Economic Modelling of Climate Change

OECD Workshop Report

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The ideas expressed in this volume are those of the authors and not necessarily those of the OECD or its Member countries.

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT
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Preface

In April 1998, the OECD Council at Ministerial Level (Ministers of Finance, Economy, Foreign Affairs and Trade), following a strong endorsement from a Meeting of OECD Environment Ministers, agreed “that the achievement of sustainable development is a key priority for OECD countries...” and called for elaboration of the Organisation’s strategy “over the next three years in the areas of climate change, technological development, sustainability indicators and the environmental impact of subsidies...”. Further, “Ministers asked the OECD to enhance its dialogue with non-member countries in these areas and to engage them more actively, including through shared analyses and development of strategies for implementing sustainable development.”

The OECD Secretariat has embarked upon this task building on previous work in these areas.

The OECD GREEN Model was developed in the early 1990s, and the Organisation engaged in a comparative modelling project with a number of other researchers in this field. The GREEN Model was also used for numerous analyses and discussions of climate change policies in Committees and Working Parties of the Organisation. A summary of this work is given in OECD (1995) *Global Warming: Economic Dimensions and Policy Responses.*

In view of the above mentioned Ministerial Mandate, and given the Kyoto Protocol, it was decided to undertake renewed efforts in the modelling area as an important aid and input to analyses of climate policies. Given the scarcity of resources at the OECD, and the large amount of work going on in other institutions, the OECD—in close co-operation with its affiliates, the International Energy Agency (IEA) and the OECD Development Centre—decided to hold a workshop in Paris in September this year to get an overview of the “state of play”, and to discuss informally on the technical level how OECD best could pursue its future modelling work.

This Workshop Report presents the papers given at the Meeting without any editing on our part. It is made available for information at COP4 under the responsibility of the Secretary-General.

The OECD, in close co-operation with the IEA and the OECD Development Centre, intends to host a follow up meeting in 1999.

Paris, October 1998

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Summary

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Introduction

Climate change is one of the most complex challenges ever faced by policy makers. First of all, its complexity extends over a broad range of areas—climate, atmospheric chemistry, oceanography, agriculture, forestry, soils, economics, energy, land use, etc. All of these areas are intimately linked, though policy analysts have only begun to formally relate the different parts to one another. Even as individual components of a large puzzle, research in each area is pushing the limits of current knowledge. It is due to the intricacy of the issues and the structures underlying climate change that policy analysts have been developing models of varying complexity to understand the mechanisms behind climate change and policies to mitigate its impacts.

Analysis of the economic implications of climate change mitigation policies has been ongoing for well over a decade. There are an increasing number of research groups working in this area—based in academia, private and public research institutes, government agencies, and international institutions. Various research groups have focused on different aspects. For example:

- a regional or country focus as opposed to a global approach,
- partial analysis, focusing specifically on energy and energy based activities, as opposed to an economy-wide approach
- atmospheric, climate, and science related aspects, as opposed to economic.

The different approaches have tradeoffs, and there is no single approach which can answer all questions. To a large extent, the "competition" among different research groups has been beneficial in understanding the economic impacts of greenhouse gas mitigation strategies. Comparison of model results has enabled a significant convergence in the understanding of the key factors determining the results. Quantitative analysis is nonetheless still yielding wide differences in results, partially explained by differences in underlying model assumptions, but also due in part to differences in approaches.

The signing of the Kyoto Protocol in December, 1997, is perhaps an historic step in reversing the inexorable increase in the emission of greenhouse gases (GHG). The primary achievement of the Protocol is the commitment by the Annex I group of countries to reduce their emission of GHGs some 5 percent below their 1990 level of emissions in the period 2008-2012. Depending on assumptions concerning future trends, this could mean a reduction of anywhere from 20 to 30 percent in GHG emissions by 2012 in the absence of policies to limit emissions. The Kyoto Protocol has additional features which provide a rich menu of options (increasing perhaps the complexity of quantitative analyses). Among the multi-faceted features of the Protocol are:

[1] This summary, as well as other contributions from OECD researchers contained in this volume, does not necessarily reflect the views of the OECD nor any of its Member Countries' governments. It has been prepared based on contributions submitted from experts from within the OECD as well as externally. Any conclusions from the different contributions are to be attributed to the authors. I would like to acknowledge useful suggestions and comments from Fatih Birol, Nils Axel Braathen, Jean-Marc Burniaux, Jan Corfee-Morlot, Marco Mira d'Ercole, and Paul O'Brien. Remaining omissions, misrepresentations, and/or errors are, as usual, my entire responsibility.

- Other greenhouse gases are specifically included in the agreement. They include methane, nitrous oxide, HFCs, PFCs, and SF_6.

- Allowance for emission credits through carbon sink enhancement.

- Ability of regional groups to cooperate to achieve targets through the concept of bubbles.

- Explicit introduction of mechanisms to achieve cost-efficient GHG reductions among the different Annex I countries, namely joint implementation (JI), and international trading of emission permits.

- Introduction of a mechanism for cooperation with non-Annex I countries, namely the clean development mechanism (CDM).

While some of these options have been the focus of past quantitative analyses, particularly regional bubbles and international emission trading, other features have received relatively little or no treatment. Most research groups are taking a two-pronged approach in their analysis of the Kyoto Protocol. The first and short term approach is to use existing tools to undertake a quick, yet incomplete analysis of the implications of the Protocol. In a second phase, existing tools will be modified to take on board the various new facets of the Protocol, and provide a better picture of its implications. Eventually, analysis of these new features can play a crucial role in the forthcoming negotiations on the precise implementation of the Protocol.

The OECD plays a notable role in the climate change debate. Different parts of the OECD (and its affiliates—the IEA and NEA) have studied various aspects related to climate change—for example, greenhouse gas inventories, new technologies, implementation mechanisms, and economic assessment. The latter was mostly undertaken in the OECD Economics Department and relied largely on the development and use of the GREEN model. The signing of the Kyoto Protocol has been a catalyst to renew the study of the economic impacts of policies to deal with GHG reductions. As part of the first phase of this new program, a workshop composed of modeling teams located in various OECD Member countries was organized to share recent results.[2] It was held at OECD headquarters in Paris on 17-18 September, 1998. The purpose of the workshop was three-fold:

- Review the state of the art of the economic modeling of climate change, including top-down versus bottom-up approaches[3], and integrated assessment models (IAM).

- Compare current analyses of the Kyoto Protocol, focusing, whenever available, on some of the specific features of the Protocol, for example, non-CO_2 GHGs, and the new mechanisms.

- Discuss longer term climate change issues, so-called "beyond Kyoto", for example the future role of non-Annex I countries, and the compatibility of the Kyoto Protocol with long-term stabilization of atmospheric GHG concentration.

2 The agenda is provided in the annex to this summary.

3 Top-down models are broadly based on economic theory. They have varying levels of detail, but typically represent economies with sufficient structural detail to capture the main interactions between energy markets and the remainder of the economy. Bottom-up models are broadly based on energy-based technology models. They model the energy side of an economy with significant detail. At their origin, they had limited inclusion of other sectors of the economy. More recent bottom-up models are more inclusive of the rest of the economy (so-called E3 models—energy, economy, and environment).

This volume of papers contains the contributions from the various modeling teams presented at the workshop.[4] The rest of this introduction will provide an overview and summary of the main messages and results to emerge from the workshop.

The rest of the introduction contains a summary of workshop discussions and is structured as follows:

- What do existing models say about the impacts of the Kyoto Protocol?
- How do the results change with the new mechanisms?
- What role could the non-Annex I countries play?
- How does the Kyoto Protocol measure in terms of the longer term goal of stabilizing atmospheric greenhouse gas concentrations?

Issues related to models and modeling approaches will be interspersed throughout the remaining discussion.

Baseline Scenarios

Critical to the results of any policy analysis is the definition of the underlying reference (or baseline) scenario, referred to here as the BaU scenario. Among the key factors and assumptions underlying the BaU scenario are:

- Population and productivity growth rates.
- (Autonomous) improvements in energy efficiency.
- Developments in the relative price of fossil fuels. Some of the underlying factors are supply-side issues, for example oil and gas reserves, development of gas distribution networks, the relative abundance of coal. Energy policies also play a role, particularly tax and subsidy policies.
- Technological developments, such as the spread of combined cycle gas turbines.
- The supply of non-fossil fuel based electricity generation (nuclear and hydro).
- The availability of competitively priced new sources of energy, so-called backstop fuels, for example solar, wind, biomass, etc.

Model comparisons have proven to be a rich source of improved comprehension in the climate change area. However, it is a time-consuming exercise, and one which was not attempted for the OECD workshop. Ideally, modeling teams coordinate the basic assumptions in the BaU scenario. Some assumptions are typically easier to coordinate than others. Population and productivity growth rates are relatively easy to harmonize, though there can be problems with models which have a different regional aggregation, or a different time frame. Different base years and base data sets can also play a role. Some of the other assumptions are more difficult to harmonize simply because models have different specifications.

[4] Note that not all workshop presentations are included in this volume. The volume also contains several contributions which were not presented during the workshop, either due to limited time or because the speaker was unable to attend.

The costs of achieving emissions reductions rely to a large extent on the baseline scenario. Factors leading to higher cost estimates include:

- High population and GDP growth rates.
- A relatively clean fuel mix (for example natural gas, renewables, and/or nuclear as opposed to coal and oil).
- Relatively high energy costs.

Among the OECD countries, the typical ranking of the direct cost of reducing emissions has Japan at the top, followed by Europe, and then the United States. Recent population and economic growth rates would tend to increase the cost to the United States compared to Japan and Europe, but the two other factors tend to reduce the relative cost of emission reductions in the United States. Not all of the models in the workshop had this ranking, though there was insufficient time allotted for delving into the particular reasons for differences. Even if baselines are fairly well coordinated, there could be other reasons for changes in rankings. Model specification, and perhaps even more importantly, differences in model parameters also play a significant role in determining the results. Among the model parameters, two are of particular importance. The first is the ability to substitute labor and capital for energy. And the second is the inter-fuel substitution elasticity. The lower these substitution possibilities, the higher will be the marginal cost of abatement.

Costs of Implementation

This section will focus on the main implications of achieving the Kyoto targets. The primary indicator will be the marginal cost of abatement expressed in terms of dollars per ton of carbon. This indicator is the easiest to compare across model results, though it does not immediately translate into a relative measure of the welfare cost. In other words, the ranking of the cost of abatement across countries is not necessarily the same as the ranking of the welfare cost. However, comparing welfare costs across models proves to be more difficult. First, not all models can produce measures of changes in welfare. For example many of the detailed energy models exclude interactions with large parts of the economy and are therefore not able to provide a complete view of the welfare impacts. Second, different modeling teams produce different measures of welfare. Some provide the net present value of the discounted changes in welfare. Others simply provide the change in welfare for a single year, for example 2010. Measures of welfare also can differ significantly. Typical measures include GDP, GNP, aggregate consumption, and/or compensated welfare measures (such as Hicksian equivalent variation). The first three are subject to accounting and indexing problems. Compensated welfare measures can be complicated in the presence of multiple households. Other complications can arise from these welfare measures. For example, the presence of unemployment raises interpretation issues, and model closure also has different implications—e.g. carbon tax revenue recycling. Finally, some models include abatement and/or ancillary benefits. Thus they integrate the benefits from reducing greenhouse gas emissions and are not simply measures of the economic cost of emission reductions.

Independent Abatement

Table 1 summarizes the main impacts from the various model results presented at the workshop on the price of the carbon tax, i.e. the tax per ton of carbon emitted calculated to be necessary to achieve the Kyoto target. Note that the taxes reported by the different modeling teams have different base years. In the table, they are all specified in a common unit of $1995, using a (somewhat arbitrary) annual inflation rate of 2.7 percent. As one can see from the table, the results vary substantially from one model to another. As mentioned earlier, to some extent these differences can be explained by differences in the baseline scenarios. Indications of the stringency of target reductions are provided in the notes. The differences in the target reductions are not substantial (except perhaps for the AIM model). In part, this is because there are few differences in population and growth projections for the OECD countries, and the income elasticity of demand for energy is relatively similar across models. A more significant difference could originate from changes in relative fuel prices and fuel specific technologies (for example combined gas cycle). However, there is insufficient information in the contributions to compare in detail the baseline scenarios.

The ordering of the marginal cost of abatement across the three regions—US, Europe, and Japan—is relatively uniform. The GTEM model has a somewhat higher cost for Europe than for Japan (though their European region actually is a greater aggregate than simply Europe). The GREEN model also exhibits a reversal between European and Japanese marginal costs. This is mainly explained by the penetration of a relatively "cheap" electric backstop in Japan in the year 2010. This effect is most likely exaggerated.

Only two of the models are predominantly bottom-up models—MERGE and POLES. They provide vastly different marginal costs for the United States, respectively $274 and $82. The remaining models are all top-down models, and the variance in the results is similarly large, ranging from a low of $38 to $375 for the US, $78 to $773 for Europe, and $77 to $751 for Japan. Aside from the results of the GTEM model, the European abatement cost is relatively uniform. Japan has a bi-modal distribution. The US exhibits no explicit pattern across models.

In addition to the model results presented in Table 1, Fatih Birol of the IEA presented the main findings from the most recent World Energy Outlook-1998. Using an econometrically estimated macroeconomic energy model the key trends through the year 2020 are projected to be:

1. world economic growth is assumed to be 3.1 percent per annum,
2. world energy demand grows by 65 percent above the 1995 level,
3. world CO_2 emissions grow by 70 percent between 1995 and 2020.

Using the model to assess carbon abatement policies, the results suggest that to achieve the Kyoto Protocol targets would require a carbon tax of around $250 per tonne of carbon (in 1990 prices) for all OECD regions (Europe, Pacific, North America).[5] Compared with some other model results, this value appears to be rather high, mainly due to the short period over which reductions in emissions have to be achieved.[6] The second reason is that the model makes no allowance for flexible measures that would allow the adoption of lower cost CO_2 reductions in the developing and transition economies.

Table 2 summarizes some of the key welfare results. As mentioned above, these are harder to compare across models. The costs, be they direct, or in terms of income, tend to be less than 1 percent of baseline GDP.

[5] Note that the tax is uniform across the three OECD regions, i.e. it explicitly assumes a coordinated policy among OECD countries. It is different from Annex I trading since it excludes the FSU.

[6] Note that some of the other presenters also discussed the role of capital turn-over and the short period to achieve the Kyoto targets.

Table 1: **Cost of Independent Implementation in 2010**

($1995 *per ton of carbon*)[1]

Model	*Paper*	*US*	*Europe*	*Japan*
SGM[2]	Sands et al.	163		
MERGE[3]	Richels and Manne	274		
G-Cubed[4]	McKibben et al.	63	167	252
POLES[5]	Capros	82	130-140	240
GTEM[6]	Tulpulé et al.	375	773	751
WorldScan[7]	Bollen et al.	38	78	87
GREEN[8]	van der Mensbrugghe	149	196	77
AIM[9]	Kainuma et al.	166	214	253

Notes:

1. Results reported in dollar values in another year are inflated at a rate of 2.7% per annum.
2. SGM data is in $1992. The SGM model does not simulate Kyoto, but produces a range from -10% 1990 emissions to +10% of 1990 emissions. At the -10% range, the cost is $173 ($1992). Stabilization would imply a rate of $108, and the +10% level implies a cost of $60. There are no reported values for other regions. Compared to the baseline 2010 emissions, a 7% reduction target implies about a 26% reduction in 2010 emissions.
3. MERGE data is in $1990. MERGE does not report results for other regions. The net reduction in the US is some 500 MMTC, where they assume some 50 MMTC is covered by sinks. This implies approximately a 29% reduction in gross 2010 emissions, and a 27% reduction in net emissions.
4. G-Cubed data is in $1995. The Europe region also includes some other OECD regions, for example Canada. 2010 carbon emissions decline by 29% in the US and Japan, and by 25% in the Other OECD region.
5. The POLES model results are interpolations based on Figure 2 of the paper, $1990. The implied reduction from baseline emissions are respectively 22.5%, 22%, and 26% for USA, EU, and Japan. The PRIMES model of EU-8 suggests that the marginal abatement cost would be some 50ECU'90 ($72US95) per ton of carbon for an 8% target. The GEM-E3 model suggests a marginal cost of 150ECU'90 ($218).
6. GTEM results are reported in $1995. 2010 reductions from baseline are respectively 28, 25, and 22 for the US, EU, and Japan.
7. WorldScan results are reported in $1992. 2010 reductions from baseline are respectively 24, 25, and 20 percent for the US, EU, and Japan.
8. GREEN results are reported in $1985. 2010 reductions from baseline are respectively 29, 27, and 24 percent for the US, EU, and Japan. Note that the carbon tax for Japan declines precipitously in 2010 (compared to its level in 2005) due to the introduction of competitive backstops. The "clean" electric backstop option gains a significant market share. This penetration is certainly exaggerated given the existing capital stock.
9. AIM results are reported in $1992. 2010 emission reductions from baseline are respectively 25, 18, and 22 percent for US, EU, and Japan.

Table 2: **Welfare Impacts**

Model	Impact	"Welfare" Measure
SGM	The -10% scenario with an independent strategy would cost about 0.4% of US GDP in 2010.	Measured in terms of direct costs as percentage of GDP.
MERGE	The independent strategy scenario would lead to a 1% loss in US GDP in 2010. This drops to 0.25% with full trading.	Measured as percent change in GDP in a given year.
G-Cubed	Under the independent strategy, GDP losses in 2010 are 1.6% in Japan and 1.5% in Other OECD, whereas the US gains by 0.1%. However, all regions lose in GNP terms, respectively 0.3%, 0.8% and 1.4% for the US, Japan, and Other OECD. In all regions, the losses decline significantly with trading.	Measured as percent change in either GDP or GNP in a given year.
POLES	The cost relative to GDP would vary from 0.2% to 0.3% assuming independent strategies.	Measured as total cost relative to GDP.
GEM-E3	GDP loss varies from 0.34% to 0.7% depending on the recycling closure.	Measured as a "total welfare" index including benefits from an enhanced environment.
GTEM	Under independent abatement, GDP losses are respectively 2.0%, 0.9%, and 0.7% for the US, EU and Japan. These fairly closely match GNP and consumption losses, except for Japan where the consumption loss is about one-half. Aggregate loss drops from 1.2% to 0.3% with full Annex I trading.	Measured as percent changes in GDP, GNP, and consumption in the year 2010 compared to the baseline.
WorldScan	No welfare results reported.	
GREEN	Under independent abatement, GDP losses are respectively 0.4, 0.8, and 0.9 percent of 2010 GDP for the US, EU, and Japan. Under full Annex I emissions trading, Annex I GDP loss drops from 0.5 to 0.1 percent.	Measured as percent change in 2010 GDP compared to the baseline.
AIM	2010 GDP losses under independent abatement are under -0.5 percent for all regions. Trading provides a relief for all region and a large gain for the FSU+EIT aggregate region.	Reported as percent change in 2010 GDP compared to baseline.

Cost of Implementation with Emissions Trading

One of the specific features of the Kyoto Protocol is the explicit introduction of emissions trading among Annex I countries. The specific implementation of any trading scheme is still being discussed and will eventually require an agreement among the Annex I parties. In terms of the quantitative assessments of emissions trading, all models assume that the trading entities are the individual countries (and/or regions), and that trading is done without friction. Most models assume that the permit market is perfectly competitive, i.e. that neither buyers nor sellers have sufficient weight to influence the price of the permit. Two papers deal specifically with the issue of market power and are discussed below.

An unresolved issue, and one that was only dealt with explicitly in one or two papers, is the so-called "hot air" issue. In many of the BaU scenarios, Russia (or the FSU), is assumed not to return to 1990 emission levels by the year 2010. Its dismal economic growth over the last decade coupled with energy subsidy reductions would in all likelihood lead to a negative growth in emissions over the 20-year span, unless growth were to pick up considerably over the next 10 to 14 years. The difference between its projected BaU 2010 emission level and its 1990 emission level is the potential size of the hot air, perhaps between 0-200 MMTC.

Several papers assessed the impacts of variations from a full Annex I trading system. The first class of variations related to market segmentation, the so-called double bubble option. Under this option, the market would be segmented into two aggregate regions. On the one-hand, the so-called umbrella region, encompassing the US, Canada, Australia, New Zealand, Japan, Russia and the Ukraine. The other region would essentially be comprised of Western and Eastern Europe. Full trading would be allowed within each of the bubbles, but no trading would occur between the two bubbles.

A second class of variations limits the amount of trading. The Kyoto Protocol explicitly states that trading is intended to be supplemental to domestic action. It has been argued therefore that permit trading needs to be restricted. No specific limits have been proffered yet, so the results from these simulations should be seen as an indication of the consequences of limiting trade.

Both of these variations should inevitably lead to an aggregate net cost relative to full unrestricted trading across Annex I countries. Departure from the uniform marginal cost rule implies efficiency losses. However, individual regions could stand to gain from these restricted trading regimes. For example, under the double bubble concept, the US could potentially gain if the removal of Europe from the permit market with Russia leads to lower aggregate permit demand, and hence a lower permit price.

Finally, some of the papers reflect the impacts of extending trading to non-Annex I countries. In all of these simulations, it is assumed that non-Annex I countries are given emission quotas equivalent to their BaU emission levels.[7] Extending trading to non-Annex I countries is likely to lead to significant cost reductions since it is assumed that the marginal cost of abatement is lower in non-Annex I countries.

Table 3: **Cost of Abatement with Emissions Trading in 2010**

($1995 *per ton of carbon*)

		Full Annex I Trading	*Full Global Trading*
SGM[1]	w/o hot air	105	21
SGM[1]	w/ hot air	76	27
MERGE[2]		114	80
G-Cubed[3]		37	13
POLES[4]		112	33
GTEM[5]		123	
WorldScan[6]		20	
GREEN		67	25
AIM[7]		65	43

Notes:

1. SGM results are interpolations.
2. The MERGE results with Annex I trading also incorporates partial CDM, where the CDM potential is assumed to be 15% of the maximum CDM potential (as measured by the results from full global trading).
3. G-Cubed also undertakes a double bubble scenario. In this scenario, the permit price drops to $18 for the umbrella group (US+Japan+FSU+), while it jumps to $167 for the Other OECD region.
4. POLES results are for an across the board 15% reduction. The results reported in this table assume that the cost of Kyoto is 2/3 of the 15% reduction (roughly based on interpolations from Figure 2). The cost of the 15% reduction with Annex I trading is $170, whereas the cost of full trading is $50.
5. GTEM Annex I emission trading has $114 for full trading, and $108 for the double bubble. In the case of the latter, the price in Europe is $176. (All values in $1992).
6. Under a double bubble, the price for the umbrella group falls slightly with respect to full Annex I trading, and the price for the EU (and Eastern Europe) rises to about $40.
7. Under the double bubble option, the price for the umbrella group is $48 and for the EU close to $200.

[7] From the point of view of actual implementation, this would lead to significant negotiations in order to agree on the appropriate level for BaU emissions.

Annex I trading with no restrictions

Model results confirm theoretical predictions, permit trading, through its mechanism of equalizing the marginal cost of abatement across countries, leads to significant declines in the overall cost of abatement among the OECD countries. The range of the permit price is $20 to $123, a narrower range than observed in the table with independent implementation of the Kyoto targets. There is also a significant narrowing between the two bottom-up models—MERGE and POLES. Generally speaking the top-down models come up with lower permit prices, but there is also significant variation among the results from these models.

Most of the model results suggest that the net supplier of permits will be Russia (or the FSU). This region has the lowest marginal cost of abatement and thus will be the main seller of emission permits. In most models, virtually every OECD country is a net permit buyer in 2010. The size of the market varies from model to model. A sample of the results concerning the market for tradable permits is presented in Table 4.[8] In general, most model results indicate that the EU and Japan would tend to meet a higher percentage of their obligations from trading than the US, due to the fact that their marginal cost of abatement tends to be higher.

Table 4: **Emissions Trading in 2010**

(*million metric tons of carbon, MMTC*)

	Annex-I Trading Only				**Global Trading**			
Model	*US*	*Europe*	*Japan*	*FSU*	*US*	*Europe*	*Japan*	*FSU*
SGM[1]	209				316			
MERGE[2]	46%				63%			
G-Cubed[3]	206	300	80	-578	415	362	92	-490
GTEM[4]	62%	75%	75%					
WorldScan	45%	78%	60%					
GREEN[5]	152	143	50	-410	264	200	70	-265

Notes:

1. SGM results concern a stabilization at 1990 levels of emissions, not a 7 percent reduction, which would most likely entail a greater volume of trading. The target is 1350 MMTC and the 2010 BaU level is somewhat over 1700 MMTC. The numbers represent some 66% and 84% respectively of the target reduction.
2. MERGE results are given as percentage of the target reduction. The MERGE results with Annex I trading also incorporates partial CDM, where the CDM potential is assumed to be 15% of the maximum CDM potential (as measured by the results from full global trading).
3. G-Cubed includes significant hot air, therefore total Annex I emissions under the trading regime are greater than emissions with independent abatement. The US, Europe, and Japan purchase respectively 39%, 76% and 81% of their obligation under the Annex I trading regime. Under global trading, between 80% and 95% of OECD obligations are met through purchases.
4. GTEM does not report any absolute numbers, hence the results are presented as percent of obligation. GTEM also has some hot air since FSU’s 2010 emissions would be some 1.6% below 1990 emission levels.
5. GREEN has no hot air. Under the Annex I trading regime, trading represents respectively 30%, 50%, and 50% of the obligation of the US, EU, and Japan. Under the global trading regime, trading represents respectively 50%, 68%, and 67% of the obligation of the US, EU, and Japan. The non-Annex I countries sell about 400 MMTC, with China representing some 57% of the total.

Though all of the models predict a significant reduction in the cost of greenhouse gas abatement, the results presented in Table 4 could be conceived as “best case” scenarios. They assume that the emission market is perfectly competitive and that the cost of administering the market is small (compared to the market size). There are also significant implementation issues, such as defining the trading entities. A key issue to have emerged out of some of the papers is the importance of the hot air issue. The existence of hot air, which cannot (and may never) be verified, affects the overall cost and efficiency of greenhouse gas reduction. In the presence of hot air, aggregate Annex I emissions

[8] Modelling teams were not asked to provide detailed tables, hence many only provide summary indicators of the tradable permit market.

could be higher under a tradable permit scheme than if countries undertake independent action to constrain emissions.

Annex I trading under a double bubble regime

The papers by Bollen et al (WorldScan), Tulpulé et al (GTEM), McKibbin et al (G-Cubed), and Kainuma et al (AIM) all presented results from a "double bubble" scenario. The key result is that the cost of achieving the Kyoto targets by the EU would likely remain very high. Under this concept, the EU would limit its cooperation to partner countries in Eastern Europe, thereby foregoing the significant benefit of trading with the Annex I countries from the former Soviet Union. On the other hand, the countries in the "umbrella" group, essentially the OECD countries in North America and the Pacific, could even benefit from the double bubble since the permit price could decline in the absence of Europe from the market. Presumably, these countries could also gain a competitive advantage over Europe since their cost structure would be less impacted.

Annex I trading with restrictions on market size

Only the paper by Bollen et al (WorldScan) assesses the impact of restricting the size of tradable permit market under Annex I trading. They analyze two different scenarios. The first limits trade to 10 percent of the quota in Annex I regions. The second raises the limit to 15 percent. They assume that the market is perfectly competitive and that the price of the permit is determined by the region with the lowest marginal abatement cost. The importing countries import at the internationally determined price, but since they are rationed, they will have to undertake domestic actions at the higher domestic abatement cost. (The rents accruing from the rationed price will be captured by the importing region under this hypothesis.) This results in several consequences. First, since abatement costs are not equalized, there are potential gains to trade which are foregone, leading to higher aggregate costs of achieving the Kyoto targets. The selling countries gain to some extent from lower costs of abatement, compared to the full trade case, but lose from lower trading volumes and a decline in the international permit price (a loss in the terms-of-trade). Under the 10% rule, all of the OECD countries are rationed. Under the 15% rule, the US is no longer rationed, and in fact would gain relative to the full trade scenario due to a lower permit price.

Global emission trading

All models assessing the impacts of global trading assumed that non-Annex I countries would have quotas equivalent to their 2010 BaU level of emissions.[9] Since abatement costs are estimated to be much lower in many of the non-Annex I countries, particularly some of the very large coal-dependent economies (for example, China and India) there are significant gains from the trade in emission rights. The drop in the marginal cost of abatement varies in a range from a low of 30 percent (MERGE) to a high of 80 percent (SGM without hot air), the average reduction being 58 percent.

Given the lower overall cost of abatement, the OECD countries would tend to purchase more emission permits than under the Annex I-only trading regime, thereby effectively reducing domestic action to meet their Kyoto obligation. Russia and the other Annex I countries of the former Soviet Union, and potentially Eastern Europe, could lose in relative terms from extending trading to non-Annex I countries. Though the abatement cost drops for their domestic economies, they would tend to lose both in terms of trading volumes and in terms of the price of the permits.

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9 To re-iterate, this is an easy assumption to make in modelling terms. It may not be a practical assumption in terms of implementation since future BaU emission levels are by definition not observable.

Global emission trading with restrictions

The Manne and Richels paper (MERGE) is the only paper to address the issue of restricting trading under a global trading regime. They assess the consequences of capping Annex I buyers' purchases to one-third of their obligations. They further look at the impact of two different market structures. The first market structure assumes a "buyers'" market. Under this assumption sellers are price takers, and the buyers have sufficient market power to force the international market price at the sellers' marginal cost of abatement. In this case, the rationing rents accrue to the buyers. In the case of a sellers' market, the international price is equal to the marginal cost of abatement in the buyer's country, and the rents accrue to the sellers.

The results (reported only for the US) indicate that the international price of trading will be much lower than the full trade price in the case of a buyers' market. The market is obviously much thinner. There is also a wide gap between the import price, some $30 per ton of carbon, and the domestic abatement cost of $130. The rents per ton are on the order of $100 per ton of carbon. With a sellers' market, the domestic price of abatement increases slightly. The loss in GDP to the US is substantial in both cases compared to a full trading regime. However, the losses in the case of a sellers' market are higher since the rationed rents accrue to the seller, not to the US. As Manne and Richels state, global trading is a necessary condition for reaping the full benefits of "where" flexibility, but by no means a sufficient condition. Further, if the number of sellers is going to be limited, there might be significant potential for extracting monopoly rents.

Emissions trading with imperfect competition

While Manne and Richels discuss some of the potential consequences of imperfect competition, Burniaux's paper deals with the role of imperfect competition directly. The basic context of the paper assumes that Russia and Ukraine (aggregated into the larger FSU region), act as monopolistic suppliers of emission rights, since in 2010, they would be the largest, if not sole supplier of emission permits among the Annex I countries. There are three underlying assumptions. First, Russia and Ukraine would behave as a sole agent, i.e. individual entities from these countries, such as firms, would not be able to sell permits. On the other hand, the purchasing entities would have no market power. The third assumption is that Russia and the Ukraine ignore other potential effects of their monopoly power, notably the potential negative terms of trade consequences. Russia, being highly dependent on oil and gas exports could lose in relative terms from setting a high permit price through its negative impact on international oil and gas prices.[10]

Assuming imperfect competition first of all leads to a higher permit price than under perfect competition. In 2010, the permit price could be some 38 percent higher under imperfect competition. The wedge between the permit price and the marginal abatement cost in the FSU represents the mark-up on permit sales.[11] The higher abatement costs leads to a deterioration in the income gains from trading (compared to the competitive market situation). In aggregate the OECD countries would cut GDP losses by some one-half with competitive trading compared with independent strategies. But this relative gain would be cut by one-third with monopolistic price setting.

10 The model also ignores imperfect competition on the goods market, as well as any strategic consequences of using market power.

11 Note that the mark-up declines over time. Under a "Kyoto-forever" scenario, the US eventually enters the market as a net seller, thereby dampening the market power of the FSU. Also, the introduction of new "carbon-free" technologies, gives buyers a competitive alternative method for reducing carbon emissions.

One of the interesting conclusions to emerge from this paper is that the allocation of permits has a direct consequence on the aggregate cost of abatement. Under perfect competition, the initial quota allocation has virtually no impact on aggregate cost (though it can have a significant impact on the distribution of the costs across individual regions). With imperfect competition, providing a larger share of quotas to the region with the lowest abatement cost (i.e. to the monopoly seller), leads to a larger aggregate cost as it can extract larger monopoly rents.

Other Features of the Kyoto Protocol

While much of the focus analyses of the Kyoto Protocol has been on the targets and emissions trading, the agreement includes a number of other elements which have not only received less attention in the public dissemination of the agreement, but among research teams as well. For instance the Protocol explicitly introduces five other (than CO_2) greenhouse gases—notably methane and nitrous oxide. It also includes a mechanism for achieving credit through carbon sink enhancement. And beyond emissions trading, two other cross-border mechanisms are integrated parts of the agreement—joint implementation (limited to Annex I countries), and the clean development mechanism. (The latter is the only mechanism designed to allow for “trading” between Annex I and non-Annex I countries. The word trading is in quotes because it is not trading in the usual sense of the word. But Annex I countries can obtain carbon from certain types of development projects in non-Annex I countries which lower emissions in those countries. The rules regulating CDM are still to be determined.)

Other greenhouse gases

No model presented at the workshop dealt in a comprehensive fashion with the other greenhouse gases. The other gases pose some data and modeling problems not associated with CO_2. Carbon emissions are to a large extent almost exclusively associated with the burning of fossil fuels.[12] Energy plays a major role in all economies, and has been widely modeled and analyzed. There is also little uncertainty concerning the energy-carbon link. The combustion of a given volume of coal, oil, and gas, leads to a rather uniform volume of carbon emissions, independently of how the combustion occurs. Therefore, knowledge of the energy input is all that is required to determine the emission output. Most of the other GHGs require more knowledge of the processes in which they are involved, and under what conditions. For example methane is a by-product of livestock and rice production, landfills, and mining activities. Furthermore, the quantity of methane produced by any given activity will depend on how it is produced, not simply the level of production. Nonetheless, inventories of the other greenhouse gases is improving, and eventually, important strides will be made to include them in a systematic fashion in economic models of climate change.

The paper by Gielen and Kram does undertake a rather thorough analysis of the other GHGs for the European countries. It describes the processes which underlie the emissions of the other gases, including the range of variations for each type of process. They also include a description of potential abatement options, including substitution possibilities. Finally, they provide some estimates of the costs of emission reductions (in terms of ton of carbon equivalents).

Currently, CO_2 accounts for some 79 percent of total GHG emission in Europe.[13] Methane accounts for 11 percent and N_2O for an additional 8 percent. The three other gases represent less than

[12] However, carbon sinks could play a significant role in limiting atmospheric carbon concentration.
[13] The paper provides a complete breakdown for EU-15.

2 percent.[14] Note that they estimate that the level of uncertainty regarding the non-CO_2 gases is in a range of 1.5-2 (i.e. current estimates could be wrong by 100-200 percent). Using individual EU country submissions concerning future trends, they report that the total emission of GHGs will only increase by 1 percent between 1990 and 2010. While carbon emissions would grow by some 5.5 percent and HFCs by perhaps 70 percent, these will largely be offset by huge declines in the emissions of methane and nitrous oxide.

Using a spreadsheet model, they have estimated that in order to reach the Kyoto target in Europe, non-CO_2 gases will contribute about 27 percent to the total effort, with CO_2 abatement responsible for the remaining 73 percent. Three abatement options are deemed the most important. Substantial emission reductions are possible from either replacing landfills and/or recuperation of methane from landfills. The second concerns cheap abatement possibilities for nitrous oxides in the chemical industry. And the final concerns finding substitutes for HFCs. They are more pessimistic concerning methane and nitrous oxide abatement in agriculture, and transport related nitrous oxide emissions.

Finally, they question whether the results for Europe can be directly translated to other regions because local emission sources, costs, and trends may differ significantly. It is clear from their analysis that the other GHGs could play an important role, if, similar to Europe, low cost abatement options are available.

Carbon Sinks

The issue of carbon sinks was only briefly touched upon at the workshop, though their potential is not negligible. In his overview presentation, Jae Edmonds made several points regarding sinks:

- Carbon emissions from land-use are about 1,600 MMTC per year, compared to 6,000 MMTC from the consumption of fossil fuels.
- Carbon stock numbers provide a sharper contrast. Terrestrial carbon stocks are about 560 PgC with soils containing an additional 1200 PgC. Carbon captured in fossil fuel stocks amounts to over 15,000 PgC. Finally, the atmosphere contains about 750 PgC.
- Kyoto essentially covers only afforestation and reforestation, not soils. In the Kyoto time framework, sinks are mainly an accounting issue since there is insufficient time to make major changes to above ground stocks of carbon.
- In the long term sinks are a biomass energy issue. In a steady-state trees have a neutral impact in terms of carbon emissions. However, they can be used to back out of fossil fuels.
- Soils have significant potential for carbon removal, but may prove difficult to exploit for institutional reasons. In early years, soils have the potential to sequester somewhat over 1,000 MMTC per year, though the long run steady state potential is somewhat less.

Joint implementation and the clean development mechanism

The paper by Bollen et al (WorldScan) was the only paper to model the clean development mechanism explicitly.[15] They implement the CDM in terms of capital retro-fitting, as opposed to capital replacement. The intention is to minimize any impact from carbon-leakage. This they cite as one of the key problems with the CDM in that the host country (i.e. the non-Annex I country), is not

[14] Though according to IPCC documents they are growing rapidly and have a long lasting impact in the atmosphere.

[15] No presented paper analyzed joint implementation specifically. Bollen et al discuss the differences between JI and international emissions trading. The former leads to a trading price which is specific to each project, whereas the latter leads to a uniform trading price.

subject to any carbon emission constraint. By limiting CDM to retro-fitting projects, it maintains essentially the same productive capacity in the host country but reduces its carbon intensity (either by reducing energy inputs or switching to cleaner fuels). Under these assumptions they find that there is indeed little carbon leakage, though there is some. The marginal cost of abatement declines in the Annex I countries as the emissions constraint is relaxed. However, compared to a situation of full Annex I trading, the non-OECD regions in Annex I would tend to be worse off. They become net importers of permits. The other result is that a majority of the projects are expected to occur in China.

Beyond Kyoto

While in his remarks Jeffrey Frankel urged researchers to focus on the short to medium term consequences of the Kyoto Protocol, there is little doubt that the Protocol itself is only an initial step in most likely a sequential series of agreements to deal with climate change. Future agreements will of course depend on the initial steps ("path dependency"), as well as on improved knowledge as research improves our understanding of global warming.

Two key issues are at the heart of the so-called "beyond Kyoto" agenda. The first relates to the eventual role of the non-Annex I countries in the development of a global approach to deal with climate change. The second issue concerns the consistency of the Kyoto Protocol with the long term goal of stabilizing atmospheric emissions. Two subsidiary questions to this latter issue were addressed in the workshop. First, is the Kyoto Protocol consistent with a least cost approach to stabilize GHG atmospheric concentration? Are the terms of the Protocol shrinking the opportunity set for successfully dealing with climate change?

Non-Annex I participation

Two different papers dealt with the participation of non-Annex I countries. The paper by Carraro focuses on some theoretical aspects of endogenous formation of coalitions. Carraro stresses some of the important features of global environmental negotiations, particularly the incentive for free-riders.[16] Carraro concludes that the emergence of a global agreement is unlikely. A more likely outcome is the emergence of a set of regional agreements which incorporate other packages of incentives (for example transfers, or issue linkages). He suggests that there are a number of issues which require more research, for example the potential role of a supra-national authority, and linking global environmental negotiations to other global negotiations, for example trade. Finally, there is a need for more empirical analysis, particularly to assess the importance of asymmetries across countries in terms of their economic size, their natural resource endowments, etc.

The paper by Jacoby et al (EPPA) assesses the consequences of adapting a specific accession and burden-sharing rule for enlarging the group of countries committed to reducing GHG emissions. The rule explicitly incorporates a measure of a country's ability-to-pay, as captured by per capita income levels. The rule also contains parameters which control the rate of reduction of emissions as a function of income levels. To assess the viability of this rule in terms of long term stabilization of atmospheric concentration, the authors assign parameter values and incorporate the rule in a global dynamic general equilibrium model. Their results show first of all that the timing of accession will depend on the assumed income threshold determining when a country starts action. For example, with a threshold of $3,000, China would begin reducing the growth rate of emissions in the year 2030, and with a threshold of $4,500, China would only begin action in 2050. Under the parametrisation they have chosen, either threshold levels could lead to global stabilization of atmospheric concentration by

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16 Since reducing GHG emissions benefits all countries, there are strong incentives to let other countries carry the burden of reducing emissions, without taking part oneself.

the year 2150.[17] In the absence of emission trading, the rule would lead to a long-run convergence in per capita emissions, with OECD emissions dropping significantly, and non-OECD emissions never rising very high. The income threshold level could have some impact on the long term distribution of welfare gains since the rule could have an impact on relative comparative advantage. For example, the OECD countries would be relatively better off with the lower threshold since the burden sharing will occur earlier. Emissions trading would have only negligible effects on atmospheric concentration levels, but would not lead to any convergence in per capita emissions.

Long term stabilization of atmospheric concentration

The Jacoby et al. paper assesses the consistency of their accession rule with long term stabilization of atmospheric concentration. Two other papers also discuss the relevance of long term stabilization. The paper by Manne and Richels questions whether the Kyoto Protocol is consistent with the least-cost path for achieving stabilization (using the same target of 550 ppmv, though with a target year of 2100). Manne and Richels assess the impacts of three different scenarios:

- Kyoto followed by arbitrary emissions. Non-Annex I countries start undertaking actions in 2030, and countries move towards equalizing per capita emissions. Global trading starts in 2020.
- Kyoto followed by "least-cost" scenario. This implies that global trading starts immediately after the first budget period.
- Least cost today. Global trading starts immediately.

Their least cost scenarios essentially allow for more near term emissions, with more reductions occurring in later periods. This allows more time for capital turnover, development of new "clean" technologies, and atmospheric carbon removal via the carbon cycle. It also reflects time discounting of mitigation costs.

They conclude that Kyoto-forever is unlikely to stabilize emissions, much less concentration levels. Emissions from non-Annex I countries are rapidly overtaking Annex I emissions. Of the three alternative scenarios, all lead to stabilization of atmospheric concentrations but have different cost implications. The first, Kyoto followed by arbitrary reductions would cost some 240 percent more than the least-cost strategy. Kyoto followed by least-cost would cost some 40 percent more than introducing least-cost policies immediately.

A second paper, presented by Ferenc Toth (ICLIPS), uses a very different approach to assess the long term impacts of climate change policies. Using an integrated assessment model (IAM), Toth and his colleagues look at the long term impacts of near-term emission targets. They use a so-called Tolerable Windows Approach, which is based on an inverse modeling concept. This approach generates climate protection strategies from perceived unacceptable impacts of climate change as well as from intolerable socio-economic implications of mitigation measures. This results in complete sets of permitted emission paths.

Their study suggests that near-term emission targets do not matter much if the only focus is on the long term climate stabilization objective. However, they do matter if rates of change in different climatic attributes turn out to be a serious concern. For example, less near-term reduction implies greater long-term reduction. While this may be feasible in terms of long-term stabilization, the higher initial concentrations could lead to unacceptable rapid changes in other variables, for example, rapidly rising sea levels. In other words, the targets in their analysis not only include long term goals,

[17] They have chosen stabilization at 550 ppmv, similar to other studies. There is as yet no consensus as to what constitutes a "dangerous interference" concentration level, which the FCCC makes reference to.

but also permissible rates of change of related variables. They also stress the importance of path dependency. Choices already made rule out a certain number of options. For example, their model rules out a temperature change of less than 1.5ºC. The paper also assesses the important role SO_2 has had in slowing the rate of change atmospheric temperature, and that reductions in SO_2 emissions could limit the permissible corridors for CO_2 emissions. They conclude by arguing that more research needs to be devoted to the long-term consequences of climate change. While being wrong on near-term targets may cost in the billions of dollars, being wrong on long-term targets could cost in the trillions.

Climate Change and Economic Modelling: Background Analysis for the Kyoto Protocol

OECD Headquarters
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New Building, Room 6

Agenda

September 17th, Morning (9:30-12:30): Session I — Introduction and Model Overview

Opening remarks

9:30-9:45 Thorvald Moe, Deputy Secretary-General

The Role of Models in Climate Change Policy Making

Speakers:

9:45-10:15 Jeffrey Frankel, Council of Economic Advisers, Washington, DC

10:15-10:45 Jean-Charles Hourcade, CIRED, Paris

Overview of Models

11:15-12:30 Jae Edmonds, Battelle Laboratories, Washington, DC

September 17th, Afternoon (14:00-18:00): Session II — Assessment of the Kyoto Protocol

Speakers:

14:00-14:35 Richard Richels, EPRI, Palo Alto, CA
"The Kyoto Protocol: A Cost Effective Strategy for Meeting Environmental Objectives?"

14:35-15:10 Robert Shackleton, U.S. Environmental Protection Agency, Washington, DC
"The Potential Effects of International Carbon Emissions Permit Trading Under the Kyoto Protocol"

15:10-15:45 Tom Kram, ECN, Netherlands
"The Energy Technology Systems Analysis Programme: History, the ETSAP Kyoto Statement and Post-Kyoto Analysis"

16:15-16:50 Pantelis Capros, National Technical University of Athens, Athens
"Economic and Energy System Implications of European CO_2 Mitigation Strategy: Synthesis of Results from Model Based Analysis"

16:50-17:25 Fatih Birol, International Energy Agency, Paris

17:25-18:00 Vivek Tulpulé, ABARE, Canberra
"An Economic Assessment of the Kyoto Protocol using the Global Trade and Environment Model"

September 18th, Morning (9:30-12:30): Session III — Other Features of the Kyoto Protocol

Speakers:

9:30-10:00 Johannes Bollen, RIVM, Netherlands
"Compliance with the Kyoto Protocol"

10:00-10:30 Bjart Holtsmark, CICERO, Oslo
"From the Kyoto Protocol to the Fossil Fuel Markets: An analysis of costs of implementation and gains from emission trading taking benefits from revenue cycling into account"

11:00-11:30 Dolf Gielen, ECN, Netherlands
"The Role of Non-CO_2 Greenhouse Gases in Meeting Kyoto Targets"

11:30-12:00 Jean-Marc Burniaux, Economics Department, OECD, Paris
"How important is market power in achieving Kyoto?: An assessment based on the GREEN model"

12:00-12:30 Carlo Carraro, Fondazione Eni Enrico Mattei, Venice
"Beyond Kyoto: A Game-Theoretic Perspective"

September 18th, Afternoon (14:00-17:30): Session IV — Beyond Kyoto

Speakers:

14:00-14:40 Ferenc Toth, Potsdam Institute for Climate Impact Research, Potsdam
"Kyoto and the Long-Term Climate Stabilization"

14:40-15:20 Henry Jacoby, MIT, Cambridge, MA
"Toward a Useful Architecture for Climate Change Negotiations"

15:20-15:50 Leo Schrattenholzer, IIASA, Laxenburg
"The IIASA-WEC Scenarios and the Kyoto Protocol"

Concluding remarks

Abbreviations

AA	Assigned amounts (of emission reductions).
ABARE	Australian Bureau of Agricultural and Resource Economics. Web site www.abare.gov.au
ACT	Achieving Commitments by Trading Model, developed by CICERO.
AEEI	Autonomous energy efficiency improvement. The AEEI is a model parameter for expressing the exogenous annual growth in energy efficiency.
AGBM	Ad Hoc Group on the Berlin Mandate. Group established to assist and prepare COP meetings.
AIM	Asian-Pacific Integrated Model, developed by NIES.
Annex I	Group of countries specified in the annex to the FCCC. Essentially composed of industrialized countries, plus most of Eastern Europe and the countries of the former Soviet Union.
BaU	Business-as-Usual, refers to the reference (or baseline) scenario in the absence of policies to reduce carbon emissions.
Billion	Equivalent to one-thousand million (or 10^9).
CDM	Clean Development Mechanism. One of the mechanisms in the Kyoto Protocol allowing Annex I countries to get credit for reducing emissions in non-Annex I countries through “clean development” projects.
CER	Certified emission reductions.
CFC	Chlorofluorocarbon. An ozone depleting gas, as well as a greenhouse gas.
CGE	Computable General Equilibrium models, also known as applied general equilibrium (AGE) models, or more simply GE.
CICERO	Center for International Climate and Environmental Research in Oslo.
CH_4	Methane, one of the six greenhouse gases included in the Kyoto Protocol.
CHP	Combined Heat and Power.
CO_2	Carbon dioxide. CO_2 is one of the key greenhouse gases. Energy combustion is the major source of CO_2 emissions.
COP	Conference of the Parties. Periodic international meeting of the parties signatories of the Framework Convention on Climate Change. COP-3, held in Kyoto in 1997, was the venue for the signing of the so-called Kyoto Protocol.
E3	System analysis incorporating energy/economy/environment issues.
EIS	Energy intensive sectors, typically pulp and paper, iron and steel, non-ferrous metals, and chemicals.
EPPA	Emissions Prediction and Policy Analysis model, developed at MIT.
EPRI	Electric Power Research Institute.
ERU	Emission reduction units.
ETSAP	Energy Technology Systems Analysis Programme. Web site http://www.ecn.nl/unit_bs/etsap
Exajoule	A measurement of energy equal to 10^{18} joules. One exajoule is equivalent to 23.88 million tons of oil equivalent (MTOE), or 174 million barrels of oil (mb).
FCCC	(United Nations) Framework Convention on Climate Change. Web site http://www.unfccc.de
FSU	Countries of the former Soviet Union, i.e. the three Baltic republics and the CIS countries.
G-Cubed	Global General Equilibrium Growth Model.
GAMS	General Algebraic Modeling System. Software used to solve mathematical programming models (linear, non-linear, integer, etc.). Web site http://www.gams.com
GEM-E3	General equilibrium model for the European Union.
GHG	Greenhouse gas.

GREEN	The OECD GeneRal Equilibrium ENvironmental model for assessing the economic impacts of limiting carbon emissions.
GTEM	Global Trade and Environment Model, developed by ABARE.
HFC	Hydrofluorocarbon, essentially a substitute for CFCs.
IAT	Interagency Analytical Team, U.S. government sponsored network of climate change research groups.
IAM	Integrated assessment models.
ICLIPS	Integrated Assessment of Climate Protection Strategies, developed at PIK.
IEA	International Energy Agency, based in Paris. Web site http://www.iea.org
IET	International emission trading.
IPP	Independent Power Producers.
IPCC	Intergovernmental Panel on Climate Change. Group jointly set up by World Meteorological Organization (http://www.wmo.ch) and the United Nations Environment Programme (http://www.unep.no) to assess the available scientific, technical, and socio-economic information in the field of climate change. Web site http://www.ipcc.ch
JI	Joint implementation.
KATREN	Kyoto Advanced Technologies and Renewables scenario, developed for the PRIMES model.
Kwh	Kilo-watt hour is a measure of electricity consumption.
MARKAL	A class of models for representing technical energy systems.
MERGE	Model for Evaluating the Regional and Global Effects of greenhouse gas reduction policies. Model developed by Stanford/EPRI. Web site http://www-leland.stanford.edu/group/MERGE
MMTC	Millions of metric tons of carbon.
MUSS	MARKAL Users Support System. User-friendly model shell for supporting MARKAL users.
N_2O	Nitrous oxide, one of the six greenhouse gases in the Kyoto Protocol.
NIES	National Institute for Environmental Studies in Japan.
OECD	Organisation for Economic Co-operation and Development. Web site http://www.oecd.org
OPEC	Organization of Petroleum Exporting Countries
PAM	Policies and Measures package.
PFC	Perfluorocarbon, a by-product of aluminum production, as well as a CFC substitute.
PgC	Petagrams of carbon, equivalent to 1000 MMTC.
PIK	Potsdam Institute for Climate Impact Research.
POLES	Prospective Outlook on Long-term Energy Systems model, developed at the Institut d'Économie et de Politique de l'Énergie (IEPE) in Grenoble, France. Web site http://www.upmf-grenoble.fr/iepe/
PRIMES	An energy model for Europe.
QELRO	Quantified Emission Limitation and Reduction Objective. Country proposals for greenhouse gas targets.
ROW	Rest of the World.
SBSTA	Subsidiary Body For Scientific And Technological Advice. Group established to assist and prepare COP meetings.
SF_6	Sulphurhexafluoride, a gas used as an insulator in electrical equipment, and a by-product of magnesium casting.
SGM	Second Generation Model. CGE model developed at Battelle Laboratories.
TWA	Tolerable Windows Approach.