights for the LDCs.

- *The CO2-only scenarios*

Figure 4: SL-COO scenario, CO2 endowments

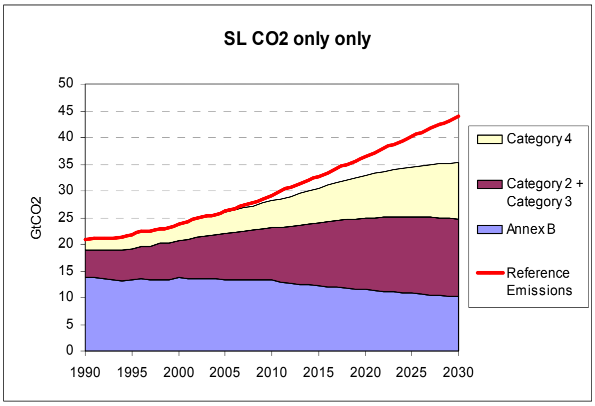
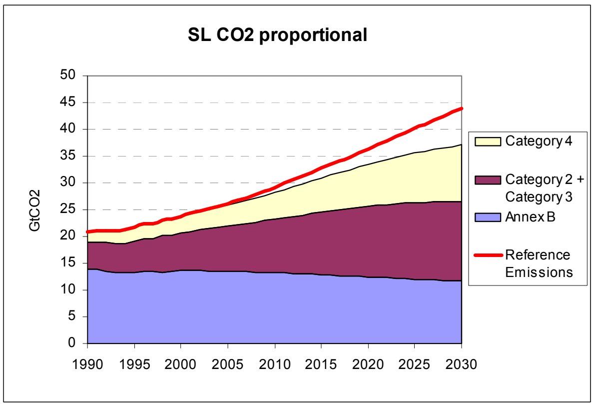


Figure 5: SL-COP scenario, CO2 endowments



The 2030 global endowment in terms of energy-CO_2 emissions is of course less important in the COO case than in the COP case: 35 vs.. 37 $GtCO_2$, the reference POLES energy-CO_2 emissions being of 44 $GtCO_2$ in 2030). In both cases, Developing Countries are allocated the largest share (14.5 $GtCO_2$ for COO and 14.8 $GtCO_2$ for COP). Least Developed Countries get the same allocation in the two cases (10 $GtCO_2$) while Annex B gets slightly more in the COP case: 11.6 $GtCO_2$ vs.. 10 $GtCO_2$.

3 GHG Emission Trends, Abatement Technologies and Marginal Abatement Cost Curves (GECS work package 2a.)

This section explores the sources, abatement technologies and potentials for the key non energy-CO_2 greenhouse gases, i.e. successively the non CO_2 gases of the energy sector, the CO_2 from cement and other GHGs from industry and the methane and nitrous oxide from wastes, landfills and wastewater. It then turns to two different issues: that of carbon sinks through forest plantation and that of transaction costs in the “flexible mechanisms” of the Kyoto Protocol.

3.1 Energy-related non-CO2 GHGs: sources of emissions, outlook and abatement options (CNRS-IEPE)

This section proposes a short description of the emission projections and abatement technologies related to the “energy sector non-CO_2 GHGs”, as defined in the framework of the Kyoto protocol (CH_4, N_2O, PFC, HFC and SF_6).

3.1.1 Methane Emissions from the oil and gas industry

Sources: The main sources of methane emissions in the energy sector correspond to natural gas associated to oil production and to leakages in natural gas production and transport facilities. The most significant contribution to emissions stems from gas production, followed by emissions from gas transportation. Together, these two activities account for about two thirds of CH_4 emissions from oil and gas industry. Most emissions from the oil industry are due to the venting and flaring of associated gaseous compounds, as the emissions from oil transportation and distribution are relatively small.

Outlook: CH_4 emissions from oil and gas production are projected to decrease slightly in the Industrialised Countries, due mainly to improvements in oil and gas production technologies that allow to recapture a larger share of the associated gas. In the Economies In Transition and in Developing Countries, emissions are expected to increase rapidly after 2010, reflecting the dynamics in oil and gas production in those regions. The POLES energy projections indeed suppose significant increases in the use and production of gas, particularly before 2020. This will lead to high growth rates for methane emissions in the key producing regions, of about 5% annual growth rate in DCs and 3% in Russia during the 2010-2020 decade. At world level, methane emissions from oil and gas production should reach 1.05 $GtCO_2$ in 2020 and 1.2 $GtCO_2$ in 2030, a doubling from the 0.64 $GtCO_2$ in 2000. As far as gas transport is concerned, the corresponding emissions are projected to increase by only 50 % over the next thirty years. Most of the increase comes from the developing regions, following the dynamics in production, while the huge losses that characterised the gas transport systems in the EITs are projected to be significantly reduced over the next decades, resulting in more standard “loss to quantity transported" ratios.

Abatement: It is estimated as technically feasible to reduce over 70% of present-day emissions from oil and gas industries taking into account only currently available technologies. Depending on regional conditions and current technologies, maximum reduction potential ranges from 25% to 80%. The key abatement technologies are identified as following:

i Gas emitted during well testing could be reduced by improved procedures, which in particular reduce the duration of field equipment testing.

ii Associated gas from oil production can be recovered and used, if possible, by injecting the gas into the same oil pipeline for separation at the LPG production. Another alternative is the re-injection into the well to enhance oil recovery. Given the differences in Global Warming Power, the choice of flaring can also reduce emissions in comparison with venting.

iii Replacement of pneumatic devices (with a typical lifetime of 7 years) can easily reduce the leakage of CH_4.

3.1.2 Methane from coal production and handling

Sources: Methane is released mostly as a by-product of coal production and the quantities emitted depend on multiple such factors as : the grade of coal (the methane stored in bituminous coal is more abundant than in lignite), the pressure temperature and depth of the coal seam, local geological conditions and technological factors (mining method, rate of extraction of the coal). Methane is emitted as well during handling, preparation, storage, transportation and end-use, but generally these emissions represent less than 10% of total emissions from coal production. Generally, the coal industry methane emissions are considered separately for underground and for surface mining. Approximately 90% of all emissions in this category are due to underground mining activities. Most of this methane (about 70%) is exhausted to the atmosphere by mine ventilation systems, a smaller part arises from methane drainage schemes that are designed to reduce the requirement for ventilation.

Outlook: The emissions from coal mining activities have been declining over the past ten years in the industrialised countries and the EITs, while they increased slightly in the DCs. The restructuring and closing of many gas-rich underground mines in Russia and European countries are major causes for this decline. Additionally, coal mines in industrialised countries are increasingly recovering methane from degasification systems. While the projected trends for methane emissions from coal industry correspond to a significant increase over the next thirty years, this increase is in relative terms less pronounced than for gas production activities: with 1.03 GtCO2 in 2030, world methane emissions from coal mines would be only 25 % higher than in 2000. The most important factor contributing to this increase in emissions from coal mining is the development of underground coal mines in developing countries, with a large amount of emissions coming from the Chinese coal mining industry that represents one third of world emissions.

Abatement: Generally four options are identified in order to recover methane from coal mining :

i gob well recovery;

ii pre-mining degasification ;

iii ventilation air utilisation;

iv and integrated recovery.

The current methods capture about 30% of the potential methane emissions. It should be possible to increase this to about 50 % by improved engineering systems. The cost of methane recovery vary from under \$100 /tCH_4 to over \$350 /t. The recovery of up to 50% of the total methane can generally be performed at costs that remain relatively low.

3.1.3 N_2O emissions in road transport

Sources: N_2O emissions from fuel combustion in transport are limited, except for the automobiles equipped with catalytic converters. For cars equipped with the new "three-way" converters, emissions may be 4 to 5 times higher than cars without any converter. An important feature is also that, as the catalyst ages, N_2O emissions tend to increase up to 10-16 times the emissions of car with no catalyst.

Outlook: The driving factor for nitrous oxide emissions from transport in the different world regions is the projected increase in automobile fuel consumption, as simulated in the other modules of the POLES model. Beside this, nitrous oxide emissions from automobiles and airplanes are closely related to the fuel mixture and combustion temperature, as well as pollution control equipment on transport vehicles. These factors have been taken into consideration through regional trends in catalytic converter equipment, combined with autonomous technological improvement parameters. N_2O emissions from transport represent however less than 2% of total N_2O emissions (40 MtCO_2e compared to a total of 2.4 GtCO_2e in 2030). The overall growth in nitrous oxide emissions from transport is projected to be substantially lower than for other GHGs. For developing countries however, N_2O emissions are projected to increase significantly due to the increase in distance travelled and fuel consumption resulting from strong economic growth combined with a growing share of catalyst-equipped automobile park. The slow increase of N_2O emissions in transport in industrialised countries is due to fact that these countries are planning to phase-in new emissions control technologies that produce lower N_2O emissions, and also to increasing overall energy efficiency of the passenger cars

Abatement: The key options to reduce the emissions from cars with catalytic converters are:

i the improvement in the catalyst design aimed at reducing N_2O emissions,

ii a better maintenance

iii and a frequent replacement of the old catalyst.

3.1.4 N_2O emissions from stationary combustion

Sources: Emissions from stationary combustion account for about 10-15% of N_2O emissions of the energy sector. The emissions from this category of activity are generally limited, except for two sources: Fluidised Bed Combustion, where the lower bed temperature lead to higher emissions, and Non Selective Catalytic Reduction technologies (NSCR) that are used to control NOx emissions. N_2O emissions due to the fuel combustion are highest for the combustion temperature range of 730 $\pm$ 200 °C; for combustion temperatures below or above this range, almost zero or negligible amounts of N_2O are emitted.

Abatement: The key options for reducing N_2O emissions from FBC are the following :

i Optimisation of operating conditions.

ii Use of gas afterburner.

iii Catalytic decomposition of N_2O.

iv Reversed air staging.

v Use of more advanced technology such as pressurised fluidised-bed combustion (PFBC) or integrated coal gasification (ICG).

More advanced clean coal technologies such as pressurised fluidised-bed combustion (PFBC) or integrated coal gasification (ICG) can also reduce significantly N_2O emissions. The emission level is remains higher than with conventional fossil fuel plants, but are lower than for atmospheric FBC plant. In addition, their higher efficiency helps to reduce emissions per unit of electricity produced. The abatement costs corresponding to the use of these technologies are estimated in the range of 50 to 180 $/tN2O abated.

3.1.5 SF_6 from electric power transmission and distribution systems

Sources: SF6 has a 100 year-GWP that is 22 200 times that of CO2 and is part of the so-called high global warming potential gases (HGWP) it has also a very long lifetime. SF6 is a manufactured gas, used as an electrical insulator in transmissions and distribution equipment of electric systems. In other industries, SF_6 emissions come mostly from semiconductor manufacturing and magnesium production (see below). This gas is also used in insulated windows, in the tyre industry and in the manufacturing of sport shoes and tennis balls. During recent years, the electric sector absorbed about 80% of total SF_6 sales. Most of this SF_6 is stored in gas insulated switchgear for high and mid-voltage electric networks. The sources of emissions come from fugitives emissions and release when equipment is opened for routine services or the disposal of equipment. At present, the typical annual leakage from switch is about 2%, but for the new generation of switches, the annual leakage is reduced to about 0.4% in developed countries due to tighter leakage protection, longer time for routine services, and better leak detection technologies.

Outlook: Concerning SF_6, the OGHG module projections are based on the regional electricity consumption forecasts from the main POLES model. Though the industrialised countries are still by far the largest source of those pollutants, emissions from electric utilities have been stabilised in the last decade, in spite of the growth in total electricity consumption and thanks largely to improved technologies and practices. In developing countries, the economic growth and industrialisation process will lead to a significant increase of these gases over the projection period. However, the price increase of SF6 in the mid-90s encouraged electric power system developers to improve equipment maintenance and serving in order to conserve the gas. After 2010, the implementation of new generations of switches will also contribute to moderate the emission through reductions in leakage rates. Altogether, these high GWP gases emissions will double between 1995 and 2030.

Abatement: The options available to reduce SF_6 emissions can be grouped into four main categories :

i *Recycling equipment* allow to capture and recycle SF_6 during maintenance and retirement instead of their venting to the atmosphere.

ii *Leak detection and repair* is probably the most promising and cost effective option to reduce SF_6 emissions from electric power systems.

iii *Equipment replacement,* since much of the SF_6 emitted from old switch gears, which often use larger amounts of SF_6 and have higher leak rates than new ones. Replacing these old equipments would reduce SF_6 emissions and avoid the leak.

iv *Use of advanced leak detection technologies* in order to reduce the time to detect a leak. Laser leak detection systems (such as GasVue laser camera) allow to find leaks without having to take out of service these equipments any modifications to switch gears.

3.2 Greenhouse gases from the Industry Sector: sources, outlook and abatement options (ICCS-NTUA)

Greenhouse gas emissions are produced as a by-product of several industrial activities, especially from those that include chemical processes. The GECS study has allowed to develop an emission outlook to 2030 regarding all non-energy related greenhouse gases from industrial processes and furthermore to estimate their respective marginal abatement cost curves. In order to produce the emission outlook base year (1995) emission data were collected and harmonised. The main source of the data was the EDGAR v3.3 database. Information on abatement technologies and costs has been extracted mainly from ECOFYS-NTUA “EU Sectoral Objective Study” and from several other published reports. By combining all available information it was possible to elaborate the Marginal Abatement Cost Curves for the industry sector of all countries by indirect methods, taking into account their structural differences, for which technological data have not been obtained.

The contribution of GHG emissions from industry to the global radiative forcing effect is relatively small compared to the emissions produced from the energy, waste and the agricultural sectors. In particular, non-energy related GHG emissions from industry sector at the base year were 1.2 $GtCO_2e.$, which accounts for a 4% of world total emissions. From the emissions generated by the industrial sector, CO_2 emissions from cement were of 0.7 Gt in 1995, holding the largest share of 59 %, while N_2O had the second largest share with 19 %. In addition to these two gases that are produced as a by-product of various non-energy related industrial activities, there are also industrial sources of several classes of man-made fluorinated compounds High Global Warming Potential Gases: hydrofluorocarbons (HFCs), perflurocarbons (PFCs), and sulfur hexafluoride (SF_6).

3.2.1 CO_2 emissions from cement industry

Sources: Non-energy related CO_2 from industry is mainly generated in the cement industry and during the production of clinker. In particular, during the production of Portland cement there is a stage where lime is combined with silica-containing materials to produce clinker: when this chemical process takes place, CO_2 is released in the atmosphere. Moreover, for the production of masonry cement from Portland, additional lime is required resulting in additional CO_2 emissions. Usually the CO_2 emissions from cement production are calculated based on total production of clinker or on the equivalent production of cement. IPCC suggests an emission factor of about 0.5 tCO_2 per tone of clinker or cement.

Outlook: In order to project CO_2 emissions from the cement industry, it has been necessary to identify the future trends in cement demand, which is itself connected to the overall growth of the construction industry. CO_2 emissions in most developed countries increased by an average rate of 15% from 1990 to 1998. Since the largest cement-producing countries are China, Japan, US and India, the cement demand forecasts of these regions are of particular interest. The outlook also takes into account the anticipated high increase in cement demand in the Asian countries. In general, the highest emission growth is expected in the least developed regions such as Asia, Africa and the Middle East, where demand for cement increases quite rapidly. Economies in transition show modest increases in CO_2 emissions, while it is relatively flat in developed countries.

Abatement: One abatement option is the use of blended cements, using such ingredients as coal fly-ash, where the CO_2 emissions are slightly reduced by a maximum of 10%-15%. There is no known technology to reduce carbon dioxide emissions of Portland cement any further.

3.2.2 HFC and PFC emissions

Sources: HFC and PFC emissions are generated during the process of construction, operation and maintenance of the following materials/equipment: aerosols, solvents cleaning, refrigeration and Air Conditioning equipment, foam production, sterilisation, fire extinguishing, aluminium production and semiconductors.

Moreover, primary aluminium production that is an electrolytic process has been identified as a major anthropogenic source of emissions of two perfluorocarbon compounds, CF_4 and C_2F_6, which are potent global warming gases as compared to CO_2. The magnitude of the PFC emissions during aluminium production depends on the frequency of the anode effects.

Another source of PFC and HFC emissions is the semiconductor manufacturing, where semiconductor industry uses these gases in plasma etching and chamber cleaning processes. The major PFC emission producers from semiconductor production are the US, EU-15, and Japan.

Outlook: HFC emissions are assumed to have a very high increase in the mid term, with a slowdown in the longer term. This is mainly because HFCs, being one of the main substitutes for ozone depleting substances and within the Montreal protocol, have increased rapidly in the 1995-2000 period. However, the 2000 Climate Change Policy report suggests that whilst HFC *use* will continue to grow, HFC *emissions* will soon reach their peak. Furthermore, HFCs emissions from HCFC-22 production are expected to decrease because the latter is scheduled to be phased-out in 2020.

Primary aluminium production-related emissions of PFCs are estimated to have declined since 1990, due to reductions in aluminium production and actions taken by aluminium smelting companies to reduce the frequency and duration of anode effects (Voluntary Aluminium Industrial Partnership). However, global aluminium production is anticipated to increase through 2010 and the production growth to result from additions to current aluminium capacity, mostly in the developing world. The developed countries as a whole will realise a substantial decrease in emissions because of the combined effect of production moving to developing countries and of reduced emission rates.

Market demand for semiconductors is projected to continue its current rapid growth. The semiconductor industry has imposed to itself an aggressive target PFC emission reduction. This ambitious and voluntarily undertaken program of emissions limitation is reflected in the outlook.

Abatement: The HFC-23 emissions can be reduced by 90% through cracking installations and afterburners. Along with the substitution from CFC to HFC, recycling systems should be developed for all cooling equipment and leakages should be reduced. Two options have been identified as technically viable measures to reduce HFC-23 emissions from HCFC-22 production: manufacturing process optimisation and destruction of HFC-23 by thermal oxidation.

There are three ways for reducing PFC emissions from aluminium production:

- i Improving Alumina Feeding Techniques.
- ii Using Improved Computer Controls to optimise cell performance (30% reduction).Training Cell Operators on methods and practices to minimise the frequency and duration of anode effects.

Aluminium production is being upgraded from highly inefficient smelters and practices in order to reduce the frequency and duration of the anode effect. Because aluminium smelters are large consumers of energy the cost of mitigating PFC emissions will be offset by savings in energy costs.

PFC Capture/Recovery technology is about separating unreacted and/or process-generated FCs from other gases for further processing. Currently available capture systems are guaranteed to remove 90% of emissions.

3.2.3 N_2O emissions from the chemical industry

Sources: Nitrous Oxide is emitted during the production of adipic and nitric acid (adipic acid is mainly used in the production of nylon, while nitric acid is a major component of adipic acid) and fertilisers. There are only few adipic acid plants worldwide. The United States is the major producer, with three companies in four locations accounting for approximately one half of total world production. N_2O emissions from the chemical industry are the second largest industrial source (19% in 1995) of non-CO_2 greenhouse emissions.

Outlook: Although these emissions have decreased dramatically from 1990 to 2000, they are expected to stabilise at the 2010 levels thereafter. This is mainly due to the fact that both nylon and fertiliser demand in developed countries is stagnant or even declining. On the other hand, these productions experience some growth in less developed countries (accompanied also by shifts in fertiliser production). The net result of these developments for the outlook is a virtual stagnation of world-wide emissions.

Abatement: Two options exist to reduce emissions from nitric and adipic acid production:

- i Process-integrated measures that require new plants
- ii End-of-pipe measures that are more promising in the short term. Emissions can be reduced by more than 90% through end-of-pipe equipment based on catalytic conversion.

3.2.4 SF_6 emissions from Magnesium and Aluminium production

Sources: Sulphurhexafluoride (SF_6) is an extremely stable atmospheric trace gas. All studies concur that this gas is entirely anthropogenic. Its unique physico-chemical properties make this gas ideally suited for many specialised industrial applications. Its 100-year GWP of 23,900 is the highest of any atmospheric trace gas. The magnesium metal production and casting industry uses SF_6 as a cover gas to prevent the violent oxidation of molten magnesium in the presence of air. The industry adopted the use of SF_6 to replace sulfur dioxide (SO_2). SF_6 is also emitted during the production of aluminium.

Outlook: SF_6 emissions growth are projected to decline due to the voluntary agreement on SF_6 emission reduction partnership for the magnesium industry. Since magnesium production in the developed countries is assumed to stabilise at low rates of growth, the increasing demand for magnesium parts will be initially satisfied by the less developed countries. This shift in magnesium production will induce LDCs to considerably increase their SF_6 emissions within the next 10 years.

Abatement: The most promising options to reduce SF_6 emissions from magnesium production and processing can be grouped into the four categories listed below:

i Good Housekeeping.

ii Process Optimisation (The practices referred to as "process optimisation" also result in the more efficient use of SF6 in magnesium production and processing (these measures are incremental to "good housekeeping").

iii Capture/Recycle SF6. The captured SF6 can be reused by the industry on-site. In many cases the recovery cost would be lower than market prices for virgin SF6.

iv Replace SF6 with SO2.

3.2.5 An assessment of global abatement potentials in industry

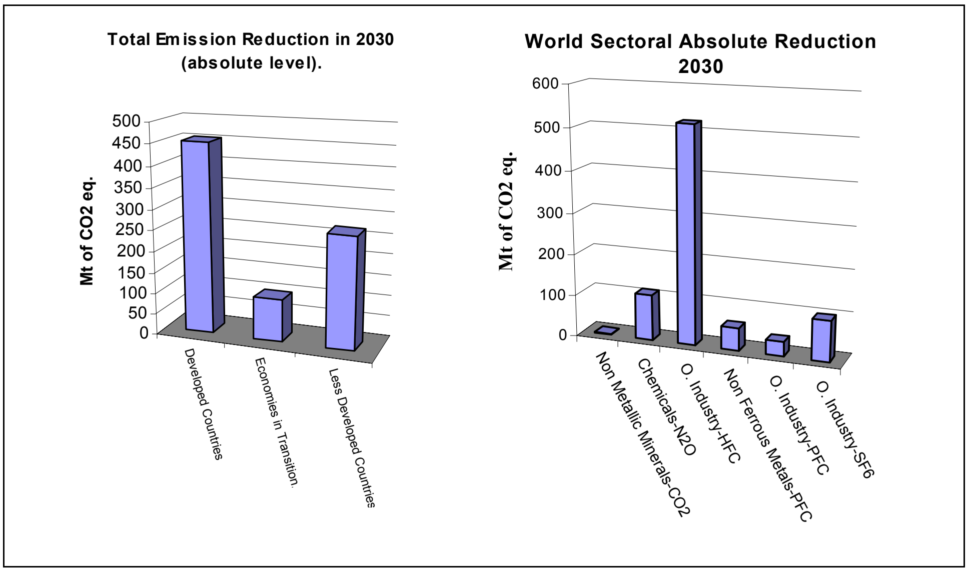
In order to explore the abatement potential of each gas and sector, an exercise has been conducted with the industry GHGs module developed in GECS. The carbon values used in the scenario resulted from an exercise carried out using the POLES model and that simulates a version of the "Soft-Landing" scenario.The results clearly showed that:

i The major potential of emission reduction lies in the HFCs from other industry (Figure 6). In both Annex-B and non Annex-B regions, HFCs from other industry exhibited the major mitigation possibilities.

ii Although less developed countries are exhibiting the higher emission growth rates (see above), the greatest potential for emissions abatement lies in the developed countries (Figure 6). This is due to the fact that the majority of emissions from less developed countries come from the cement industry, where there are little abatement opportunities, while developed countries emit the majority of HFC emissions where the abatement potential is high.

iii In Annex B countries, 69% of the abatement potential comes from the HFC, which is more than four times the potential from N_2O. SF_6 from other industry abatement potential is almost 9%, exceeding the combined abatement potential of PFC in non-ferrous metals and other industry that sums up to less than 6%. Abatement potential in HFC is more than half of the total in non-Annex B countries as well, with each of the SF_6 from other industry and the combined abatement potential of PFC exceeding a quarter of the total. N_2O from chemicals has a share of about 10% in the abatement potential, which is less than half of that of the Annex B countries. CO_2 from non-metallic minerals has a negligible abatement potential of less than 1% for both Annex B and non-Annex B countries.

Figure 6: Regional and Sectoral Absolute Emission Reduction – 2030



3.3 Emissions from Landfill and Wastewater (RIVM)

For the purpose of the GECS project, a list of greenhouse-gas (GHG) emissions and the associated activities, including cost-calculations for GHG abatement options matching the IMAGE and POLES models has been developed. The marginal abatement cost curves have been developed for two view years, i.e. 2010 and 2030. For landfilling and sewage, the regional emissions are taken as a basis for cost calculations, since IMAGE does not produce estimates of the volume of organic wastes dumped in landfills. For C sinks the potential area of carbon plantations is taken into account, based on the GECS baseline scenario. In all cases we use the bottom-up engineering approach for estimating costs of abatement, while distinguishing three types of Emission Reduction Measures:

i Add-on technology (AOT) or end-of-pipe (EOP) oriented ERMs,

ii Integrated measures or packages of measures, for instance the introduction of biotechnology and changes in food trade and consumption patterns,

iii Fully mixed measures (i.e., mixes of the above two types).

For several regions data on specific activities such as waste handling and sewage treatment, and abatement strategies and associated costs or benefits are scant or not available. In such cases the regional outcomes have been adjusted on the basis of other regions with adequate data. In practice, the feasible adjustments are constrained by the data used and model approach in the IMAGE model. The IMAGE 2.2 model includes a number of factors that can be used to translate cost curves to other regions, for example, the management factor, cropping intensity, fertiliser use, land-use (arable), availability of land, food efficiency, demand for animal products.

3.3.1 Abatement options and MAC curves for CH_4 emissions from landfills

Waste comprises a mix of materials of varying composition. When deposited in a landfill, a proportion of the organic waste fraction will begin to degrade through biological and chemical processes. Bacteria decompose the organic fraction, via an anaerobic phase to several products. Degradation results in biochemical breakdown products, water and the liberation of landfill gas, which is a mixture of CH_4 and CO_2. Two major categories of options for reducing and controlling CH_4 emissions from landfills need to be distinguished: the first one aims at reducing the mass of waste to be landfilled by recycling or treatment of the waste; the second one aims at reducing CH_4 emissions from landfill sites in place. Both approaches can be used independently or in combination.

- *Reduction of landfilling*

Paper recycling: Recycled paper will normally return in the process of paper and board production. In 1997 about 44% of paper waste was recycled in the EU member countries. Paper makes up 27% of Municipal Solid Waste (MSW) in the EU and about 60 to 70% of biodegradable C in MSW. Paper and board flows not going to landfills are assumed to have zero CH_4 emissions. It is currently assumed that 25% of landfilled paper waste can be recycled by 2010, and 50% by 2020. We therefore assumed that the potential for abatement of CH_4 emissions from landfills for 2010 is 25% of the current 17.4%, or 4.4%. For 2030 we assumed 50% abatement, which is 8.7% of the current landfill emission.

Composting: The degradable organic fraction of the waste can be composted to stabilise the organic matter. The residue is then landfilled or, if the feedstock waste is uncontaminated, the composted product can be used as fertiliser. Different systems are available for composting organic waste, centralised and decentralised. Current large-scale centralised systems are energy intensive and require sorting and multiple handling of the waste using machinery. Estimates of the energy use within composting facilities range from 20 to 70 kWh/t. The MSW consists of about 32% of organic waste. It is estimated that 30-50% of the waste will be turned into compost while 25% of the material is residue, which may be landfilled with negligible CH_4 generation potential.

Anaerobic digestion: It is primarily a method of energy recovery based on the natural decomposition of organic material in the absence of oxygen. Anaerobic digestion normally occurs in landfills, but this ERM involves optimisation of the process to decrease the period of gas generation to about three weeks rather than three or more decades in uncontrolled landfills. The process produces biogas, a mixture of CH_4 and CO_2, which is burnt to allow energy recovery, with a significant part of the energy generated will be needed to facilitate the fermentation process.

Incineration: During waste incineration the municipal waste is burnt and the energy released is used for heat or electricity production. In the EU, incineration is one of the most common options for pre-treating biodegradable wastes prior to landfilling. Incineration reduces the waste volume to 30% of its original volume and produces an inert residue suitable for landfilling. Incineration can be used to treat all fractions of MSW. Therefore, theoretically, all CH_4 emissions from newly formed waste can be avoided when all the waste is incinerated.

- *Reduction in the emissions of landfill sites.*

Capping of landfill sites: Where controlled landfills are in operation, improved site engineering can help to reduce uncontrolled emissions of CH_4 from the site. Capping of landfills with an impermeable clay layer reduces CH_4 emission by providing a physical barrier. Over many years, the clay cap may deteriorate or crack under dry weather conditions, however, if the restoration layers are engineered to take advantage of biological CH_4 oxidation activity, the CH_4 emissions are relatively unimportant. It is assumed that 80% of the landfill gas can be collected and combusted for all modern landfills. The remainder of the CH_4 produced by the waste (20%) will pass through the restoration layer.

Flaring of landfill gas: Gas collection and combustion can dramatically reduce uncontrolled CH_4 emissions to atmosphere. Modern flares are designed to work continuously. Costs of landfill gas collection can only be calculated on a site by site basis because of site-specific factors such as waste type, depth and area. Costs of flaring depend on local regulations and best practice requirements. Only where no suitable end use can be found and/or the project cannot achieve sufficient financial returns, flaring of CH_4 is the most suitable option.

Direct use of landfill gas: Landfill CH_4 can be used directly in boilers or indirectly for electricity generation or process heating. If direct combustion of landfill gas is not a viable option at a site, the most likely alternative is to generate electricity, with or without heat recovery. Electricity generation from landfill gas is a successful demonstration technology within the EU; currently more than 200 schemes are in operation.

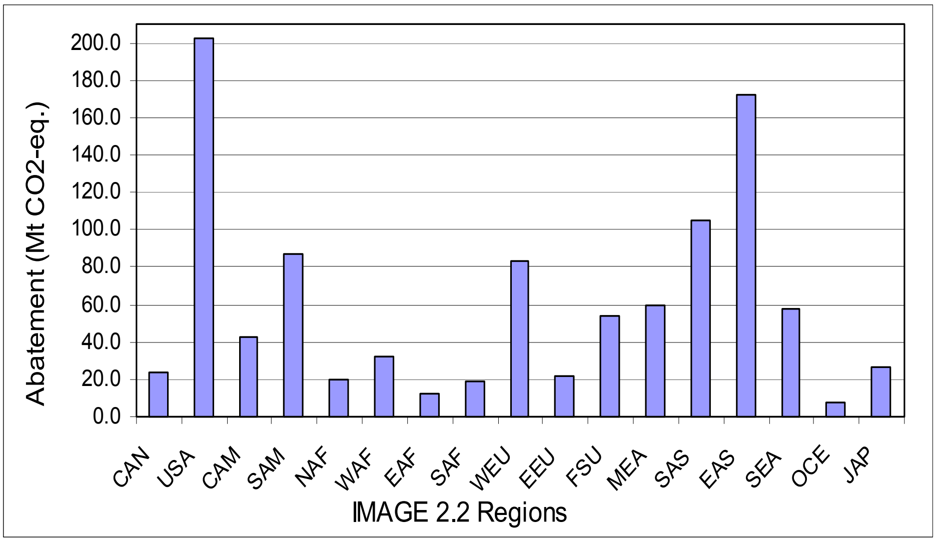
Methane oxidation in topsoils: CH_4 emissions from landfills can be reduced by optimisation of the conditions for oxidation by modifying the level of biological activity, the availability of nutrients, structural aspects of the cover material, etc.. Global CH_4 emissions from landfills could be reduced by an estimated 10 to 20% as a result. An economically interesting way to increase CH_4 oxidation is the addition of waste materials to the top-layer. Extensive large-scale experiments have not been made so far.

Aerobic landfilling with biological-mechanical pre-treatment: Methane in landfills is generated under strictly anaerobic conditions. Small amounts of oxygen in a landfill will inhibit the methanogenesis process and limit CH_4 generation. One way of maintaining the aerobic conditions in the landfills is a process where air enriched with oxygen is compressed and injected into the landfill, through specific needles. A further way the aerobic pre-treatment to reduce the CH_4 emission potential of the waste upon landfilling. This is generally part of mechanical-biological pre-treatment of waste, comprising: (i) mechanical treatment with separation (paper, plastics), size reduction and homogenisation; (ii) biological pre-treatment generally with a composting step and (iii) waste incineration.

- *Potential emission reduction*

The estimated reduction potentials for the year 2030 indicate that in the currently industrialised world regions the reduction potential will roughly double. The growth of emissions and hence the increase in reduction potential in the GECS baseline scenario is much larger in the less developed than in industrialised countries, as their share in the total emission reduction potential increases from 48.3 % in 2010 to 66.5 % in 2030 (Figure 7).

Figure 7: Potential CH_4 emission abatement for landfills for 2030 for 17 IMAGE regions

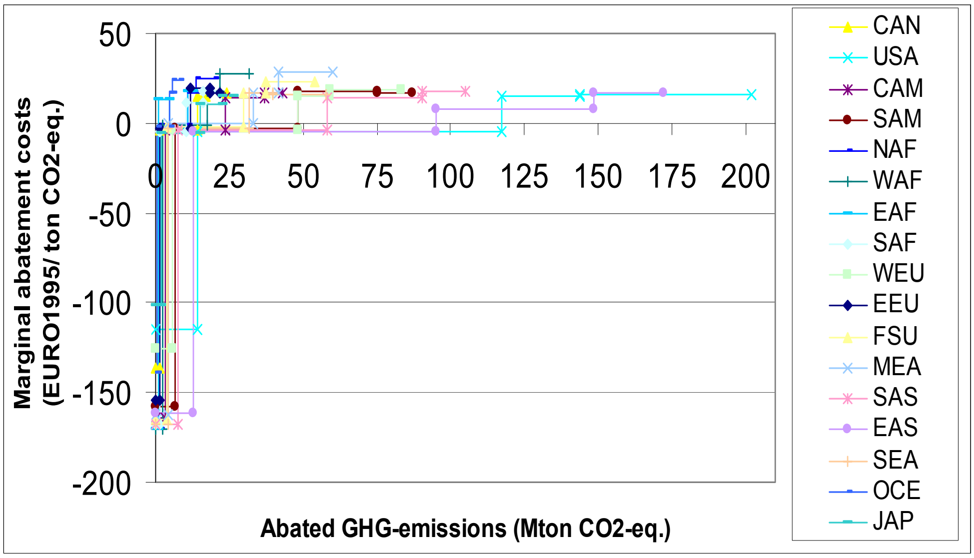


- *Costs of ERMs and cost curves for 2030*

For each ERM costs have been estimated first for European countries on the basis of several studies on emission reduction and associated costs, then these costs have been adjusted for other regions. The most cost-effective ERM is paper recycling, followed by ERMs involving the direct use of landfill gas. These options are in fact no-regret options, as the benefits from gained energy like heat or avoided expenditures for landfilling, for example, more than offset the costs of the ERMs. Flaring of landfill gas and electricity generation from landfill gas are both cost-effective options (22 and 36 €99/tonne CH_4, respectively). The cost of abating CH_4 by capping landfills is an order of magnitude higher than that of options involving the recovery of landfill gas. Apart from paper recycling, the options involving diversion of organic waste from the waste stream all have significantly higher costs of abatement (>1000 €99 /tonne CH_4).

In the GECS baseline scenario the CH_4 emissions from landfills strongly increase in most world regions until 2030. As a result, the potential emission reduction also increases. For the estimation of the implementation degree assumptions were based on estimates or expert judgements from the literature. It has been assumed that in 2030 the implementation degree of the various ERMs is higher than in 2010, particularly for ERMs requiring investments in high-tech installations.

Figure 8: Aggregated cost curves for reduction of CH_4 emissions for 2030 for the 17 IMAGE regions



3.3.2 Abatement options and MAC curves for CH_4 and N_2O from wastewater

Wastewater is produced in increasing quantities as a result of the growing world population and economy. Two major sources of wastewater are distinguished:

i Domestic and urban waste water stemming from toilets (black wastewater), kitchens and bathrooms; and combined wastewater (domestic wastewater combined with urban run-off water).

ii Industrial wastewater. Wastewater from the food and beverage industry contains by far the highest concentrations of organic compounds; further important sources are the petrochemical and the iron and steel industries.

In treatment plants in developed countries N is removed by nitrification and subsequent denitrification, whereby N_2 is the main product. N_2O and NO are intermediate products of denitrification which may escape to the atmosphere. Treatment methods for CH_4 and N_2O emissions vary considerably between systems. In most developed countries, most municipal and industrial wastewater is collected and treated in an integrated sewage system. After treatment the residue is disposed of on land or discharged into aquatic environments such as rivers or lakes. Integrated systems are not common in developing countries. The highest potential for reducing CH_4 emissions from wastewater is in developing countries, where waste streams are often unmanaged or maintained under anaerobic conditions without control of CH_4.. Industrial sources generate the majority of CH_4 emissions in OECD countries, especially food processing, pulp/paper and chemical industry.

- *Options and potentials to reduce methane emissions from wastewater*

Abatement options: The CH_4 formed in integrated sewage systems prior to full stabilisation of the sludge can be collected and flared or used as a fuel. Therefore, the available abatement options are similar to the ones for landfills. Several ERMs are available: aerobic wastewater treatment, upgrading of existing overloaded wastewater treatment plants or plants with sub-optimal aeration, aerobic treatment to stimulate CH_4 generation, which can be collected and re-used as fuel. An additional benefit is the substitution of fossil fuels. Most abatement options for CH_4 give reductions of close to 100%. Theoretically, full implementation of wastewater treatment could reduce annual global greenhouse gas emissions from raw discharged wastewater and latrine and septic tank wastewater by about 78%.

Potentials: On the basis of the above elements the reduction potential for CH_4 from wastewater have been estimated in the 17 IMAGE regions. In industrialised regions, the most important reductions can be achieved in the USA and OECD Europe. In Japan, Eastern Europe and OECD Europe where CH_4 emissions decline in the period 1995-2030, the reduction potential also declines. For developed countries we assumed a lower degree of implementation as less sanitation and wastewater treatment plants are in place. For 2030 we assume that for certain regions a maximum degree of implementation of 60% can be achieved. We also assume slight improvement in the effectiveness of CH_4 emission reduction over time, increasing from 60% in 2010, to 70% in 2020 and 80% in 2030. For the world as a whole the CH_4 emission from sewage (and reduction potential) strongly increase.

- *Options and potentials to reduce nitrous oxide emissions from wastewater*

Abatement options: N_2O emissions can be reduced by anaerobic denitrification in existing large scale and centralised treatment plants. In Europe most sewage treatment plants are optimised to achieve maximum N removal, with no consideration of the end-product (N_2O or N_2). Optimising the N removal process to achieve more complete reduction of NO_3^- to N_2 rather than to N_2O could reduce N_2O emission by 50%. It has been assumed that optimisation of these processes could reduce N_2O formation by one-third during nitrification and by two-thirds during denitrification. The total reduction in an aerobic-anaerobic system is about 40%. As a consequence of the increased N removal rates, the N load of surface water from sewage treatment plants is decreased significantly.

Potentials: Generally abatement measures for N_2O are not expressed in quantitative terms because of large uncertainties and lack of quantitative information. Therefore, conservative estimates were used for the reduction effectiveness. The maximumreduction of the N_2O emission from treated wastewater is considered of 20% in 2010, 30% in 2020 and 40% in 2030. Emission reductions are lower in high-income than in low-income regions, assuming that ERMs are already in place in many treatment plants. For 2010 the assumed implementation degree is 30% of its potential in high-income regions, 20% for medium-income regions and 10% for low-income regions. For 2030 the values for implementation degree are 70%, 40% and 30%, respectively.

- *Costs of ERMs abatement cost curves and potentials*

Cost estimates for sewage treatment are scarce. Some studies assume low or even at zero costs. Other studies estimated a cost of CH_4 abatement in the waste sector of around 50-100 US$ per ton of CH_4 abated (2.5-5 €99 per tCO_2e). For methane, aggregated cost estimates from the literature for the ERMs for OECD Europe were used. The operation and maintenance costs include those for treatment and sludge disposal. We used the corrections for regional labour and capital costs. The measures for N_2O can be applied against low or zero costs, and can be considered as no-regret options.

In the GECS baseline scenario the CH_4 emissions from sewage strongly increase in most of the world regions between 1990 and 2030. As a result, the potential emission reduction also strongly increases for most regions. Depending on the assumed implementation degree this leads to a strong increase in the emission reduction between 1995 and 2030.

The estimated emissions are within the range of uncertainty in the estimates of EPA and other studies however our estimates for abatement of CH_4 emissions differ strongly from some other studies that assumed much more optimistic CH_4 emission abatement with a maximum of almost 50% from total emissions for the U.S.A. for 2010. For comparison, our results indicate an abatement of only about 10% for the U.S.A. for 2010. This is due mostly to the strong increase in abatement costs beyond 30% abatement.

3.4 Emission abatement by carbon sequestration (RIVM)

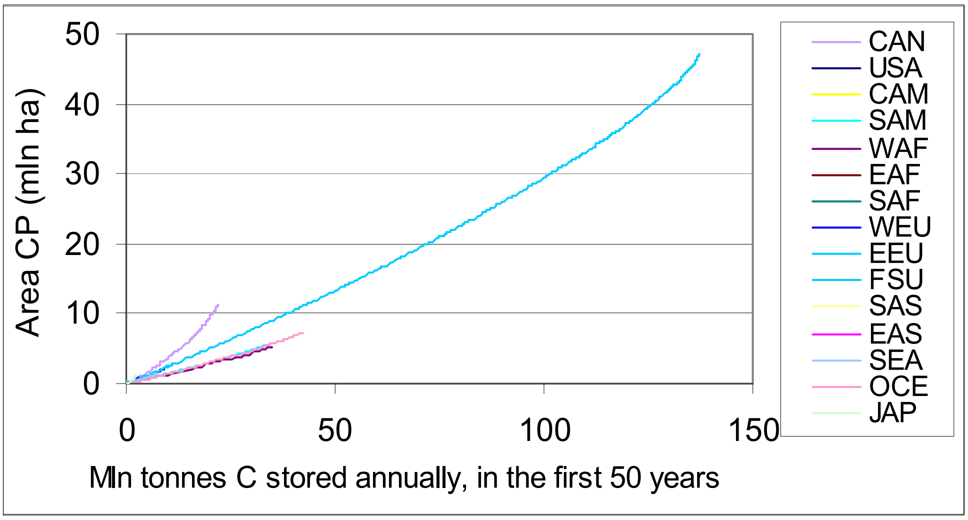
The potential C sequestration is calculated on the basis of the Land Cover and Carbon cycle modules of IMAGE 2.2 and it is based on the Surplus Potential Productivity (SPP). The Carbon Sink module generates the SPP and area for each 0.5 by 0.5 degree grid cell, the potential and actual yield for the different crops, the original vegetation and the planted tree species for specific years. This information is aggregated to the level of the IMAGE 2.2 regions, resulting in a physical C sequestration curve.

Between 1995 and 2030, the GECS scenario period, those areas that will be abandoned from their original agricultural or forestry use are added to the potential plantation area if they remain unused during at least the next 50 years. For projections of land use changes after 2030 the SRES A1B scenario has been used because it most closely matches the GECS Reference storyline and hpyothses. In this study we do not consider the conversion from primary and secondary natural vegetation to carbon plantations. This is based on the assumption that the concern about nature conservation and biodiversity has a high priority, while in addition the SPP for conversion from existing natural vegetation will in most cases be much lower than for conversions from agricultural land to C plantations, leading to much higher costs than conversion of agricultural land with much higher SPP.

3.4.1 Potential carbon sequestration

Figure 9 presents the physical C sequestration potential as a function of the area planted for 2030, for abandoned agricultural land for all IMAGE regions for 2030. Since the area of abandoned agricultural land in the former Soviet Union in the period 1990-2000 is very large, the potential C sequestration in this region dominates that of the whole world.

Figure 9: Regional contribution to the global potential C sequestration in C plantations on abandoned agricultural land in 2030



3.4.2 Costs of sequestration

Various categories of costs and benefits related to C plantations can be considered. Here, a selection has to be made that fits the aims of the Kyoto Protocol article 3.3, based on the following considerations:

Since we consider abandoned agricultural land, the use of opportunity costs is not correct, because the land has no alternative use. Where the agricultural land is still in use for food and fibre production, the compensation would have to be equal to the opportunity costs or lost net income, i.e., the market value of the crop minus production costs. In such cases this compensation would be an incentive for the agricultural sector (farmers or land owners) to increase productivity and efficiency elsewhere on the farm or within the country or region. Therefore the land cost estimates have to be based on the equivalent of land prices, using World Bank data. These are consistently based on land values derived from the present discounted value of the return to the land. The IMAGE Land Cover model assumes that abandoned agricultural areas have a lower productivity than the average for agricultural areas.

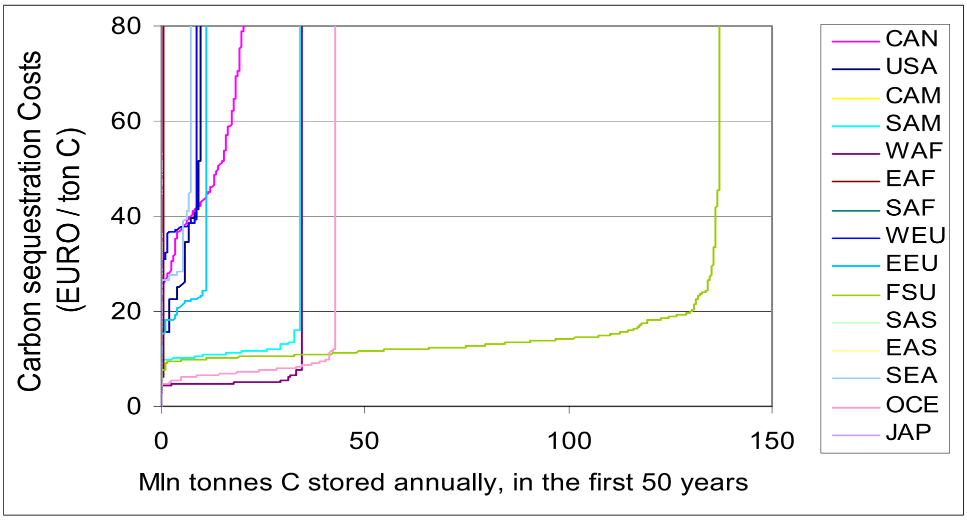
Forest establishment costs include costs of nurseries to produce seedlings, land clearing and planting. Costs of land clearing depend on the original type of vegetation and other (landscape and soil) factors. In this study, we consider abandoned agricultural land, for which costs of land clearing are assumed to be lower (roughly half) than for any of the transitions from natural vegetation types. In most studies no annual operation and maintenance costs are considered, but only the establishment costs. Regional information on establishment costs summarised by IPCC have been translated into the IMAGE 2.2 region level. For annual operation and maintenance costs of carbon plantations a standard value of €95 25 per hectare for OECD Europe have been used, while for the other regions the maintenance costs were varied on the basis of per capita incomes, as costs of maintenance operations primarily involve labour costs.

3.4.3 MAC curves

The costs of C sequestration are obtained by combining the annualised costs per hectare for each region with the per hectare average annual C sequestration rate. Annual C sequestration rates are calculated as the mean sequestration rate during a 50-year period. First we consider the potential C plantation area. The results are presented in Figure 10.

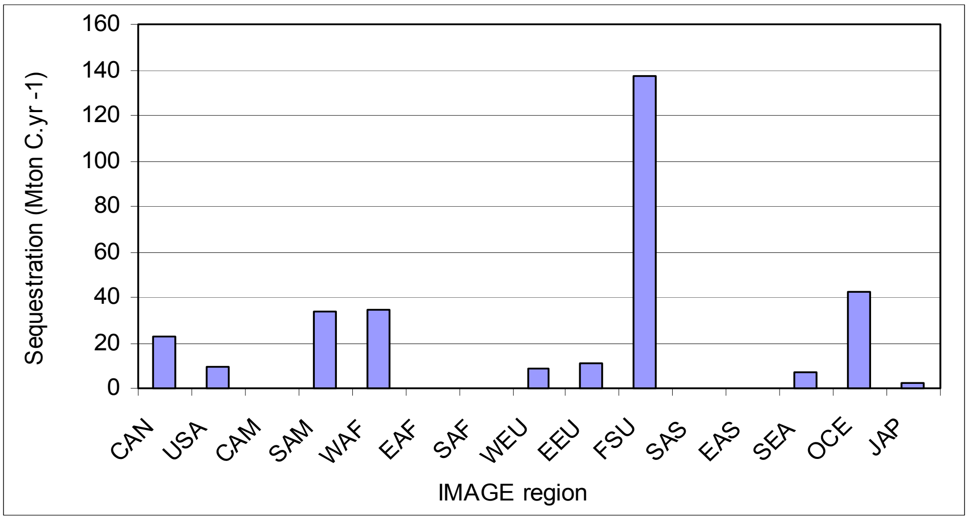
It is clear that the former Soviet Union by far has the highest potential and that West Africa, Oceania, Former USSR and Eastern Europe has the lowest cost per tonne of C sequestered. Japan has the highest costs followed by East Asia (due to the limited potential plantation area), Southeast Asia, OECD Europe, Canada and United States. The differences are primarily caused by the difference in annual land costs per hectare.

Figure 10: Aggregated cost curves for the 17 IMAGE regions for C plantations established on agricultural land only in 2030 (100 % implementation)



The former USSR has the highest potential in 2010 and in 2030 followed by Oceania, West Africa and South America. Together these regions contribute about 80% to the world's potential in 2030 (Figure 11).

Figure 11: Average potential annual C sequestration for the 17 IMAGE regions by C plantations established on agricultural land for 2030



These results have been compared with the current area of forest plantations and its annual change. The area of forest plantations according to FAO for 2000 is 187 Mha world-wide, while the area that is currently planted each year is 4.5 Mha. Therefore, two variants with lower implementation degrees that reflect the effect of certain socio-economic and other barriers that may prevent the realisation of carbon plantations. Using an implementation degree of 10% and 30% for 2010 and 2030, respectively, results in annual plantation of forests for carbon sequestration of 5.0 and 15.0 Mha, respectively. These estimates are in good agreement with the area of forest plantations of 4.5 Mha reported by FAO (2001b) for 2000. The annual carbon sequestration on abandoned agricultural land for the world as a whole is 16 Mton C for 2010 for the low implementation degree (10%). For 2030 an implementation degree of 30% results in annual global carbon sequestration of 93 MtC for abandoned agricultural land.

3.5 Transaction Costs and Risk in Climate Change Context (ZEW)

The Flexible Mechanisms in the Kyoto Protocol encompass the Joint Implementation (JI) of projects among industrialised countries, joint implementation between industrialised and developing countries within the multilateral framework of the Clean Development Mechanism (CDM) and the establishment of an International Emissions Trading scheme (IET) amongst industrialised countries. In the evaluation of these instruments however, transaction costs have usually not been taken into account.

The most obvious impact of transaction costs is that they raise the costs for the participants of the transaction and thereby lower the trading volume or even discourage some transactions from occurring. Within the context of climate change, transaction costs are important because they may influence the scope and extent of the use of flexibility mechanisms. Closely linked to the problem of transaction costs is the issue of risk. To reduce or avoid risks the purchasing party might insure the projects or diversify through carbon funds. Further options would be more stringent rules for project verification and certifications. These strategies would be associated with higher transaction costs.

3.5.1 Estimates of transaction costs in JI and CDM

For the GECS study, the assessment of transaction costs in CDM and JI projects undertaken by PriceWaterhouseCoopers and EcoSecurities have been analysed and compared. Although the reports stress different aspects, both surveys make clear that the size of the project is significant for the costs per ton of carbon reduced. Therefore a classification of project size and transaction costs into a limited number of groups will cover the basic conclusions that can be drawn from the data and can be regarded as the most useful way of presenting the data. The values for JI and CDM differ only slightly.

Table 2: Correlation of projects and project size

Type	Typical projects
Very large	Large hydro, gas power plants, large CHP, geothermal, landfill/pipeline methane capture, cement plant efficiency, large-scale afforestation
Large	Wind power, solar thermal, energy efficiency in large industry
Medium – upper	Boiler conversion, DSM, small hydro
Medium – lower	Energy efficiency in housing and SME, mini hydro
Small	PV

Table 3: Classification of project size for JI projects

Type	Reduction (t C/a)	Low €/ton C	Central €/ton C	High €/ton C
Very large	> 50,000	0.05	0.1	0.2
Large	5,000 - 50,000	0.5	1	2
Medium-upper	500 - 5,000	3	10	15
Medium-lower	50 - 500	35	100	300
Small	< 50	400	500	600

Table 4: Classification of project size for CDM projects

Type	Reduction (t C/a)	Low €/ton C	Central €/ton C	High €/ton C
Very large	> 50,000	0.08	0.2	1
Large	5,000 - 50,000	0.25	0.5	2
Medium-upper	500 - 5,000	5	10	15
Medium-lower	50 - 500	67	100	300
Small	< 50	670	1,000	2000

The literature suggests that it is very likely that transaction costs for both instruments will fall over time due to learning effects and increasing competition in these markets. PwC suggest a 20% cost reduction in the implementation phase due to learning effects, which may even be regarded as minimum reduction. As already mentioned the implementation of the flexible mechanisms in the Kyoto Protocol is likely to influence the size of the transaction costs. Crucial factors are the final specification of liability and the provision of regulating institutions. Especially for the small projects any such institutions or streamlining will reduce transaction costs significantly.

The Parties agreed that renewable energy projects of a capacity below 15 MW, energy efficiency projects saving up to 15 GWh and other projects emitting less than 15 kt of CO2 annually, will benefit from simplified modalities and procedures. Thus, the medium and small categories in Table 4 above can then be adjusted to those levels presented in Table 5

Table 5: Transaction Costs for streamlined small-scale CDM projects (PwC)

Type	Reduction (t/a)	Low ($/ton C)	Central ($/ton C)	High ($/ton C)
Medium – upper	500 - 5,000	0.45	0.9	1.35
Medium – lower	50 - 500	6	9	27
Small	< 50	60	90	180

3.5.2 International Emissions Trading (IET)

An emissions trading scheme will allow emissions reduction to be made wherever in the Community it is cheapest to make them. Thus, the benefits of trade will be available to sellers as well as buyers, who may not have as cheap reduction possibilities themselves.

It is difficult to set up transaction costs for international emissions trading. For this purpose data from national emissions trading can serve as a reference. The most frequently referred programs in this context are the US lead trading and SO2 trading schemes. Transaction costs in these programs amount for 5-10% of project capital costs. According to some authors, brokerage fees will be the most significant component of transaction costs in trading schemes. They are estimated to be in the range of 2% to 10% depending on the trading price. However, these schemes are national schemes and it can't be taken for granted that transaction cost ranges will be the same for international emissions trading. A lot will again depend on the trading rules that will be established.

3.5.3 Transaction Costs in quantitative models

Until now transaction costs have not been implemented into the GEM-E3 model. The inclusion of transaction costs will be a significant improvement, because model simulations that neglect the existence of transaction costs over-estimate the potential benefit from emissions reduction abroad by means of the flexible mechanisms compared to domestic abatement. Some illustrative simulations have been performed after introduction of transaction cost in the GEM-E3 model to get a first idea about the effects of transaction costs. However, these simulations do not yet provide empirical foundation, distinction of the costs between countries, a step-function for transaction costs nor a sectoral disaggregation.

Not surprisingly, transaction costs reduce the magnitude of efficiency gains from emissions trading with non-Annex-B countries. The higher the transaction costs, the higher are the global effective permit prices (indicated by the MAC of Annex-B countries) and the lower is the overall level of permit trading.

Transaction costs, which apply to emission trading with non-Annex-B countries but not to emission sales from Annex-B countries are beneficial to CEA and FSU. These countries now can sell their permits at higher prices than in a scenario without any transaction costs (noTC). Mainly due to this "mark-up" for FSU and CEA, OECD countries do worse than under the scenario with no transaction costs because they move to higher marginal abatement costs. Except for CHN which is the largest non-Annex-B supplier of emission permits in absolute terms, transaction costs do hardly affect welfare for the other non-Annex-B countries simply because their level of trade is already rather small without any transaction cost.

The results show that transaction costs are significant cost elements in the proposed implementation of the flexible mechanisms under the Kyoto Protocol. Moreover, it is likely that they will matter in the decision as to whether an individual JI or CDM project will be undertaken or not. Whilst the lack, and inconsistencies, within the empirical data at present makes it difficult to verify, the existing estimates illustrate that the absolute level of transaction costs is similar over all project types. Therefore the size of a project is significant for the costs per ton of carbon reduced. This underlines the importance of simplified modalities for small-scale projects, which were decided in the Marrakech Accords. An elaborated project cycle may enhance up-front transaction costs but lower them ex post. Moreover, rules that enhance transparency will be critical to reduce search costs even if they entail ex-ante costs. Funds such as the Prototype Carbon Fund (PCF) can reduce transaction costs by developing generic procedures such as standardised contracts. They can also specialise in specific project types.

4 GHG EMISSIONS FROM AGRICULTURE: WORLD PROJECTIONS WITH THE IMAGE MODEL AND THE MODELLING OF GHG CONSTRAINTS WITH THE AGRIPOL MODEL (GECS WORK PACKAGE 2B.)

This Section concentrates on the GHG emissions of the agricultural sector and first presents the modelling framework – based on the IMAGE model – that has been used to project these emissions in the GECS 2030 reference projection. Then it describes the new modelling framework that allows – through the AGRIPOL model – to simulate the consequences of the introduction of a carbon value in agriculture and thus to develop the corresponding MAC curves, to be used by the other models in GECS.

4.1 Scenario development for agriculture, land use and greenhouse gas emissions (RIVM)

The results of the RIVM team include the development of the GECS baseline scenario in general and for agriculture, land use and associated greenhouse gas emissions in particular. In this chapter we will present:

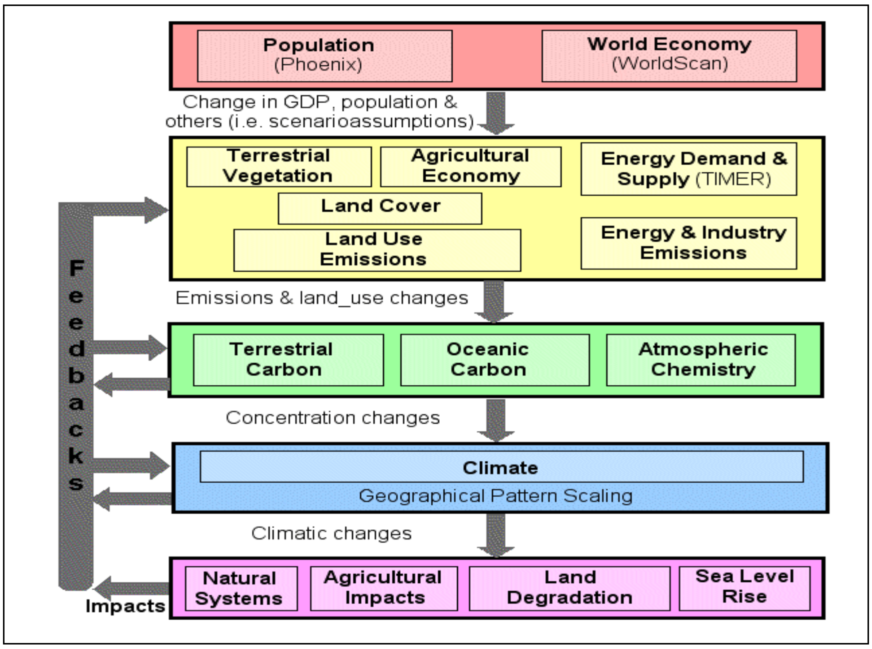
- i the background of the relevant components of the IMAGE 2.2 model,
- ii the computation of land-use related GHG emissions,
- iii scenario assumptions for land use and agricultural production and trade,
- iv and the baseline scenario projections for land use and associated emissions.

4.1.1 Description of relevant IMAGE 2.2 sub-models

- *Structure of IMAGE 2.2 model*

The objective of the IMAGE-2.2 model is to explore the long-term dynamics of global environmental change. The model is an integration of many disciplinary models as illustrated in Figure 12. Throughout the model interactions and several feedbacks are modelled explicitly. Routinely, in the IMAGE 2.2 framework the general equilibrium economy model, WorldScan of the Central Planning Bureau, and the population model, PHOENIX, supply the basic information on economic and demographic developments for 17 socio-economic regions. In the GECS project, the population and economic scenarios are provided by CNRS-IEPE.

Figure 12: The framework of the IMAGE 2.2 model



- *Calculation of land-use related greenhouse gas emissions*

The non-CO_2 GHGs like CH_4 and N_2O are more potent greenhouse-gases than CO_2 and these gases are significant contributors to the total greenhouse gas emissions expressed in CO_2-equivalent emissions. Land-use related (including natural) sources are the major contributors to the emissions of CH_4 and N_2O. The Land Use Emissions model in IMAGE 2.2 covers the following gas species: carbon monoxide (CO), methane (CH_4), nitrogen oxides (NO_x), nitrous oxide (N_2O) and volatile organic compounds (VOC). In general the emissions for a specific GHG are calculated as the product of an activity level, e.g. fertiliser use, feed intake, amount of biomass burnt, and of an emission factor, i.e. the emission per unit of the activity, at time t.

Methane emissions stem from a variety of sources. A major source is microbial decomposition of organic material under anaerobic conditions occurring in natural wetlands, wet rice cultivation and landfill sites for solid waste dumping. Methane is also formed in the digestive tract of ruminating animals and by various insects, the major species being termites (10-50 $MtCH_4$ per year). The burning of biomass is another source, coming next to fossil or non-living CH_4 from CH_4 hydrates. For CH_4 emissions from cattle a model approach is used based on EPA. In this approach CH_4 emissions are directly related to the feed intake. Hence, the CH_4 generation is calculated on the basis of the scenario for animal productivity considered, and no additional assumptions are needed. For the other animals (sheep and goats, pigs and poultry) a different approach is taken. Here it is assumed that emission factors of livestock in developing countries slowly evolve to those of industrialised countries.

Nitrous oxide is formed in soils during nitrification and denitrification. The precise dynamics of N_2O emissions are largely unknown, but are related to several sources, such as N-fertiliser use, animal manure and biomass burning, aquatic sources (oceans and coastal waters, sewage treatment, freshwater systems, aquifers and irrigation) and global warming, which accelerates biological N_2O forming processes. The land-use related N_2O emissions stem from application of synthetic N fertilisers and animal wastes to croplands and grasslands, animal waste management systems, grazing, soil incorporation of crop residues and cultivation of leguminous crops, as well as indirect sources caused by leaching of N and by human sewage. The calculation of N_2O emissions from soils under natural vegetation is based on a modification of a regression model using NPP, soil moisture, oxygen and fertility. The regression now includes more measurement data covering a wider range of ecosystems and explains about 70% of the variability in reported measurements. Deforestation (i.e. land clearing) may lead to accelerated decomposition of litter, root material and soil organic matter in the first years after disturbance, causing a pulse of N_2O emissions. This effect is taken into account only for tropical rain and seasonal forests, where in the first year after clearing, the N_2O flux amounts to five times the flux of the original ecosystem, which then decreases linearly to the flux of the new ecosystem in the subsequent 10 years; this is usually lower than the flux from the original forest.

4.1.2 Scenario assumptions for land use and associated emissions

Except for those sources where a global estimate is used, emissions from all sources vary according to the scenario considered. For example, the CH_4 emissions from cattle per unit of product decrease with increasing productivity. Natural N_2O emissions change according to land cover and climate changes. Fertiliser-induced emissions change according to the scenario of fertiliser use and substitution of synthetic fertilisers by animal manure. For the GECS baseline scenario the following scenario assumptions were used:

Trade. For each product, trade is based on the self-sufficiency ratio (SSR, i.e., the ratio between regional production and consumption), and the desired self-sufficiency ratio (DSSR). Generally, DSSR is assumed never to exceed a value of 2. In other words, the regional export will – provided some exceptions – not exceed the regional consumption.

Livestock production. For animal production assumptions are made on the carcass weight at slaughtering, the off-take rate (the percentage of the animal population that is slaughtered each year) and the feed efficiency (the amount of feed required to produce one kg of product, i.e. milk or meat) for the animal categories non-dairy cattle, dairy cattle, pigs, poultry and sheep and goats. In general the assumption is that when countries reach the 1995 OECD Europe income level, their productivity and feed efficiency will also reach the OECD Europe level of 1995.

Crop Production: In temperate regions the cropping intensity is generally less than 1, because part of the arable area is fallow. In some tropical regions with an important share of irrigated crops, the cropping intensity exceeds unity, indicating that more than one crop is grown each year. Regional cropping intensities move towards region-specific maximum values. Increasing cropping intensities reduces the need for expansion of the agricultural area used.

Fertiliser use. For crops the maximum nutrient input (fertiliser plus animal manure) is 300 kg NPK/ha each year, which is 90% of the rate in OECD Europe in 1995. Industrialised regions are assumed to move in a linear fashion towards this rate in 2025. The fraction of synthetic fertilisers applied to grass and fodder species is also assumed to grow towards the fraction of OECD Europe. The fraction of animal manure that is available for application to crops and grasslands is assumed to approach the 1995 OECD Europe level when regions approach the per capita GDP of that region. This is to simulate intensification of livestock production whereby more animal manure becomes available and gradually substitutes synthetic fertiliser.

CH4 Emissions. For CH_4 emissions from agricultural waste burning, landfills and wetland rice assumptions are used as indicated below :

Agricultural waste burning	OECD-regions: fraction of crop residues burnt in the field changes towards 1995 OECD Europe level in 2025
	Non-OECD regions: fraction of crop residues burnt in the field changes towards 1995 OECD Europe level when GDP reaches the 1995 OECD Europe level
Landfills	OECD-regions: production of organic waste moves towards the 1995 OECD Europe level in 2025
	Non-OECD regions: production of organic waste moves towards the 1995 OECD Europe level when GDP reaches the 1995 OECD Europe level
Wetland rice	All regions: emission factor moves to the 1995 USA level in 2020.

4.1.3 GECS baseline scenario results for agriculture, land cover and associated emissions

In general terms the developments in the GECS scenario are driven by fast economic growth leading to fast changes in the demand for food. In developing countries the demand for meat and milk increases strongly along with rising incomes. In developed countries the consumption patterns do not change much with increasing incomes, and meat and milk consumption may even decrease. On top of the changes in demand caused by economic growth, the total volume of the demand changes as a result of population growth. We present base-line scenario calculations for a number of characteristics of crop and animal production systems, and for emissions associated with landfilling of human organic wastes and sewage.

- *Crop production*

Agricultural productivity also strongly increases in the GECS baseline scenario. Despite this increase there is a fast world-wide expansion of the arable area. Most of the expansion occurs in developing countries where population and economic growth and a continuing towards more livestock products in the human diet lead to increasing demand for food products. Figure 13 to Figure 16 show the implications for arable areas, crop yields, fertiliser inputs and emissions of N_2O in the GECS baseline scenario for the world and for four selected regions varying in their GDP and degree of industrialisation. These elements are presented here, because they are also the factors to be used for assessment of emission reductions. In crop production these relate to the efficiency of fertiliser use, crop yields and associated N_2O emissions.

Figure 13: Areas of arable land, GECS baseline

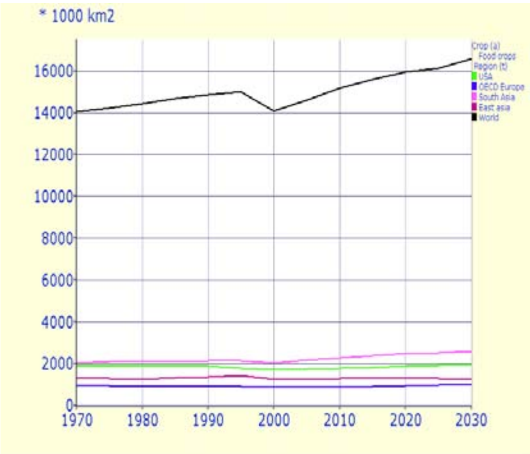


Figure 14: Yields of temperate cereals

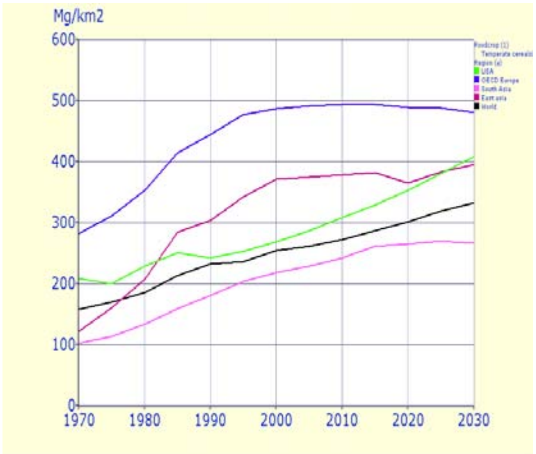


Figure 15: N_2O from fertilisers and manure

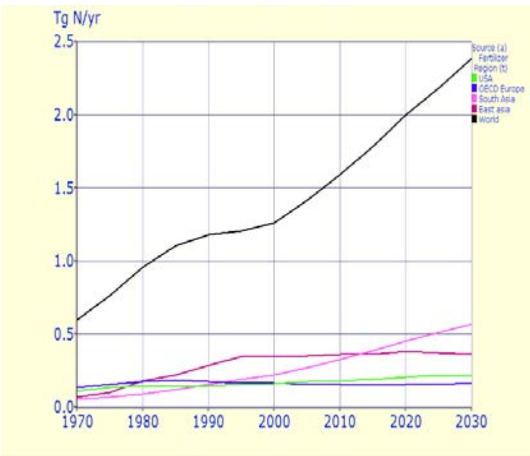
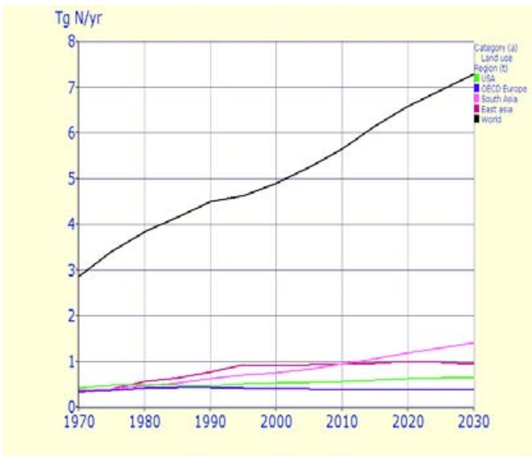


Figure 16: Total land-use related N_2O emission



- *Livestock production*

We present some of the characteristics of the milk production system and associated emissions of CH_4 to illustrate the results for animal production On the basis of demand and trade projections for milk the model calculates the domestic regional milk production. The required number of animals (Figure 17) results from this domestic production (Figure 19). The amount of animal feed required for this production is related to the efficiency of feed use per kg of milk produced, which tends to increase along with economic development (Figure 18). The CH_4 emission associated with enteric fermentation is shown in Figure 20. It is clear that CH_4 emissions show a slow increase in most developed regions and is a fast increase in most developing regions.

Figure 17: Dairy cows, GECS baseline

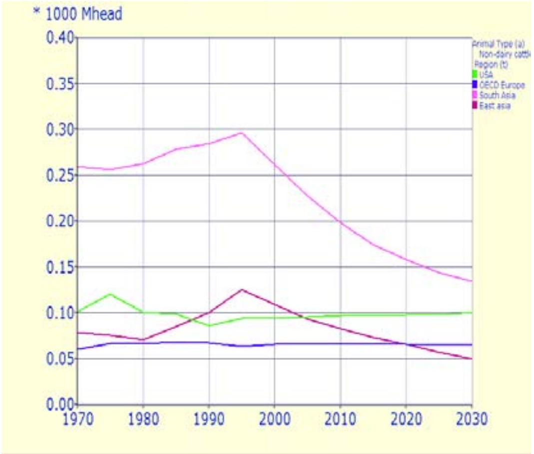


Figure 18: Feed requirement for milk production

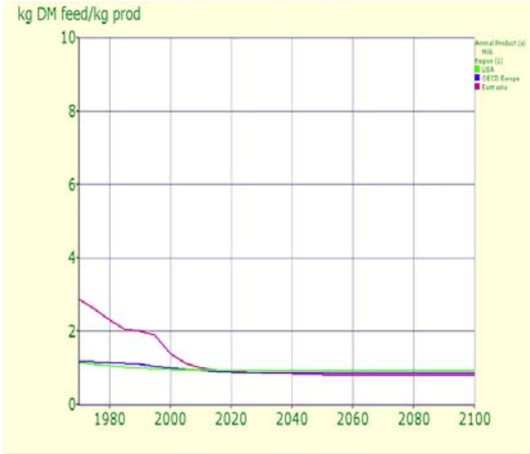


Figure 19: Milk production

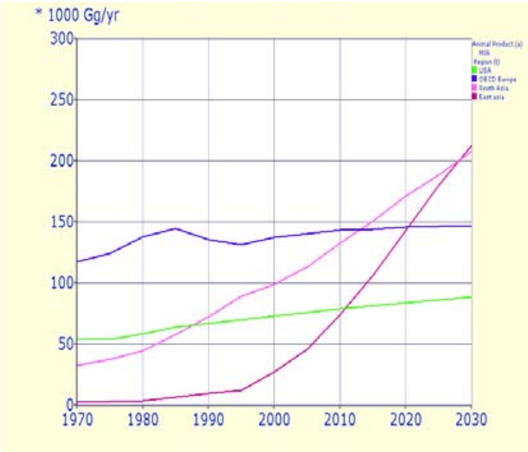


Figure 20: CH_4 from enteric fermentation

The uncertainties of emissions associated with land-use and food production systems and thus of estimates of potential emission reductions are much greater than those for energy and industry systems. These uncertainties are related to the availability and reliability of statistical and other information on agricultural production systems and land use. In addition, land-use related emissions are difficult to quantify because they are diffuse with a great variability in space and time. In contrast, energy and industry systems are generally point sources of emissions.

4.2 The AGRIPOL model and the development of Marginal Abatement Cost curves for the agriculture (CIRAD-Ecopol)

The purpose of the study carried out by CIRAD is, in face of the climate change issue, to evaluate the room for manoeuvre provided by changes in land use, agricultural practices and technological options, for the 2030 horizon. The approach chosen estimates the reaction of the agricultural sector to the introduction of plausible carbon prices for benchmark years (2000, 2010 and 2030). This reaction could be the consequence of the implementation of alternative GHG saving and/or Carbon sequestrating agricultural techniques in different regions of the world. These alternatives are considered with their respective GHG and economic balances. The inclusion of a Carbon price affecting GHG emission or sequestration allows for the explicit evaluation of the response the agricultural sector may show.

4.2.1 A model of land-use, agricultural practices, and emission constraints

The integrated assessment model IMAGE, thanks to its detailed representation of land-uses, consequent agricultural productions and associated GHG emissions, provides a reference source of information on future emissions. It also provides a consistent representation of the reference scenario that takes into account population, economic growth, and changes in consumption patterns, three factors that affect significantly the demand for agricultural products. IMAGE namely provides a whole consistent framework, in which AGRIPOL introduces a set of economic behaviour function and explicit agricultural practices. The structure of the POLES and GEM-E3 models, where choices in the different sub-systems are a function of the Carbon prices, induced the selection of a modelling option in which land allocation and technological choices are dependent of the carbon price and thus represent the actors' (farmers and herders) economic behaviour..

- *GHG emitting activities and resource constraints within AGRIPOL*

Being an economic model, AGRIPOL focuses on activities rather than on physical emission processes, e.g. on livestock management rather than on enteric fermentation and manure management, because they constitute economic entities as such. In its present version, AGRIPOL has only integrated some of the major GHG emitting activities as well as reduced consideration of other land uses, namely forestry and grassland, to allow land use changes when technical choices liberates or requires more of less area. The activities modelled in AGRIPOL are:

i dairy livestock producing milk, emitting CH_4 and N_2O,

ii non-dairy livestock producing beef, emitting CH_4 and N_2O,

iii rice production, as a source of CH_4,

iv cereals productions, source of N_2O; gathering 3 of IMAGE categories (temperate cereals, tropical cereals, maize), excluding rice,

v pulses and oilseeds productions, source of N_2O,

vi roots and tubers production, source of N_2O,

vii pastures or grassland management.

For each activity, energy consumption is also considered, as an indirect emission source of another GHG (CO_2), so as to constrain the attractiveness of processes that would be CH_4- or N_2O-saving but also energy-intensive. In an attempt to be more comprehensive, two additional land-uses are accounted for: biofuels crops, and reforestation. However, information on techniques and costs elements for MAC curves to be constructed and provide insights for carbon sequestration strategies have not been included in the GECS current version. The activities compete for land and other resources such as:

i inputs (for crop cultivation only),

ii skilled labour (veterinarians or trained herders for livestock activities for instance), that may become a limiting factor when activities become technically more sophisticated,

iii unskilled labour, required during harvests for instance,

iv capital that may be a limiting factor when heavy investment are required in the agricultural sector,

v and two endogenously available resources: feed for animal (for the two livestock activities), of which cereals whose production requires areas to be reassessed, and grassland.

However, only land availability is binding the model, as for the other resources the endowment data were not available. They are used only as ex post "metering" variables, accounting for the quantity of resources required.

- *Alternative techniques taken into account*

Whether for cropping or livestock activities, modes of production are many, within large ranges of technical possibilities, in contexts of many kinds: climate, relief, soil, people, prices, subsidies and other economic incentives… AGRIPOL focusses at this first stage on the analysis of main regional technical alternatives offering differentiated GHG balances, so as to consider the potential contribution of agriculture to abatement efforts. Answers to GHG constraints are looked for at the level of the production *options* from an economic point of view and at the level of agricultural *practices* from a technological point of view.

The term *"practice"* is widely understood, for instance, a practice may have to do with the use of natural resources, the use of new inputs, the change in varieties or breeds… Practices definition corresponds to the finest level of technological description, leading to the definition of *"techniques"*, as *combination of practices*. Techniques considered in AGRIPOL are those relevant to the GHG issue, they are alternative and exclusive by definition and the whole technological situation can be described as a basket of alternative techniques. Such *baskets of techniques* constitute *"options"*. In each region, a reference *option* is accounting for the situation in technological terms when no climate policy introduces any carbon price. Any modification in the respective shares of alternative *techniques* constituting the option, if leading to a lower emission level, defines an abatement option.

- *Introducing price and cost elements: a basic cost-benefit analysis including carbon price, production variability and a risk aversion coefficient*

Linking technical choice to carbon price implies the introduction of an economic balance for each activity led with each technique considered in AGRIPOL. Basically this balance implies the inclusion on a unitary basis − i.e. per animal raised or per hectare cultivated − and for each of the alternative technique considered, of the following elements:

- all revenues attributable to the activity, including direct revenues from yields, additional revenues obtained with co- or by-products, and subsidies[5],
- all costs directly attributable to the activity considered, usually distinct whether operational and structural costs,
- a risk premium, a function of yield variability and risk aversion,
- the carbon cost proportional to GHG emissions and to the carbon price.

The values of these elements across regions and for each year of simulation were gathered from various sources, in the literature and by expert-say. No database or model provides such systematic information for activities of different types for the whole world at the regional scale. Due to time constraints, in AGRIPOL many extrapolations were made from limited and punctual information. Additionally, land-use changes between harvested areas, pastures and forest are not cost-neutral. Accounting for this, some average costs and revenues needed to be included (on a per hectare basis):

- cost of ending pasture,
- average annual income of a forest,
- cost of deforestation,
- cost of reforestation,
- average annual income of a newly planted forest.

4.2.2 The modelling framework

AGRIPOL is a static economic optimisation model with, for each region considered, a double constraint, of production levels and of resources. The availability of resources is either exogenous or endogenous, depending on the type of variables considered. The optimisation process is being applied recursively 40 times, without any interdependencies amongst regions. The representative agent whose choice of activities and techniques is modelled, is the "commodity producer" that maximises his net revenue from the agricultural activity and minimises the risk associated, according to the attitude prevalent for the commodity.

Risk is represented through the variance of the different gross margins, co-variances are assumed to be zero. The parameter α represents attitude regarding risk (α=0 if the farmers of a given commodity are risk takers, α>0 if risk averse). The choice of activity levels of each technique is a linear function of Carbon cost and a non linear one of risk, as in standard optimisation models with risk.

Production levels to be attained are provided by the IMAGE scenario and AGRIPOL computes for the different available techniques, activity levels that on the whole, fulfil these production levels. The production level constraint is strict, to satisfy the consistency with GECS scenario. Other constraints

[5] The latter is not yet functional, for lack of data differentiating techniques.

are included, mainly referring to resource endowments. Of the exogenously determined constraints, only land is, for the time being, effective, the other resources are included, but do not influence its outcome because of lack of data. The endogenous constraints are on the other hand active, mainly feed (cereals crops used to feed animals) and grassland availability.

When the carbon price is modified, from one simulation to the other:

- i within each activity, substitutions take place between technologies (more intensive or extensive),
- ii such substitutions may modify land requirements for the different activities and grassland;
- iii the model allows for the incorporation of pastures and forest in agricultural land, and for deforestation.

4.2.3 Analysis of results, interpretation

- *Comments on the shape of MAC curves*

Three main issues have to be highlighted before analysing the results, which, in order to improve the understanding of the model's behaviour, are presented in the form of incremental abatement curves (i.e. the abatement obtained for each 5 € increase of the carbon value per ton of CO_2)

First, the incremental abatement curves show in most cases a very limited impact of the introduction of a carbon value and, at times, irregular profiles of incremental reduction when the carbon value increases. Several factors can explain these responses: land availability is constrained and technical substitution is consequently limited; the production constraint implies that there is no substitution in consumption as a response to the higher costs of agricultural products; while simplified demand function could have been introduced in the model, this would at this stage have implied that the outcomes might not have been consistent with the initial IMAGE-GECS scenario.

Second, the model is, as expected, very sensitive to the risk aversion coefficients. These coefficients were adjusted to allow a good fit of AGRIPOL results with those of IMAGE. In some cases, for the 2000 period, the coefficients represent a stronger risk aversion attitude than in the other periods, which explains the lower response to Carbon prices.

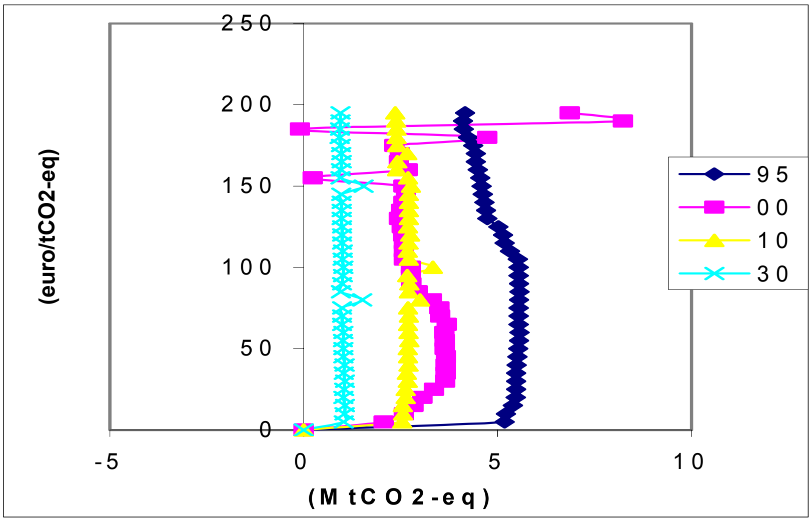
Third, the transformation of the 17 regions IMAGE into the AGRIPOL 40 regions provides the necessary outcomes but it should be further investigated. The use of the same coefficients for the four time benchmarks possibly induces inadequate responses in the cases where demand growth are quite different between countries within the original IMAGE region. In the following, the global response of the agricultural sector is presented first, then some country-regional cases will be further analysed.

- *Global results*

One of the key results of the exercise on abatement projections from the agricultural sector at the global level, is that the abatement profiles present marked dynamic features : globally as in most regions, there will be less abatement from the agricultural activities considered in the study as time passes by. This is the consequence of several factors (Figure 21):

- i the increased food demand as considered in AGRIPOL, which is considered as inelastic in AGRIPOL and which increases the pressure for production from the sector,
- ii the limits on land availability, which forces the intensification of production,
- iii only known technologies or practices are included in the model, while even if some of them can be input intensive and produce low emissions, some technological improvement in the sector will certainly take place in the future to provide improved practices in terms of emissions and input use.
- iv the existence of estimated "intermediate" technologies in AGRIPOL, for which the changes in the ratio variance of cost-benefit/emission is linear, but the response to Carbon prices is non linear because of the risk aversion consideration. This implies switches between practices that are non linear, e.g. more surface is dedicated to one practice than is abandoned from other practices.

Figure 21: World, Incremental abatement curves for agriculture (1995, 2000, 2010, 2030)



The second key feature is the very limited impact of the introduction of a carbon value when product outputs are considered as exogenously given from the scenario. To this feature should be added the instability in the response as it comes out of the model: although the total abatement is always increasing, the incremental abatement curves show in many cases a maximum abatement but with a rapidly decreasing incremental abatement level thereafter. This means that there might be a plateau for the reaction of the sector, plateau after which the reaction of the sector turns to be sub-optimal when the price of carbon continues to increase.

- *Conclusions and perspectives*

In this first version of the AGRIPOL model for the agricultural sector abatement assessment, the main limitations can be analysed as follows:

Specifying different activities: For the sake of a simple economic representation, sources of emissions have been linked to each activities and considered separately with a cost-benefit analysis. In reality, farmers and herders react in a systemic way on their farms, combining agricultural activities and practices, involving crop rotations, cover crops, cattle dropping manure to fertilise the fields, etc. The model would probably need to be further refined in order to take into account more complex behaviours that consider the possibility of complementation between activities.

Qualifying techniques: For the sake of a classification, techniques were qualified (as basic, improved, advanced, optimal), but they may have different meaning in each context and synergies/conflicts may arise between them. Some examples are: better use of natural resources locally available, intensification of farmers' micro-environments, diversification with regenerative components, better use of non-renewable inputs and of external technologies, access to affordable financing, reducing losses and increasing yields, higher value added thanks to better prices.... Some conflicts/synergies have been identified, namely on local versus global environment but others are ignored.

High levels of uncertainty: The levels of uncertainty remain high on future emission levels in the baseline, especially as far as the dynamics of N_2O are concerned.

Lack of data: AGRIPOL data base was estimated based on several sources: national sources, IMAGE, expert-say. The purpose was to provide the first indications of the type of outcome that can be obtained. More research is still required to improve the quality of the data, specially on energy consumption or agriculture activities, on carbon sequestration mechanisms, in particular for developing countries. Besides, the model specifies no link between the costs (structural and operational) and the technical coefficient, which are obviously linked.

The risk parameters: The parameter that multiplies the yield variability and hence provides the risk premium, has its value set in the calibration process. Further research is required to find, check and justify the value of this particularly important parameter.

Resources and production constraints: Regional resource endowments and constraints should be better quantified and introduced in the model in order to improve the representation of the capacity of agriculture to respond to carbon prices. The linkage with the rest of the economy should also be checked in order to avoid inconsistencies such as the consistency of the use of inputs, compared with input production by the industrial sector.

However, AGRIPOL already provides a detailed “behavioural” model for the development of marginal abatement cost curves for agricultural and forestry activities in 40 world regions. Allowing the carbon price to introduce a "deformation" of the agricultural system, within quite tight boundaries fixed by production levels, it is "contained" by IMAGE projections in the sense that it strictly sticks to production levels in the IMAGE GECS scenario.

5 The Development of the POLES World Energy Model and of the GEM-E3 Economy Model for Multi-Gas Assessment Studies (GECS work package 3.)

This section briefly summarises the main features and results of the process that allowed for the improvement and extension of the POLES and GEM-E3 models in the GECS project. Principally, these extensions consisted in the introduction of new GHG emitting activities and of their corresponding MAC curves. But both for POLES and GEM-E3, new features were also added that considerably improved the quality and relevance of these model’s results.

5.1 POLES 5: The Other Greenhouse Gas modules (CNRS-IEPE)

5.1.1 The modelling framework for the Other Greenhouse Gases

The OGHG module simulates and projects emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFC), hydrofluorocarbons (HFC), and sulphur hexafluoride (SF_6) gases, i.e. the 5 GHGs identified in the Kyoto protocol on top of energy CO2. All GHGs are treated as related to one activity (production or consumption) and each time it is possible this activity is represented through an endogenous or exogenous variable of the POLES model. A generic relationship has been elaborated for each main category of emissions. The standard equation in the model analyses the variation of a given category of emissions as the result of changes in three factors, i.e. the emission intensity of the activity, the activity indicator and an autonomous technical change factor

For the scenarios with multi-gas targets and control, the abatement options for the OGHGs, unlike for energy CO_2 emissions that are restricted mostly to fuel combustion and substitution (via energy prices and consequent behavioural and technological changes), involve a series of particular abatement technologies. Thus, to capture the impacts of the introduction of a Carbon Value, the OGHGs emissions are calculated by the model for each tax level as a combination of:

i A price effect through energy demand and substitutions as far as energy related OGHGs are concerned (methane, N2O, …).

ii An activity effect through production changes in the different sectors.

iii A long-term elasticity simulating the response to the implementation of Emission Reduction Technologies that have been elaborated from the detailed bottom-up evaluations in the GECS studies.

In order to take into account the latter effect, Marginal Abatement Cost Curves have thus been developed for all OGHGs emissions. The development of MAC curves for the POLES model is based on three different approaches.

- *CO2 and N2O from fuel combustion*

CO_2 emissions from energy combustion and N_2O emissions from some activities (transport, power generation) are directly derived from the POLES energy demand module. Non-energy emission reductions of corresponding activities or sub-sectors and CO_2 emission reduction are calculated by POLES and result from the change of fuel-mix structure and energy consumption in the energy model functions at each carbon tax level.

- *Non CO2 gases from energy and industry GHGs*

For most non-CO_2 energy and industry GHGs, endogenous interactions of POLES activity variables with emission intensity (EI) or emission intensity index (EII) equations have been elaborated. They are linked to the activity variables that are directly simulated by POLES and this allows to simulate MAC behaviours in POLES.

- *OGHGs from agriculture*

For the agriculture sector, the optimisation model AGRIPOL provides a spreadsheet with activity indicator AI and emission intensity EI. This allows to obtain the set of agriculture GHG emission abatement curves in €/tCO_2e. These are added into POLES through reduced-form independent functions from regression. From this, both activity and emissions results are simulated for the different GHG tax levels.

5.1.2 The reference projection

The set of hypothesis and parameters such as GDP growth, economic structure, population growth and urbanisation have been developed under a reference case that serves as a base for all modelling studies in GECS. The goal of this Section is to present the POLES GHG emissions projections by main categories and regions. Table 6 provides the aggregate results of the POLES 5. model

Table 6: The POLES 5. world GHG Reference projection

	MtCO2					*Annual % change*				
	1995	2000	2010	2020	2030	*1995/2000*	*2000/2010*	*2010/2020*	*2020/2030*	*2000/2030*
co2ene	21 685	23 783	29 379	36 742	44 502	*1.9%*	*2.1%*	*2.3%*	*1.9%*	*2.1%*
ch4oil	212	203	222	240	243	*-0.9%*	*0.9%*	*0.8%*	*0.1%*	*0.6%*
ch4gap	418	439	556	810	986	*1.0%*	*2.4%*	*3.8%*	*2.0%*	*2.7%*
ch4gat	604	670	769	882	920	*2.1%*	*1.4%*	*1.4%*	*0.4%*	*1.1%*
ch4cos	76	81	90	106	125	*1.1%*	*1.1%*	*1.6%*	*1.7%*	*1.5%*
ch4cou	742	743	757	816	904	*0.0%*	*0.2%*	*0.8%*	*1.0%*	*0.7%*
n2otra	31	33	35	37	40	*1.4%*	*0.8%*	*0.6%*	*0.5%*	*0.6%*
sf6ele	87	92	113	142	169	*1.0%*	*2.1%*	*2.3%*	*1.8%*	*2.1%*
GHG Energy	23 854	26 043	31 922	39 775	47 889	*1.8%*	*2.1%*	*2.2%*	*1.9%*	*2.1%*
co2ind	698	855	1 215	1 502	1 690	*4.2%*	*3.6%*	*2.1%*	*1.2%*	*2.3%*
n2oind	222	179	157	165	170	*-4.2%*	*-1.3%*	*0.5%*	*0.3%*	*-0.2%*
hfcind	131	285	757	1 220	1 585	*16.7%*	*10.3%*	*4.9%*	*2.7%*	*5.9%*
pfcsem	17	23	34	51	69	*6.7%*	*3.8%*	*4.1%*	*3.2%*	*3.7%*
pfcalu	69	59	58	61	63	*-3.0%*	*-0.1%*	*0.4%*	*0.4%*	*0.2%*
sf6ind	52	55	69	82	91	*1.0%*	*2.3%*	*1.7%*	*1.1%*	*1.7%*
GHG Industry	1 189	1 456	2 290	3 080	3 668	*4.1%*	*4.6%*	*3.0%*	*1.8%*	*3.1%*
ch4agr	3 036	2 994	2 981	2 755	2 536	*-0.3%*	*0.0%*	*-0.8%*	*-0.8%*	*-0.6%*
n2oagr	1 020	1 019	1 073	1 610	2 176	*0.0%*	*0.5%*	*4.1%*	*3.1%*	*2.6%*
ch4w st	1 242	1 393	1 775	2 228	2 719	*2.3%*	*2.5%*	*2.3%*	*2.0%*	*2.3%*
GHG Agr+Waste	5 298	5 405	5 829	6 593	7 430	*0.4%*	*0.8%*	*1.2%*	*1.2%*	*1.1%*
GHG TOTAL	30 341	32 904	40 041	49 448	58 988	*1.6%*	*2.0%*	*2.1%*	*1.8%*	*2.0%*

The detailed analysis of GHG emissions, respectively by region and GHG category under the reference case assumptions indicate that they basically reflect the economic growth and technological progress dynamics over time. Generally the developing countries show a rapid growth in emissions, whereas the other regions show a lower growth in emissions. However, within each economic group and each GHG emission category, broad generalisations should be avoided and the key outcomes of the Reference Multi-Gas projections can be stated as follows:

- Reference CO_2 emissions are projected to increase substantially at the rate of 2.1%/year to reach 46.2 $GtCO_2$ in 2030. Most of the increase comes from China (10 $GtCO_2$ from 3.2 $GtCO_2$ in 1995), and from the Asia regions, due to rapid increases in energy consumption. The CO_2 emissions in the Economies In Transition are projected to recover the 1995 level in 2010 and to increase slowly afterwards.
- CH_4 emissions in Industrialised Countries are practically stable. But they are expected to increase significantly in the Developing Countries, mostly in relation with agricultural activities (livestock and manure, waste management) and fossil fuel production. In the Economies In Transition the increase in emissions is mostly due to fossil fuel production and transport. Total CH_4 emissions would reach 8.4 $GtCO_2$ in 2030 up from 6.3 $GtCO_2$ in 1995 if no policy action were taken during this period.
- The growth in nitrous oxide emissions is substantially lower than for other GHGs. For developed countries, N_2O emissions are even projected to decline in Western Europe or stabilise in North America. As in the case of methane emissions, developing countries represent the largest increase in N_2O emissions, related to agriculture activities such as fertiliser utilisation and animal waste, and to industrial activities such as nitric and adipic acid production. N_2O emissions from transport represent less than 2% of total N_2O emissions (2.4 $GtCO_2$ in 2030 compared with a total of 40 Mt CO_2 in 1995).
- Concerning the so called High Global Warming Potential gases (HFC, PFC, and SF_6), a remarkable economic growth in developing countries through industrialisation process will lead to an exceptional increase of these gases during the period. The developing countries will become the largest source of those pollutants by the year 2030. Altogether, these three HGWP gases will reach the level of 2 $GtCO_2$ in 2030 compared with 355 $MtCO_2$ in 1995.

However, these analyses by emission category may give a misleading interpretation of the relative impact of the different gases on climate change. CO_2 emissions are, and will remain, by far the dominant source of GHG. Despite emissions growth of non-CO_2 emissions, the weight of CO_2 in total GHG reference case is even projected to increase, accounting for about 79% of total GHG emissions in 2030). This implies that fossil fuel combustion will remain the first responsible for GHG emissions in the future, while methane emissions will remain the second major source, although with a slightly decreasing share, to 14 % of total GHG emissions in 2030.

5.1.3 Marginal Abatement Costs and Economic Assessment of Multi-Gas strategies

In order to assess the global impacts of Multi-Gas abatement policy, this sub-section considers the whole set of marginal abatement cost curves developed for the POLES 5 model in the GECS project. The key outcome of this detailed analysis of MAC curves is probably that it reveals strong differences among the 17 activities and across regions. They can be described as follows:

- Some activities – such as CO_2 from cement industry or CH_4 and N_2 O from agriculture – are highly inelastic in all regions, with reductions of about one or two percentage points even for high carbon values. While this weak sensitivity is straightforward for the case of cement, the interpretation for agricultural activities involves much more complex elements. They are mostly related to the definition of technologies in the agriculture and to the limitations imposed to the agriculture model (e.g. the fixed demand and regional production hypothesis described in Section 4.2).
- Conversely a set of activities show a high – or even extreme – sensitivity to the introduction of a carbon value, with reductions beyond 50 % when the carbon value is sufficiently high (50 €/tCO2e, i.e. 180 €/tC). This is the case for CH_4 from gas transport and coal mines (surface and underground), for N2O from chemical industry and for PFC, both from aluminium and semi-conductor industry. The extreme case is the one of SF6 from industry, where a 100 % reduction is obtained with a 20 €/tCO_2e carbon value.

- Most other activities show an intermediate sensitivity level, with reductions in the range of 15 to 30 % for a 50 €/tCO2e carbon value. This is in particular the case for the largest activity in terms of emissions, i.e. CO_2 from the burning fossil fuel. CH_4 from oil and from gas production, CH4 from waste and landfills, SF_6 from electricity sector and finally HFC from industry show a similar reduction profile.

Figure 22 and Figure 23 show the world global 2010 MAC curves, respectively by key sector and by GHG category. These curves provide a rough description of the behaviour of the model and of the potential gains from Multi-Gas policies. From the results of a simplified case for 2010 with an intermediate carbon value of 25 €/tCO2e (90 €/tC) and a hypothetical world full flexibility, world 2010 GHG emissions would be reduced by 7.8 $GtCO_2e$, from 40 $GtCO_2e$ in the Reference case. This represents a 20% reduction from the Reference, but a 11 % increase from the 1990 GHG emission level. The results synthesized in Figure 22 allow to identify the key sectors for GHG abatement and illustrates the predominance of the energy sector at world level, as fossil fuel combustion represents 72 % of the total abatement and as the other GHGs from the energy sector – mostly methane – represent an additional 17 %. Industry is the following sector with 7 % of the total abatement, while agriculture and waste/landfill – indeed mostly waste/landfill – correspond to 4% of the total.

Figure 22: Global 2010 MAC curves, by sector

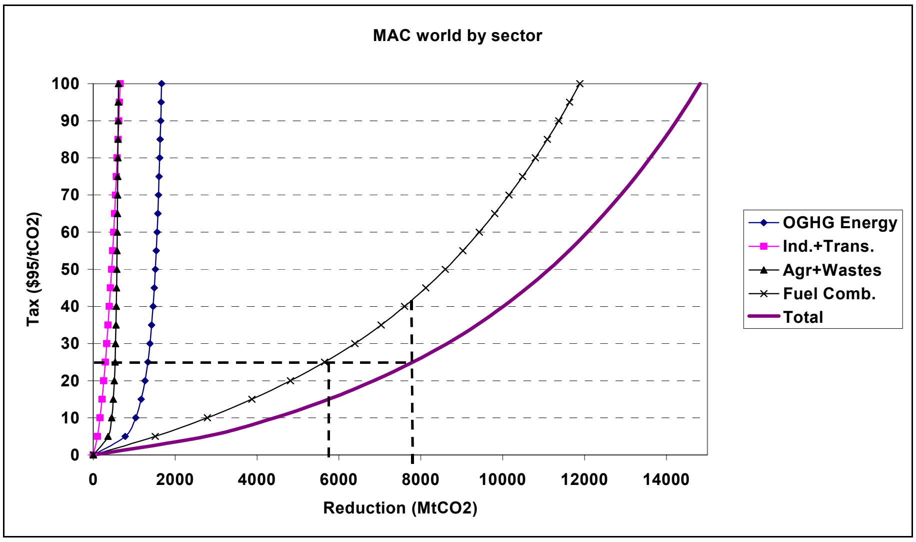


Figure 23: Global 2010 MAC curves, by gas categories, 2010

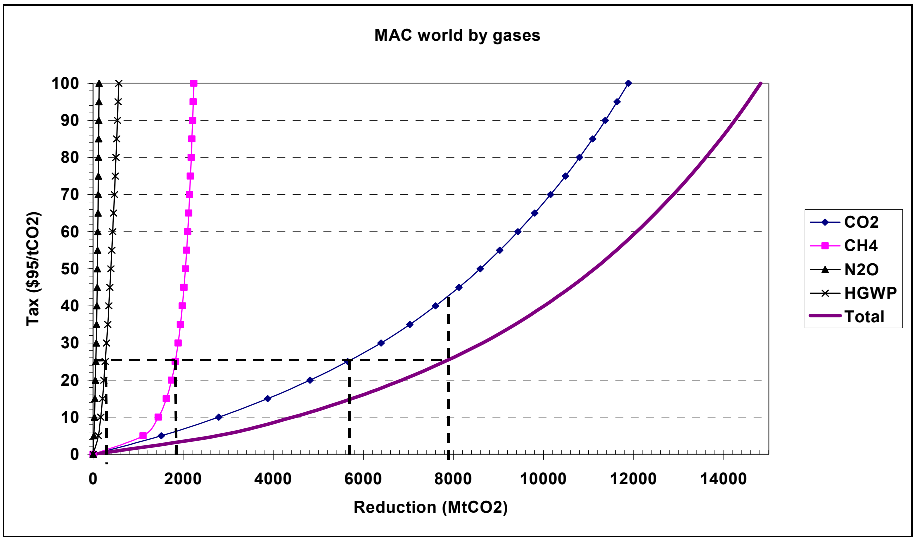
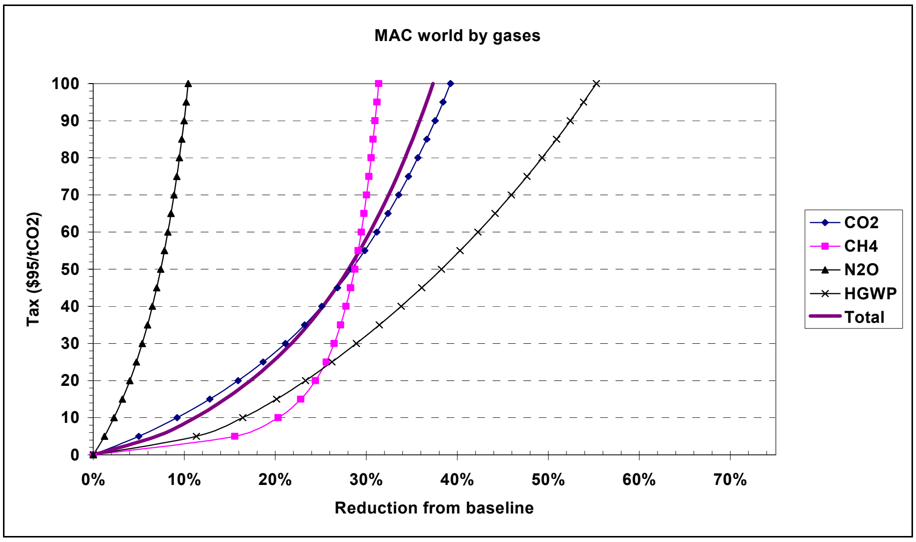


Figure 23 illustrates the contribution to abatement by type of GHG and it appears that CO2 is, not surprisingly the main contributor to total abatement, in quantities (5.6 $GtCO_2$) and proportion (72%). Its contribution is indeed almost equal to the one of the "fossil fuel burning" activity, as the contribution of the cement industry to total abatement is negligible. Methane is the second option in total abatement with a significant 23 %, followed by the more modest contributions of HGWP gases 4% and N_2O, only 1%. This predominance of the fossil CO_2 in potential abatement, doesn't mean at all that Multi-Gas strategies do not have an important impact on abatement costs or environmental effectiveness. The key conclusion of this first-cut quantification of the Multi-Gas approach can be formulated in two different but complementary ways:

- for the 25 €/tCO_2e carbon value supposed here – corresponding to a relatively ambitious abatement program – the inclusion of other gases would allow to increase total reductions by 38 % (from 5650 tCO_2 to 7800 tCO_2e)
- in another perspective, reaching the same total reduction in a "CO_2 only strategy" would imply a carbon value slightly superior to 40 €/tCO_2 (147 €/tC) and thus cost approximately 60 % more – also in terms of total cost – than a Multi-Gas approach.

These gains in total abatement for a given carbon value or in marginal and total cost for a given abatement in volume doesn't mean however a significant change in the total MAC curve plotted against percentage reductions, whether it is expressed for CO_2-only or for the 6 GHGs. Surprisingly enough, the two MACs are very near to each other, as shown in Figure 24. This is because the lower abatement costs for CH4 and HGWP gases are compensated by the steeper MAC curve for N2O, originating in the low response of agriculture. This means in particular that in the Multi-Gas analyses, the gains in total cost for the same volume abatement is allowed principally by the supply of new abatement opportunities and not by relatively cheaper options for the other gases, on average.

Figure 24: Global 2010 MAC curves in % from baseline reduction, by gas categories



While taking into account the fact that sinks and CO_2 from Land Use are not modelled and accounted for in the exercise, these first analyses are largely consistent with the corresponding results from the other studies on this issue. In any case, they fully confirm the relevance and importance of the Multi-Gas approach for economically sound emission control strategies.

5.2 Endogenisation of Carbon Emission Permit Prices in the POLES 5. model (JRC-IPTS)

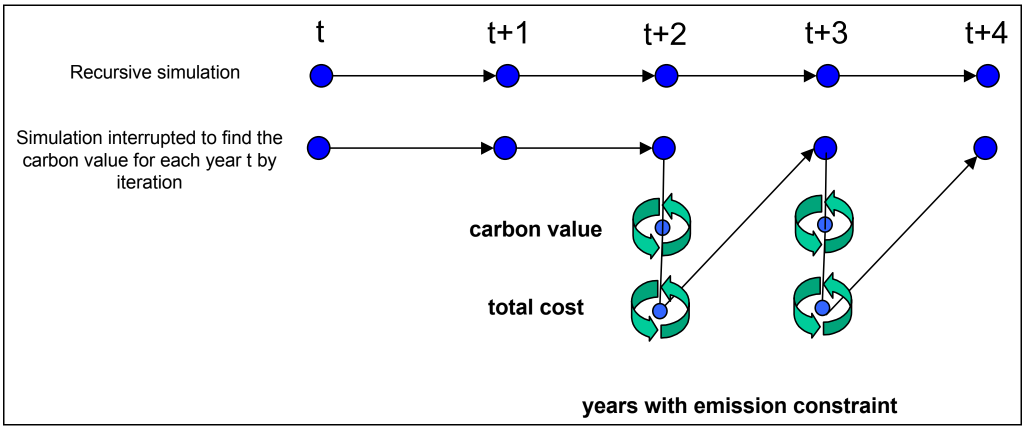
- *From exogenous to endogenous permit price in a recursive simulation model*

The usual approach used in the POLES model to analyse emission trading has up to now been to obtain marginal emission reduction cost curves from the models and subsequently carry out a static, ex-post analysis of emission trading based on these cost curves. The drawbacks of this approach is that many effects resulting from the introduction of different carbon constraints (change in prices, demands, etc) are not taken into account and that an ambiguity remains surrounding the timing of emission reductions and the introduction of shadow carbon values or permit prices. Timing of options and transaction cost can be captured only to a small extent. This has been the reason for developing a methodology to endogenise the calculation of carbon values in the POLES model within the GECS project.

The new model version allows to calculate inter-temporal pathways for carbon values corresponding to year-by-year emission targets. Since the calculation is carried out inside of the model, all price effects caused by the emission reduction are taken into account. The model also incorporates a routine for the calculation of total costs, allowing for appropriate discounting instead of the static calculations currently effected by integrating single MACs. The model therefore allows to assess different systems and possibilities of "When" flexibility while taking into account a changing value of carbon and different national discount rates. It thus provides insights in advance to an issue that may prove as important in the next stages of the international negotiation as the "Where" flexibility is in the current stages.

The considerable impact of the intertemporal allocation of emission reduction can be analysed. The methodology used is illustrated in Figure 25. In order to find the carbon value that corresponds to the emission limit defined for a specific year iterative methods have to be applied.

Figure 25: Calculation scheme for the simulation with exogenous versa endogenous carbon values.



- *The implementation in POLES*

The POLES model simulates the energy system year by year in a recursive process. This sequential recursive calculation cannot be directly applied if carbon values are to be calculated endogenously. The carbon value has indeed to be calculated in a converging iterative approach. For every year, the given emission target is compared with the emissions for a zero carbon value (no-climate policy case). If the emissions exceed the limit, the carbon value that is necessary to meet the emission constraint is sought for by applying the iterative method. There are several root finding algorithm available. Currently, the *False Position or "Regula Falsi" method* is being used. The iteration process requires the recalculation of the energy system (or at least a major part of it) for each iteration step with a new carbon value. Once the solution is found, the simulation proceeds to the next year. This method is simple and has proven to converge sufficiently fast for the problem at hand. Less than 10 iteration steps are necessary to reach the solution under normal conditions.

Besides the carbon value (i.e. the marginal abatement cost) also the total abatement cost are of prime interest in the assessment of abatement policies. The total abatement cost corresponds to the area under the marginal abatement cost curve. The total cost can be quantified by numerical integration. For that purpose various points on the MAC are needed. This again means that the model has to be rerun a number of times for various carbon values in order to evaluate the integral.

The endogenous carbon value version therefore presents a considerably more complex and CPU intensive model than the old standard version. Even more so because all software simulation packages on the market are designed for standard sequential simulation. The implementation of endogenous carbon value calculation therefore requires programming interfaces or macros linking the iteration with the standard simulation.

- *Conclusions*

Within the GECS project a POLES model version has been developed that allows the endogenous calculation of carbon values. The main advantages of the endogenisation as presented here over the hitherto method of ex-post processing are:

- It removes all ambiguity surrounding the timing of emission reductions and the introduction of shadow carbon values or permit prices
- It provides time profiles for carbon values which in themselves are analytically significant
- It assures fuller consistency by automatically taking into account secondary effects (such as primary price movements) resulting from the introduction of carbon constraints
- It allows for a very wide variety in scenario construction regarding bubbles and supplementary restrictions (e.g. with respect to transaction costs)
- It opens the way for analyses involving permit banking either by exogenous manipulation or by the incorporation of simple banking rules
- It enables discounting in the calculation of both emission reduction costs and the value of permit sales/purchases

The presented method already has been successfully applied and will be extensively used in the future to analyse a wide range of flexibility schemes for carbon emission trading.

5.3 GEM-E3 developments for multi-gas assessment (ICCS-NTUA)

5.3.1 Incorporation of other greenhouse gases in GEM-E3

There are three mechanisms in the GEM-E3 model that allow to reduce emissions, the substitution of fuels, the decline in production and the use of end-of-pipe abatement technologies:

i Substitution of fuels: as the production of the sectors is specified in nested CES-functions, there is (at least for an elasticity of substitution greater than zero) some flexibility on the decision of intermediate inputs, the input demand of which is linked to their relative prices. Hence, if there is an extra cost on energy inputs, there will be a shift in the intermediate demand away from ‘expensive’ energy inputs towards less costly inputs. A politically imposed cost on emissions therefore drives substitution towards less emission intensive inputs, e.g. from coal to gas or from energy to materials, labour or capital.

ii Decline in production: in a system that covers the interdependency of agents’ decisions, imposing an environmental constraint (through standards, taxes or other instruments) causes additional costs to production (which is linked to the costs of substitution or abatement installation). An increasing selling price decreases demand of these goods even if this demand is inelastic to price changes (which is usually not the case) because of budget constraints. This lowers production and accordingly the demand for intermediate inputs. Hence, there is an emission reduction due to a demand-driven decline in production.

iii End-of-pipe abatement technologies are formulated explicitly by bottom-up derived abatement cost functions (when information is available). These cost functions differ between sectors, durable goods, pollutants, and countries. The marginal cost of abatement is an increasing function of the degree of the abatement (these costs differ between sectors and countries according to the abatement efforts already undertaken). *Firm’s Behavior*

In order to incorporate the other GHGs, several modifications were made in the model. Installing abatement technologies has been considered as an input for the firms and not as an investment. The major advantage of this formulation is its simplicity, especially as the available abatement cost functions are in terms of annualised cost, and because, with this framework, the abatement costs do not increase directly GDP as it would if modelled as investment. For the latter purpose a depreciation and replacement mechanism would have to be introduced. The user's cost of the abatement equipment would have to be added to the capital income, avoiding however any double counting.

From the optimization problem as formulated in GEM-E3, it follows that the firm has to make an additional decision beyond the one for the bundle of utilized resources: either to abate and to face the cost of the corresponding reduction measure or to pay the permit price for each unit of emissions produced.

- *Market for Permits*

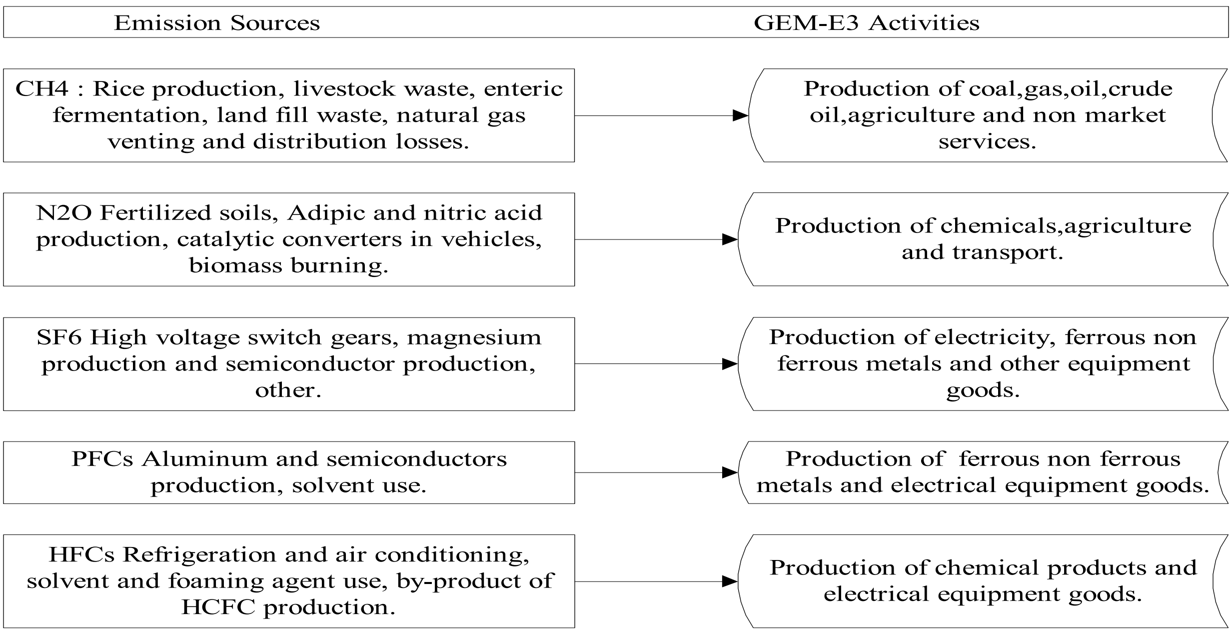
A market for pollution permits is created when a limited amount of "property rights" on emissions are distributed to the economic agents. These represent a right to pollute proportional to the amount of property rights owned by the polluter. These rights can be traded among economic agents (and among all countries).

The economic agent has then to compare the cost of reducing emissions below its endowment to the benefit from selling his permits to the market. At the equilibrium point, the permit price will be equal to the marginal cost of abatement allowing for maximum flexibility in the adjustment of the economy. The firms and the households that want to pollute more than the allowed by the allocated emission rights owned have to pay the permit price. In the case of the households, the revenues (losses) from permit sales (purchases) increase (decrease) directly the disposable income. In the case of the firms, the revenues from permit sales increase the capital income that indirectly increases the disposable income of households. Thus the revenues from permit sales increase the consumption capabilities of the households.

- *Link of greenhouse gases sources to GEM-E3 activities.*

In GEM-E3 energy related greenhouse emissions levels are a function of the production level of the sector responsible for the pollution. These emissions are linked with each GEM-E3 activity according to the scheme:

Figure 26: Sources and GEM-E3 Activities Links.



5.3.2 Depletable Resources Module and the depletion mechanism in GEM-E3.

Natural resources are classified according to their physical properties and their time-scale of their adjustment process. Based on physical characteristics, resources are divided into biological, non-energy mineral, energy, and environmental resources, whereas based on their time-scale adjustment are classified as expendable, renewable, or depletable. In particular, depletable resources are those whose adjustment speed is so slow that we can meaningfully model them as made available once. Currently we will deal with the resource depletion mechanism of gas and crude oil.

In particular, the energy supply sectors in GEM-E3 were modelled up to now in an identical way to any other industrial sector, without taking into account certain particular features, such as the finite nature of the fossil fuel resource base, and without taking into consideration a mechanism for depletion. In an attempt to create a more complete and realistic representation of the supply behaviour of these sectors, an energy resource sub-model was developed. Coal reserves are assumed to be sufficiently abundant in the horizon to 2030, so as to obviate the need to represent restrictive mechanisms constraining them. Therefore, only the supply of crude oil and natural gas are derived from the specific sub-model.

- *The Resource Depletion Mechanism in GEM-E3.*

In this version of GEM-E3, reserves are considered as an additional factor of production. Thus reserves of each fuel constitute the top level of the CES production function along with the capital, labour, energy, and the material bundle.

- *Elasticity of Substitution among Production Factors[6].*

One crucial issue emerging from this modification is the determination of the elasticity of substitution among the production factors. In the conventional case, resources are not essential in the sense that they are not indispensable for the production of output: as the input of resources declines and approaches zero, the marginal and average product of capital tend to a positive limit and do not decline to zero. In the case of resource constraint, for each level of output there is some minimum quantum of R that is required to make production possible. Evidently, with the substitution possibilities available in this second case, production possibilities are ultimately limited. Even with an infinite capital stock, there is a limit on the amount of output that can be produced with a given quantum of reserves. Under these circumstances, it is evident that consumption must eventually decline over time as with declining resources, the marginal product of capital falls to zero.

- *The Price Path and Resource Depletion.*

As the resource is depleted, the price rises and as the price rises the demand and hence the quantity consumed falls. This continues until a price is reached where an alternative technology or a substitute for the resource becomes economically viable. This is known as a backstop price. The backstop resource is on the flat part of its exploitation curve, so that the price of the resource is blocked and production ceases. At this point, the resource is said to be economically exhausted, even though there is very likely a considerable amount of the resource remaining in the ground.

Finally, the discovery of new deposits, new technologies, and new strategies of conservation will introduce downward pressure on prices and extend the lifetime of the resource. If this happens at discrete times, the price path can take on a saw tooth pattern, but always displaying downward convexity Thus the sub-model makes production of each energy good to be a function of the respective reserves, the latter being in turn a function of unproven reserves (yet to find reserves). Prices and quantities are derived through the optimisation behaviour of the economic agents.

- *Simulations.*

To demonstrate the feasibility of the approach in the context of a large general equilibrium model some preliminary runs were made. The main aim of these simulations was to examine the properties

[6] The discussion on substitution elasticity follows Michael G. Webb, Martin J. Ricketts, “The economics of energy”, The Macmillan Press, (1980) p.59-60.

of the model, thus three scenarios were developed. The first is the baseline scenario, where it was assumed that oil and gas yet to find reserves are the ones specified in the 50% probability case, as provided in USGS. The other two scenarios are a pessimistic scenario with an assigned probability of 95% and an optimistic scenario with an assigned probability of 5%. The simulations clearly demonstrated the dependency of oil production and oil price to the level of reserves with which each region is endowed.

- *Backstop Technologies.*

Finally, regarding the activation of the backstop technology mechanism, a suitable candidate for this in the horizon to 2030 is the non-conventional oil resources. These are mainly the Orinoco extra-heavy oil resources in Venezuela and the Athabasca tar sands in Canada. Several technologies for the development for such resources exist and production is already taking place at a modest scale. Large-scale development is awaiting the reduction of downward uncertainty on oil prices as these technologies are characterised by very large and long-term capital commitments. A suitable backstop technology for natural gas would be some solid fuel (or biomass) gasification option. The inclusion of such backstops adds realism to the GEM-E3 depletable resource module simulation exercise results.

6 MULTI-GAS ASSESSMENT STUDIES WITH THE POLES WORLD ENERGY MODEL AND OF THE GEM-E3 ECONOMY MODEL (GECS WORK PACKAGE 4.)

This Section presents the key results of the GECS project, as outcomes of a process of full integration, in the POLES and GEM-E3 models of specifically designed policy scenarios and of new activities, corresponding emissions and abatement technologies. It first provides an synthetic analysis of the key outcomes of the multi-gas abatement scenarios with the partial equilibrium POLES model before to describe the results for the same scenarios, from GEM-E3 in a general equilibrium perspective.

6.1 The Multi-Gas Scenario analysis with the POLES world energy model (CNRS-IEPE)

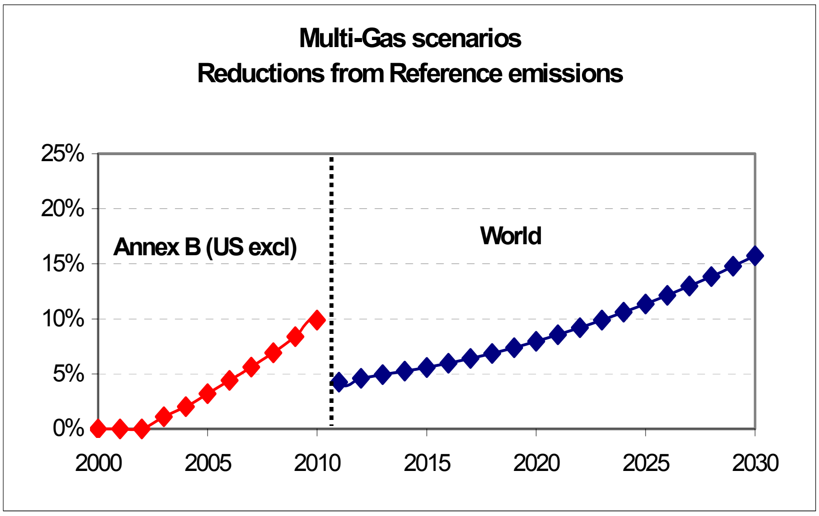
Once the international endowments corresponding to the four scenarios presented in the first Section of this report have been calculated, the Multi-Gas Assessment (MGA) studies have been performed with the POLES 5. For each of the four scenario the analysis has been performed in a two stages approach:

i the calculation with the endogenous permit price version of the model of the time-path of the carbon value that would allow for the global compliance to the emission target considered in the scenario;

ii the assessment, on a region by region basis of the domestic emission reductions, traded emissions and abatement costs (whether domestic costs or costs/benefits from trade).

Until 2010 the “bubble” of the countries submitted to quantitative targets consists in the Annex B countries, from which the USA have been withdrawn. According to the so-called “Bush Plan” this country follows a “dynamic target” of a reduction of 18% of the emission intensity of GDP over the 2002-2012 period. This is translated into a reduction of 15% of the same emission intensity over 2002-2010 in this study. After 2010, all the 38 POLES countries/regions are included in the bubble and thus receive constraining quantitative emission targets, according to the different endowment schemes and under the “global cap”.

Figure 27: Emission Reduction from Reference in the GECS Multi-Gas Analysis



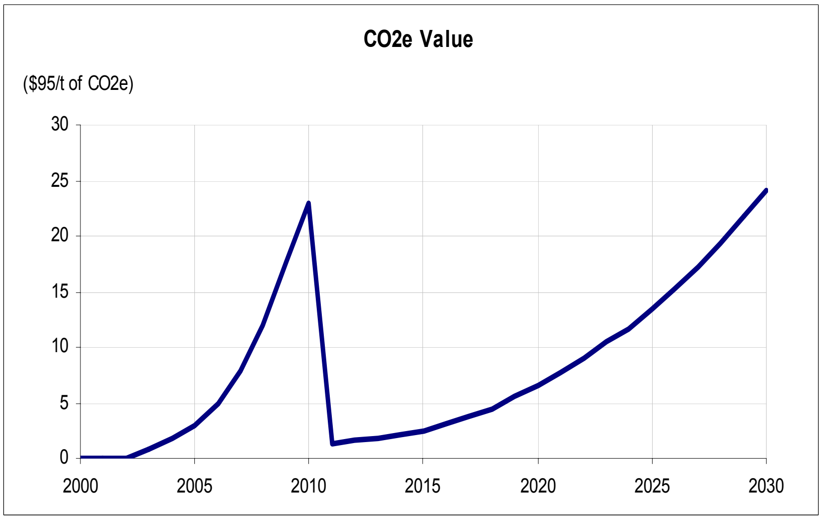
6.1.1 The time-path of the Carbon Value

The endogenous permit price module developed in GECS by IPTS for the POLES 5. model allows to compute – through a year-by-year iterative process – the carbon-equivalent value (expressed in 99€/tCO_2e, equivalent to 95$/t$CO_2$e) that allows for compliance to the quantitative emission targetsin a fully dynamic approach of the carbon value.

- *The Multi-Gas Soft Landing and Per Capita Convergence (SL and PCC) scenarios*

Both Multi-Gas scenarios differ by the way allocations are distributed in the various regions/countries but they have identical global emissions profiles. Therefore, in a full-trading hypothesis framework, the related endogenous carbon value is the same for both schemes. Figure 28 below displays the value of a ton of CO2e from 2000 to 2030 for both the SL-MG and PC-MG cases.

Figure 28: Multi-gas scenarios CO2e value



The Kyoto Protocol horizon: The carbon value increases from a zero value in 2002, when it is supposed that the constraint doesn't still operate, to 23 €/tCO_2e in 2010, when Annex B countries (except the US) reach their Kyoto objectives. Preceding exercises on the Kyoto Protocol assessment with the POLES model and ASPEN software showed carbon values of around 12 €/tCO_2 , in the initial configuration of the Protocol with the US and the hot air from the Annex B Eastern European countries but also, interestingly, in a configuration without the US and full hot air exclusion or banking. The key factors that can explain the doubling of the carbon value in this new assessment can be identified as follows:

i In this new case it is indeed supposed that the US are out of the Annex B, while all hot air has been excluded and translated to the following commitment periods. This two factors probably compensate each other in terms of impacts on the carbon value, as it already did in the static approach of the same configuration with ASPEN.

ii As explained above in the preliminary analysis of the Multi-Gas results with POLES, the transition from the former CO_2 analysis to the new MGA may have only a limited impact on the carbon value itself (not of course in the total quantities abated). Indeed the shape of the 6 GHG MAC is similar to the shape of the CO2 only curve for a given percentage reduction from baseline, especially for levels of carbon value in the range of 25 €/tCO_2e and at world level.

iii Thus the transition from the static to the dynamic approach of permit prices is the key factor that explains the doubling of the carbon value in the GECS MG simulation. Very clearly, while the static approach supposed a full introduction of the carbon value since the beginning of the simulation, it is understandable that the carbon value comes out to be higher with a dynamic progressive introduction. Besides, it does make sense that, starting from zero, the dynamic value represents, by the end of the period considered, approximately the double of the value used for the whole period in the static approach.

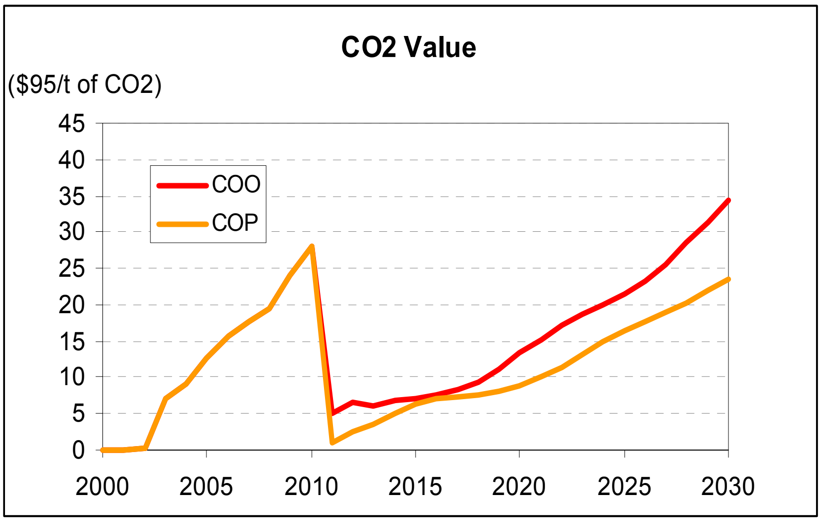
Beyond the Kyoto Protocol: In 2011, the entry of all non-Annex B countries in the bubble of constrained countries entails a sharp decrease in the CO_2e value that drops to 1.3$/t CO_2e. Of course, the explanation for this drop is to be found in Figure 27, which shows that the relative reduction burden imposed to the global bubble is suddenly much less severe immediately after 2010, as the constraints on non-Annex B regions is almost nil at the very beginning of the Post-Kyoto period. Basically the discontinuity in the carbon value is explained by the discontinuity in the space of the emission reduction potentials, as for the sake of simplicity and realism, no hypothesis have been made for CDM reductions in the Kyoto time-frame.

Later on, in the 2011-2030 period, the carbon value then increases regularly with the growing effort of global reductions up to 24$/tCO2e in 2030. This carbon value is almost identical to the one obtained in preceding POLES exercise for the 2030 horizon. However, taking into account the dynamic introduction of the carbon value, and referring to the analysis for the 2010 horizon, this value may have been expected to be higher, even much higher. The key reason that explains this apparently surprising result is the fact that, although the GECS Soft Landing scenario is based on similar global cap profiles than for preceding exercises, the use of a cap from the B1-IMAGE SRES scenario has induced a clear softening of the constraint. The global constraint now represents a 15 % reduction from baseline, instead of approximately 20 % in preceding POLES-ASPEN exercises. Quite logically, given the slopes of the MAC curves, the reduction in the carbon value may be more important than the corresponding one-fourth reduction in the target reduction from Reference, from 20 to 15 %.

- *SL CO2-only “only” (COO) and “proportional” (COP) cases*

In these two scenarios it is hypothesised that after the Kyoto time-frame, the economic instruments of Climate Policies are concentrated on CO_2 reductions. Up to 2010 both CO_2-only “only” and CO_2-only “proportional” scenarios correspond to the Kyoto reduction target from base-year CO_2 emissions, supposing that the same percentage reduction is obtained for the other gases, for instance through Policies And Measures. This results of course in the same carbon value for COO and COP that reaches 27 €/tCO_2 in 2010. After 2010, with the inclusion of the non-Annex B countries in the bubble, it is supposed either that the Policy And Measures are applied to the other gases (COP) or that the multi-gas flexibility is abandoned and that the overall cap is now reached only through CO_2 reductions (COO). In both cases, the carbon value drops sharply almost to zero in the COP case. As expected, the COP carbon value is continuously lower than the COO value over the entire period. By the end of the simulation, the 2030 values are of 23 €/tCO_2 in the COP case and of 34 €/tCO_2 in the COO case (Figure 29).

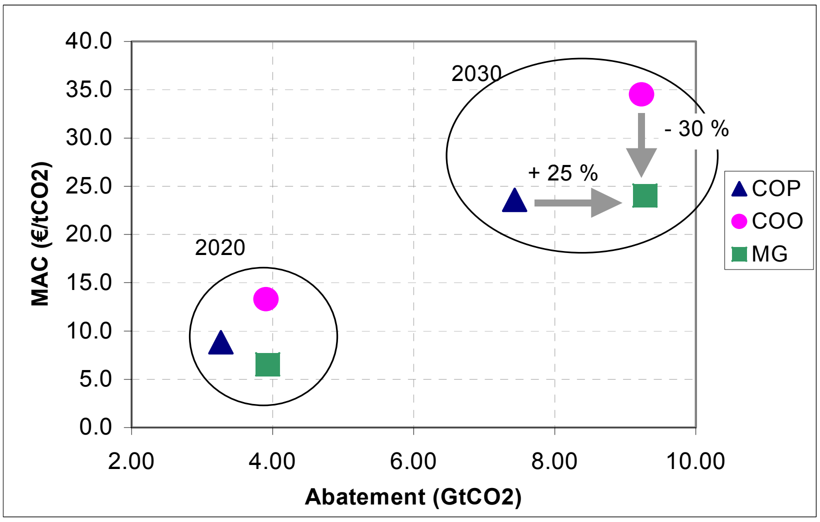
Figure 29: COO and COP cases CO2 value



Finally, the key advantages of Multi-Gas strategies relatively to CO_2-only approaches are clearly illustrated in Figure 30 : Going from CO_2-only to MG strategies either allows:

- to significantly increase the total abatement for the same marginal cost (+ 25 % in 2030)
- or to significantly reduce the marginal (and total) cost for the same quantity abated (- 30 % in 2030).

Figure 30: MAC vs. total abatement in 2020 and 2030, MG, COO and COP scenarios



6.1.2 Emission reductions, costs and effort rates

The following exercise analyses the impacts of MG strategies for the key world regions and for the key countries, while comparing the regional costs for the MG-Soft Landing and MG-Per Capita Convergence, or for the MG-Soft Landing and CO2-Soft Landing scenarios. The regions' or countries' emission reductions are calculated over the 2000-2030 period, costs are expressed in 95 US$ PPP, and a 5%/yr discount rate is used for cost calculations over the entire period. Finally, the 'effort rates' are defined as the ratio of the regional total discounted cost over the discounted GDP.

- *The Multi-Gas versus the CO2-only "only" in the Soft Landing hypothesis*

These two scenarios result in identical "net" cumulative reductions, i.e. the sum of domestic + imported reductions for importing countries and the difference between domestic reductions and exports for exporting regions. It has to be noted here that Figure 31 reveals the existence of "hot air" (over the whole period) in each of the three aggregate developing region considered, as cumulative exports exceed cumulative domestic reductions.

Figure 31: Cumulative reductions, regions

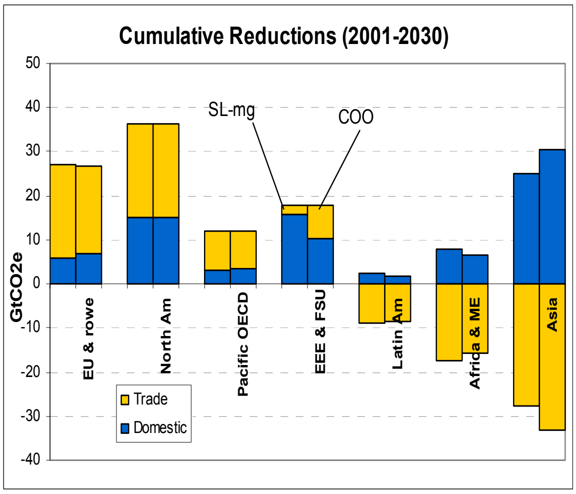


Figure 32: Discounted cost, regions

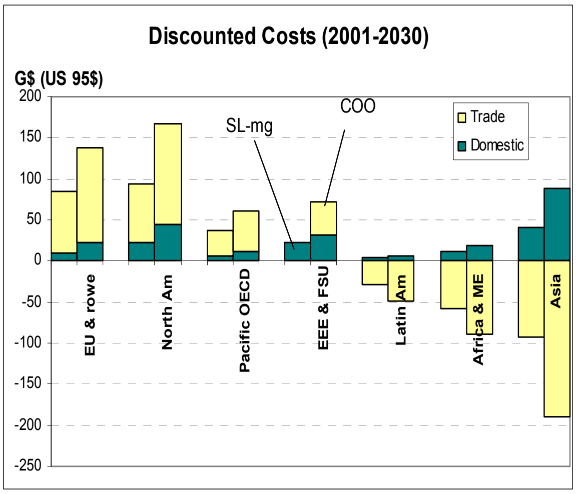


Figure 33: Discounted effort rate, regions

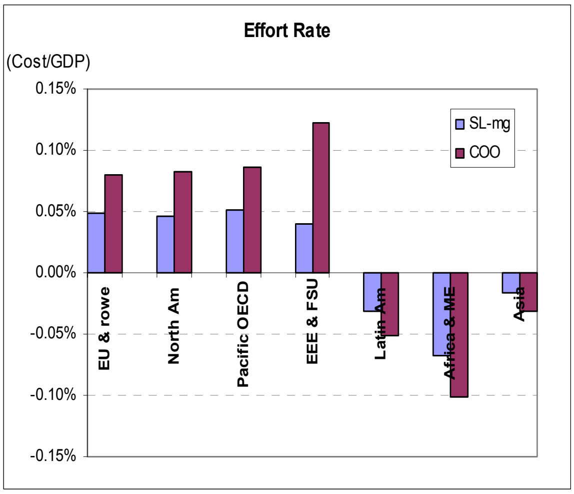
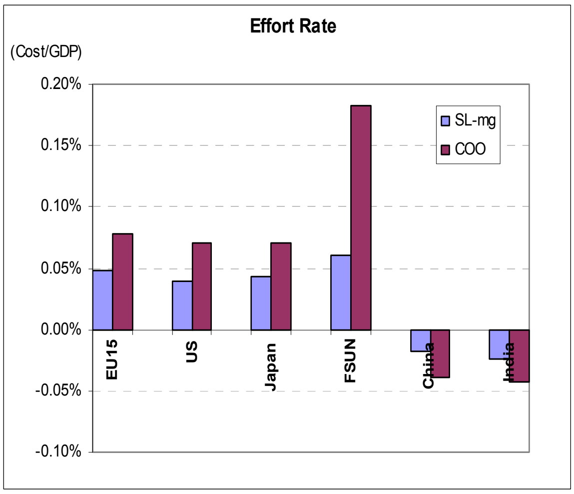


Figure 34: Discounted effort rate, key parties



The comparison allows quantifying, on a region by region basis, the gains and losses of the introduction of the Multi-Gas flexibility. Two key factors explain the differences in costs between the two cases: the first factor is the possibility for the countries to abate internally at lower costs if all six Kyoto Protocol greenhouse gases are included in the abatement strategies; the second factor is the difference in carbon value on the international trading market, which is lower in the Multi-Gas than in the CO_2-only case (COO) because of the large low cost reduction opportunities provided by the MG framework.

Therefore, both domestic and trading costs for buyers are cheaper in the SL-MG case (Figure 32). Although the sellers have higher reduction costs in the COO case, they make greater benefits in selling permits because of both the larger number of permits sold and the higher permit price. Last but not least, the existence of net benefits in each aggregate developing regions simply comes from the above-mentioned existence of hot air. Figure 33 on effort rates shows an amplified outlook of these results. Furthermore, one can notice the fact that buyers have roughly the same effort rate in the SL-

MG case, while EEE-FSU is the most affected in the COO case. For sellers, Africa - Middle East gains the most in terms of cumulative effort, followed by Latin America and Asia in the two cases.

- *The CO_2-only "only" vs. CO_2 "Proportional" case in the Soft Landing hypothesis*

The analysis of the COO case vs. the COP confirms the statement proposed above from the global carbon value analysis: the COP scenarios allows to significantly reduce the total cost (Figure 36) and cumulative rate of effort for the importing regions, although reducing also the benefits for the exporting ones (Figure 37), but this is obtained through a significant decrease in total abatement in each region (Figure 35).

Figure 35: Cumulative reductions, regions

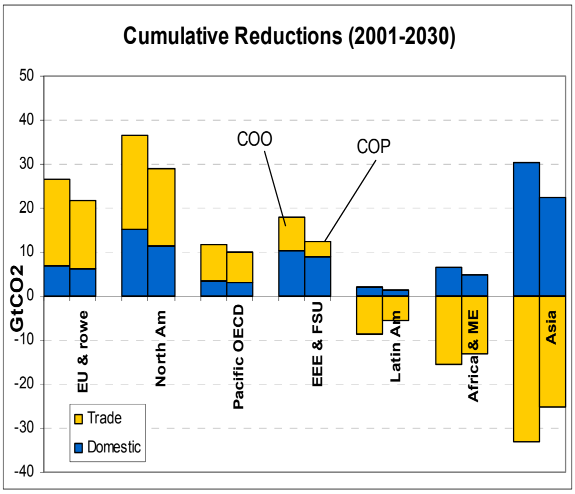


Figure 36: Discounted cost, regions

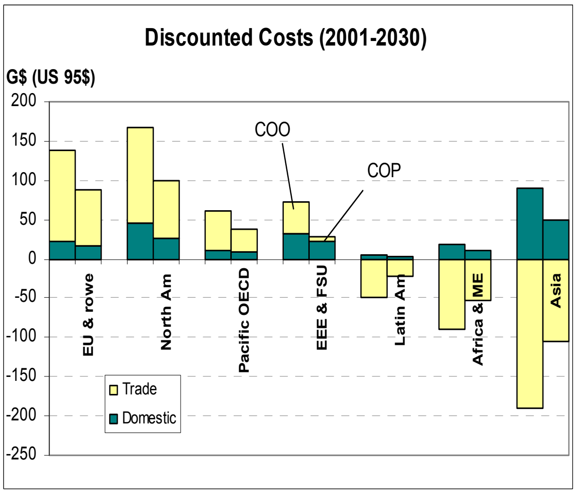


Figure 37: Discounted effort rate, regions

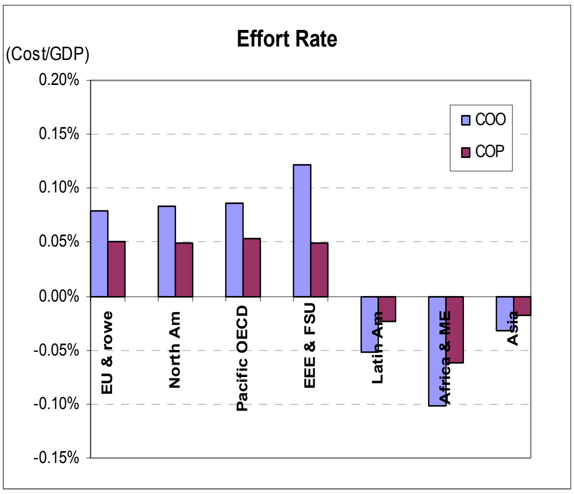
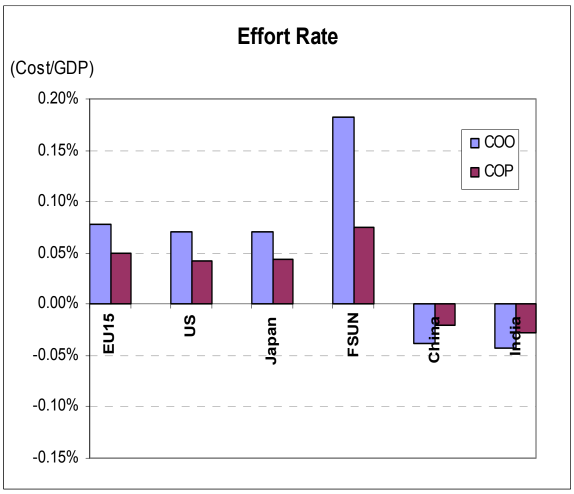


Figure 38: Discounted cost, key parties



- *Main Regions: Soft Landing vs. Per Capita Convergence in a Multi-Gas framework*

The comparison of the SL-MG and PC-MG scenarios allows to illustrate the impacts of different endowment schemes on the key regions and parties. In that case, cumulative domestic reductions and total discounted domestic costs are identical in both scenarios, as seen in Figure 39. This is due to the fact that the international carbon value, that determines the domestic abatement and costs, is identical in the two scenarios. Within the period studied, the change from the SL to the PC scenario has differentiated impacts both among the importing regions – the Annex B – and among the sellers – the non-Annex B, developing regions.

As shown in Figure 40, North America and Eastern Europe – FSU would incur much higher costs in the PC scenario, while Western Europe and Pacific OCDE would on the contrary draw some benefits, at least for the period under review (while the convergence effort is pursued and increased up to 2050, at which date it gets very constraining for all countries with high per capita emissions in 2010, Western Europe and Pacific OECD included. EEE – FSU is the only importing region that do more domestically than it buys on the international emission trading market. The three other regions meet a much larger part of their targets with permits than with domestic reductions.

On the exporter's side, Latin America gains more in the SL scenario, although it represents only a modest share of the overall trading. Africa-Middle East and Asia, which sell most of the permits, benefit more from the PC scenario because of their very low levels of per capita emissions at the beginning of the 2010-2030 period. It has be noted that both regions benefit from hot air, as they sell a greater volume of reductions than what they reduce domestically.

Figure 39: Cumulative reductions, regions

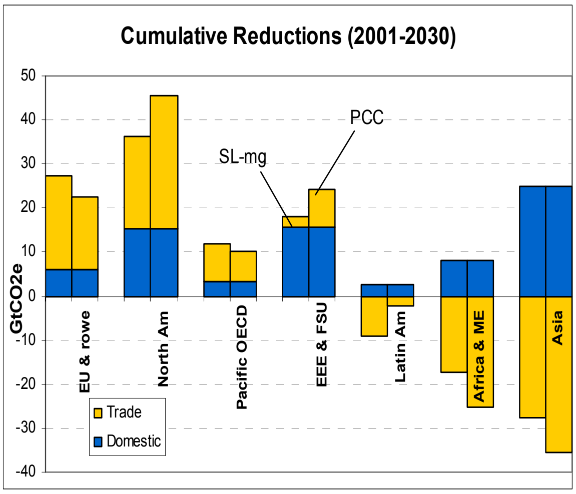


Figure 40: Discounted cost, regions

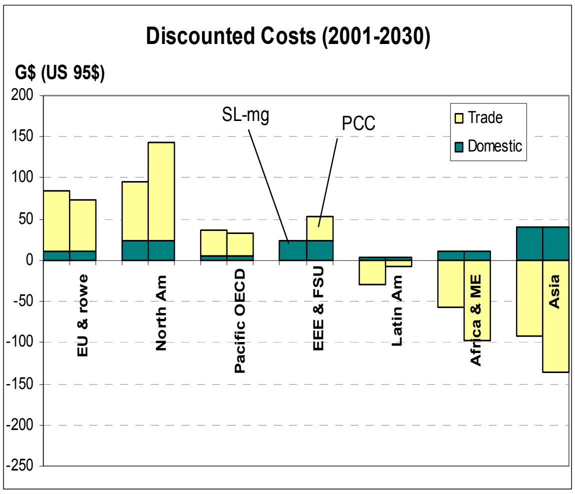


Figure 41: Discounted effort rate, regions

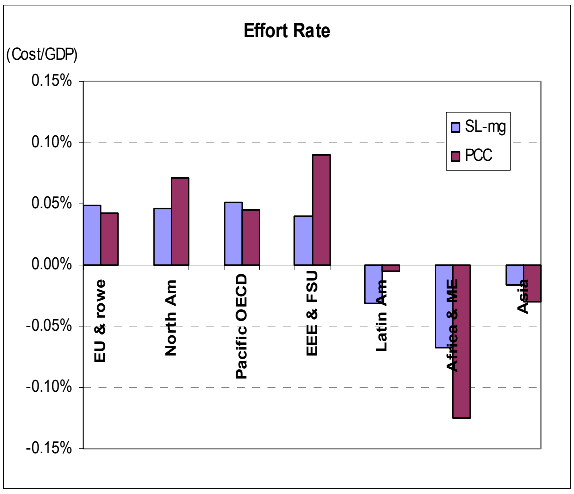
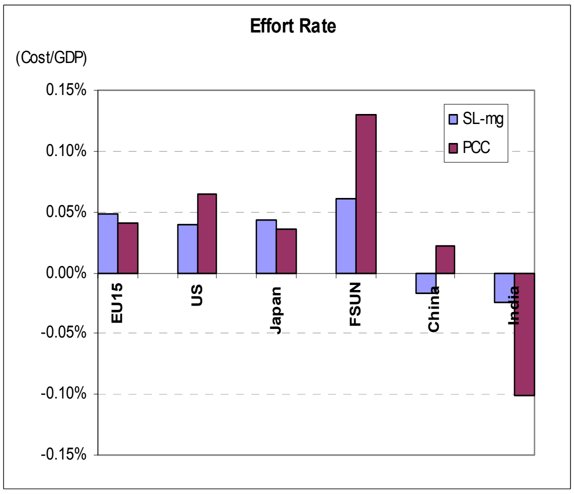


Figure 42: Discounted effort rate, key parties



In terms of cumulative "effort rate" the results in Figure 41 are highly homogenous among buyers in the SL case – the effort rate ranges from 0.04% to 0.05% of the GDP – while Africa-Middle East shows the largest benefits - 0.07%. The benefits of the Asia region, which are quite significant when measured in volume, represent however a smaller share of the total GDP than in Latin America.

The PC case shows much higher disparities among importers: EEE – FSU have the heaviest cost per unit of GDP, followed by North America (which has a much larger absolute cost), and the Western Europe and Pacific OCDE regions, each with similar effort rates (slightly lower than 0.05%). For the sellers, Africa-Middle East discounted benefits reach a very high level of 0.12% of total GDP, followed by Asia, 0.03%, and Latin America, 0.01%.

Figure 42 shows the discounted effort rates for key parties and reveals that China and India present very different profiles in the PC case, as China incurs a net cost instead of a net benefit in the SL case. This results basically from very differentiated features of the energy system and in particular from the high per capita emission level that characterises China. On the contrary, India would draw large benefits from the PC scheme, although it is still a net seller in the SL scheme. The diverging perspectives for these two large non-Annex B countries – and already key parties in the climate change policy arena – casts some light on the nature of the difficulties that will arise when the climate negotiation will deal with the issue of targets or endowments for developing countries.

On this key issue of the international acceptability of the endowment schemes, the Soft Landing scenario demonstrates that it is possible to design a solution that to some extent harmonises and limits the costs for the permit importing countries, while still ensuring reasonable net benefits for the developing regions. This is confirmed in Table 7 that presents not the discounted effort rate over thirty years, but the current effort rate in 2030 (for 20 regions that are almost compatible with the GEM-E3 regions in Table 17 below). As such, this Table 7 provides a better comparability with the GEM-E3 results presented below, although the sectoral costs are of course not fully comparable with the welfare losses in the general equilibrium approach.

As it was to be expected, the current effort rate in 2030 is much higher than the discounted effort rate over thirty years, simply because most of the constraint and costs/revenues have to be borne by the end of the period. Generally, these results confirm the fact that the Soft Landing scheme involves more evenly distributed costs and gains from the combination of the global cap and world permit trading system. Only for very few exceptions are the 2030 costs/revenues more important, as a percentage of GDP, in the SL-MG case than in the PC-MG case. This confirms the fact that the Soft Landing approach might be an internationally more acceptable case while, as it will be shown with the GEM-E3 simulations below, this scenario minimises the initial shock to the different regions and as such the total loss of welfare associated with world abatement strategies.

Table 7: Effort rate for the 20 POLES regions in 2030 (with GEM-E3-type regions)

	CO_2OO	CO_2OP	SLMG	PCMG
USA	0.36%	0.21%	0.24%	0.55%
Canada	0.68%	0.37%	0.45%	0.56%
Australia + New Zealand	0.62%	0.34%	0.44%	0.53%
Japan	0.33%	0.19%	0.23%	0.23%
France	0.25%	0.14%	0.17%	0.14%
Germany	0.26%	0.13%	0.18%	0.25%
UK	0.28%	0.18%	0.20%	0.23%
Italy	0.34%	0.18%	0.24%	0.22%
Rest EU	0.39%	0.22%	0.28%	0.30%
Central & Eastern Europe	0.16%	0.09%	0.09%	0.30%
Former Soviet Union	0.93%	0.42%	0.46%	1.02%
Central America	-0.17%	-0.09%	-0.13%	-0.08%
South America	-0.15%	-0.07%	-0.11%	-0.01%
Mediterranean	-0.13%	-0.06%	-0.09%	-0.25%
Middle East	0.11%	0.06%	-0.07%	0.82%
Africa	-0.90%	-0.58%	-0.68%	-2.93%
India	-0.14%	-0.09%	-0.10%	-0.54%
Rest of South Asia	-0.57%	-0.29%	-0.44%	-2.22%
Rest of East Asia	0.09%	0.07%	0.09%	0.09%
China	-0.06%	-0.03%	-0.03%	0.15%

6.1.3 Impacts on the World Energy Balances

The impacts of the different scenarios can also be analysed in terms of impacts on the World Energy Balance (WEB). In the following section, the WEBs of the different emission control scenarios are compared with the POLES model Reference projection to 2030. Table 8 present the key results of the Reference scenario, while Table 9, Table 10 and Table 11, present the percentage changes from the Reference of respectively SL and PC-MG, COO and COP.

The first conclusion from the analysis of these tables is that the different scenarios lead to a decrease in primary energy use of 7-10 % according to the scenario. As expected, the energy sector is less affected in the multi-gas cases, as the other GHG emissions offer significant additional opportunities for least cost reductions. The reduction in primary energy consumption is mostly due to the sharp decrease in the use of solid fossil fuels (coal, lignite) in all scenarios. In 2030 and compared to the reference scenario, the solid fossil fuel consumption is 27 to 37 % lower in the abatement scenarios. The use of oil and the gas are also affected, although in much smaller proportions for the gas: reductions (- 8 to 10 % for oil, - 2 to 3 % for natural gas). The impact on oil consumption also results in a lower world oil price, in a range of 6 to 9 % in 2030.

These lower level of fossil fuel consumption are compensated by an increased use of non-fossil energies: large hydro and geothermal energies, other renewables and nuclear energy. Most of the increase in non-fossil fuels goes to the renewable energies (from 30 to 50 %) and to nuclear energy (from 20 to 30 %, with an increase mostly in the last decade due to the time constant for the deployment of this technology).

As should be expected, the stronger the constraint, and the greater the possibility for new technologies to substitute to fossil fuels. Therefore the development of the non fossil energy options is greater in the COO case, than in the multi-gas cases. This constitutes an unavoidable effect of any Multi-Gas strategy: while decreasing the pressure imposed on the energy sector, they create a global context with slightly less incentives for the development and diffusion of new carbon-free energy technologies.

Table 8. The POLES Reference scenario - World Energy Balance

POLES - REFERENCE WORLD	1990	2000	2010	2020	2030	y.a.g.r 2000-2030
Population (M)	5248	6102	6855	7558	8164	1.0%
Per capita GDP (95$/cap)	5867	6786	8513	10506	12590	2.1%
GDP (G$95PPP)	30793	41407	58350	79400	102788	3.1%
Energy Intensity of GDP (toe/M$95)	282	241	206	182	165	-1.3%
Primary energy (Mtoe)	8682*	9990	12012	14458	16971	1.8%
Carb intensity of energy (tCO2/toe)	2.41	2.38	2.43	2.52	2.59	0.3%
CO2 emissions (MtCO2)	20930	23775	29210	36426	43970	2.1%
All GHGs emissions (MtCO2e)	NA	32904	39856	49119	58430	1.9%
Primary Energy Supply (Mtoe)						
Solids	2168	2348	2858	3611	4599	2.3%
Oil	3104	3604	4254	5102	5881	1.6%
Gas	1747	2146	2876	3710	4331	2.4%
Others	1665	1892	2024	2035	2160	0.4%
of which						
Nuclear	509	663	800	795	890	1.0%
Large Hydro + Geoth	193	238	290	342	393	1.7%
Trad. Biomass	791	820	682	569	477	-1.8%
Other Renewables	171	170	252	329	400	2.9%
World Oil Price ($95/bl)	27.2	26.5	23.7	28.7	34.9	0.9%

* 1992 figure

Table 9. The multi-gas scenario World Energy Balance compared to the Reference

Multi-gas Scenarios / Reference	2000	2010	2020	2030
Energy Intensity of GDP (toe/M$95)	0.0%	-1.2%	-2.2%	-6.7%
Primary energy (Mtoe)	0.0%	-1.2%	-2.2%	-6.7%
Carb intensity of energy (tCO2/toe)	0.0%	-2.1%	-3.6%	-8.2%
CO2 emissions (MtCO2)	0.0%	-3.3%	-5.7%	-14.3%
All GHGs emissions (MtCO2e)	0.0%	-6.7%	-7.4%	-15.0%
Primary Energy Supply (Mtoe)				
Solids	0.0%	-5.0%	-10.1%	-27.0%
Oil	0.0%	-2.6%	-3.5%	-7.6%
Gas	0.0%	-1.4%	-1.4%	-1.9%
Others	0.0%	7.2%	13.9%	29.3%
of which				
Nuclear	0.0%	0.0%	1.3%	18.9%
Large Hydro + Geoth	0.0%	0.2%	0.5%	1.8%
New Renewables	0.0%	4.9%	8.5%	29.9%
World Oil Price ($95/bl)	0.0%	-2.9%	-3.5%	-6.5%

Table 10. The carbon-only "only" scenario WEB compared to the Reference

COO Scenario / Reference	2000	2010	2020	2030
Energy Intensity of GDP (toe/M$95)	0.0%	-2.2%	-4.8%	-9.6%
Primary energy (Mtoe)	0.0%	-2.2%	-4.8%	-9.6%
Carb intensity of energy (tCO2/toe)	0.0%	-2.4%	-5.4%	-11.3%
CO2 emissions (MtCO2)	0.0%	-4.6%	-9.9%	-19.8%
Primary Energy Supply (Mtoe)				
Solids	0.0%	-6.4%	-18.6%	-37.2%
Oil	0.0%	-3.7%	-5.7%	-10.2%
Gas	0.0%	-3.3%	-2.2%	-3.3%
Others	0.0%	8.2%	17.2%	38.1%
of which				
Nuclear	0.0%	-0.1%	3.5%	31.7%
Large Hydro + Geoth	0.0%	0.4%	1.0%	2.5%
New Renewables	0.0%	12.9%	22.6%	48.6%
World Oil Price ($95/bl)	0.0%	-4.3%	-5.3%	-8.8%

Table 11. The carbon-only "proportional" scenario WEB compared to the Reference

COP Scenario / Reference	2000	2010	2020	2030
Energy Intensity of GDP (toe/M$95)	0.0%	-2.2%	-3.7%	-7.5%
Primary energy (Mtoe)	0.0%	-2.2%	-3.7%	-7.5%
Carb intensity of energy (tCO2/toe)	0.0%	-2.4%	-4.6%	-8.9%
CO2 emissions (MtCO2)	0.0%	-4.6%	-8.1%	-15.7%
Primary Energy Supply (Mtoe)				
Solids	0.0%	-6.4%	-14.5%	-29.5%
Oil	0.0%	-3.7%	-5.0%	-8.2%
Gas	0.0%	-3.3%	-2.4%	-2.4%
Others	0.0%	8.2%	16.0%	31.1%
of which				
Nuclear	0.0%	-0.1%	2.5%	19.9%
Large Hydro + Geoth	0.0%	0.4%	0.8%	1.9%
New Renewables	0.0%	12.9%	17.9%	37.3%
World Oil Price ($95/bl)	0.0%	-4.3%	-4.9%	-7.4%

6.1.4 Conclusions : Multi-Gas Strategies from an energy model perspective

The key conclusions of the GECS Multi-Gas study with the POLES 5 model can be summarised as follows:

i The Multi-Gas analyses first of all demonstrate the importance of the impacts of this new framework on the design of global abatement policies. Changing from a CO_2 to a Multi-Gas approach either allows to increase total abatement of 25 % for the same Marginal Abatement Cost or to decrease the MAC of approximately 30 % for the same total abatement.

ii The picture drawn at world level for the Multi-Gas Approach is confirmed by the region-by-region and country-by country analyses as the two Carbon-only cases either show lower cumulative reductions or higher total discounted costs and effort rates.

iii The global cap chosen in the exercise along the B1-SRES scenario, although respecting climate targets of 550 ppmv and temperature increases of less than 0.5°C (from 1990 level) provides a relatively soft constraint case in a Multi-Gas analysis framework, which allows relatively generous endowment to developing countries, with in most gains net gains from the participation in the endowment scheme.

iv The Soft Landing scenario developed for the GECS project presents interesting features as it allows to produce – in the POLES partial equilibrium analysis – a world endowment system with homogenous results in terms of total discounted cost/revenues on discounted GDP, at least for the key Parties to the climate negotiation. What is more, most developing countries benefit from net gains in this scenario, although these gains are generally smaller than in the alternative Per Capita Convergence case.

v The impact of the GHG constraint on the energy systems is significantly reduced in the Multi-Gas approach which allows to limit the required reduction from this sector. This may even be considered as a drawback from this scenario as it is less stimulating for new technology development than pure CO_2-only cases. This is however an unavoidable fact that any low cost abatement opportunity, which will be highly welcome in the design of climate policy, will also reduce the incentive for more costly options.

6.2 The Multi-Gas Scenario analysis with the GEM-E3 model (ICCS-NTUA)

This section presents the results obtained from simulating with the GEM-E3-World general equilibrium model the different GECS abatement and endowment scenarios. The presentation concentrates on the general equilibrium aspects of the analysis although the GEM-E3 had also to be fitted with many attributes of specialised partial equilibrium models and naturally produces results connected with them. This emphasis was given in an effort to avoid duplication and enhance complementarity with the other analytical tools used in the GECS project.

The main characteristic of the GEM-E3 model is that all markets reach equilibrium simultaneously by assuming optimising behaviour of different economic agents and through the interaction of prices and costs. In order to overcome the risks of oversimplification in the presentation of results, this section is divided into two principal parts. The first concentrates on the activity adjustment process that takes place in order to meet the emission constraints implied by the GECS scenarios. The discussion in this part is restricted to world aggregates but expands on sectoral detail. The second part deals with the re-distributive aspects of the scenarios across the different regions of the world, introduces country detail but keeps sectoral analysis to the minimum while concentrating on the key elements for the determination of changes in welfare.

6.2.1 World economic activity implications of the abatement scenarios

The imposition of a binding GHG emission constraint in the GEM-E3 model generates a non-negative shadow cost (dual variable). This corresponds to the cost of reducing the last tonne of GHG (in CO_2 equivalent) before meeting the constraint at the level of the abating club, which in the cases under consideration consists of the Annex B countries for the period up to 2010 and the whole world for the rest of the projection horizon (to 2030). This shadow cost corresponds to the marginal abatement cost, which according to economic theory in the absence of market imperfections will be equal to the market-clearing price of emission permits. This price is used for increasing the costs of GHG emitting activities and at the same time constitutes, together with emission allowances and the emissions themselves, a key element for determining the value of permit trade transfers between agents and countries.

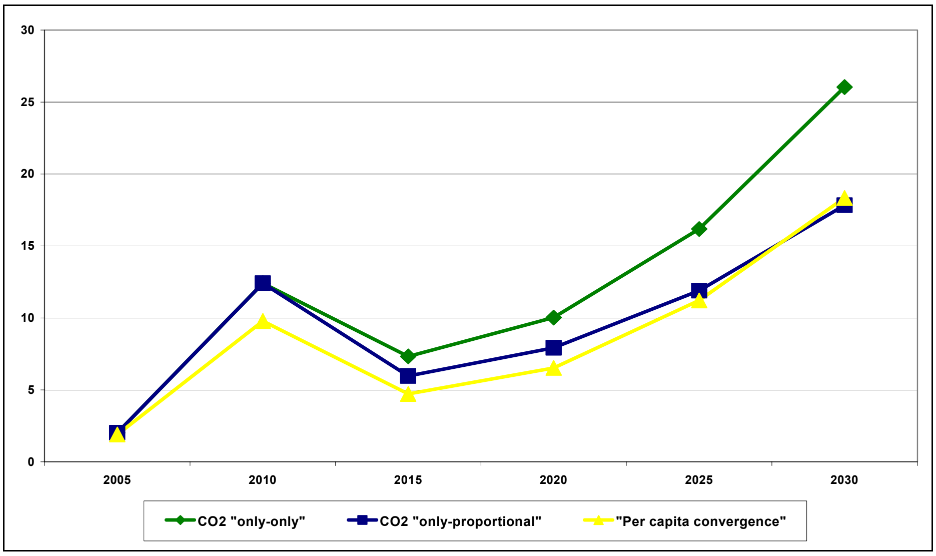
General equilibrium models such as GEM-E3, for a given abatement scenario tend to produce lower market clearing prices than partial equilibrium (energy) models such as POLES even when total elasticities and elasticities of substitution between fuels together with marginal abatement cost relationships (for non-energy GHGs) are equivalent. The main reason for this tendency is the additional flexibility that characterises general equilibrium models: abatement is achieved not only through reduction of energy use and inter-fuel substitution but also through reduction of overall activity as well as the substitution between energy intensive activities with less energy intensive ones. These reductions occur as part of the standard behaviour of economic agents (households and firms) as they adjust their decisions (consumption patterns and input configurations) while maximising (welfare or profits) in the face of altered prices (of goods and services and factors of production including intermediate purchases).

Furthermore prices in GEM-E3 have a different meaning than the conventional one that characterises neo-Keynesian and indeed partial equilibrium models: they are measured in terms of a base year "numeraire" and in a growing economy would tend to decrease as increased productivity enables the production of more goods and services with fewer inputs. In this sense the lower prices (in terms of the base year numeraire) are manifestations of the growth itself. Under this light, for example, a constant carbon value produced by GEM may well be equivalent to an increasing one if measured by the more traditional methods of calculating "real" prices.

- *The carbon value profiles with GEM-E3*

The temporal profile of the carbon value that results from the implementation of the different scenarios in GEM is highly consistent with the one obtained from the POLES partial equilibrium model. In the period to 2010 (Kyoto horizon) the carbon value, which is applicable to Annex B countries only, increases sharply. The enlargement of the permit market to include non-Annex B countries immediately after 2010 implies enhanced overall flexibility and a relative relaxation of the constraint as non-Annex B countries are eased into the abatement effort, many of them even possessing substantial amounts of "hot air". This produces a situation of excess supply of permits leading to a sharp drop in carbon values in 2015 (intermediate years between 2010 and 2015 are not available from GEM-E3 simulations) and relative stability in the 2015-2020 period. Beyond 2020, tightening availability in less developed regions and the gradual elimination of the cheaper abatement options in Annex B regions result in a shrinking supply and increased demand for permits which lead to increases in the permit price at an accelerating pace.

Figure 43: The evolution of carbon value in the CO_2OO, CO_2OP, and PCMG scenarios



This broad pattern notwithstanding, the choice of scenario does affect the levels of the carbon value. The "CO_2 only-only" scenario produces the highest values as it implies a considerable abatement effort while restricting flexibility in the emission reduction options. Introducing Multi-Gas flexibility produces carbon values that stand approximately at two thirds of their "CO_2 only-only" levels. An interesting observation is that – exactly as in the POLES model simulations – the "CO_2 proportional" scenario, by 2030, results in carbon values that are substantially the same as the multi-gas flexibility scenarios despite the fact that it implies a considerably smaller environmental impact than they do.

This is primarily due to the fact that the case of methane emissions from the production of fossil fuels apart, non-energy GHG abatement is unconnected with abatement of CO_2 emitted through fuel consumption. In fact in the earlier decade (2010-2020) the "CO_2 only proportional" scenario gives carbon values that are higher than those of the multi-gas flexibility cases due, to a large extent, to the existence of a substantial early low cost emission reduction potential for non-CO_2 GHGs such as SF_6 and methane from primary fuel production. The two multi-gas scenarios produced carbon values that are effectively identical because the differences in the regional and sectoral activity structures they imply, though important at a detailed level tend to cancel out at the world level and the result is basically dominated by the fact that the two scenarios involve identical emission constraints. This behaviour plays an important role in moderating the adverse impact of the emission reduction scenarios on the current account and welfare of these regions.

- *Changes in GDP*

As mentioned earlier overall activity levels in GEM-E3 are a means of achieving emission reductions (once other cost effective ways are exhausted) but at the same time are useful summary indications of the overall abatement effort being as they are a distillation of a multitude of adjustments taking place in the world economy.

Table 12: Changes in GDP and production at the world level (2030)

	CO_2OO	CO_2OP	SLMG	PCMG
GDP	-0.85%	-0.67%	-0.65%	-0.78%
Agriculture	1.49%	0.88%	-0.31%	1.12%
Coal	-31.38%	-26.40%	-26.79%	-27.85%
Petroleum Refineries	-12.74%	-9.58%	-9.29%	-9.71%
Distribution of Gasseous Fuels - Manufacture of Gas	0.46%	0.47%	-0.72%	-0.81%
Electricity	-8.84%	-6.64%	-6.72%	-7.07%
Ferrous and non-ferrous metals	-4.23%	-3.08%	-3.25%	-3.52%
Chemical Products	-4.07%	-3.03%	-3.30%	-3.18%
Other energy intensive	-1.78%	-1.31%	-1.62%	-1.55%
Electronic Equipment	-0.35%	-0.25%	-0.43%	-0.37%
Transport equipment	-0.45%	-0.34%	-0.42%	-0.24%
Other Equipment Goods	-2.61%	-1.89%	-1.93%	-2.03%
Other Manufacturing products	-1.32%	-0.94%	-1.13%	-1.05%
Construction	-0.91%	-0.69%	-0.70%	-0.64%
Food Industry	0.43%	0.17%	-0.09%	0.58%
Trade and Transport	-0.61%	-0.46%	-0.42%	-0.26%
Textile Industry	0.21%	0.12%	-0.52%	-0.07%
Other Market Services	-0.76%	-0.56%	-0.51%	-0.46%
Non-Market Services	0.04%	0.02%	-0.03%	0.06%

It is clear that all four scenarios involve reductions of GDP compared to the baseline. The most pronounced negative impact characterises the "CO_2 only-only" scenario as it involves considerable abatement with more limited flexibility in the emission reduction options. It is also worth noting that the "CO_2 only proportional" scenario produces GDP reductions of the same order of magnitude as those obtained when running the multi-gas "Soft-Landing" scenario. This is due primarily to the factors that produce equivalent carbon values for the two scenarios (see above).

A more important result is the increased cost (in terms of world GDP) obtained with the "Per Capita Convergence" scenario compared with "Soft Landing" although they involve identical emission constraints at the world level and as discussed earlier produced virtually the same carbon values. The main reason for this difference lies in the more radical re-distributive character of the "Per Capita Convergence" scenario, a feature built in by design. GEM-E3 like all general equilibrium models incorporates at many levels the notion of diminishing returns and in particular diminishing returns to substitution. This is an essential characteristic of such models and in many ways a formal requirement for obtaining an equilibrium at all. The redistributive “shock” of the PC scenario sets into motion changes in demand of goods, services, intermediate inputs and primary factors of production (labour and capital) in response to which supply is capable of adjusting only partially. In other words the more pronounced effect on GDP reflects additional adjustment costs.

The overall contraction of GDP in all the scenarios is accompanied by a more than proportional reduction in world trade which corresponds to the stylised fact observed over many decades that trade tends to exaggerate movements in overall activity.

Adjustment to the emission constraints naturally involves significant changes in sectoral activity. These result mainly from the direct and indirect impact of carbon values on prices of fuels and the relative prices of production of the sectors that use fuels or emit non-CO_2 GHGs. To a lesser extent, it also involves overall income effects as well as the income re-distribution to regions with different consumption and production patterns.

- *Impacts on the energy sector*

The energy sectors at a world level play the most important role in the re-adjustment process. GEM-E3 results do not deviate in substance from what could be expected from the POLES results for energy. The demand for coal is substantially reduced under the weight of the large surcharge implied by the carbon value. Oil demand is also affected especially in some non-Annex B countries where oil is used to a considerable extent for substitutable purposes (power generation and industry). Electricity use to the extent that it is produced from coal and gas also experiences substantial price increases and subsequent reductions in demand. All these effects are markedly more pronounced in the “CO_2 only-only” scenario in view of the higher carbon values involved. Natural gas on the other hand is generally unaffected implying large increases in its share as an energy source.

Concerning primary fuels it is worth noting that world trade prices of coal and, very significantly, petroleum decrease substantially as a result of the reduction in demand. This excess supply effect has been considerably enhanced in GEM-E3 since the introduction of the depletable resources module. On the other hand low cost producers such as the Middle East (in the case of oil) do not experience volume losses, since their export volumes increase implying large increases in their share of a shrinking market: because Middle East producers enjoy higher rents as payments to their resource ownership, they are capable of responding better to a drop in overall demand by undercutting competitors who are forced to reduce their output due to deteriorating profitability resulting from lower selling prices.

- *Impacts on other sectors*

After the energy sectors themselves it is the energy intensive sectors that contribute most to the economic adjustment following the imposition of the emission constraints. World output reductions are sharper for the metal and chemical industries as a direct consequence of energy intensities and fuel mix (heavy dependence of the iron and steel industry on solid fuels). Again the effect is more pronounced in the “CO_2 only-only” scenario due to the higher carbon values. The effect on these industries is clearly more pronounced than it is for activity as a whole and this conforms with expectations.

Apart from these overall effects, energy intensive industries also experience important geographical shifts as a result of the imposition of the emission constraints. This takes broadly the form of a decrease in the share of some key developing countries such as China and India as well as the important energy exporting regions and a subsequent increase in the share of highly developed economies. In the baseline the most energy intensive components of these industries tended to concentrate in areas where either low cost coal and electricity was available (the case of China and India) or where internal energy prices were low due to deliberate policy (very low taxation or preferential pricing) which is the case for major energy exporting regions such as the Middle East, the Former Soviet Union or even the Mediterranean (essentially North Africa). The imposition of a common carbon value tends to reverse dramatically such comparative advantages and produces a sharp fall of exports and even an increase in imports of the former countries. Table 13 illustrates the shift in production for the “CO_2 only-only” scenario where the impacts are most pronounced.

Table 13: Changes in production of energy-intensive industries in the "CO_2 only-only" scenario (2030)

	Ferrous & Non-Ferrous Metals	Chemicals	Other Energy Intensive
Europe	-0.16%	-2.51%	1.22%
Rest of Annex B	0.07%	-3.46%	1.08%
Major Energy Exporters	-4.36%	-5.66%	-3.16%
LDCs	-10.39%	-6.11%	-7.30%

Among the other sectors "Other equipment goods" and "Other manufacturing products" being more energy intensive than the economy as a whole register activity reductions that are sharper than GDP while the rest including all market services decrease less than GDP.

The case of agriculture, the food industry and textiles present particular interest as their movement is influenced by the re-distribution of income across regions. All the emission abatement scenarios considered involve to a lesser or greater extent a transfer of income from highly developed economies to less developed ones. However the latter have different consumption patterns where the products of the above sectors figure larger than in developed economies. As a consequence, output is maintained or even increased.

To illustrate the impact of these re-distribution effects a closer look at agriculture reveals that in the "CO_2 only-only" case, which involves substantial re-distribution of income towards less developed regions global demand for agricultural products increases by 1.5 percent despite a drop in world GDP of around 0.9 percent. In the multi-gas scenarios the agricultural sector is penalised as many of its activities (notably dairy farming and rice production in paddies) emit large quantities of methane and abatement options are relatively costly. Yet in the "per capita convergence" case that involves the largest income transfers to less developed areas among all the scenarios examined (see discussion on welfare below) the emission penalty is not enough to reverse the positive impact on global agricultural output (1.1 percent increase in a case where global GDP falls by 0.8 per cent).

It is only in the "soft landing" scenario with its weaker transfers that global agricultural output drops (however at a smaller rate than GDP). It is worth noting that in the scenarios where agricultural output increases it is not necessarily the agricultural sectors of regions benefiting from net permit sales that register the highest growth: permit revenues ease current account constraints of permit selling regions enabling them to import more food for domestic consumption. This is particularly the case in the "per capita convergence" scenario where the major beneficiary in terms of output is North American agriculture, the exports of which consist to a large extent of grains and are therefore less hit by the emission penalty. This discussion therefore points also to the issue of changes in human diet patterns as a response to Climate Change constraints, which largely remains to be explored.

6.2.2 Income redistribution and welfare implications of the abatement scenarios

The discussion in the previous section concentrated on activity adjustments to the imposition of the emission constraints, in order to demonstrate the key general equilibrium mechanisms that operate in allocating the abatement effort. In this context it also hinted at the effects of income re-distribution between regions to the extent that they affected activity levels. However re-distribution of effort, costs and income are interesting in their own right since they form the essential principles on which the scenarios were built and against which they must be judged. Furthermore the discussion of these effects can provide useful insights on possible negotiation stances in preparation of an international post-Kyoto climate change policy, which in order to be effective will have to involve all the countries of the world (or at least the main present and future polluters).

In order to assess the economic costs or benefits of a particular permit allocation scenario for a particular country/region a measure of economic welfare is a much more suitable indicator than GDP which essentially measures activity in the economy. The main reason for this is that substantial net permit sales generate an income flow to the selling country that can be used to increase investment and productive capacity in that country but can also be used to increase imports of goods and services. These imports according to national account conventions carry a negative sign in the GDP balance while it is clear that consumers can benefit equally from them as they do from consumption of domestically produced goods. In this sense GDP would tend to underestimate the benefits (or indeed the costs to net purchases of permits for regions who may have to forgo consumption in order to increase exports to finance the purchase).

GEM-E3 uses a welfare or utility function incorporating household consumption, leisure and the value of savings in terms of future discounted consumption. This utility function is assumed to be maximised by households in the face of income, the relative prices of goods and services and discount factors. Household income includes receipts as payment for labour (wages) and returns to investment (dividends). Permits in the current scenario exercises are allocated to polluters (firms or households) according to the grandfathering principle and the net sales of firms find their way to household income in the form of increased dividends. Permit availability to the different agents is assumed to follow proportionally the evolution of the national permit allowance.

- *Regional permit endowment patterns*

Both the “Per Capita Convergence” and the “Soft-Landing” scenario with its “CO_2 only” variants are designed to favour countries with low present emissions per capita. The “Soft Landing” scenarios also consider relative income in the form of GDP per capita but allows for a more gradual evolution towards more “equitable” emission patterns. Since low emissions per capita usually characterise the poorer countries, both scenario types are designed to favour poorer countries *inter alia* in order to provide a sufficient incentive for their engagement in the GHG abatement process.

Table 14 gives the ratios of the allowances to baseline emissions under the different abatement scenarios for the year 2030. Entries that are larger than unity indicate the presence of so called “hot air” (allowance that exceeds baseline emissions). “Hot air” is very markedly present in the “Per Capita Convergence” scenario and characterises some of the poorest regions in the world in particular South Asia and Africa. It also occurs to a much lesser extent (although the choice of 2030 masks earlier occurrence) in the “Soft Landing” scenarios. On the other hand most of the highly developed economies appear to have low permit allocations relative to their baseline emissions: this is particularly the case for Canada, Northern Europe and Australia/New Zealand. The major hydrocarbon exporting regions (Middle East and Former Soviet Union) have low allowances compared to baseline in the “per capita convergence” scenario because their emissions per capita are relatively high, their relatively low incomes per capita notwithstanding.

Table 14: Permit endowment to baseline emissions, ratio (2030).

	CO_2OO	CO_2OP	SLMG	PCMG
Africa	0.98	0.98	0.99	1.65
Australia-New Zealand	0.43	0.54	0.54	0.48
UK	0.62	0.66	0.67	0.51
Central America	1.07	1.04	1.05	0.92
Canada	0.40	0.52	0.53	0.32
Central EU Associates	0.79	0.84	0.84	0.69
China	0.89	0.91	0.91	0.80
Former Soviet Union	0.58	0.71	0.71	0.51
Germany	0.61	0.70	0.70	0.56
India	0.92	0.94	0.94	1.27
Japan	0.58	0.65	0.65	0.59
Middle East	0.88	0.91	0.91	0.65
Mediterranean	1.06	1.03	1.05	1.27
Nordic EU	0.44	0.54	0.54	0.54
Other Europe	0.38	0.51	0.51	0.53
Rest of East Asia	0.83	0.86	0.87	0.87
Rest EU	0.56	0.65	0.65	0.62
ROW	0.97	0.98	0.98	1.24
Rest of South Asia	1.31	1.20	1.20	2.70
South America	1.08	1.04	1.05	1.07
USA	0.63	0.70	0.71	0.44

Concerning the potential for cost effective emission reductions, a good indication is the simulated abatement for the different scenarios bearing in mind that the “CO_2 only-only” scenario implies considerably higher carbon values than the other scenarios. Table 15 below gives emission reductions for main country groupings and emission type.

Table 15: Emission reductions by region (2030)

	CO_2OO	CO_2OP	SLMG		PCMG	
	CO_2	CO_2	CO_2	NON CO_2	CO_2	NON CO_2
EU	-11.80%	-9.00%	-9.10%	-12.00%	-9.60%	-12.10%
Rest Developed Countries	-16.90%	-12.80%	-12.60%	-17.10%	-13.70%	-17.50%
Major Energy Exporters	-25.90%	-20.70%	-20.80%	-22.30%	-23.00%	-23.30%
LDCs	-23.00%	-19.00%	-18.90%	-12.20%	-18.90%	-11.00%

In broad terms, major energy exporters have very considerable CO_2 reduction potential as their baseline energy consumption patterns favour energy intensity through fossil fuel prices. They also have a very high potential for reduction of non-energy related GHGs mostly because of highly cost effective options for reducing methane emissions associated with primary hydrocarbon production. Other less developed regions taken as a whole also offer considerable potential for CO_2 emission reductions but more limited possibilities for reducing non-energy GHGs. The latter is due to very high cement production by 2030 and the virtual non-existence of options for reducing corresponding CO_2 emissions as well as the large share of their agricultural sectors marked by methane emissions with only very costly abatement possibilities. On the contrary in highly developed economies non-CO_2 GHG abatement offers comparatively good cost effective prospects (SF_6 and HFCs) while energy related CO_2 emissions can only be reduced at a relatively high cost since most of the easier options have already been exhausted under the weight of higher fuel prices and taxation as well as environmental concerns.

The combination of baseline emission projections, allowances as provided in the scenarios, the relative ease of abatement and the carbon value as it emerges from the equilibrium in the permit markets produces a transfer of income to net sellers of permits. The magnitude of this transfer represents the initial “shock” to the different economies, which weighed against abatement costs and the costs of re-adjustment to a new equilibrium arising from relative price movements for all flows in the economy, finally determines the welfare implications of the different scenarios. This initial “shock” closely correlates with the ultimate costs and benefits to the participants in the abatement effort implied by the scenarios.

Table 16: Purchases/Sales of Permits as % of GDP (2030)

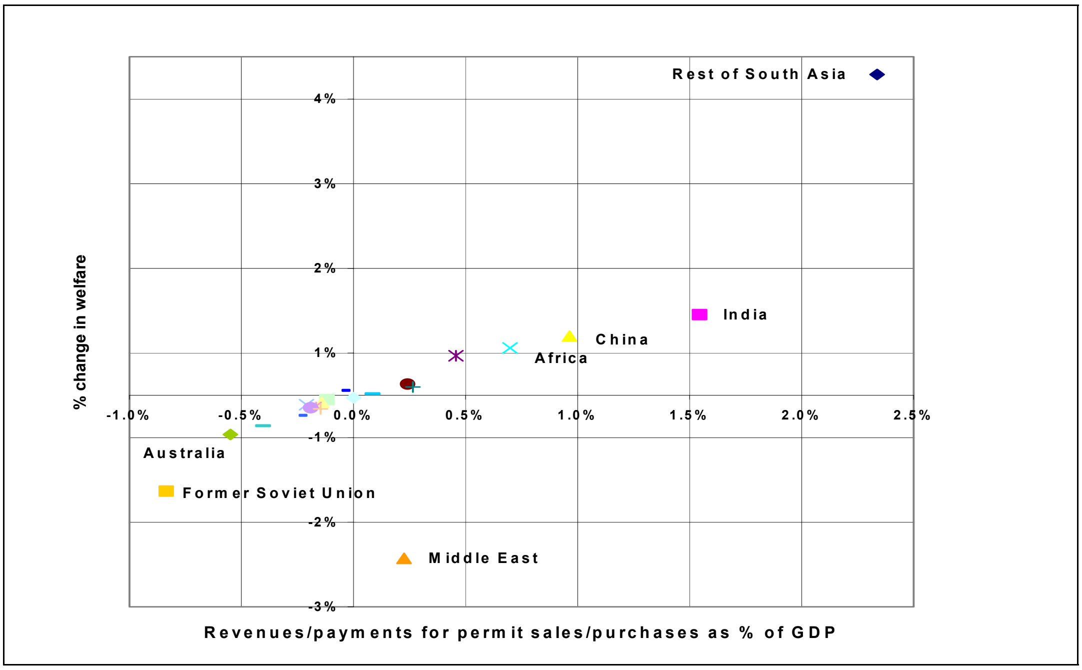
	CO_2OO	CO_2OP	SLMG	PCMG
Africa	0.70%	0.36%	0.60%	3.94%
Australia-New Zealand	-0.55%	-0.31%	-0.42%	-0.50%
Canada	-0.40%	-0.22%	-0.31%	-0.49%
Central America	0.26%	0.13%	0.17%	-0.01%
Central EU Associates	0.08%	0.05%	0.03%	-0.33%
China	0.96%	0.54%	0.58%	0.13%
Former Soviet Union	-0.84%	-0.21%	-0.34%	-1.72%
Germany	-0.14%	-0.08%	-0.09%	-0.15%
India	1.54%	0.97%	0.99%	3.25%
Japan	-0.12%	-0.07%	-0.08%	-0.10%
Mediterranean	0.46%	0.12%	0.30%	0.72%
Middle East	0.23%	0.22%	0.20%	-0.33%
Nordic EU	-0.24%	-0.14%	-0.18%	-0.18%
Other Europe	-0.15%	-0.08%	-0.11%	-0.11%
Rest EU	-0.21%	-0.12%	-0.14%	-0.15%
Rest of East Asia	-0.05%	-0.04%	-0.07%	-0.06%
Rest of South Asia	2.34%	1.12%	1.85%	10.29%
ROW	0.12%	0.06%	0.66%	1.46%
South America	0.24%	0.11%	0.17%	0.20%
UK	-0.19%	-0.12%	-0.14%	-0.23%
USA	-0.17%	-0.10%	-0.12%	-0.31%

Table 16 gives the value of this initial “shock” as a percentage of 2030 GDP. In general it can be seen that highly developed regions are net purchasers of permits but the value of these purchases rarely represents more than 0.5 percent of GDP (the only exception being Australia in the “per capita convergence” and “CO_2 only-only” cases). The picture for the other regions is more mixed. The net inflow in South Asia is very considerable in all cases and naturally highest in the “Per Capita Convergence” case where Africa also registers a strong positive result. For some regions like South East Asia, permit trade is virtually balanced for all scenarios while the same holds for Central European Associates with the exception of the “Per Capita Convergence” scenario. For the latter scenario the Middle East also becomes a net purchaser of permits instead of a very moderate net seller. The FSU is a net purchaser in all scenarios but among all regions affects the largest income outflow (as a proportion of its GDP) in the “per capita convergence” scenario.

Before proceeding with a closer look at the welfare implications of the scenarios for the different regions it is worth demonstrating the close correlation between welfare gains/losses with the income inflows/outflows arising from permit trade. This holds with relatively minor variations for all scenarios. Figure 44 plots the transfers implied by permit trade as obtained from the previous table against the welfare gains/losses obtained at the new equilibrium. A cursory glance is sufficient to indicate that most countries/regions lie approximately on a straight line passing from the origin, suggesting broad proportionality of the two impacts. There are however some exceptions that are worth pointing out because they help understanding the welfare change results that are presented later. These deviations are mainly due to differential impact on the terms of trade.

The most notable among them concerns the Middle East which although a net exporter of permits, albeit at a modest scale, registers the biggest losses in terms of welfare. This is mainly due to a drastic deterioration of the terms of trade with the price of crude oil, the main export of the region, falling in the face of slackened world demand. An increase in the volume of crude oil exports is not sufficient to reverse the adverse effects that end up by more than offsetting the modest inflows of goods and services. As a consequence imports must be reduced and non-oil domestic production cannot compensate for the shortfall with subsequent reductions in household consumption.

Figure 44: Change in Welfare and Sales/Purchases of Permits as % of GDP



Similarly the Former Soviet Union that is also a major crude exporter deviates from proportionality but to a much lesser degree because of a better diversification of its exports. India and to a lesser extent China also display a slighter downward deviation which is linked more to falling export prices and increasing costs of some of their energy intensive sectors which in the Reference had gained substantial shares of the world market based on the availability of cheap coal (an advantage that in the scenario is severely curtailed). Opposite forces operate in the case of the “Rest of South Asia” region, which is characterised by low dependence on fossil fuels and can use the windfall of emission permit sales to boost consumption with a multiplier effect.

- *Welfare implications of the scenario for the different regions*

Table 17 below summarises the impact of the scenarios on the welfare of the different countries/regions identified in the GEM-E3 model. As mentioned earlier welfare is the indicator selected for measuring the re-distributive effects of the abatement scenarios and in this sense the table contains the essential results concerning the equity implications as they emerge from the GEM-E3 analysis carried out using GEM.

Table 17: % changes in Welfare from Baseline (2030)

	CO_2OO	CO_2OP	SLMG	PCMG
Africa	0.56%	0.26%	0.28%	1.42%
Australia+New Zealand	-0.46%	-0.30%	-0.27%	-0.25%
Canada	-0.36%	-0.24%	-0.22%	-0.27%
Central America	0.10%	0.02%	-0.02%	0.00%
Central EU Associates	0.02%	-0.02%	-0.08%	-0.14%
China	0.70%	0.41%	0.30%	0.07%
Former Soviet Union	-1.13%	-0.40%	-0.61%	-2.38%
Germany	-0.09%	-0.06%	-0.05%	-0.26%
India	0.95%	0.64%	0.33%	1.71%
Japan	-0.05%	-0.04%	-0.04%	-0.37%
Mediterranean	0.47%	0.17%	0.12%	0.80%
Middle East	-1.93%	-1.70%	-1.18%	-2.62%
Nordic EU	-0.24%	-0.17%	-0.16%	-0.12%
Other Europe	-0.16%	-0.11%	-0.10%	-0.03%
Rest EU	-0.11%	-0.07%	-0.08%	-0.07%
Rest of East Asia	0.06%	0.02%	-0.04%	0.08%
Rest of South Asia	3.79%	2.03%	1.53%	3.19%
ROW	-0.03%	-0.06%	-0.37%	0.46%
South America	0.13%	0.03%	0.04%	0.19%
UK	-0.15%	-0.11%	-0.11%	-0.12%
USA	-0.13%	-0.09%	-0.08%	-0.88%

With a single notable exception (that of the FSU) it is clear that the “CO_2 Only Proportional” scenario does not produce better welfare results than alternative scenarios. This is an apparently surprising result in view of the fact that this scenario in principle implies a reduced abatement effort (and certainly produces a smaller environmental impact) compared to all the others. The key to this apparent paradox lies less in the eventual cost associated with “CO_2 only Proportional” but rather in the existence of more attractive alternatives (the CO_2 Only Only with its higher carbon values for major permit sellers and the multi-gas cases offering additional flexibility for the rest). For this reason the “CO_2 Only Proportional” scenario does not figure in the discussion that follows.

In regions such as Sub-Saharan Africa, India and the Mediterranean (N. Africa and the Near East) that include some of the poorest regions in the world the “Per Capita Convergence” scenario offers the best welfare prospects and the multi-gas “Soft Landing” scenario the weakest. These regions are net exporters of permits in all cases. This finding is dominated by the fact that the “Per Capita Convergence” scenario offers the most favourable allocation of rights while the multi-gas “Soft Landing” scenario results in lower carbon values than the “CO_2 Only-Only” case. The same order of preference results for South America and the Rest of East Asia region where, however welfare gains are much smaller for all scenarios. In the Rest of South Asia region (excluding India) the “Per Capita Convergence” is clearly preferable to the multi-gas “Soft Landing” scenario but the amount of “hot air” enjoyed by the region means that the “CO_2 Only-Only” case with its high permit prices is even more attractive.

The multi-gas scenarios are relatively unattractive for China because of large non-energy related emissions associated with cement and rice production offering few cost-effective abatement options while the “Per Capita Convergence” case additionally proves unfavourable for this country that is characterised among less developed economies by relatively high emissions per capita. On the other hand China with ample opportunities for energy related CO_2 abatement is favoured particularly by the“CO_2 Only-Only” case characterised as it is by higher permit prices as well.

Welfare in Western European regions is relatively unaffected by the abatement scenarios though the high carbon values of the "CO_2 only-only" case make it somewhat more costly given the more limited potential for abatement in the energy field. Between the two multi-gas scenarios European regions have little to choose as they result in very similar net purchases of permits and the welfare impacts are of the same order of magnitude. Rather surprisingly even most of Europe according to the results would even prefer PC-MG to SL-MG. A notable exception is Germany, which among European countries has relatively high emissions per capita.

Australia & New Zealand and Canada are in all cases large purchasers of permits and therefore experience the largest welfare losses in the "CO_2 Only–Only" case, where such purchases are less onerous. On the other hand, the United States suffers relatively minor welfare losses in all the "Soft Landing" scenarios, including "CO_2 Only-Only", while they are rather severely affected in the "Per Capita Convergence" case where the rapid reductions in allowances generate large income transfers in the form of permit purchases.

Caught between relatively unfavourable permit allocations and a substantial deterioration in its terms of trade, the Middle East registers the largest welfare losses among all regions and for all the scenarios examined. Such losses are smallest in the case of the multi-gas "soft landing" scenario where the relatively low income of the region is taken into account in the emissions rights allocation, the terms of trade deteriorate less than in the "CO_2 Only-Only" case and some relatively cheap opportunities for hydrocarbon related methane abatement are afforded. A rather similar situation emerges for the FSU where the negative impacts on welfare are generally somewhat smaller because of the better diversified economy. The FSU sees a very substantial degradation when moving from "Soft Landing" to "Per Capita Convergence" because of the large reductions of permit rights this scenario implies for regions with high emissions per capita. In fact as mentioned earlier, the FSU is the only region out of those identified in GEM-E3 that obtains the smallest welfare reduction in the "CO_2 Proportional" case which for it represents a "least disturbance" case.

6.2.3 Conclusions: Multi-Gas strategies in a general equilibrium framework

From the discussion of the synthesis of results obtained using GEM E3 for analysing the different GECS scenarios a number of broad themes have emerged which are summarised below:

- i General equilibrium models can provide useful insights on the economic mechanisms involved in adjusting to emission constraints. While they are less detailed in terms of the various emission sources they do provide a framework within which economic feedbacks can be calculated giving a more complete representation of the abatement process. They are also capable of calculating welfare implications of different permit allocation schemes.
- ii The cost of achieving the reductions implied in the scenarios ranges between 0.65 and 0.85 percent of World GDP in 2030 with widely varying impacts on activity in the different sectors of economic activity
- iii Multi-gas flexibility reduces the global cost of meeting the emission targets by around one quarter. The inclusion of abatement options involving non-energy related GHGs is particularly beneficial in the adjustment process of highly developed economies.
- iv Results for the scenarios examined broadly satisfy the equity and efficiency principles which motivated their design and they imply sufficient incentives for participation of the least developed economies in the abatement effort. The more "egalitarian" scenario clearly favours the latter economies substantially but it also involves higher adjustment costs for the world economy as a whole.
- v The dominant redistributive element in the scenarios consists of the opportunities they provide for income transfers in the form of net permit sales/purchases. However, significant deviations from this dominance occur through effects on the terms of trade, especially among major energy exporters and economies with a structure favouring energy intensive activities.

The particular situation of major energy exporters has not been taken into account in designing the scenarios and as a consequence they experience large welfare losses in all the scenarios retained. These are mostly middle to low income countries (often with high emission intensities) the specificities of which will probably have to be taken into account in negotiating emission rights allocation schemes if they are to be engaged in a world climate change abatement

7 GECS: GENERAL CONCLUSIONS

The GECS project has demonstrated both the feasibility and usefulness of a research programme that proposed to combine different sources of information and expertise as well as different modelling approaches in order to produce coordinated economic assessments of policy scenarios. The key conclusions that came out of this process can be synthesised as follows:

- The abatement scenario that has been developed in the project, while taking into account the recent developments in the climate negotiation (including the US withdrawal as regards the First Commitment Period of the Kyoto Protocol) remains in line with the key targets of the UN-FCCC. The resulting abatement in world emissions of the 6 Kyoto GHGs corresponds to a reduction of about 15 % from the reference case in 2030.
- The international emission permit endowment scenarios associated to this “global cap”, namely the Per Capita Convergence and the Soft Landing schemes, both respond to clear principles, respectively the “equality of rights in the future” and “the differentiated slowdown in emission growth for developing countries”. When applied to the different world regions, they provide contrasted but consistent profiles. Both allow for endowments that largely benefit to the least developed regions of the world, these benefits being of course larger in the Per Capita Convergence.
- The detailed examination of the abatement options for other GHGs, whether in the energy and industry sectors or for waste, landfills and wastewater, has proved the importance of the corresponding potentials. The bottom-up analysis, confirmed by analysis of the global MAC curves produced by the models, show that the emissions of some activities are almost inelastic to the introduction of a GHG penalty, as in the case of CO_2 from cement production, while on the contrary other show an extreme sensitivity with reductions of more than 50 % for a high penalty level of about 50 €/tCO_2e (case of methane in gas transport, nitrous oxide in the chemical industry, PFC in aluminium and SF6 in semi-conductor industries). For the same level of penalty, most other activities show intermediate reduction levels, in the range of 20 to 40 %.
- As far as agricultural activities are concerned, the use of the IMAGE model has allowed for the development of an emission scenario that is consistent with the reference scenario in the project (the IMAGE scenario also provided the basis for the projection of emissions from waste, landfills and wastewater).
- Connected to this scenario, the development of the AGRIPOL model has introduced innovative treatments for simulating the impacts of a GHG penalty on emissions from agriculture, through changes in the basket of agricultural techniques. Given the hypothesis of a fixed demand for agricultural products that has been adopted in the project, the reaction of the agricultural sector has shown to be very limited, as the substitutions among techniques are either limited or entailing only a minor shift in the emission balance. This is all the more true when one considers that the margins for freedom in the choice of techniques will be substantially reduced to the 2030 horizon, when the pressure on available land and for higher productivity will strongly increase.
- This indicates that the contribution of agriculture to emission reduction abatement may be limited, unless significant changes in the structure of the demand for agricultural products occur. This issue remains to be explored as it implies a careful consideration of many complex economic factors, including international trade issues, and probably also sociological factors.
- Valuable information on two issues of fully different nature, carbon sinks and transaction costs, have been gathered in the project and are presented in the above report. However, for the sake of simplicity and consistency of the modelling exercises, these two items have not been included in the full economic analysis of the multi-gas scenarios with the partial and general equilibrium models.
- The analyses of the abatement scenarios − two multi-gas with Soft Landing or Per Capita Convergence endowments and two CO_2-only with different abatement targets − have been performed with two complementary modelling tools, POLES and GEM-E3. Their results provide useful insights for the design of global GHG abatement policies insofar as some of them are in full convergence, while other illustrate impacts that can only be seized by each

particular model, the former focusing on the sectoral/technological aspects and the latter on the macro-economic consequences of the abatement scenarios.

- Among the common statements to be drawn from the two families of exercises one can identify:
  - The demonstration of the relevance of the multi-gas strategies, as it appears that going from a CO_2-only to a multi-gas policy either allows to increase of about one fourth the total GHG abatement for the same Marginal Abatement Cost or to reduce of around 30 % the Marginal Abatement Cost for the same abatement in volume in 2030.
  - The level and profile of the GHG penalty induced by the emission constraint are highly consistent: in the POLES multi-gas exercise, the level of the penalty ends at 25 €/tCO_2e in 2030, while the corresponding value is of 18 €/tCO_2e in the GEM-E3 exercise. This is easily understandable as in the general equilibrium model, the macro-economic impacts of the abatement policy also result in changes in the level and structure of the economic activity, thus lowering the penalty that is necessary to meet the emission constraint.
  - As regards the comparative assessment of the two international endowment schemes under review, both models point to the fact that the Per Capita Convergence scheme, although globally more favourable to the least developed regions, may impose very high costs not only to the industrialised permit importing countries but also to regions such as the former Soviet Union and, to a lesser extent, China. On the contrary the Soft Landing scheme may be more acceptable for the developed regions of the world, while preserving net benefits and thus sufficient incentive for participation of the least developed regions.
- On top of these common statements, the main insights provided by the POLES model are related to the impacts of the abatement scenarios on the world energy system and list as follows:
  - All scenarios imply a significant restructuring both in the world primary energy supply and in the global demand for energy. In 2030, the latter is 7 to 10 % lower in the different abatement cases than in the reference. But the fuel mix in energy supply is of course also profoundly modified, with reductions in coal consumption of 27 to 37 % in 2030 and increases in nuclear and new renewable energy of respectively 19 to 32 % and 30 to 49 %, according to the case considered.
  - Not surprisingly indeed, the impacts on world demand and primary fuel mix are less pronounced in the multi-gas than in the CO_2-only cases. This phenomenon may be viewed as an adverse consequence of the multi-gas approach, but it is easily understandable as being the counterpart of introducing more margins of freedom in the abatement effort, with the corresponding gains in terms of total cost of the programme to be implemented.
- The results of the GEM-E3 model also provide rich insights in terms of understanding of the impacts of abatement policies on the activity of the different sectors and welfare of the world regions, with consequences for policy design:
  - The cost of achieving the abatement cases ranges between 0.65 and 0.85 percent of world GDP in 2030. The introduction of the multi-gas approach is particularly beneficial to the adjustment process of the most developed economies that have to face the bulk of the abatement costs.
  - However, the energy exporting regions, such as the Middle-East and to a lesser extent Former Soviet Union, may be severely affected in terms of welfare loss, principally due to the relative decrease in the price of their main exports. This might legitimate the fact that more attention has to be paid to the definition of the emission endowments for those particular regions.
  - Finally it appears from the endowment schemes comparison that the more egalitarian Per Capita Convergence rule clearly favours, as mentioned above, the developing world but that it also involves significantly stronger initial shocks and thus higher adjustment costs for the world economy as a whole. This demonstrates the nature of one of the key trade-offs that have to be carefully considered in the design of international climate policies.