Int. J. Global Energy Issues, Vol. 14, Nos. 1-4, 2000 169

Kyoto and technology at the European Union: costs of emission reduction under flexibility mechanisms and technology progress

Pantelis Capros and Leonidas Mantzos

Department of Electrical Engineering, National Technical University of Athens, 9 Iroon Politechniou Str., Zografou Campus, GR-157 73, Athens, Greece. E-mail: kapros@central.ntua.gr

Abstract: This paper presents the analysis of the consequences of CO_2 emission reduction policies, as derived, in a European Union perspective, from the Kyoto Protocol for the 2010 horizon. The first section provides a thorough assessment, based on the PRIMES model results, of the marginal and total costs of compliance to the Kyoto Protocol for a 'no trading' case and for two cases of emission trading, respectively at Annex B level and at world level. The second section deals with the importance of technical change both in the demand and the supply side for the achievement of the Kyoto emission reduction targets. Finally, the paper concludes with the key messages of the analysis.

Keywords: CO_2 emission reduction; Kyoto Protocol; marginal abatement costs; flexibility mechanisms; emission trading; technology change; European Union.

Reference to this paper should be made as follows: Capros, P. and Mantzos, L. (2000) 'Kyoto and technology at the European Union: costs of emission reduction under flexibility mechanisms and technology progress', *Int. J. Global Energy Issues,* Vol. 14, Nos. 1-4, pp. 169-183.

Biographical notes: Pantelis Capros is a Professor of Energy Economics and Operation Research at the Department of Electrical and Computer Engineering of the National Technical University of Athens. He is a member of the Board of Directors of the Greek Public Corporation. Prof. Capros holds an engineering degree from NTUA, 3 DEAs in Economics, Informatics and Operations Research from ENSAE, University of Dauphine, Paris and a Doctorat d'Etat in mathematical Economics from University Pierre et Marie Curie, Paris. He has widely published (more than 100 publications) and conducted research programmes in the areas of Energy Modelling, Macro-Economics, Operations Research and Mathematical Programming. He has built and used a variety of large-scale mathematical models. He has more than 15 years professional experience of consultancy in the domain of energy and economic policy.

Leonidas Mantzos holds an engineering degree and a Ph.D. degree in Energy Economics and Modelling from the National Technical University of Athens. He has been a senior researcher at ICCS-NTUA since 1998. He has 10 years experience in energy modelling, in particular in the construction and running of the MIDAS energy model for all European countries and the market equilibrium energy model PRIMES. He participated as main researcher in several energy analysis projects of the European Commission.

1 The cost for Europe of meeting Kyoto targets under different flexibility schemes

1.1 Introduction

Three CO_2 emission reduction scenarios, reflecting different flexibility schemes, have been examined using the PRIMES model in order to estimate the likely degree of difficulty and possible energy system impacts of imposing restrictions on the amount of CO_2 emissions that the EU energy system will be allowed to emit in 2010. It is assumed that the obligation about the basket of greenhouse gases under the Kyoto agreement applies equally to energy-related carbon dioxide emissions and the rest of greenhouse gases. Therefore the EU energy system should emit 2823 $MtCO_2$ in 2010 (-8% from 1990 levels).

In all scenarios considered the PRIMES analysis assumes full flexibility adjustment within the European Union member-states. The carbon constraints have been applied as global constraints treating the EU energy system as one economic system without any *a priori* allocation of emissions reductions to any sector, fuel or country. The only criterion used was that of economic efficiency. The methodology adopted was similar to that of a EU wide carbon permit trading scheme.

The dual price associated with the global emission constraint signifies the marginal abatement cost. It can be also interpreted as an equilibrium permit price, balancing demand and supply for emission rights under a hypothetical auctioneering regime. The term ‘carbon value’ is also used to denote the dual price associated with the global emission constraint. In mixed-complementarity terms, economic agents perceive a carbon value as a carbon tax, however no tax revenues are generated.

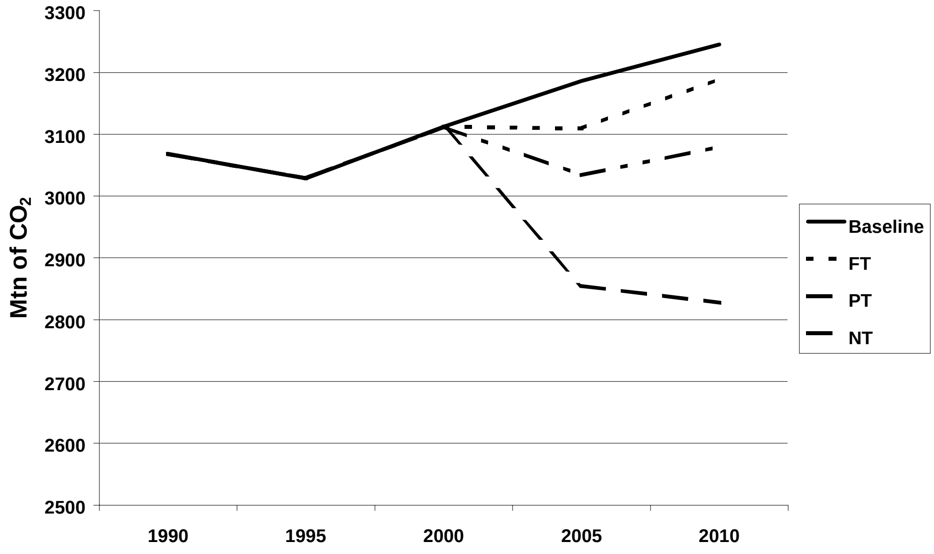
1.2 Definition of scenarios for PRIMES

The scenarios constructed with PRIMES cover the European Union. To study different emission trading schemes it is necessary to consider trading with non-European regions. For this purpose the analysis with PRIMES has been coordinated with similar analysis carried out by using the POLES world energy model. The two models have been first synchronised in building the baseline cases: energy prices from POLES have been used by PRIMES. Then a stepwise procedure has been followed to synchronise emission reduction scenarios. The POLES model first estimated the permit prices that were derived for three cases: full trading, Annex B countries trading and no trading conditions [1]. For the trading cases, the construction of emission reduction scenarios with PRIMES started from assuming the POLES’ permit prices as given.

However, the comparison of marginal abatement costs as generated by the two models for the European Union under the no trading case revealed differences between the PRIMES and POLES models. This led to a redefinition of the level of the marginal abatement carbon costs (permit prices) used in PRIMES as compared to the level generated by POLES.

The achievement of the Kyoto target with the POLES model requires a permit price of 135.8 $90 (or 107 Eur’90) per ton of carbon avoided while the corresponding value in the PRIMES model is 138 Eur’90 per ton of carbon avoided. It was assumed that the difference between the permit prices required in the two models so as to achieve the same target expresses the differences of the model structures and that the corresponding correction factor in terms of permit prices (1.29 which roughly corresponds to the exchange rate in 1990 between dollar and Euro) can act as a calibration parameter between the two models**.** Under this assumption, the correction factor of 1.29 has been applied to the permit prices obtained from the POLES model for the full trading and the Annex B trading flexibility schemes. The corrected permit prices were those used for the analysis of the different flexibility schemes with the PRIMES model.

Figure 1 EU emissions under baseline and the three scenarios



Source: PRIMES

The three scenarios analytically examined for the European Union and presented in this paper are as follows (see Figure 1, Table 1):

- NT or no trade scenario: in this scenario no trading of CO_2 emissions with countries outside the EU is permitted. CO_2 emissions amount to around 2825 $MtCO_2$ in 2010, reflecting a reduction of 8% from the level of emissions in 1990. The emissions avoided compared to baseline in 2010 reach 420 $MtCO_2$, a reduction of just under 13% [2];
- PT scenario: this scenario represents a situation where only partial trade (PT) of CO_2 emissions is allowed, i.e. only between Annex B countries. The carbon value imposed leads almost to the stabilisation of emissions for the EU in 2010 at around 3080 $MtCO_2$ (a 12 $MtCO_2$ increase from 1990 and 166 $MtCO_2$ less than in the baseline). Other Annex B countries sell to the EU permits equivalent to 257 $MtCO_2$ in order for the EU to achieve the Kyoto target;
- FT scenario: a full trade (FT) flexibility scheme is allowed in this scenario hypothetically involving all regions of the world. Meeting the Kyoto target for the EU energy system becomes possible mainly through purchasing of pollution permits

from the rest of the world. CO_2 emissions in the EU increase by 4% in 2010 compared to 1990, reaching 3189 $MtCO_2$ (56 $MtCO_2$ less than the baseline). Permits for 367 $MtCO_2$ are purchased from countries outside the EU so as to achieve the Kyoto target in 2010.

Table 1 Baseline and sensitivities emissions 1990, 2010

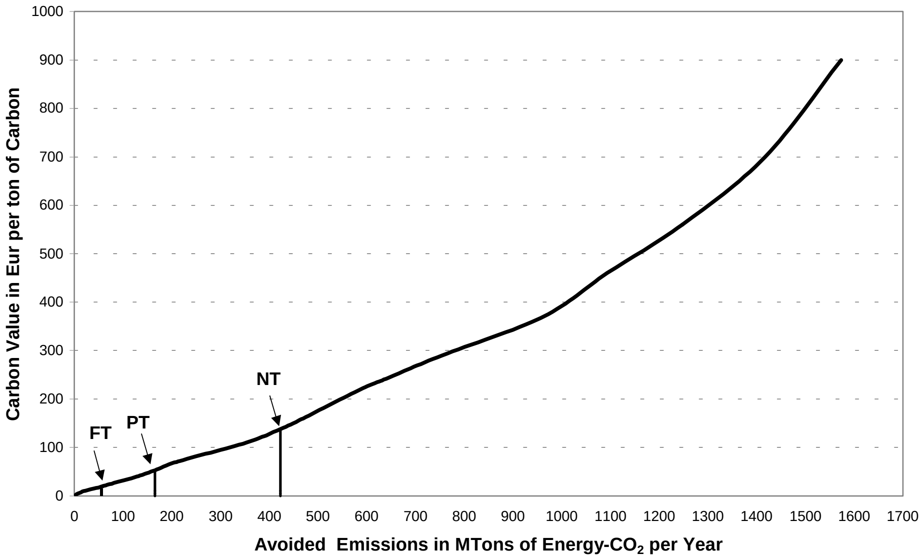
	1990	**2010**			
		Baseline	**FT**	**PT**	**NT**
CO_2 Emissions (Mtn CO_2)	3068	3245	3189	3080	2827
Reduction from Baseline (Mtn CO_2)			-56	-166	-418
% of 1990 level		106	104	100	92
Carbon value (EUR'90/tn of Carbon avoided)			19	53	138

Source: PRIMES

The achievement of the Kyoto target for the EU under the full trading flexibility scheme requires a carbon value of 19 Eur in 2010 (all carbon values are given in terms of 1990 Eur per ton of carbon avoided). The carbon values for scenarios PT (trading with Annex B countries) and NT (no trading outside the EU) are 53 Eur and 138 Eur respectively.

The model provides simultaneous estimations of the marginal cost of avoided emissions and of the energy system costs of these changes, by sector and member-state. Following a least cost methodology, the marginal costs plotted against the varying levels of emission reduction, in other words, the model-based marginal abatement cost curves, can be used as a basis for defining the sharing of the emission reduction effort by country and by sector.

Figure 2 Carbon values and CO_2 emissions avoided compared to baseline, 2010



Source: PRIMES

Figure 2 illustrates the marginal abatement cost curve for the EU energy system in 2010 and the targets for the three examined scenarios, as derived from the PRIMES model. The area bounded by the target, the marginal abatement cost curve and the horizontal axis represents the total abatement cost in order to meet the target.

As can be seen there is a tendency for carbon values to increase non linearly as the emissions target becomes more severe. In other words, beyond a certain level of emissions reduction, for each additional ton of carbon reduction the cost increases disproportionately. The issue of non-linear costs in incremental reductions in CO_2 emissions has been discussed in [3], in greater detail.

1.3 Energy system impacts

The economic system can respond to the imposition of the carbon constraint, while assumed to maintain the same level of GDP, either by reducing the energy intensity and/or by changing the fuel-mix to reduce the carbon intensity.

Table 2, presents these two effects for each of the three carbon constraints examined for the EU as a whole and for the period to 2010. It can be seen that in all three scenarios under consideration nearly half of the overall reduction in emissions is achieved through a reduction in energy consumption. For example, under the PT scenario, emissions are about 5.1% less than in the baseline while primary energy demand has declined by only 2.7% from its baseline level. Thus, for the level of adjustment difficulties implied by the three scenarios, it seems that at the margin it is as difficult for the system to reduce overall energy demand as it is to change the mix in primary fuels. The latter effect is, of course, somewhat weakened by the assumption that nuclear power generation will not be allowed to increase beyond the level assumed in the baseline irrespective of any carbon constraint imposed on the system.

Table 2 Primary fuels and CO_2 emissions in the four scenarios

	1990	**2010**	**%Difference from baseline in 2010**		
		Baseline	**FT**	**PT**	**NT**
Gross Inland Consumption (Mtoe)	**1313**	**1524**	**-0.8%**	**-2.7%**	**-6.9%**
Solid Fuels	301	191	-1.9%	-7.5%	-22.2%
Liquid Fuels	543	633	-2.1%	-4.4%	-10.9%
Natural Gas	222	394	-0.1%	-2.6%	-4.4%
Nuclear	181	216	0.3%	2.3%	4.1%
Electricity	2	2	-1.1%	-2.8%	-5.7%
Renewable Energy Sources	64	88	4.2%	6.6%	17.4%
Total CO_2 (Mtn CO_2)	**3068**	**3245**	**-1.7%**	**-5.1%**	**-12.9%**

Source: PRIMES

By far the most significant effect in terms of primary energy fuels is the decline of solid fuel consumption, which falls not only because of the overall fall in energy consumption, but also because its use is replaced by less carbon intensive fuels. The reverse effect operates on nuclear (through higher utilisation rates of installed capacities) and renewable energy forms both of which increase by 2010, compared to their consumption level under baseline assumptions. The modest negative effect on natural gas and, secondarily, liquid fuels, is due mostly to a small reduction in overall demand rather than to substitution.

In terms of changes in final consumption, the reduction in demand accounts for about two thirds of the overall reduction in emissions originating from adjustments in final energy (see Table 3).

Table 3 Impact on final demand by sector

	1990	2010	%Difference from baseline in 2010		
		Baseline	FT	PT	NT
Total Energy (Mtoe)	**852**	**1037**	**-1.0%**	**-3.2%**	**-7.4%**
Industry	257	281	-0.9%	-2.4%	-5.4%
Tertiary	110	152	-1.8%	-7.2%	-14.1%
Household	232	263	-0.9%	-2.5%	-6.0%
Transports	253	341	-0.8%	-2.7%	-7.1%
CO_2 Emissions (Mtn CO_2)	**1800**	**2001**	**-1.6%**	**-4.6%**	**-10.7%**
Industry	424	376	-2.4%	-5.9%	-12.3%
Tertiary	193	212	-4.5%	-12.8%	-26.6%
Household	447	429	-1.5%	-3.8%	-9.6%
Transports	735	984	-0.8%	-2.7%	-7.2%

Source: PRIMES

The contribution of energy and carbon intensity improvement in the different demand sectors is not homogenous. Reduction of emissions in industry and tertiary is achieved through energy intensity improvement, which contributes around 50%, as well as changes in the fuel mix. In households the reduction in demand accounts for just under two thirds of sectoral reduction in emissions, while in transport the reduction in demand accounts for almost 100% of emissions reduction. Table 4 summarises the improvement of energy intensity indicators for the different demand sectors:

Table 4 Energy intensity improvement in the demand side

indicator (1995=100)	1995	2010			
		Baseline	FT	PT	NT
Industry (production related)					
iron and steel	100.0	88.5	87.0	84.6	80.9
non ferrous metals	100.0	83.0	82.7	82.6	82.3
chemicals	100.0	82.2	81.5	80.2	78.2
building materials	100.0	98.0	97.8	97.5	96.7
paper and pulp	100.0	94.1	93.8	93.2	91.7
food drink tobacco	100.0	97.6	97.1	96.4	94.7
engineering	100.0	96.9	96.4	95.6	93.3
textiles	100.0	97.5	97.0	96.1	94.4
other	100.0	97.1	96.8	96.1	94.3
Tertiary (value added related)	100.0	82.3	80.8	76.4	70.7
Households (income related)	100.0	78.4	77.7	76.4	73.7
Transport					
passenger (income related)	100.0	89.0	88.4	87.3	83.3
goods (GDP related)	100.0	84.6	83.8	81.0	77.2

Source: PRIMES

In industry most of emission reduction comes from restructuring of industrial processes (e.g. more electric arc processing, more recycling of materials, etc.). Energy intensity improvement ranges from up to 7.5% in iron and steel industries (NT scenario) to less than 1% in non ferrous metals production (NT scenario), compared to baseline in 2010, reflecting the different levels of exploitation of sectoral restructuring and technological potentials. Improved electrical technologies and heat pumps seem to be attractive and cost-effective options. Consequently, although demand in industry decreases below demand sectors' average levels, emissions decrease at higher levels than demand sectors decrease.

The tertiary sector, which was the fastest growing sector both in terms of energy and emissions in the baseline scenario, seems to have large possibilities for emission reduction both through adopting more efficient electric appliances and through reducing thermal needs by improving building construction. Energy intensity improves by up to 30% (NT scenario) from 1995, in comparison to 18% improvement observed in the baseline.

The household sector seems to exhibit strong inertia to the introduction of carbon values. As a result, emissions in the household sector decrease below demand sectors' average values. One of the main factors leading to this result is the high penetration of electricity, in combination with significant efficiency improvement for electric appliances, already achieved in the baseline scenario.

The most noticeable changes in the transport sector concern trains and aircraft. In both cases, the average efficiency progresses, but trains gain market share while air transport loses. The effects in the road sector mainly concern behavioural changes in car purchasing and use rather than in car technology itself. While energy intensity exhibits very moderate improvement in FT and PT scenarios, both for passenger and goods transport, in the case of the NT scenario this improvement reaches 6% for passenger and 7.5% for goods transport additional to that of baseline for 2010. High emission reduction constraints are necessary to enable further significant technology change in the transport sector.

The power and steam generation system of the EU appears to be the sector that can adjust in the most cost-effective way to emission reductions. It is partly because the power and steam generation system is more flexible in the reduction of emissions and that its output does not declines as sharply as that of other forms of final energy. Electricity and steam consumption decline by less than 40% the amount of reduction in other fuels in scenarios FT to NT. There are many reasons for this flexibility of the generation system. Firstly, since nearly half of electricity generation takes place with the use of carbon free primary fuels, such as hydro and nuclear, a 1% reduction in emissions in the system can take place with only half as much reduction in output. Only generation through fossil fuels needs to be reduced. Secondly, generation through carbon free fuels can actually increase although this is not allowed to a significant extent, by assumption, in the case of nuclear power. Thirdly, the system can respond by increasing its overall efficiency of generation through fossil fuels. This can be achieved by adopting improvements in the technology used, through alternative combinations of technologies and fuels, such as the use of gas-turbine combined cycle as opposed to thermal coal plant, or through changes in the allocation of the available plants in the merit order. Finally, the generation system can improve its overall efficiency by increasing the degree of co-generation of steam and electricity.

The operation of at least some of the above mechanisms can be seen in Table 5, where a sharp difference can be seen to exist between the decline in the system's output and fossil fuel inputs. In all three scenarios examined the decline in inputs is multiple to the corresponding decline in electricity and steam output for 2010. For example, in NT, electricity and steam generation in 2010 is 2.6% below its level in the baseline scenario while the corresponding generation inputs are 11% below their baseline level.

Table 5 Impacts on power and steam generation, energy and emissions, 2010

	1995	**2010**	**%Difference from baseline in 2010**		
		Baseline	**FT**	**PT**	**NT**
Electricity and steam output (TWh)	**3376**	**4289**	**-0.1%**	**-1.5%**	**-2.6%**
Nuclear	810	851	0%	2%	4%
Hydro and Renewables	294	353	5%	-2%	16%
Total CO_2 (Mtn CO_2)	**1220**	**1244**	**-1.9%**	**-5.9%**	**-16.3%**
Electricity and steam	1162	1201	-1.9%	-6.0%	-16.6%
Energy sector	59	43	-1.7%	-4.0%	-8.8%
Fossil fuel inputs in electricity and steam generation	**365**	**416**	**-1.0%**	**-3.7%**	**-11.0%**
of which			**%**		
Solids	47%	34%	35%	34%	30%
Gas	23%	40%	41%	41%	46%
Biomass/Waste	6%	8%	8%	9%	11%
Efficiency rates of Electricity and steam generation	0.54	0.64	0.65	0.65	0.68
% of CHP in steam generation	45.7%	62.5%	62.5%	62.5%	62.5%
% of total CO_2 reduction by Electricity and steam			39.9%	43.3%	47.7%

Source: PRIMES

The flexibility of the power and steam generation sector to respond to carbon constraints is shown most dramatically by the changes achieved in emissions. In the NT scenario, for every 1% reduction in generation output there is a seven-fold decline in CO_2 emissions. Thus, by reducing electricity and steam generation by just 2.6%, the generation system reduces its emissions by 16.6% and this accounts for almost half of the overall system reduction in emissions in order to reach the carbon constraint. This reduction is achieved through improved efficiency, increase in non fossil fuels generation and changes in the generation fuel mix.

Renewable energies and nuclear expand as a result of the imposition of the carbon constraints. The use of renewable energy forms expands substantially while the effect of nuclear is limited to the higher utilisation of existing plants. Similarly, the improvement in efficiency of generation in the three scenarios only accounts for a modest part of the reduction in emissions while the share of co-generated steam from thermal plants remains rather stable. Significant changes occur in the generation fuel mix. The use of natural gas and biomass/waste increase by up to 6 and 3 % units, respectively, in NT scenario, compared to baseline scenario in 2010. This substitution occurs to the detriment of solids (loss of a market share of 4% from baseline) and liquid fuels.

The mechanisms described above lead to the improvement of energy and carbon intensity in the European energy system (see Table 6). The stricter the emission reduction target, the greater the improvement. There is also an improvement regarding the EU energy import dependency, which from around 55% in 2010 in the baseline scenario declines by up to 5 percentage points in the NT scenario.

Table 6 Impacts on main energy system indicators, 2010

	1995	2010	%Difference from baseline in 2010		
		Baseline	FT	PT	NT
Energy intensity (toe/MEUR90)	240.2	186.1	-0.8%	-2.7%	-6.9%
Carbon intensity (tn CO_2/toe)	2.2	2.1	-0.9%	-2.4%	-6.5%
Import dependency (%)	46.4	54.8	-0.7%	-1.9%	-4.7%

Source: PRIMES

1.4 Cost of CO_2 emission reduction

Under the three different flexibility schemes examined, the European energy system has to achieve a different level of emission reduction from within the EU and, consequently, faces different costs.

Table 7 summarises the way in which the Kyoto emission reduction target is achieved by the EU energy system and the corresponding costs under the three scenarios.

Table 7 Cost of achieving Kyoto target for EU energy system, 2010

	1990	Kyoto target	2010			
			Baseline	FT	PT	NT
Carbon value (EUR'90/tn of Carbon avoided)				19	53	138
CO_2 Emissions (Mtn CO_2)	3068	2827	3245	3189	3080	2827
of which abated in 2010 within EU				-56	-166	-418
traded from other countries				-362	-253	0
Cost (MEUR'90) of abated emissions				145	1222	7803
traded emissions				1878	3653	0
Total Cost				2023	4874	7803
as % of GDP				0.025%	0.060%	0.095%

Source: PRIMES

In the case that EU should achieve the Kyoto emission reduction target by itself – without being able to buy emission permits from the rest of the world – the amount of CO_2 emissions that should be abated is 418 $MtCO_2$. The corresponding cost reaches 7800 MEur’90 or 0.095% of EU gross domestic product.

Under the PT scenario, when trade with Annex B countries is allowed, the European Union abates around 40% of CO_2 emissions needed to achieve Kyoto target and buys through permits the remaining 253 $MtCO_2$ at a cost of 53 Eur’90 per ton of carbon. As a result, the total cost decreases to 4875 M Eur’90 or 0.06% of EU gross domestic product. The economic gain for the European Union, achieved through trading with other Annex B countries, amounts to 2930 MEur’90.

Under the FT scenario, when trade with all countries is permitted, the EU energy system abates only 56 $MtCO_2$ (around 13.5% of Kyoto target). The bulk of the emissions target is achieved through purchases of 362 $MtCO_2$, at a price of 19 Eur’90 per ton of carbon. The cost of attaining the Kyoto target drops to around 2000 MEur’90 or 0.025% of EU gross domestic product, which is 5780 MEur’90 less than the cost under the NT scenario.

1.5 The impact of non-CO_2 greenhouse gases

The uncertainty surrounding non-CO_2 GHG emissions is comparable to that of CO_2. Given the variety of sources of non energy related GHG emissions it could be even argued that the non-CO_2 GHG emissions outlook is even more uncertain than that of CO_2 originating from the burning of fossil fuels. Table 8 presents some views on the outlook for 2010 of non-CO_2 emissions. The figures presented in the table are preliminary and are based on information provided within the studies that actually prepare the 6th Environmental Plan of the European Commission. It is important, however, to note that these figures are based on a very large number of assumptions, some of which have a weak basis. Consequently, they are meant to be only indicative of likely developments and they are provided in order to highlight some of the issues that arise. The most significant among non-CO_2 GHGs is methane, the biggest source of which is agriculture. Changes in the structure of agriculture in the EU are expected to lead to a decline of methane emissions in the period to 2010.

Table 8 Projections of non-CO_2 greenhouse gases and required changes in CO_2 emissions for EU, 2010

Mtn of CO_2 equivalent	**2010**		
	Baseline	**With measures**	**Max economic potential**
CH_4	446.0	337.8	274.1
N_2O	341.6	262.2	221.5
HGs	93.4	77.5	45.8
Total non-CO_2 GHGs	881.0	677.5	541.5
Total GHGs (under baseline for CO_2)	4126.4	3922.9	3786.9
Required % reduction compared to 1990 (Kyoto target)	-8.00		
Required % CO_2 change compared to 1990	-10.6	-4.0	0.4

Source: NTUA estimates based on a number of sources, PRIMES model

Under a baseline estimate, which assumes that no effort is undertaken so as to reduce emissions, total non CO_2 GHGs emissions are expected to show a very small increase, of less than 2%, over the period to 2010. The undertaking of a series of relatively simple and inexpensive measures of reducing these emissions, some of which have already been announced, will lead to a decline of non-CO_2 GHGs by more than 20% between 1990 and 2010. Finally, the Table also includes an even lower estimate for 2010 as regards non-CO_2 GHGs emissions, which is based on the assumption that maximum economic potential measures will be implemented over the period to 2010.

The Kyoto target requires that GHGs emissions should decline by 2010 to a level that is 8% below their level in 1990 for the European Union. The determination of policy measures as regards the achievement of this target for total GHGs is highly related to developments in non-CO_2 GHGs. In the case that the maximum reduction possible was to be reached for non-CO_2 GHGs in 2010, a simple stabilisation of CO_2 emissions would be sufficient to reach the Kyoto target. In the contrary, if ‘baseline’ non-CO_2 emissions were to be accepted for 2010, a CO_2 emissions reduction of more than 10% would be required in the EU energy system so as to achieve the Kyoto target.

2 Value of technology change in the EU

The European energy system exhibits, under baseline conditions, significant improvement in terms of both energy and carbon intensity [2]. Energy intensity improves by around 22.5% in 2010 compared to 1995. Over the same time period carbon intensity improves by about 5%.

There are many interrelated factors behind the significant evolution of energy intensity in the baseline scenario:

- The trend towards the dematerialisation of European economies, responsible for the declining share of industry in GDP;
- The structural shift towards less energy intensive energy uses, especially in industry;
- Changes in the fuel mix; and
- Technical progress, both in the demand and supply side.

In order to have an estimate of the significance of technical progress for the evolution of the European energy system in the period to 2010, a sensitivity analysis was run using the PRIMES model. The sensitivity, named hereafter as the 'frozen technology' scenario, was based on the assumption that no technological evolution will occur in the period to 2010. All other types of improvement of the energy system, i.e. structural shifts, changes in the fuel mix etc., were not restricted.

2.1 Comparison of the 'frozen technology' to the baseline scenario for 2010

The lack of technical change leads to important changes, compared to baseline scenario, in 2010. Table 9 provides the key results for the 'frozen technology' scenario in comparison to baseline.

Table 9 The 'frozen technology' scenario, 2010

	1995	**2010**		
		Baseline	**Frozen technology**	**% Difference from baseline**
Gross Inland Consumption (Mtoe)	1363	1524	1609	5.6%
Fossil fuel inputs in electricity and steam generation (Mtoe)	365	416	455	9.2%
Electricity and steam output (TWh)	3376	4289	4452	3.8%
Final energy demand (Mtoe)	885	1037	1083	4.4%
Total CO_2 (Mtn CO_2)	3029	3245	3467	6.8%
Energy intensity (toe/MEUR90)	240.2	186.1	196.4	5.6%
Carbon intensity (tn CO_2/toe)	2.2	2.1	2.2	1.2%
Import dependency (%)	46.4	54.8	56.5	1.7%

Source: PRIMES

Total CO_2 emissions increase by 13% from 1990 compared to 5.8% in the baseline. In 2010, gross inland consumption is 5.6% higher than in the baseline, while final energy demand and fossil fuel input in electricity and steam generations are, respectively, 4.4% and 9.2% higher. Electricity and steam output is only 3.8% higher than in the baseline since the lack of technical change inhibits the shift towards their use, as observed in the baseline scenario.

Energy intensity improves by less than 20%, compared to 22.5% in the baseline. Carbon intensity remains stable at 1990 levels and import dependency increases to reach 56.5%.

At the sectoral level, sectors that do not have significant potential regarding structural changes and changes in the fuel mix are the more heavily affected (see Table 10).

Table 10 Energy intensity improvement under the 'frozen technology' scenario, 2010

indicator (1995=100)	1995	2010	
		Baseline	**Frozen technology**
Industry (production related)			
iron and steel	100.0	88.5	91.1
non ferrous metals	100.0	83.0	89.8
chemicals	100.0	82.2	85.4
building materials	100.0	98.0	99.5
paper and pulp	100.0	94.1	96.4
food drink tobacco	100.0	97.6	99.9
engineering	100.0	96.9	99.7
textiles	100.0	97.5	100.0
other	100.0	97.1	99.3
Tertiary (value added related)	100.0	82.3	87.2
Households (income related)	100.0	78.4	82.2
Transport			
passenger (income related)	100.0	89.0	93.9
goods (GDP related)	100.0	84.6	86.7
Efficiency rate of electricity and steam generation	100.0	83.2	87.5

Source: PRIMES

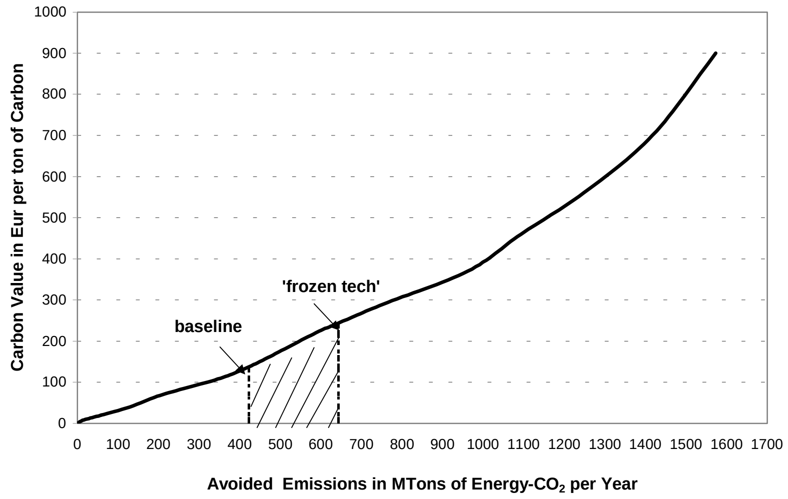
The efficiency rate of electricity and steam improves, in a more moderate manner compared to baseline. This improvement is mainly achieved through greater utilisation of non fossil fuels and changes in the fuel mix.

2.2 Meeting targets with and without technical change

The lack of technical change results in increased CO_2 emissions in 2010 by 220 $MtCO_2$. As illustrated in Figure 3, the achievement of the Kyoto target under no trading conditions becomes much more difficult in the case of the 'frozen technology' scenario compared to baseline with technical change. The corresponding carbon value increases from 138

Eur’90 in the baseline to 244 Eur’90 per ton of carbon avoided in the ‘frozen technology’ scenario.

Figure 3 Carbon values and CO_2 emissions avoided compared to baseline 2010



Source: PRIMES

The area bounded by the marginal abatement cost curves, the two targets and the horizontal axis represents the additional cost required to achieve the Kyoto target in the absence of technical change. This cost is defined here as the ‘value of technical change’ achieved in the baseline scenario as regards the achievement of the Kyoto target. This value is equal to 11580 MEur’90 or 0.14% of European Union gross domestic product. Thus, the value of technical change achieved in the baseline scenario is around 50% higher than the additional system cost required for the achievement of the Kyoto target under no trading conditions (7800 MEur’90 or 0.095% of EU gross domestic product) with technical change.

Table 11 Additional cost of achieving the Kyoto target for the EU energy system under frozen technology assumption, 2010

	1990	Kyoto target	2010 under frozen technology			
			Frozen technology	**FT**	**PT**	**NT**
Carbon value (EUR'90/tn of Carbon avoided)				19	53	138
CO_2 Emissions (Mtn CO_2)	3068	2827	3467	3404	3313	3242
of which abated in 2010 within EU				-62	-153	-225
baseline technical change effect				-221	-221	-221
traded from other countries				-356	-265	-194
Additional trade of CO_2 emissions (Mtn CO_2)				7	-12	-194
Cost (MEUR'90) of additional trading				-34	177	7288
as % of GDP				0.000%	0.002%	0.089%

Source: PRIMES

Table 11 summarises the results obtained from the sensitivity analysis made for the three CO_2 emission reduction scenarios in the absence of technical change. By assuming that the lack of technical change is, as in the case of the ‘frozen technology’ scenario, responsible for additional emissions of 221 $MtCO_2$ in 2010, the cost of the additional purchase of pollution permits so as to satisfy the Kyoto target is considered to express the value of technical change for each of the scenarios examined.

In the full trade scenario without technical change 62.5 $MtCO_2$ are abated in 2010 within the EU, 6.5 $MtCO_2$ more than in the full trade scenario with technical change. Purchase of pollution permits decreases by the equivalent number resulting in a profit of 34 MEur’90. In other words, at the level of full trade scenario the additional to the baseline role of technical change is negative.

Under the ‘frozen technology’ assumption, abated emissions inside the EU reach 153 $MtCO_2$ in 2010 in the case of trading of pollution permits between Annex B countries. The EU, in comparison to the corresponding scenario with technical change, should purchase 12 additional $MtCO_2$. Assuming that the purchase price of pollution permits remains stable at 53 Eur’90 per ton of carbon, the lack of technical change leads to an additional cost of 177 MEur’90 or 0.002% of EU gross domestic product.

The role of technical change is much more important in the case that EU should achieve the Kyoto emission reduction target by itself. In the absence of technical change and for the same carbon value as in the Kyoto target under the no trading condition scenario, the EU energy system abates only 225 $MtCO_2$ in 2010. In this case 194 $MtCO_2$ are missing in order to meet the Kyoto target. Making the assumption that this quantity can be purchased through pollution permits at the price of 138 Eur’90 per ton of carbon, the corresponding, additional to the baseline, value of technical change reaches 7288 MEur’90 or 0.09% of EU gross domestic product. Of course, the additional demand for permits coming from the EU would push permit prices upwards and would lead to even higher value for technology progress.

The above-described findings further signify the role of technology improvement in the context of the baseline scenario to 2010. Under the full trading and the Annex B countries trading flexibility schemes the additional role of technical change is rather limited. However, additional technical change becomes very important if the EU must satisfy the Kyoto emission reduction target by itself. In this case the value of technical change has an equal level of magnitude to the cost of achieving the Kyoto target.

3 Conclusions

The findings from the analysis of the EU energy system confirm the significance of international flexibility in the achievement of the Kyoto target [1]. The cost of achieving the Kyoto target drops by almost 75% in the case of full trading compared to the no trading case for the European Union. This occurs to the detriment of technology improvement. However, the analysis showed that the technical progress that occurs even in the absence of any emission reduction target in the period to 2010 for the EU energy system, is of great importance for the limitation of EU emissions and its realisation should be ensured. The cost savings resulting from this technical progress are 1.5 times higher than the cost required for achieving the Kyoto target in the absence of trading mechanisms.

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