Patission 42,
Athens 106 82, Greece
Phone 00-30-1-7723641, 29
Fax 00-30-1-7723630
e-mail
kapros@softlab.ece.ntua.gr

National Technical University of Athens

Note on the Costs for the EU of Meeting the Kyoto Target (-8%)

Preliminary Analysis

by P. Capros

14 April 1998

Table of Contents

Note on the Costs for the EU of Meeting the Kyoto Target (-8%)

Preliminary Analysis

1. Introduction

In December 1997, at the Kyoto Conference on climate change, the European Union agreed to decrease the CO2 emissions in 2010 by 8% compared to the level of emissions in 1990.

The present note attempts a preliminary analysis of the costs for the EU arising from the adaptation of the energy and economic system needed to comply with the Kyoto target.

The analysis is based on model runs. Since the second version of the energy system model PRIMES was not operationally reliable when writing this note, the analysis has been based on the following models:

- MIDAS energy system model version 5.2, covering 14 EU member-states, updated in March 1997 and used for the preparation of the pre-Kyoto business as usual scenario (Spring 1997)
- GEM-E3 general equilibrium macro-economic model version 2.23, covering 14 EU member-states, updated in October 1997 and used for the analysis of the economic costs for the EU of reaching the pre-Kyoto targets (Fall 1998)
- PRIMES energy system model version 1, covering 8 EU member-states, updated in June 1997 and used for the analysis of the energy system implications for the EU of reaching the pre-Kyoto targets (Fall 1998).

To prepare this note, new model runs were performed only with the models MIDAS and GEM-E3. In both cases, the baseline scenario was that of the pre-Kyoto business as usual scenario, prepared in 1997. The results of the model PRIMES version 1 were those obtained in October 1997.

2. Methodology

2.1. Marginal and Average Costs

The objective of the analysis, in this note, is to evaluate the marginal cost of reaching the Kyoto target of -8% emissions of CO2, in 2010 compared to 1990. Since the EU-14 system emitted 3187 Mtn of CO2 in 1990

The marginal cost is defined as the incremental system cost that is necessary to abate the emissions of an additional unit of CO2. It is easy to prove that there is a primal-dual relationship between the marginal cost associated to a global emission constraint and the level of a carbon tax that is necessary to achieve the same constraint.

In other terms, if a carbon tax (a tax on fossil fuels proportional to their CO2 emission rates) is used to obtain the overall emission reduction, then the optimal level of the carbon tax is equal to the marginal cost of CO2 emission reduction. The economic interpretation of the costs for the economy arising from the marginal cost is complex. The additional costs for the economic agents arising from that marginal cost are recycled in the domestic economy and in the EU, in the form of additional purchases of goods and services. Their distributional economic consequences are important, but in any case they cannot be interpreted as losses at the macro-economic level.

A marginal abatement cost curve is obtained by varying the level of the global (system) emission constraint or equivalently the level of the carbon tax. Then the curve shows the level of the marginal system cost as a function of the tons of CO2 abated in 2010 (or as a function of the emission reduction percentage with respect to the emission level of the base year, that is 1990).

The average system cost of CO2 emission reduction can be obtained at the system level by dividing the integral of the marginal abatement cost curve by the cumulative tons of CO2 abated, that is $AC(Q) = \int_0^Q MC(q) \cdot dq$ where Q denotes the tons of CO2 abated and MC is the marginal cost curve.

The concept of the average system cost is difficult to understand at the macro-economic level. This concept is more meaningless in engineering-oriented studies, for example a project analysis, in which the average cost can be obtained from the total cost of a project that needs to be minimised. At the level of a project, when an additional constraint is added, as for example an environmental constraint, then the total cost will be increased, in comparison with the cost corresponding to the baseline solution. This is also true at the global level of an economic system. For example, if the global economic problem is written as a global minimisation one, then again an additional environmental constraint will imply higher total system cost, then a positive average cost per unit of pollution abated. But, when the economic system evolves decentralised economic agents that are competing each other, then the determination of an average cost at the level of each agent is not necessarily positive, any more. An additional environmental constraint will imply for some agents to be losers but may for example imply for some other to be winners. Especially under circumstances involving economies of scale and non marginal cost pricing, such a situation can occur.

From a modelling point of view, to compute average costs at the level of decentralised agents, one needs to explicitly represent the cost-minimisation objective function for each economic agent. This is the case of the energy model PRIMES, which follows a mixed-complementarity approach that ensures that the algebraic systems representing demand or supply behaviour are formally derived from an optimisation problem defined at the level of each agent. Again, we note that one cannot guarantee positive average costs (per unit of pollution abated) for all agents. The energy model MIDAS uses reduced-form econometric functions for the demand side, that are not necessarily integrable to reproduce the primal optimisation problem of the agent. Therefore, it is not possible to compute the average cost per agent with MIDAS. On the contrary, one can compute average costs per agent with the GEM-E3 model, as this uses demand functions formally derived from the decentralised optimisation problems. However, the average costs from GEM-E3 include all indirect and general equilibrium effects, that are of course absent in an energy system partial equilibrium model. Therefore, when computing with GEM-E3, there are more chances to obtain negative average costs (per unit of pollution abated) for some agents, as these are identified to be the winners from the new allocative equilibrium.

2.2. Sectoral and country allocation of abatement effort

The analysis presented in this note applies a global system constraint regarding CO2 emissions in 2010. Then the analysis assumes that the model will allocate effort to the sectors and agents to globally meet the target. Based on the logic of each model, this allocation of effort will be optimal. As the models follow the complementarity approach, the result correspond to the new market equilibrium, either partial or global equilibrium depending on the model. In any case, this is methodologically equivalent to a result of a global optimisation model in which the allocation of the effort would be determined as a result of the additional environmental constraint.

The same methodology applies when considering allocation of abatement effort to the set of the EU member-states. In the case of the general equilibrium model GEM-E3, this allocation is automatically optimal, since the model computes an EU-wide general economic equilibrium. The energy models (MIDAS and PRIMES) are used separately for each member-country. The optimal allocation of effort can be obtained by equalising the marginal costs of CO2 emission reduction across the member-states at a level that is globally necessary to meet a given target at the level of the EU. The optimality of this result is limited by the fact that the structure of exports and imports of energy, mainly electricity, is not affected by the additional environmental constraint.

The equality of the marginal abatement costs across the EU member-states is of course one of the possible policy making criteria. This is the only one used in the present analysis. Other criteria could radically change the allocation by country. For example, one could include macro-economic costs regarding growth potential (cohesion countries, for example), unemployment, etc., or security of supply considerations and credits for past performance in terms of CO2 emissions.

2.3. The baseline scenario

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. All three models, MIDAS, PRIMES and GEM-E3, have ran under similar assumptions to quantify the pre-Kyoto scenario. It has been taken care to project a similar evolution for energy and the CO2 emissions, with all three models.

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 co-generation of heat and power. All these policies and trends lead, already in the baseline, to relatively limited growth of primary energy consumption and CO2 emissions. For example, as shown in Table 1 the overall energy intensity improves at an average rate of -1.5% per year, which is beyond the historical average. In the power generation sector, the scenario projects a spectacular growth of the use of gas and a substantial increase of cogeneration and (at a less degree) renewables.

Table 1 : 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

As shown in Table 2 the change of emissions by country differ substantially. The cohesion countries increase their emissions considerably, while mature industrial economies show more moderate emission increases. Only Germany decreases emissions in 2010 (from 1990), as a result of the unification. In Sweden, the high growth of emissions is due to a phase-out of nuclear stations.

The last column of Table 2 shows the distribution of effort as agreed in the pre-Kyoto period at the Council. The comparison between the target and the baseline projection shows a large difference.

Table 2 : CO_2 Emissions per Country

	pre-Kyoto scenario				pre-Kyoto target
	1990	1995	2010	% change from 1990	
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%**

The target set for the EU at the Kyoto conference, that is -8% of emission reduction in 2010, leads to a need to avoid the emission of about 514 Mtn of CO2 in 2010, which represents -15% from the emissions in 2010 according to the baseline scenario.

3. Results from the MIDAS model

The MIDAS model has been used to construct a marginal abatement cost curve for CO2. Each point at the curve is obtained by running the model, separately for each EU member-state, by applying a uniform and pure carbon tax level, measured in terms of ECU'90 per ton of Carbon emitted. A set of discrete points of the curve is built by varying the level of the carbon tax from 0 to 400 ECU/tnC by using a step of 50 ECU.

Table 3 : MIDAS results in % of CO2 reduction in 2010 from 1990

	MIDAS: Marginal Cost of CO2 reduction in 2010, in ECU'90/ton of Carbon						
	0	50	100	200	300	350	400
AU	4.5%	0.9%	-1.0%	-3.9%	-6.3%	-7.4%	-8.4%
BE	18.8%	10.9%	4.9%	-5.5%	-15.0%	-19.5%	-23.9%
DN	9.6%	2.0%	-3.6%	-13.3%	-22.0%	-26.1%	-30.1%
FI	36.9%	30.2%	25.6%	17.7%	10.7%	7.4%	4.3%
FR	5.9%	1.9%	-0.3%	-3.8%	-6.6%	-7.9%	-9.1%
GE	-8.8%	-12.5%	-14.5%	-17.7%	-20.2%	-21.4%	-22.4%
GR	43.7%	34.6%	27.5%	14.6%	2.8%	-2.8%	-8.4%
IR	24.9%	19.7%	16.5%	11.3%	6.8%	4.8%	2.8%
IT	18.3%	13.5%	10.6%	6.0%	2.2%	0.4%	-1.3%
NL	23.5%	19.7%	17.6%	14.4%	11.7%	10.5%	9.4%
PO	55.9%	51.3%	48.6%	44.3%	40.6%	39.0%	37.4%
SP	38.0%	33.2%	30.3%	25.7%	21.8%	20.1%	18.4%
SV	31.2%	26.1%	22.9%	17.6%	13.2%	11.1%	9.1%
UK	1.4%	-2.4%	-4.4%	-7.5%	-10.1%	-11.2%	-12.3%
EU-14	**8.1%**	**3.7%**	**1.1%**	**-3.1%**	**-6.6%**	**-8.2%**	**-9.8%**

The above Table 3 shows the emission reduction per country (in 2010 from the level of 1990) as corresponding to different levels of the carbon tax. As explained in a previous section, the level of the carbon tax is equivalent to the level of the marginal abatement cost associated to a given emission reduction constraint per country. Therefore, this table provides a classification of the emission reduction targets per country for equal and uniform levels of the marginal abatement cost (across countries). In this sense, Table 3 provides the optimal (in terms of marginal costs) allocation of effort across the EU member-states.

According to the MIDAS results, to reach the Kyoto agreement of -8% reduction in 2010 from 1990, the EU will face (per year) a marginal abatement cost of about 350 ECU per ton of avoided carbon. By comparing the corresponding column of Table 3 with the last column of Table 2, one can see that the optimal (according to MIDAS) allocation is substantially different from the pre-Kyoto decisions for some few countries.

The marginal abatement cost curve is shown below:

Figure 1 : Marginal abatement cost curve with MIDAS

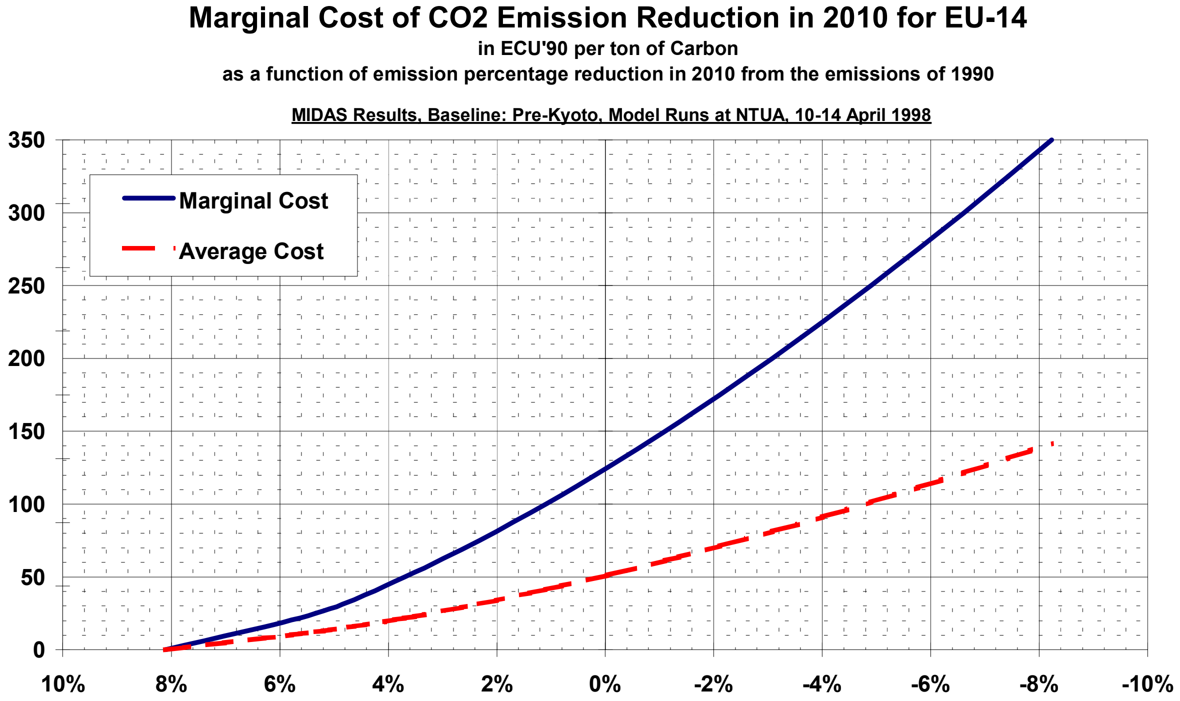


Figure 1 also shows the average cost curve at the global system level. The average cost for the EU of reaching the Kyoto agreement is estimated, according to MIDAS, at 137 ECU per ton of Carbon avoided[1], leading to an amount of 19 billion ECU, or about 0.3% of the EU's GDP in 2010.

We must note that in all the scenario runs with MIDAS, we keep the same assumptions as in the pre-Kyoto baseline scenario. For example, we do not allow the possibility to the model to expand nuclear generation capacities, beyond the level of the baseline scenario (except for France, which however is not found to expand nuclear beyond the baseline). Also, the results show that the additional, from the baseline, needs for natural gas are small, since the gains in energy efficiency compensate the changes in the fuel mix. Renewables and cogeneration increase their contribution, but the progress is not spectacular, as there is no additional assumption about economies of scale or other type of cost-reducing technical progress in these technologies. The results in terms of CO2 emission reduction are largely attributable to gains in energy efficiency in the demand-side, and secondarily to changes in the fuel mix of power generation.

---

[1] The -8% target involves abatement of 514 Mtn of CO2 or 140 Mtn of Carbon.

The MIDAS model uses econometrically estimated logit demand functions. Based on the results we estimate that the average (overall) price elasticity of the system is about -0.15 to -0.20. The logit functions do not have constant elasticities, as these depend on the degree of approaching the saturation level. For example, if a fuel mix has already approached a saturation level (for example in favour of a particular fuel) in the baseline, the price-elasticity to move further in the fuel mix is generally small, while if the fuel mix shows equal distribution between the competing fuels, the price-elasticity is high. The power and steam generation models, in MIDAS, operate in a way that is equivalent to optimisation models, but also take into account an overall reliability constraint. However, in the present model runs, we have not allowed for full flexibility in the power sector, as at some degree fuel or technology obligations may have been restrictive in some countries.

4. Results from the GEM-E3 model

The exercise with the general equilibrium model GEM-E3 has been organised in a similar way. A marginal abatement cost curve is constructed by running the model for a set of global (EU) emission reduction targets. The marginal cost is obtained as the dual variable of the emission constraint (in the sense of mixed complementarity). The emission constraint is imposed at the EU level, and the model computes the simultaneous optimal allocation of the effort among the sectors and the EU member-states.

The following Table 4 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 4 : 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

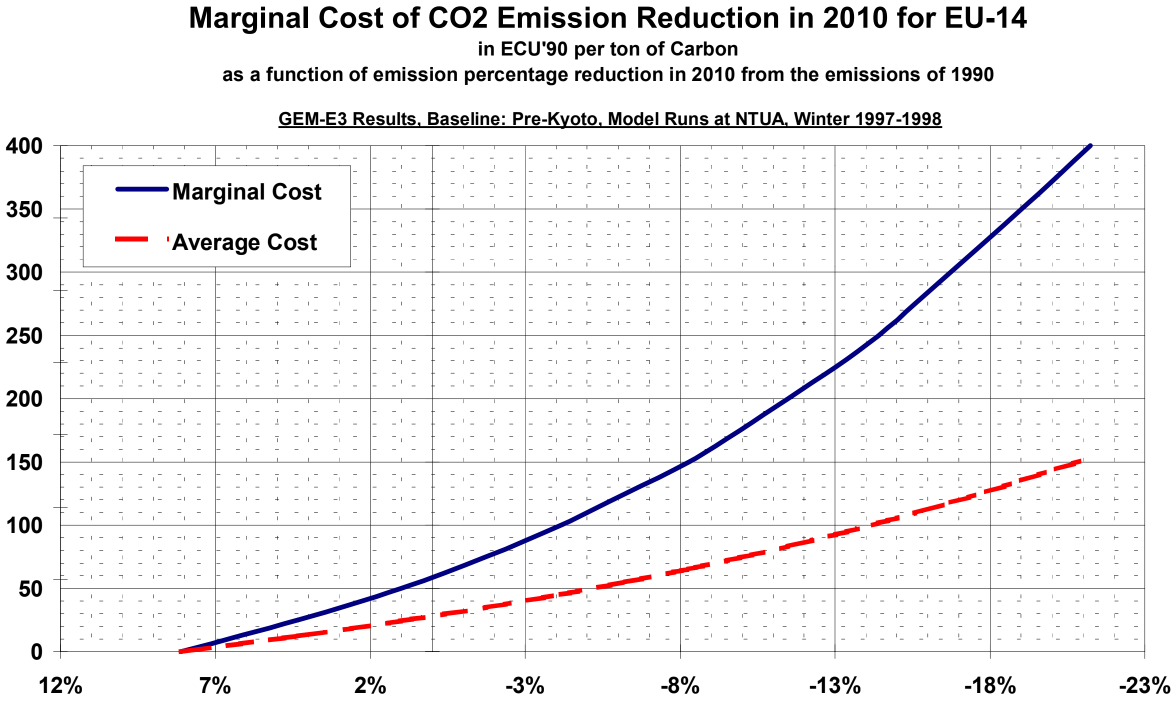
	0	50	100	150	200	300	350
AU	4.5%	-2.7%	-8.0%	-12.1%	-15.3%	-20.6%	-22.9%
BE	18.8%	7.7%	0.2%	-5.3%	-9.3%	-15.6%	-18.3%
DK	9.6%	1.9%	-3.5%	-7.7%	-10.9%	-16.1%	-18.3%
FI	36.8%	26.1%	18.7%	12.9%	8.5%	1.3%	-1.7%
FR	5.9%	-0.3%	-4.7%	-8.2%	-10.9%	-15.4%	-17.4%
GE	-8.8%	-13.9%	-17.9%	-21.3%	-24.0%	-28.4%	-30.3%
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%**

According to the results of GEM-E3, the -8% target for the EU as agreed at Kyoto, implies a global marginal abatement cost of about 145 ECU'90 per ton of avoided emissions of Carbon.

At that level, the global average cost of the EU is found, according to Gem-E3, to be equal to 65 ECU'90/tnC, which corresponds to 9 billion ECU, or 0.13% of the EU's GDP in 2010.

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

Figure 2: Marginal abatement cost curve with GEM-E3



The following Table 5 shows a decomposition of the average costs by sector, according to the results of GEM-E3. The table presents only the results corresponding to the target of -8% emission reduction in 2010 from 1990.

Table 5 : GEM-E3 results on average costs per sector for the -8% target

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

	Industry	Services	transports	Power sector	Households
AU	102	35	123	57	355
BE	54	47	211	37	273
DK	250	58	75	55	115
FI	183	29	108	53	178
FR	58	25	116	24	201
GE	174	11	186	51	210
GR	88	15	43	18	70
IR	47	20	128	24	245
IT	64	28	70	44	197
NL	125	32	232	37	225
PO	79	26	67	48	138
SP	81	12	118	41	91
SV	104	15	49	22	139
UK	194	33	45	37	260
EU-14	**117**	**26**	**101**	**40**	**199**

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.

The transport sector aggregates costs of the column of the Input-Output table corresponding to transports (in fact the professional transport activities) and the costs of the households for cars and public transport. The industry sector aggregates 6 sectors of the model, while the services aggregate the model's service sectors, construction and agriculture. Finally, the households sector includes only costs for heating and electric appliances in the houses.

The table shows that the cost of the environmental constraint affects primarily the households and the industrial sector. Power generation meets the allocated (by the model) target at relatively low costs. The sector of services gain from additional activity addressed to the corresponding sectors, so their final costs are found to be low.

5. Results from the PRIMES model

As mentioned before, we reproduce in this section the results of the energy PRIMES model version 1 as used in October 1997. The baseline run is again based on the pre-Kyoto scenario. The evaluation of the marginal and average cost curves is made by successively applying an additional environmental constraint. The model computes the corresponding marginal abatement cost and the optimal allocation to the sectors.

The PRIMES model version 1 has been used only for 8 EU member-states, namely Germany, France, Italy, UK, Spain, Belgium, Netherlands, Sweden. These countries represent about 90% of CO2 emissions of the EU-15.

The optimal allocation of effort to the EU member-states is such that the EU-8 have to make more effort than -8%, so as to allow the EU-14 to reach the global target. Based on the results of GEM-E3 and MIDAS, we estimate that EU-8 has to abate about 450 Mtn of CO2 in 2010, which corresponds to -9.8% of emission reduction from the EU-8 level of 1990.

The PRIMES model version 1 has estimated that the marginal cost for such a reduction target is about 110 ECU'90/tn of Carbon. The allocation by country (EU-8) is shown in Table 6:

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%**

Considered by column, the table indicates the optimal allocation of emission reduction effort among the EU-8 countries, for a given overall reduction target (last line) and the corresponding marginal cost (first line).

The PRIMES model allows for the computation of the total system cost per sector. By dividing the additional sectoral system cost implied by the environmental constraint with the amount of emissions avoided, we compute the average cost per sector. As the environmental constraint is imposed at the national system level, the sectoral allocation might involve different average costs per sector. In the PRIMES version 1 model runs of October 1997, there has been an additional exogenous assumption regarding car technologies, consisting in accepting the introduction of a 5 lt/100 km car only in the CO2 reduction scenario. As the additional capital cost is low (15%) in comparison with the fuel savings (35%), the existence of the new car technology involves negative costs (gains) for transports in the environmental constrained scenario. It has not been possible, for the present note, to run again the PRIMES model with different assumptions about transports. In the runs with the other models (MIDAS and GEM-E3) this exogenous assumption about the car technology has not been introduced in the environmental constrained scenario, as these models use different concepts to model the reaction of the transport sector to the environmental constraint.

The average costs by sector, as computed by PRIMES version 1, corresponding to the emission target of -9.8% for EU-8, are given in the following table:

Table 7 : Average costs per sector, PRIMESv1

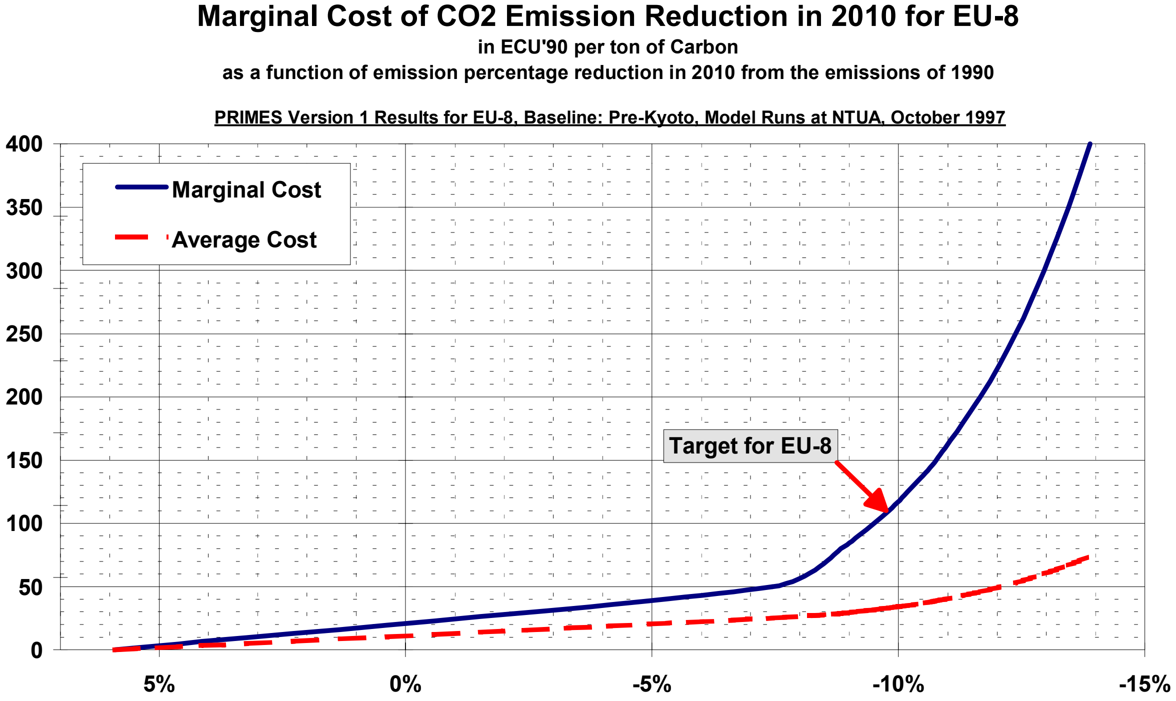
PRIMESv1: Average Cost of CO2 reduction in 2010, in ECU'90/ton of Carbon

	Industry	Services	transports	Power sector	Households
EU-8	73	26	-105	25	142

Table 7 shows higher costs for households and industry, and significant lower costs for services and power generation.

The marginal cost and the overall average cost curves for EU-8 are plotted against different levels of the environmental constraint in 2010.

Figure 3: Marginal abatement cost curve with PRIMESv1



In Figure 3 the marginal and average costs for the target for EU-8 should be seen at the point -9.8%. At that point the marginal cost is 110 ECU’90/tnC and the average cost is equal to 33 ECU’90 per ton of Carbon, which corresponds to about 4 billion ECUs, or less than 0.1% of the EU-8’s GDP in 2010.

The same figure shows that 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.

The PRIMES model allows for a computation of the contribution of different energy domains to the overall target. The following table provides this information, as extrapolated from the October’97 results of PRIMES to the level of the current target for EU-8.

The last column of the table provides our estimate about the level of the cost associated with each energy domain. Although the direct engineering cost per unit is known through the inputs to the model, the cost per energy domain in a scenario is conceptually difficult to estimate. As a matter of fact, this cost depends on the order and the magnitude of measures that the scenario will activate to reach the target. For each level of target, all measures and all sectors contribute, even a little, to environmental reduction. It is not then easy to isolate each measure and provide a cost estimate at the level of the system.

Table 8 : Contribution by energy domain

PRIMESv1: Contribution of sectoral measures

	in Mtn CO2 avoided	in %	cost indicator
Heavy Industry - Processes	66	15.0%	medium
Electric Appliances	26	6.0%	low
Cars	145	33.0%	low
Buildings	7	1.5%	high
Renewables			
- intermittent	28	6.4%	high
- biomass and waste	51	11.6%	medium
Power Generation			
- fuel mix	86	19.5%	low
- cogeneration	31	7.0%	medium
TOTAL Mtn CO2 avoided in 2010	**440**		

6. Concluding Remarks

The following table presents the allocation by country as obtained with the three models and compares to the allocation decided in the Council of 3.3.97.

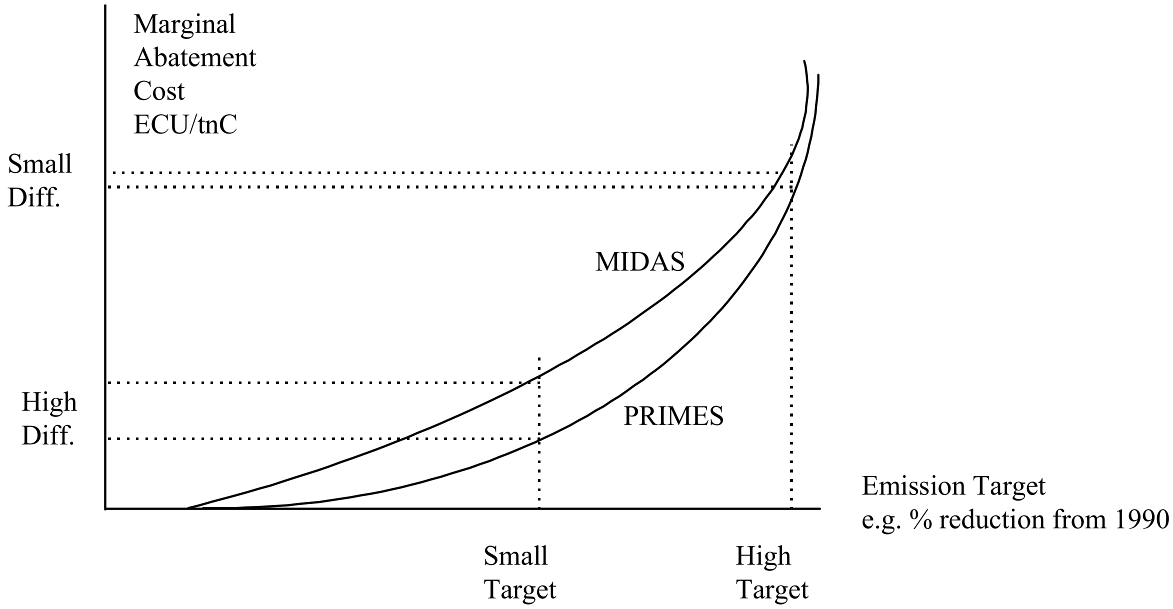
Table 9 : Optimal Allocation per country according to the models

	GEM-E3	MIDAS	PRIMESv1	Council 3.3.97
AU	-12.1%	-7.4%	NA	-25.0%
BE	-5.3%	-19.5%	-7.3%	-10.0%
DN	-7.7%	-26.1%	NA	-25.0%
FI	12.9%	7.4%	NA	0.0%
FR	-8.2%	-7.9%	-2.2%	0.0%
GE	-21.3%	-21.4%	-23.5%	-25.0%
GR	15.1%	-2.8%	NA	30.0%
IR	1.0%	4.8%	NA	15.0%
IT	0.8%	0.4%	-4.3%	-7.0%
NL	9.1%	10.5%	1.7%	-10.0%
PO	34.2%	39.0%	NA	43.0%
SP	15.5%	20.1%	16.7%	17.0%
SV	13.7%	11.1%	16.3%	5.0%
UK	-16.0%	-11.2%	-10.4%	-1.0%
EU-14	**-8.3%**	**-8.2%**	**-9.8%**	**-10.0%**

The marginal costs as estimated by the models differ substantially. This should be attributed to the different algebraic structure of the models. The GEM-E3 and the MIDAS models use algebraic demand functions for the evaluation of demand on each disaggregated use or sector. Although these functions have complex algebraic forms with varying price-elasticities, however they behave rather smoothly. This explains why the marginal cost curves from these two models, even though nonlinear, have a slowly increasing gradient. On the contrary, the PRIMES model shows a steeply increasing marginal cost curve, in other terms a highly increasing gradient, at least in a range. This is associated to the fact that PRIMES does almost linear optimisation in the demand and supply sides, at least for the initial range of increasing environmental constraint. Therefore, the model immediately exploits all low cost opportunities even when a small CO2 emission constraint is imposed. After some limit, along with imposing stricter emission constraint, the model behaves nonlinearly and can then use only high cost options. This behaviour would be correct if in reality such a low cost potential actually exists.

The following graphic illustrates this explanation:

Figure 4 : Illustration to explain differences



At a small emission target, a model like PRIMES that accepts the existence of a low cost potential that can be easily exploited will show a lower marginal abatement cost, compared to a model that assumes smooth substituability (like MIDAS) independently of the level of the emission constraint. At such a small target, the differences in the model results may be big, while the two models may converge at a high emission target.

Of course the uncertainty regards the assertion about the existence of a low cost potential exploitable even at a small emission target. This issue will be further investigated with the new PRIMES model.