Economic and energy system implications of European CO_2 mitigation strategy: Synthesis of results from model based analysis

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Abstract: Since the decision of the Council of Ministers of the EU member states (3.3.1997) specifying a decrease of green house gas emissions by 15% in 2010 compared to the 1990, there has been a wide-spread study of the appropriate policy instruments and the costs associated with this goal. The task of meeting the emission reduction targets should not be underestimated. Reducing CO_2 emissions for the EU as a whole over the next 15 years would amount to no less than breaking the historical link between economic growth and energy use. Especially in the short term the problem of stranded costs is important. The paper attempts a synthesis of results coming from several new generation models developed recently and examines the economic and energy system implications of both short-term policies and measures for emission reduction as well as long-term technology options.

Keywords: climate technology strategy, competitive energy markets, pollution permits, general equilibrium, partial equilibrium, GEM-E3, PRIMES, POLES.

1. Introduction

The paper attempts a synthesis of results coming from a number of new generation models that where developed under the auspices of DG XII of the European Commission. The views however expressed in this paper do not engage the European Commission. The models are the result of collaborative research projects involving a large number of participants, mentioned in the acknowledgements. The analysis presented in this paper was mainly derived from work done within the JOULE-III project “Climate Technology Strategy within Competitive Energy Markets” (see Capros et. al., 1997).

All the models addressed, from different perspectives, the issue of defining and evaluating a policy mix that would simultaneously:

- Lead to a reduction of CO_2 emissions for the EU.
- Meet sustainability targets for the economy.
- Consider technological development and the long-term prospects of the energy system.
- Ensure consistency with global economic and energy system trends.

The sets of policy measures discussed are those for which the costs of curbing emissions are compensated (partly or fully) by external (environmental) benefits. Additionally, policy instruments were designed to operate towards meeting non-environmental goals, such as for example RTD prioritisation, employment or economic cohesion of countries. The analysis was detailed enough to lead to concrete policy recommendations, that contributed to the preparatory **analysis for the Kyoto negotiations** and for the **5th Framework Programme of the European Commission for Research and Development**.

All projections and assessment activities have been empirical and numerical. All were based on large-scale models for the energy system and the economy. The coverage was detailed for all EU countries, but the international perspective was also satisfied. The model assumptions were uniformly used in all modelling work to ensure compatibility of the results.

Three models where mainly uses.

- The GEM-E3 computable general equilibrium model for the EU-14. The model integrates the energy system with the rest of the economy, including several policy instruments for the environment such as taxes and pollution permits. Benefits from better atmospheric quality are also quantified. The model was used for macro-economic projections and the analysis of combined energy and economic policies for CO2 mitigation. A description of the GEM-E3 model is given in Capros et. al. (1997).
- The **PRIMES** partial equilibrium model for the European energy system. The PRIMES model provides simulation of the energy system, the decisions of the agents and the markets, covering in detail several sectors, uses and technologies. The model was used for the evaluation of the European energy system policies and measures, regarding their potential and costs (see Capros et. al., 1996).
- The **POLES** world energy system model. This ensured the consistency between the projections for Europe carried out with the two previous models and served for them as input for world prices and demand. The POLES model provided international comparisons of CO2 abatement marginal costs and conducted analyses of world-level implications from the development of energy technologies. The authors of the model and the results presented in this analysis are Patrick Criqui (IEPE) and Niko Kouvaritakis (ECOSIM). A description of POLES is given in P. Criqui et. al. (1996).

The model-based analysis dealt with technology and policy options to tackle the problem of rising emissions in the period to 2010. As the model-based energy and economic outlook that was constructed within the project showed, under “business as usual” assumptions CO_2 emissions are likely to grow substantially in the period to 2010. For Europe, emissions were projected to increase by almost 8.8% above their level of 1990, while for the whole world the rise was projected to be considerable: 53.8%.

Yet over the past couple of years there has been a great deal of debate on how to reduce emissions even in the medium term. This debate reached a turning point as approaching the Kyoto Conference of the Parties (December 1997). The European Union, through a decision of the Council on 3.3.1997, agreed to decrease the CO_2 emissions in 2010 by 15% compared to the level of emissions in 1990. The Council agreed also upon a scheme distributing the emission reduction effort among the member-states and envisaged a set of policies and measures in all sectors.

The task of meeting the Kyoto targets should not be underestimated. It is taken for granted, of course, that the reduction in emissions should be designed so as to minimise the effects on economic growth. For most developed economies, while there is a tendency for energy demand to grow with economic growth, there is a very strong tendency for any sizeable economic expansion to be associated with an increase in energy demand of about 1% less than GDP. Furthermore, as the baseline scenario indicates, energy patterns are almost certain to continue to be dominated by CO_2 emitting fossil fuels in the period to 2010, as a result of saturation in the progress towards lower carbon intensity of the energy system. Even if renewable fuel technologies were more competitive than they are currently, it would take much longer than 15 years for their massive introduction. Hence, reducing CO_2 emissions for the EU as a whole over the next 15 years would amount to no less than breaking the historical link between economic growth and energy use. This link has been very strong in most countries throughout the post war period and it has survived even the upward energy price shocks of the 1970s.

However, the main factor that makes the Kyoto targets difficult to reach is related to the fact that 2010 is short-term for the energy system, implying limited scope of contribution by new technologies. New technologies can either break the link between energy and growth, through equipment that is much more energy efficient, or make energy much less carbon intensive, through energy from renewable sources or through much more efficient generation of final energy. However, even if these new technologies were fully available at present, there is simply not enough time to replace the bulk of energy using capital stock and equipment by 2010 without causing substantial economic damage as a result of stranded costs. A number of analyses have been carried out on this subject. See for example Grubb, M., Edmonds J. (1993) and Wigley, T. M. L., Richels, R., Edmonds, J.A. (1996)

The difficulties mentioned above are not insurmountable in the longer run. Even by 2010, the analysis showed that there is a great deal that could be done to limit emissions and, perhaps, meet the Kyoto targets. However, there is associated a net economic cost at the macroeconomic level. Moreover, using carefully designed accompanying policies, it may even be possible that environmental protection is compatible with economic objectives such as employment or competitiveness.

Technology plays a key role in these scenarios. However, most of its contribution will be in the form of integrating faster existing energy efficient technologies or accelerating the introduction of known advanced technologies. As it is shown in the analysis, much of the reduction in emissions by 2010 can only be reached through means that improve energy efficiency.

It is very important to examine the likely economic costs of CO2 mitigation. The research showed that, both for the EU and for the rest of the world, there are large differences between the average and marginal costs of meeting any target. Furthermore these differences increase as the emissions target gets more severe. Indeed, one of the key messages of the results is that the more severe the target and the shorter the time horizon over which it must be reached, the greater the likely economic costs.

The CO_2 reduction policy, whether through a tax or through a permit system, is likely to invoke important changes for the whole of the economy of all the EU member states. The impact on sectors, countries and consumer’s is likely to be, at least on a first approximation negative. If however, economic inefficiencies are currently present in the economy, then the environmental policy, properly accompanied by a re-structuring that reduces the inefficiencies may lead to a situation where multiple benefits may be effected. One often cited example of such inefficiency concerns the labour market. It is argued that by using the environmental revenues from a carbon tax to reduce the employer’s social security contribution employment gains may result, giving an example of the so-called “double dividend” hypothesis. These issues were studied in detail within the project. A discussion of different approaches on this subject is given in Carraro, C. and D. Siniscalco (1996), while Bovenberg, L. and L. Goulder (1993) give a theoretical presentation of the double dividend issue.

Another important aspect of the likely costs of policy on emissions is the differential impact on different countries and regions. This impact clearly depends on the level of development of a country, its economic and industrial structure, and on its natural resource endowment and the carbon intensity of its energy system. The results for the EU member states indicate that, even when the degree of the severity of the target is similar, mitigation costs are likely to diverge a great deal between countries. This issue has been also studied in detail with the GEM-E3 model (see for example Conrad, K. and T.F.N. Schmidt, 1996).

The international dimensions of emissions target for 2010 are also important. The environmental threat is perceived with different degrees of concern by governments, decision-makers and the general public in different world regions. Amongst the developed nations, the European Union has taken a leading role in recognising the problem as an important issue to be solved, and in proposing co-ordinated efforts to achieve a cost-efficient solution. As the POLES world energy scenario shows, most of the emissions over the next 15 years are likely to originate from non-OECD regions. Consequently, any uncoordinated action by the EU, or even the OECD, is likely to have a very small impact on long term carbon concentrations. Large, rapidly growing countries, such as China, India and some other in the Asian continent give priority to economic development, often accompanied by massive increase in energy consumption. Joint implementation may provide the opportunity to reduce the CO_2 emissions in developing countries, possibly the most important emitters in the future. The results indicate that there is even more of a difference in the likely costs of emission reductions among world regions than there are among European countries. Thus, there is plenty of scope for an international market approach to the issue, if important practical problems can be resolved, complemented with joint implementation for the shorter term.

The work presented here was concluded before the Kyoto summit. Indeed, the major motivation of the analysis was to assist the debate within the EU by providing quantitative estimates of the impact and cost of a number of policies and measures.

The analysis was extended beyond 2010 and emphasised on the longer run up to 2030. The analysis was technology-oriented aiming at providing strategic analytical information to assist in the formulation of the Community 5th Framework program for research and technological development.

It is clearly over a long time horizon that the impact of technological improvements can really be important for climate change policy. The role of policy regarding technology is also different between the medium and long term. In the medium term, policy measures cannot lead to the development of new technologies but they can encourage the faster introduction and the more intensive utilisation of existing technologies. On the other hand, government and industry objectives through spending on RTD can influence the nature of technological progress in the longer term.

Several technology development pathways for the power generation sector are examined in this research in relation to their energy system implications and the global CO2 emission problem. Important though the power generation sector may be, it still accounts for about 40% of the projected world CO2 emissions by 2030.

The long-term technology development may provide opportunities for economic growth. The accelerated capital turnover that is necessary for the short term to meet the CO2 targets, resulting in net economic costs because of stranded investments, also involves acceleration of technology evolution further leading to net economic benefits in the longer term.

2. Energy and economic outlook

2.1 World energy outlook

The world energy outlook is based on POLES' simulations and aims at providing a consistent and detailed description of the world energy situation until the year 2030.

Table 1: CO_2 emissions by world region (source: P. Criqui and N. Kouvaritakis, POLES model)

		Increment		Increase Ratio
MtC	**1990**	**2010-1990**	**2030-2010**	**for 2010**
World	5986	3178	4710	1.53
OECD	2949	774	419	1.26
Trans. Econ.	1290	-283	295	0.78
Dvg Asia	1069	2055	2448	2.92
Dvg Oth	679	632	1548	1.93

The simulations project a rapid increase in the weight of developing regions in the world economy and energy system, so that most part of the energy consumption in the next forty years will originate from them. By 2010, they will contribute to half the world GDP and almost half the world energy consumption.

International energy markets will be affected by this shift, as oil demand will largely grow along the development of transport and car equipment in these regions. Although oil resources are large and might be extended by technological progress, non-conventional fuels will need to be used after 2010. Oil prices are projected to increase in order both to satisfy the growing demand and to encourage the development of non-conventional resources. Natural gas prices may also increase, as gas demand will be especially strong in every region of the world.

Consequent on the growth in world energy demand, world CO_2 emissions will be on an upward trend. While "flat rate" reductions provide ambitious but reasonable targets for industrialised countries and the economies in transition, they are fully inadequate for CO_2 policies in the developing world. The expected increase in developing country emissions is very large and stems directly from the strong dynamics in energy demand, particularly for transport and electricity. For the latter, coal use in power generation in Asia, and especially in China and India, is projected to be one of the main sources of incremental emissions in the medium term as well as in the period to 2030.

The world of energy will probably be very different after 2010 of what it is today. This is already the case in this baseline projection, the main characteristics of which are a higher level of demand, international prices and CO_2 emissions. Mitigation policies, particularly if they are also addressed in the developing regions will, no doubt, introduce further changes to this picture.

2.2 European economic and energy outlook

The baseline scenario for the whole analysis is based on the pre-Kyoto business as usual scenario constructed by NTUA in 1997. This scenario has co-ordinated macro-economic and sectoral growth assumptions, world energy price trajectories and energy system technical progress assumptions. The GEM-E3 model provided the macro-economic framework, while the energy system implications were derived from the PRIMES energy system model for 8 EU member states. The evolution projected by the two models follow similar trends concerning energy and CO_2 emissions.

The pre-Kyoto business as usual scenario includes policies that are in the pipeline and trends in technology progress and industrial restructuring. For example, technology progress, industrial reorganisation towards higher value-added products (and less material and energy intensive products) and the on-going energy conservation programmes are included. In addition, the on-going liberalisation in the electricity and gas markets are assumed in the scenario to allow for more gas-based competitive power generation plants and acceleration of the use of cogeneration of heat and power.

The implementation of these policies, implies that overall energy intensity will decrease significantly in the baseline (about 1.5% per year, see Table 2), which is higher than the historical average. Consequently, CO_2 emissions and primary energy consumption will increase only moderately. In the power generation sector, the scenario also projects a spectacular growth of the use of gas and a substantial increase of cogeneration and (to a lesser degree) renewables.

The scenario follows a rather optimistic path for the GDP of the EU, which remains above 2% for the first to decades of the next millennium. The main proponents of this increase are market services and high quality manufacturing (e.g. in chemicals), specialised in particular countries. Government consumption and basic processing on the other hand, is projected at best to remain to its present levels.

Table 2: pre-Kyoto scenario indicators

pre-Kyoto scenario

EU-14	2000/ 1990	2020/ 2000	2020/ 1995
	% change / year		
Population (Million)	0.8	0.1	0.2
GDP (bil. ECU1985)	2.1	2.1	2.2
Gross Inland Consumption	1.1	0.6	0.7
Gross Inl Cons./GDP (toe/1985 MECU)	-1.0	-1.5	-1.5
Gross Inl Cons./Capita (kgoe/inhab.)	0.2	0.4	0.5
Electricity Generated/Capita (kWh/inhab.)	0.9	0.9	1.0
CO2 Emission Index (1990=100)	0.2	0.6	0.6
CO2 Emissions/Capita (t of CO2/inhab.)	-0.6	0.5	0.4
CO2 / Gross Inl. Cons. (t of CO2/toe)	-0.8	0.1	-0.1

GDP per capita is projected to converge, implying higher growth rates for cohesion countries.

The differences across countries both in terms of rate of growth and structure of growth have significant implications on projected CO_2 emissions. Generally, cohesion countries exhibit strong upward tendencies, while mature industrial economies show only moderate emissions increases. In the extremes are Germany where re-structuring after unification leads to a reduction in CO_2 emissions (in 2010 compared to 1990) and Sweden where the phase-out of nuclear stations will augment emissions. Table 3 shows the evolution of emissions in the EU-14 and the distribution of effort as agreed in the pre-Kyoto period at the Council (last column).

The target set for the EU before the Kyoto conference, that is -15% of emission reduction in 2010 (for the whole basket of greenhouse gases), leads to a need to avoid the emission of about 675 Mtn of CO2 in 2010, which represents a significant reduction from the emissions in 2010 according to the baseline scenario. The fuel mix in primary energy changes smoothly, mainly allowing for substitution of solid fuels by natural gas. Nuclear and liquids preserve there shares, while the penetration of renewables is noticeable but limited (5.5% of primary energy demand in 2010, being 3.9% in 1990). The changes in fuel mix imply a moderate decrease of the carbon intensity (-0.4% per year), contributing to the decoupling of CO_2 from energy demand growth. This effect is however significantly smaller in size than the energy intensity effect.

Table 3 : CO_2 Emissions per Country

	pre-Kyoto scenario				
	1990	**1995**	**2010**	**% change from 1990**	**pre-Kyoto target**
AU	58	59	60	4.5%	-25.0%
BE	112	116	133	18.8%	-10.0%
DN	53	61	59	9.6%	-25.0%
FI	54	71	74	36.9%	0.0%
FR	367	365	389	5.9%	0.0%
GE	997	892	909	-8.8%	-25.0%
GR	72	86	103	43.7%	30.0%
IR	31	33	39	24.9%	15.0%
IT	401	413	475	18.3%	-7.0%
NL	158	172	195	23.5%	-10.0%
PO	40	49	62	55.9%	43.0%
SP	209	242	289	38.0%	17.0%
SV	52	56	68	31.2%	5.0%
UK	584	551	592	1.4%	-10.0%
EU-14	**3187**	**3166**	**3446**	**8.1%**	**-10.0%**

In final energy demand, transports (1.69% per year) and tertiary (1.30% per year) continue to grow significantly, while stagnation of energy demand is projected for industry (0.70% per year) and households (1.42% per year). Regarding the fuel mix in final demand, the projection shows a penetration of distributed heat (mainly produced by cogeneration), a decline of solid fuels and a continued, even though moderated, penetration of gas and electricity. The part of liquids is maintained, because of the their use in transports.

Power generation is projected to increase in EU-8 by 1.3% per year. The sectoral evolution involves mainly a relatively high growth of independent generation (it represents 12.5% of total power capacity in 2010, to be compared to 5.4% in 1990), and an important shift in favour of natural gas used in combined cycle power plants (more than 2/3 of all new power capacities). The progress in gas turbine technology allows also a significant increase of cogeneration (12.5 GW more capacity in 2010).

3. The costs of emission abatement in 2010

3.1 Introduction

In view of the Kyoto Conference on climate change held in December 1997, the European Union agreed to decrease the basket of greenhouse gas emissions in 2010 by 15% compared to the level of emissions in 1990.

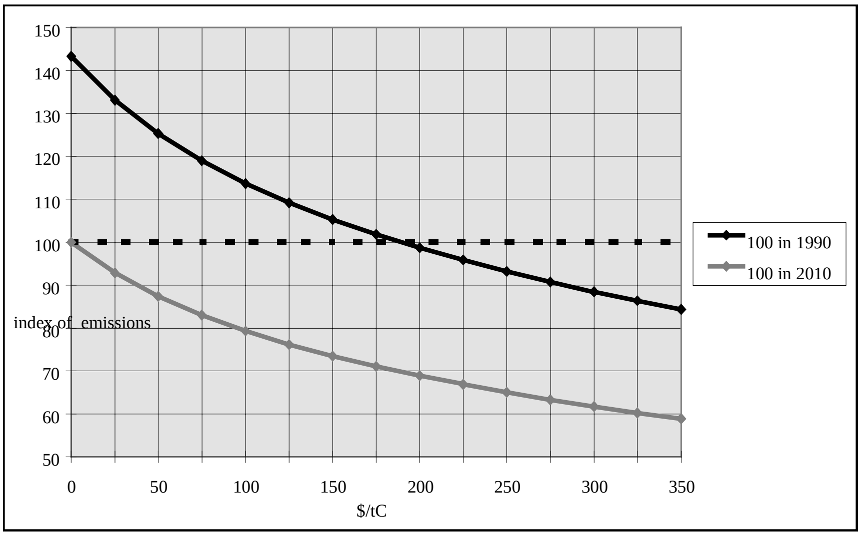
The evaluation of the costs and benefits from reducing CO_2 emissions have been based on model simulations with the same models which were used for the baseline scenario: **GEM-E3**, **PRIMES** and **POLES**.

3.2 International dimension

The **POLES** model was used in order to examine the comparative costs of emission reduction in countries and regions outside the EU. The methodology selected was to determine the marginal and total costs incurred in achieving the reduction targets by introducing a “shadow carbon-tax” in the various countries and regions identified in the model. The model is used to construct marginal cost curves for emission reduction and then to clarify the position of the various parties in the negotiations.

By introducing a shadow carbon tax into the POLES model, it is possible to calculate changes in emissions in relation to the reference case. This is illustrated, at world level, in Figure 1 on the basis of an emission index of 145 in 2010, the emission level decreases with the introduction of a shadow tax of from 25 $/tC up to 350 $/tC. If it is read vertically, this figure also represents the curve for sectoral marginal costs of emission reduction. It can thus be seen that stabilisation of emissions at the 1990 level would correspond to a shadow tax of 180 $/tC, or, in other words, that the equivalent objective of a 30% reduction in emissions in relation to the 2010 reference would be achieved at a marginal reduction cost (MRC) of 180 $/tC.

Figure 1 : World Marginal Abatement Costs as computed with POLES (source: P. Criqui and N. Kouvaritakis, POLES model)



The amount of the shadow carbon tax for a given reduction target reflects in fact all the changes imposed on the energy sector, as simulated by the model: cost of improved energy efficiency, of greater development of non-fossil energy, and of stronger penetration of fossil sources with low carbon intensity. From one region of the world to the next, the MRC will therefore depend essentially on the reference situation in each of these fields. In a seemingly paradoxical way, the more unfavourable this initial situation, the easier it will be to reduce emissions, while the more virtuous a country is with respect to CO_2 emissions, the greater will be the cost for that country of making further reductions.

There are considerable differences between the major regions of the world:

- for the OECD regions, reduction costs with respect to the 2010 reference would be higher than the world average in Europe and Pacific Asia, but lower in North America;
- the diversity of costs would be even more marked for developing regions, with reduction costs much lower than the average in China, Southern Asia and sub-Saharan Africa (all regions with high coal potential), but higher in South-East Asia, North Africa and the Middle East, and Latin America.

Thus, the analysis whereby reduction costs would be systematically higher in the industrialised countries than in developing countries is not confirmed in every case by a sectoral analysis taking into account the structural characteristics of the energy systems. This conclusion is important in that proposed permit trading systems and joint implementation schemes are based on an *a priori* vision and, as will be seen, will therefore have to be considered on a case by case basis. In fact, low cost reduction potentials exist in every country, opening up the way for "emission trading".

The results of the exercise on the introduction of a shadow carbon tax can also be examined for a single country or a group of countries. These results can thus help shed light on some of the issues at stake in the international negotiations, in particular the costs associated with quantitative objectives in the form of a flat-rate reduction compared with a base year. Thus, the marginal cost of achieving the objective proposed by the European Union before the Kyoto COP-3 can be analysed for the major Annex I partners: a 15% cut in emissions by 2010 compared with the 1990 level.

A non-differentiated reduction rate of 15% would unquestionably impose extremely different marginal costs on the various parties: 125 $/tC in the United States, 175 $/tC in Australia-New Zealand, 200 $/tC in the European Union and as much as 350 $/tC in Japan. On the other hand, equalisation of marginal costs among the various parties should result in differentiation of reduction objectives. Thus, for 200 $/tC, the reduction targets would be 25% in the United States and Australia-New Zealand, 15% in Europe, and 5% in Japan. It is important to note that projected trends up to 2010 are of crucial importance in determining the marginal cost.

The position of each country with respect to one of the objectives proposed prior to the Kyoto conference, namely to reduce emissions by a flat rate of 15% compared with 1990 levels, varies:

- for the United States and the European Union, the total costs might be comparable (less than 0.3% of estimated GDP in 2010), although the corresponding marginal costs differ considerably, with the EU level almost twice that of the United States;
- in Canada and Japan, on the other hand, the same objective could be achieved only with higher marginal costs and a total cost of about 0.45% of GDP;
- finally, Australia appears destined to bear by far the highest total cost, almost 0.6% of GDP, even though its marginal cost is lower than that of the Community.

The simulation of reduction programmes through the introduction of a shadow carbon-tax thus provides coherent information on the relative costs for the various countries. These results can then be re-examined with reference to the various plans proposed for the international negotiation, in order to asses the respective limits and advantages, in terms both of efficiency and acceptability by the various parties.

Figure 2: Marginal reduction cost curves for the major partners of annex I (in relation to reference year 2010, source: P. Criqui and N. Kouvaritakis, POLES model).

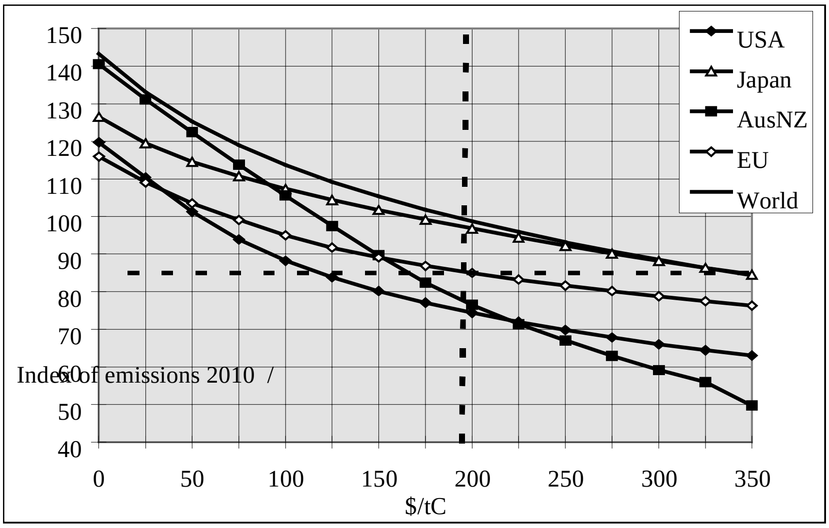
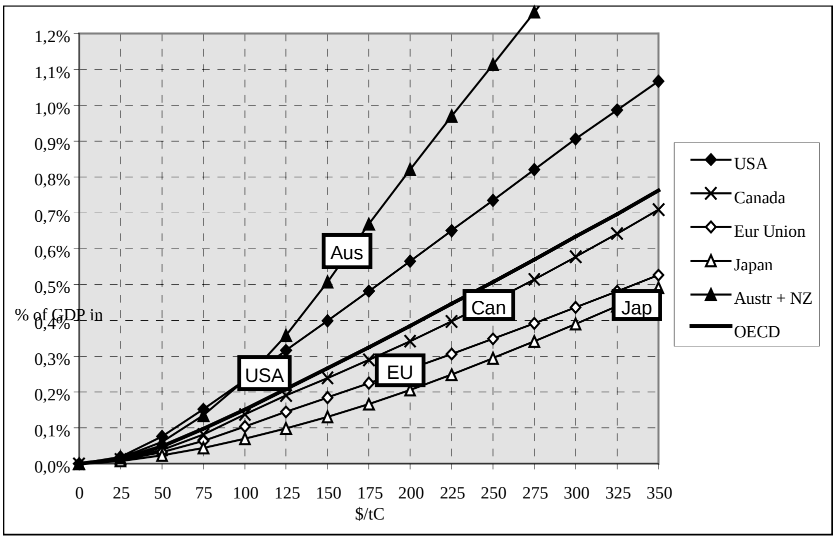


Figure 3: Total cost of reduction as a function of the marginal cost level. (source: P. Criqui and N. Kouvaritakis, POLES model)



Four hypotheses have been analysed:

A "Flat-Rate" Reduction in Emissions of 15% Compared with the 1990 Level in OECD Countries

Here, it is assumed that all the OECD countries - the EU being regarded as a "bubble" - must reduce their emissions to 15% below 1990 levels, with no possibility of emission trading outside their territory. The differences in marginal costs obtained in POLES for such a reduction per country are then significant, ranging from 125 $/tC for the United States to 200 $/tC in the European Union and as high as 350 $/tC in Japan. The figure is even higher in the non-Union region of Europe, which includes Turkey, a country where there is high potential for increased emissions. The total effort in relation GDP in 2010 depends both on the marginal reduction cost in 2010 and emission dynamics in the reference projection. Thus, the corresponding cost would represent slightly less than 0.3% of GDP for the United States, due to a low marginal cost, as in the case of Europe, in this case because of the moderate increase in emissions envisaged in the reference situation. On the other hand, this cost would be one and half times higher in Japan and Canada and up to twice as high in Australia - New Zealand. It thus appears that without the possibility of emission trading, non-differentiation of objectives is likely to create substantial disparities in the charges imposed on the various parties.

The Same Reduction, but at World Level, through a Joint Implementation System or a Generalised Emission Permit Trading System

Another theoretical hypothesis is to assume that the same reduction target as before is imposed on OECD countries, but that this is obtained through a broad joint implementation scheme, or the purchase of emission reduction certificates in other regions of the world. If such an emission trading system could be generalised to all the countries and all the sectors, marginal costs would be equalised at the world level. This would imply optimal allocation of effort and lower costs than before. A world reduction of 12% in relation to the reference could, in theory, be obtained at a marginal cost slightly below 50 $/tC. With the above scheme the emission reduction in OECD territories would be 460 MtC (about half the total objective), while the rest, would be financed by these countries (directly or through the purchase of emission rights) but correspond to emission reduction in other world regions.

Equalisation of Marginal Costs within the OECD Countries, through a Tax or Permit Trading Systems

This hypothesis is probably more operational than the previous one since it could be implemented in two quite radically different -but possibly realistic- ways: through the introduction of a common carbon-tax in the different countries or permit trading between countries that have agreed to restrictive quantitative reductions. The results of the model show that emissions could be reduced to 15% below 1990 levels at a marginal cost of about 170 $/tC for the OECD countries as a whole. The total cost of this reduction would represent approximately 0.3% of the GDP of the OECD in 2010.

When it comes to the burden sharing issue between the OECD countries, it is crucial to know whether this should be achieved through equalisation of marginal costs by means of a common tax or through permit trading. Under equalisation of marginal costs, the countries with the highest reduction potential at low or moderate cost would contribute more, so that paradoxically their total cost in relation to GDP would be higher than that of the other countries. Thus, total potential at a cost of less than 170 $/tC would represent a reduction of 23% compared with 1990 in the United States, for a total cost of almost 0.45% of GDP. For the EU, the reduction would be 13% for a cost of 0.22% of GDP and for Japan only 1% for 0.16% of GDP. Although the rejection of a carbon tax by the United States is probably based on other reasons, there are clearly limits to an international approach based on a single tax, but this does preclude "local" implementation of such a system.

Under a permit trading system, it is assumed that each country is required to contribute to a 15% reduction compared with its situation in 1990, but can buy or sell the reductions corresponding to the difference between the national marginal cost and the equalised marginal cost. The situation will then differ in each country, depending on whether their marginal cost for a 15% reduction is lower or higher than 170 US dollars per ton of carbon ($/tC).

Differentiation of Quantified Objectives to Equalise Effort

As an alternative to the solutions of a single tax or permit trading systems there is the possibility of differentiation of agreements to take into account, in a global manner, the present and future characteristics of each country. Various equity criteria can be used to formulate a system of differentiated objectives. The criterion adopted was the equalisation of the ratio of the total reduction cost expressed in terms of estimated GDP in 2010.

Equalisation of marginal costs within the OECD countries would make it possible to achieve the objective of a flat-rate reduction of 15 % for a total cost of approximately 0.3% of the 2010 GDP for the region. It is then possible to calculate the emission reduction level on the basis of each OECD country devoting 0.3% of its 2010 GDP to the reduction effort. (This figure could be compared to the objective -declared but seldom attained- of industrialised countries to contribute 0.7% of their GDP in the form of aid to developing countries).

The results of the model show that emission objectives corresponding to this kind of reduction effort can, in certain cases, reduce the disparities between the solution of equalised marginal costs and the flat-rate solution:

- for the United States, the reduction would be 15%, the same as in the flat-rate solution;
- for the EU, it would be slightly higher, about 17%;
- in the Pacific OECD region, it would be lower, reaching -10% in Japan and only stabilisation in Australia - New Zealand.

3.3 Analysis for the European Union

3.3.1 Energy System Implications

3.3.1.1 Policies and measures

The objective of the analysis with PRIMES has been mainly to re-quantify the economic potential of the "**Policies and Measures**" (PAM) package, following the agenda of the ad hoc expert group of the Council, and consider the energy markets and their interactions. Consistency analysis and quantified re-evaluation were the aims of the model-based analysis

The agenda of the PAM package includes the following:

- Energy Efficiency in Heavy Industry
- Equipment (domestic appliances, motors, air compressors, heat pumps, etc.)
- Cogeneration, district heating
- Renewables
- Transports (cars, modal shifts)
- Buildings, thermal integrity
- Taxation (minimum excise taxes on energy)
- Removal of subsidies
- No other Measures for Power Generation

A scenario constructed with PRIMES, named "**Kyoto Advanced Technologies and Renewables**" (KATREN), considered the set of Policies and Measures defined by the EU ad hoc climate group and assumed the imposition of targets by sector as regulation constraints. The PAM sectoral targets take the form of sectoral efficiency gains (for example in % of energy use) or obligations for inputs in the output of power and/or steam. These regulatory targets are imposed at the level of a sector, following a bottom-up engineering approach, represented in the model as constraints on the economic agent's optimisation behaviour.

The KATREN scenario, as constructed with PRIMES, reaches -10.6% of CO_2 emissions in 2010 compared to the 1990 level. This does not mean that it is impossible to obtain more emission reduction. It would be sufficient to impose a more severe regulation. As the marginal efficiency of the regulation in reducing emissions increases with the severity of the regulation, it would be needed proportionally higher regulation to reach a more ambitious reduction target.

Compared to the baseline, the KATREN scenario abates in 2010 about 450 Mtn of CO_2 for EU-8 (or 120 Mtn of carbon that is about 150 Mtoe of primary energy or -11.4% of primary energy demand of EU-8). The emissions are reduced by -15.4% in 2010 from the baseline scenario.

By referring to primary energy demand (gross inland consumption), as GDP growth remains unchanged from the baseline, the KATREN scenario achieves the reduction of emissions mainly by improving dramatically the energy intensity. In all demand sectors, and also through cogeneration and renewables, substantial gains in energy efficiency are obtained. This concerns all energy forms, including electricity, the use of which is highly rationalised. As natural gas penetration already was substantial in the baseline, the possibilities for further substitution in favour of natural gas are limited.

The fuel mix in power generation does not change significantly (as no policy was imposed in this respect). The only difference is derived from the non-fossil fuel obligation that was imposed. However, due to the shrinking of the electricity sector, as a consequence of demand side savings, the development of renewables is significantly lower than projected both in the work of the ad hoc group on climate change and TERES II (both engineering-types approaches). Favourable regulations lead to an impressive increase in the demand for co-generated heat and power, although this is partly balanced from direct measures implying efficiency gains in steam uses.

Additional (compared to baseline) investment in renewables for power generation amounts to 34 GW in EU-8, representing an increase of 72% from baseline. Similarly, the increase of investment in cogeneration corresponds to a doubling of capacities from baseline (25 GW additional capacities).

The structural shift in favour of independent generation is also more pronounced in KATREN than in the baseline scenario. Electricity generation from independent power producers (IPP) increases by 20% while centralised generation decreases by -13% in 2010. Investments in gas turbine technologies (mainly equipped with steam injection) in industrial and tertiary application are accompanied by premature scrapping of older plants (compared to the baseline). This of course induces higher electricity production costs.

The changes in the tertiary sector differ, despite the similarity related to the substantial energy efficiency gains obtained in this sector, as well. In this sector, it seems more preferable to give priority to electricity demand savings than to rely on distributed heat. Final energy demand in the tertiary sector decreases by -11.5% from baseline, leading to a compensation of the high energy growth of the sector as projected in the baseline.

The households act mainly through accelerating preference to advanced technology appliances, resulting in significant savings in the specific electricity uses. Savings in the heat uses are rather limited, confirming the difficulties faced by households in seeking for energy efficiency gains.

High uncertainty prevails in the analysis for the transportation sector and road transports in particular. The bottom-up engineering studies specified that there is technically possible to commercialise a new type of car (with internal combustion engine) that would be controlled by a computer to reach a specific consumption of 5 lt. per 100 km in average. Such a car, if its production were generalised, would induce a moderate increase of car purchase price (15%) and would achieve as much as 40% savings in the energy bill for the consumer. In the presence of such regulation (new cars only available for new purchases after 2002), the model projects a substantial decrease of final energy demand in transports (-17.5% in 2010 from baseline) and in road transports in particular (its share decreases in energy terms). The average car efficiency improves by 20% in 2010. Small changes occur in the other transport means and there are little effects from inter-modal transport combinations (this related also to the fact that PRIMES has ran separately by country), as these are not regulated.

As mentioned, the reduction of CO2 emissions in KATREN is a result of the combined effect of energy efficiency gains, mainly in final demand and through cogeneration (these are the main causes of emission reduction), substitutions in favour of renewables and some limited substitutions in favour of natural gas. This can be summarised in the following table.

Table 4: Main trends in KATREN (annualised growth terms)

KATREN - Annual rates of change	1995-2010
Overall Energy Intensity	-2.30
Fossil Fuel Intensity of GIC	-0.16
Carbon Intensity of Fossil Fuels	-0.53
CO_2 emissions per unit of GDP	-2.97

Table 5: Impact of PAM on CO2 emissions

	in 2010 for EU-8				
CO_2 Emissions in Mtn	**Baseline**	***Shares***	**KATREN**	***Shares***	**% Diff. from baseline**
Industry	466.6	*15.5%*	372.8	*14.7%*	-20.1%
Tertiary	194.8	*6.5%*	177.0	*7.0%*	-9.1%
Residential	396.9	*13.2%*	365.3	*14.4%*	-8.0%
Transports	899.4	*29.9%*	738.4	*29.0%*	-17.9%
Central Power	716.2	*23.8%*	545.5	*21.5%*	-23.8%
Independent CHP	192.8	*6.4%*	221.1	*8.7%*	14.7%
Other	139.1	*4.6%*	121.9	*4.8%*	-12.4%
TOTAL Emissions	**3005.8**		**2542**		**-15.4%**

The table below shows a decomposition of CO_2 emission reduction by type of PAM (policies and measures) classified according to the agenda of the ad hoc group on climate change of the Council. This decomposition needs a complex calculation on the numerical results of the model and involves certain assumptions.

The table shows a high contribution of transports. The uncertainty in the analysis for transportation sector emphasises the importance of conducting additional in depth studies. It is evident that if the corresponding potential is smaller than that of the above table, then there will be important difficulties in reaching the CO_2 emission reduction target.

The contribution of CHP and renewables is also impressive, ranking second after transports. The rest of emission reduction is attributed to direct energy efficiency gains in the end-use of energy, equally distributed between industrial processes and domestic appliances.

The KATREN scenario shows an economically and technically feasible package of standards and regulation that serves to approach the emission reduction target. Of course, additional sensitivity analysis is required to refine the regulation assumptions and their allocation to sectors and energy uses. The scenario also revealed important side effects, regarding CHP and renewables in particular, that cannot be neglected when considering the energy markets and their interactions.

3.3.1.2 Carbon tax scenario

PRIMES has been used also to construct a set of Carbon-Tax-Equivalent scenarios (starting from the baseline) to compute the shadow-marginal cost of the emission reduction target by country.

In each scenario of this type, several runs are made to determine the value of a carbon tax that is necessary to operate throughout the energy system so as to reaches a predetermined level of CO_2 emission reduction. Given that PRIMES is a market equilibrium model, the required level of carbon tax is exactly the measurement of the system's marginal abatement cost associated to a reduction level. Therefore, the so-called CO_2Tax scenario is not a taxation scenario, in policy terms, but simply serves to the evaluation of the marginal abatement cost.

Table 6 : PRIMES version 1 results in % of CO2 reduction in 2010 from 1990

PRIMESv1: Marginal Cost of CO2 reduction in 2010, in ECU'90/ton of Carbon

	0	50	100	150	200	300	350
BE	18.8%	-5.3%	-7.0%	-8.1%	-8.8%	-9.3%	-9.8%
FR	5.9%	-0.7%	-2.0%	-2.9%	-3.4%	-3.9%	-4.2%
GE	-8.8%	-21.8%	-23.3%	-24.2%	-24.8%	-25.3%	-25.7%
IT	18.3%	-1.9%	-4.0%	-5.2%	-6.1%	-6.8%	-7.3%
NL	23.5%	7.4%	2.4%	-0.7%	-2.9%	-4.6%	-6.1%
SP	38.0%	19.8%	17.1%	15.5%	14.4%	13.5%	12.8%
SV	31.2%	23.9%	17.4%	12.5%	8.5%	5.2%	2.3%
UK	1.4%	-8.0%	-10.1%	-11.4%	-12.4%	-13.1%	-13.7%
EU-8	**5.9%**	**-7.4%**	**-9.5%**	**-10.8%**	**-11.7%**	**-12.4%**	**-13.0%**

It must be also emphasised that the CO_2Tax scenario leads by construction to an optimal allocation of the CO_2 reduction effort. On the contrary, the KATREN scenario, as being a regulation scenario, is sub-optimal. This optimality rule theoretically applies to allocation for both the countries and the sectors. However, in the present CO_2Tax runs, the analysis limited the optimality only among the sectors of each country, considering the allocation by country as given following the decision of the Council on 3.3.1997. Of course, the country allocation needs not to be optimal. Therefore, the CO_2Tax scenario overestimates the optimal marginal abatement cost, compared to the case that the CO_2 effort would be allowed to be flexible among the countries, as well. The inefficiency of the allocation (regarding the countries) has been estimated to be around 36% in marginal abatement cost terms.

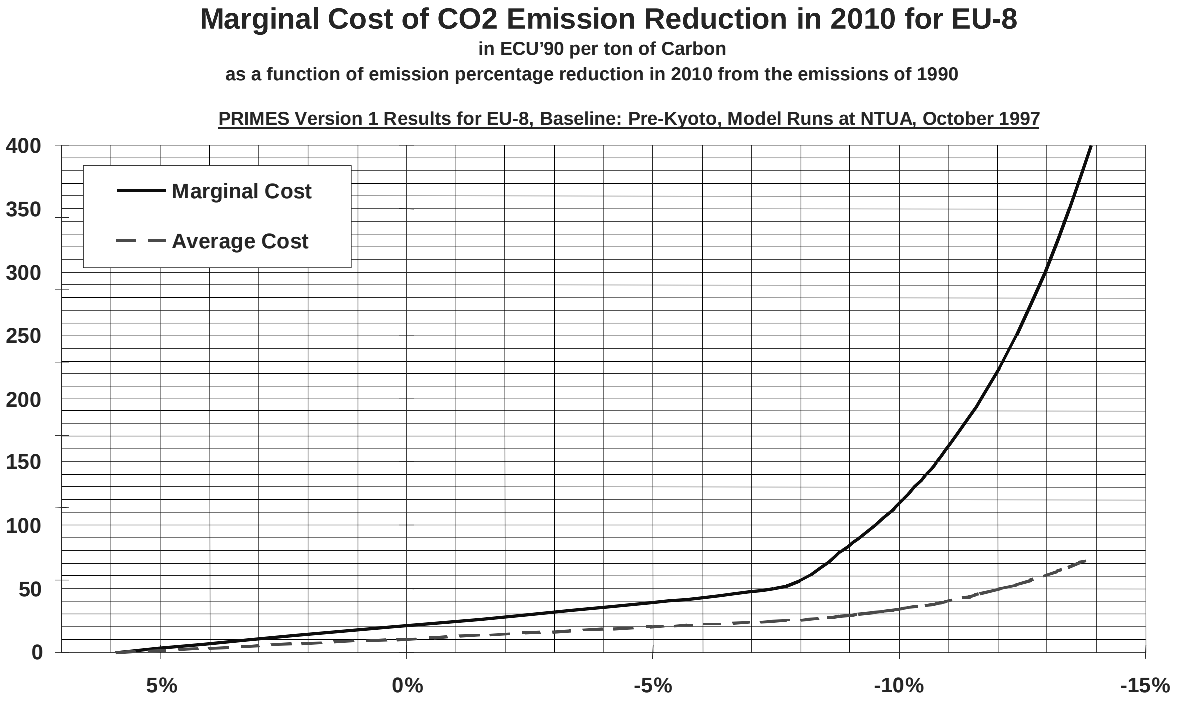
The CO_2Tax scenario showed how important is the power generation sector for least cost actions in the short run. Fuel shifts in power generation are possible and cheap leading to an important (about 20%) contribution of the sector to reach the target. Less emission reduction effort is required in the demand-side, mainly in the residential and services sectors, leading to cost savings.

The CO_2Tax scenario showed how market competition plays an important role in the allocation of effort among the sectors. It has shown for example that the CO_2Tax scenario induces higher operation costs for power generation, but the centralised generators have the advantage of exploiting economies of scale and the possibility to rely more on carbon free resources. In these circumstances, the increase in the fuel bill partly compensates the gains from the production of steam by decentralised generators, an effect that undermines their competitiveness. In such a case it seems that there is more opportunity to invest in direct savings in heat uses (as it is shown in the results for industry) than to save through the CHP, as decentralised power generation is less competitive (because of costs and economies of scale).

Regarding the magnitude of the energy system costs for the EU, the results show the following:

- The marginal abatement costs are significantly higher than the average costs. In case of optimal allocation by sector that is for the CO2Tax scenario marginal costs are 297 ECU'90/tn Carbon (-11.3% of CO_2 in EU-8), compared to average cost of 38 ECU'90/tn Carbon.
- The distribution of marginal costs per country differs substantially. This is of course related to the pre-defined allocation of the emission reduction effort, as it follows the decision of 3.3.97 which is a result of negotiation involving consideration of several factors on top of cost-engineering. In case of optimal allocation of effort by country, as in a different CO_2Tax, the marginal abatement cost is reduced to 190 ECU'90/tn of Carbon (36% more efficient).

Figure 4: Marginal abatement cost curve with PRIMES



As it can be seen from the figure above, the marginal abatement cost curve is steeply increasing, especially beyond -8 to -9% of CO_2 emissions in 2010 (compared to 1990). The average cost curve is increasing smoothly.

3.3.2 Macro-economic results

The results in this paragraph are a short summary from a very large number of simulations conducted with the GEM-E3 model over a span of several years.

3.3.2.1 Abatement cost curves

One way to depict the effort needed to achieve particular CO_2 targets, is through marginal and average cost abatement curves. Although these are not necessarily indicators of the economic consequences or costs of the target, they show the degree of difficulty of adjustment of the system to achieve the target.

To construct the cost abatement curve, alternative emission reduction targets were defined for the EU as a whole and the model was allowed to evaluate the optimal allocation of the effort needed across countries, firms and households. The emission constraints define the marginal cost of emission reduction. This is then linked to the rest of the model in a way to reflect explicitly the type of policy instrument used to achieve the target. The analysis with GEM-E3 included pollution permits as well as taxes.

Table 7 presents the results of GEM-E3 and shows the optimal emission reduction targets for 2010 per EU member-state and for different levels of the marginal abatement cost of CO2 reduction. If considered by column, this table provides the optimal allocation of effort and the corresponding marginal abatement cost for a given EU-wide emission reduction target.

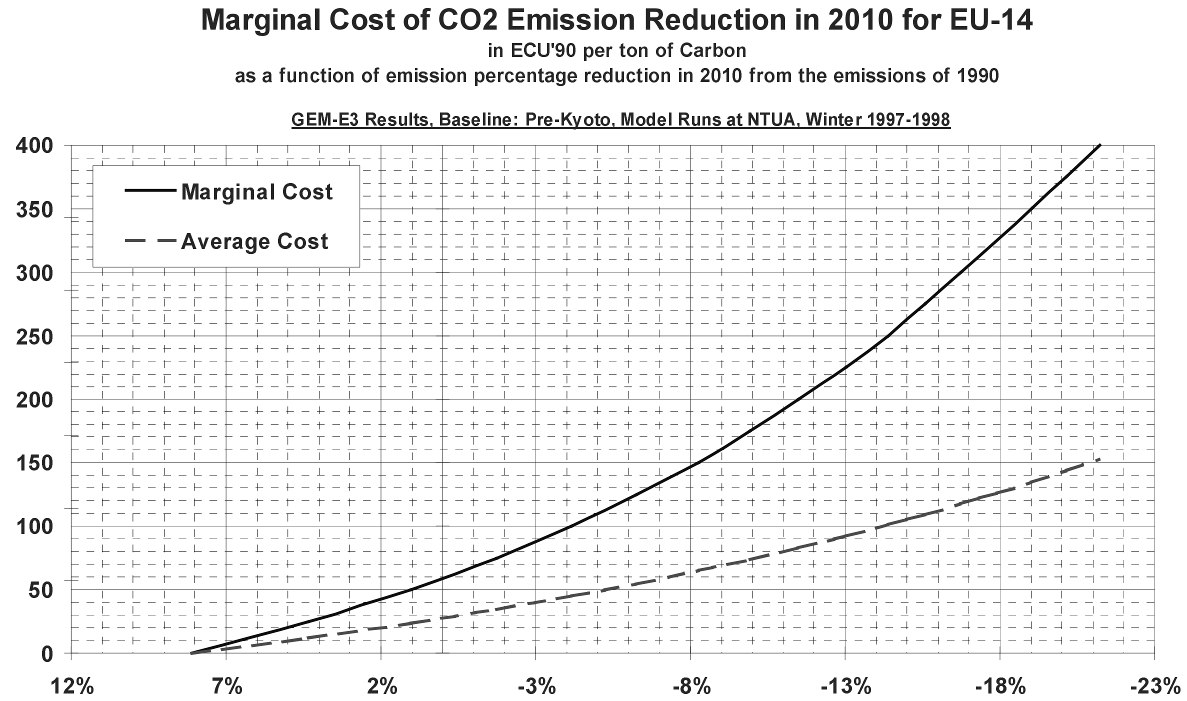
Table 7: GEM-E3 results in % of CO2 reduction in 2010 from 1990

GEM-E3: Marginal Cost of CO2 reduction in 2010, in ECU'90/ton of Carbon

	0	50	100	150	200	300	350
AU	4.5%	-2.7%	-8.0%	-12.1%	-15.3%	-20.6%	-22.9%
BE	18.8%	7.7%	0.2%	-5.3%	-9.3%	-15.6%	-18.3%
DK	9.6%	1.9%	-3.5%	-7.7%	-10.9%	-16.1%	-18.3%
FI	36.8%	26.1%	18.7%	12.9%	8.5%	1.3%	-1.7%
FR	5.9%	-0.3%	-4.7%	-8.2%	-10.9%	-15.4%	-17.4%
GE	-8.8%	-13.9%	-17.9%	-21.3%	-24.0%	-28.4%	-30.3%
GR	43.6%	30.6%	21.7%	15.1%	10.1%	2.2%	-1.2%
IR	25.0%	13.4%	6.2%	1.0%	-2.9%	-9.2%	-11.8%
IT	18.3%	10.4%	5.0%	0.8%	-2.4%	-7.8%	-10.1%
NL	23.5%	17.2%	12.7%	9.1%	5.9%	0.4%	-2.2%
PO	56.1%	46.9%	39.9%	34.2%	29.6%	22.0%	18.6%
SP	38.0%	28.6%	21.3%	15.5%	11.1%	4.0%	0.9%
SV	31.2%	23.3%	17.9%	13.7%	10.4%	4.9%	2.5%
UK	1.4%	-6.1%	-11.6%	-16.0%	-19.3%	-24.8%	-27.1%
EU-14	**8.1%**	**1.0%**	**-4.2%**	**-8.3%**	**-11.5%**	**-16.7%**	**-19.0%**

The following figure presents the marginal and average cost curves as a function of the EU-wide emission reduction target (for 2010).

Figure 5: Marginal abatement cost curve with GEM-E3



The average costs as evaluated from the GEM-E3 results include all direct, indirect and system equilibrium effects resulting from the additional environmental constraint. They are defined as the ratio of additional charges per sector (for an activity equal to that of baseline) divided by the number of tons of carbon avoided in 2010 per sector.

3.3.2.2 Macro-economic impact

As already mentioned, GEM-E3 includes the feedback from the energy system to the whole economy and therefore allows the evaluation of the economic impact of the policy on sectors, countries and households. The marginal cost curve presents insufficient information for evaluating the policy as the impacts on GDP, employment or competitiveness are not considered.

GEM-E3 by directly reflecting economic theory provides a unique criterion for policy evaluation. Under reasonable assumptions, observable quantities (such as consumption and employment) lead to a quantification of an unobservable quantity, i.e. the consumer's welfare, whose changes are used for policy evaluation.

Two problems exist in this respect: although the welfare function in GEM-E3 is derived in a standard way found in the economic literature, there remains the problem of valuation of unemployment or leisure. On one hand, for a person that is currently employed, working more can be seen as, ceteris paribus, a reduction in welfare while for an unemployed person finding a job is certainly welfare-increasing. This problem is still not resolved in the theory of welfare economics and no single satisfactory answer exists. A second problem comes for the fact that changes in environmental quality should result in welfare gains. Such a valuation is inherent in all GEM-E3 model versions, derived from EXTERNE[6] data. This leads to the computation of the "**total welfare**" index of the model, i.e. inclusive of the benefit from enhanced environment.

Two separate sets of scenarios where simulated with the model:

Pollution Permits, in which economic agents are endowed with an initial amount of property rights to the environment that are tradable across firms, households and countries. The main mechanism for the initial allocation of permits used was "grandfathering" (i.e. pollution permits allocated in proportion to base year emissions). Other initial allocations (e.g. equal per capita burden or equal per GDP burden) were also simulated as sensitivity tests. A discussion of pollution permits in general can be found in Tietenberg, T.H. (1995).

Taxes. In these policy cases, a carbon tax is imposed on all economic agents according to CO2 emissions. The government collects the tax revenues. This is the "Constrained case, no recycling" in the figure below. In the other cases, the tax revenues are re-distributed, defining two alternative policy scenarios. The first, called "double dividend for labour", involved subsidising employers' social security contributions. In this case labour becomes more competitive as a production factor and substitutes energy in some sectors. The outcome, under a wide range of initial conditions, is favourable for employment. Structural shifts away from equipment and towards consumer goods may have negative long-term implications not covered in the model simulations. In the second, called "reduction in investment costs", environmental policy revenues where used to subsidise investments. The rationale behind this scenario is to induce higher investments in the hope of achieving long-term economic growth.

All model simulations involved reaching the "Kyoto" target in 2010 and did not consider the impacts beyond that year.

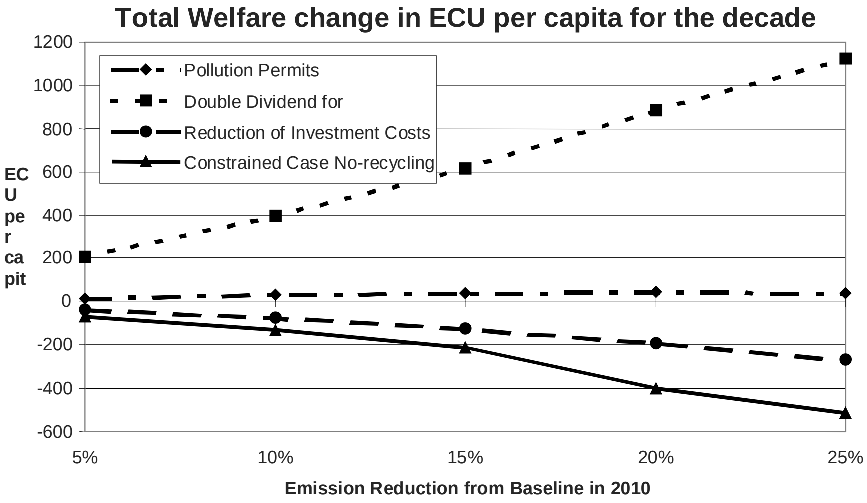
Table 8: Macro-economic effects of reaching the "Kyoto" target by 2010.

Macroeconomic Aggregates for EU-14 (all scenarios)

	PP	DD	CR	NR
Gross Domestic Product	-0.34%	-0.38%	-0.40%	-0.70%
Employment*	175	1023	-60	-362
Private Ivestment	0.01%	-0.35%	1.65%	-0.93%
Private Consumption	-1.20%	0.80%	-1.70%	-1.89%
Domestic Demand	-0.83%	-0.94%	-1.31%	-1.85%
Exports in volume	-0.31%	-3.39%	-0.97%	0.06%
Imports in volume	-2.95%	-1.57%	-3.37%	-4.30%
Intra trade in the EU	-0.29%	-3.46%	-0.87%	0.23%
Energy consumption in volume	-8.77%	-10.35%	-10.05%	-10.18%
Consumers' price index	1.20%	3.51%	0.42%	-0.32%
GDP deflator in factor prices	-0.19%	0.15%	-2.51%	-3.38%
Real wage rate	-1.19%	0.61%	-1.06%	-1.11%
Tax revenues as % of GDP	0.89%	2.70%	2.56%	2.50%
Current account as % of GDP	0.34%	-0.15%	0.35%	0.56%
Marginal abatement cost (ECU'85/tn C)	176.2	153.3	140.7	135.8
Total atmospheric emissions				
CO2	-14.7%	-15.0%	-15.0%	-15.0%
NOX	-11.8%	-11.7%	-11.8%	-12.0%
SO2	-21.9%	-22.7%	-22.4%	-22.3%
VOC	-7.3%	-6.7%	-7.2%	-7.4%
PM	-24.5%	-25.0%	-24.7%	-24.6%

Note: PP is the granfathered pollution permits scenario, DD is the labour recycling scenario, CR is the capital recycling scenario and NR is the no recycling case.

Figure 6: Welfare change in ECU per capital, for the period 2001-10 for different emission reduction targets.



The quantitative nature of the results is confirmed in the sensitivity tests performed, but the exact figures vary significantly depending on the accompanying policy and the assumption about the possibility of adjustment of the economic agents. For example under the assumption that energy intensive industries are already on the limit of their possibilities for energy conservation or that they operate in an international environment which is very competitive, the results would be more negative. Under extreme assumptions concerning labour market regimes and international competition, even the employment dividend may disappear.

If, on the other hand, there exists in the economy the potential to achieve significant efficiency gains in energy use at a moderate cost, then the negative impact of environmental constraints on the economy may be lower. In this case additional benefits from terms-of-trade effects may further reduce the cost of the policy. In this case, it is possible that there is no net economic cost for the policy, supporting the "strong" double dividend hypothesis. But this requires rather extreme assumptions (very low exposure to foreign competition, high potential for cheap energy-saving investments, high flexibility of the labour market).

The relative efficiency between pollution permits and taxes cannot be addressed with GEM-E3. Since the economic agents operate under perfect information and total resources are allocated so as to reduce total costs, there is no theoretical distinction between taxes and permits. More importantly the costs of setting up the necessary infrastructure needed for operating the pollution permits market were not included in the model.

The environmental target was always set at the EU-14 level, and the allocation of effort was distributed across the countries so as to minimise total costs. The tax burden (or equivalent permit allocation) by economic agent and country is however arbitrary. In the main model applications simplifying assumptions where made on both issues: on the permits simulations the initial endowment follows the "grandfathering" principle, i.e. permits proportional to the base year emission by agent; on the tax case the revenues where recycled within the country given to labour or investments. The chapter on burden sharing modifies this assumption and shows its importance. Under different permit allocation schemes, the results vary significantly with some countries gaining and some countries losing. There of course no single criterion exists and the question of equity is raised. To what extent some countries may take more burdens than others?

Sensitivity tests were also done on a similar issue, namely whether it is worth to exempt some sectors or derogate action in some countries for some years. Exemptions where studied for the energy intensive industries and it was found that indeed these sectors suffer much less. As a matter of fact, it may even be possible that, in a first approximation, these sectors might also benefit (e.g. from lower labour costs, from subsidised investments or from selling permits). However the additional burden facing the other sectors (because the CO2 target is given) has negative implications for the economy as a whole, so that indirectly energy intensive industries suffer as well. The final outcome of the simulations is that the overall effectiveness of the policy when energy intensive industries are exempted gets lower.

3.4 Long-term technology options.

A case study on the power generation sector was carried out to examine the issue of long-term technological developments in power generation.

3.4.1 A global perspective

The technology scenarios have been defined in terms of clusters of technological breakthroughs affecting mainly power generation. These include:

- A "**Nuclear**" scenario which assumes the advent of cheap and relatively risk-free nuclear power generation.

- A “**Clean Coal**” scenario involving rapid technical progress and price decreases in clean coal technology.
- Two “**Gas**” scenarios, both starting from the assumption that the gas resources are higher than predicted today and that the price of gas will be low. The second additionally assumes rapid technical evolution on fuel cells.
- A scenario on “**Renewables**”, which assumes major breakthroughs on renewable technologies.

The technology scenarios for the power generation sector that are examined in this research do not offer panaceas for the global CO2 emission problem. Important though the power generation sector may be, it still accounts for about 40% of the projected world CO2 emissions by 2030. Also, scenarios involving major technical-economic improvements in fossil fuel technologies produce weakened impacts on CO2 emissions because at the same time as they reduce specific emissions they make these technologies economically attractive, not only vis-à-vis more polluting technologies but also more polluting ones. It is important to note that all supply side technological improvements, result one way or another in a reduction in the cost of consuming energy and hence potentially cause consumption to increase.

Scenarios involving increased gas availability produce surprisingly weak results as far as CO2 emissions are concerned. This is due partly to the uneven geographical distribution of the enhanced resources resulting in the gas not being available at sufficiently cheap prices where it could have made the biggest impact, i.e. in China and India, but also due to the resulting lower prices for gas and electricity

There is a clear need for energy saving technology breakthroughs, as these are likely to suffer less from the ambiguities and secondary effects associated with supply technologies. It is hard to see how clusters of energy technologies could by themselves make a major impact on the global CO2 problem unaccompanied by major policy initiatives albeit market related ones. Combining technology breakthroughs with internalisation of external costs through taxation or tradable permits would magnify the impact and tend to neutralise some of the more ambiguous side effects quite apart from the fact that these policy instruments can by definition act on a much wider front.

Table 9: summary table of the impact of technology scenarios, World in 2030, Comparison with Reference Case

Scenario	**Coal**	**Oil**	**Gas**	**Nuclear**	**Hydro**	**CO_2 Emissions**
Nuclear	-94%	-0.8%	-4.0%	142%	-0.7%	-5.3%
Clean Coal	4.5%	-1.0%	-3.9%	-13.1%	-1.1%	1.0%
Gas Technology	-17.5%	-8.1%	49.7%	-19.6%	-2.2%	-2.1%
Gas and Fuel Cells	-18.6%	-8.2%	50.1%	-22.5%	-2.6%	-2.5%
Renewables	-5.4%	0.1%	-2.3%	-4.5%	-0.3%	-3.3%

A cursory glance at the table above is sufficient to realise that the technology scenarios as defined in the current work do not offer a solution for the global CO2 emission problem. The reasons for this are inherent in the way the scenarios were constructed as well as energy market structures and the way their functioning is represented in the POLES model.

3.4.2 Long term technology options for the EU

Throughout the period to 2030 and beyond, developments in power and steam generation technologies are likely to play a significant role in the trends in the energy consumption and emissions of the EU. However, the overall growth in the EU electricity and steam demand is likely to be very modest, due to the maturity of the European economies and their energy systems. Given also the longevity of the generating equipment, the speed with which new technologies can be introduced will be limited, at least in the medium term.

The scenarios analysed in this research are quite revealing for the likely future of the European Union's power generation system. The EU energy system seems to be very sensitive in the period after 2020 when the massive decommissioning of old plants will necessitate the selection of new technologies for replacement generation equipment. The differential progress of different technologies is likely to influence directly a number of strategic decisions of the EU, which could lead to highly varying profiles of the future power and steam system.

The scenarios reveal the strategic importance of natural gas and gas related technologies for limiting CO_2 emissions and for reaching objectives on the development of cogeneration and the decentralisation of the generation market. Under all sets of energy prices examined, the gas and fuel cells scenarios result in the lowest amount of emissions by 2030. These two scenarios also have the lowest generation costs although this is partly because of the lower gas prices assumed in these scenarios. Somewhat surprisingly, the gas scenario does not have dramatic implications the degree of decentralisation by 2030. The projected generation system even in the reference case is already much more decentralised in 2030 than in 1995 and this is largely due to the penetration of gas. The additional gas generation in the gas scenario is mostly to the detriment of base load nuclear and coal plants. Of course, under the gas based fuel cell scenario, the degree of decentralisation reaches its peak.

The long term outlook of coal and nuclear is highly dependent on the technological developments in these fuels. Only under the assumptions of their corresponding scenarios do these fuels play a role significantly more important than the one assumed in the baseline scenario. Of course, EU based clean coal technological developments, could prove very beneficial to the exports of power equipment. However, the clean coal scenario indicated that technological developments in this sector could have adverse effects for the emissions within the EU. The development of nuclear energy seem to be limited in scope and gains, as restricted from load constraints and the interaction with decentralised steam generation. The incremental improvement of renewable technologies is not enough to alter the profile of the system in terms of emissions and costs.

4. Acknowledgements

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The views expressed in this paper are those of the authors and do not engage the European Commission.

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