The role of Kyoto mechanisms: results from MARKAL analyses[1]

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Abstract

This paper provides an overview of recent insights from MARKAL modelling activities at ECN. The models have been extended in order to cover the full spectrum of Kyoto mechanisms. Using varying new modelling approaches the bottom-up MARKAL type models can provide new insights regarding optimal policy selection. The goal of this paper is to provide an overview of the methodology and the results. The analysis indicates that non-CO_2 GHG emission reduction is a key strategy for emission reduction representing 25% of the total EU emission reduction in the Kyoto period. The bulk of non-CO_2 emissions is not energy related. Agriculture is an important source of non-CO_2 emissions. Forestry is important because of the carbon storage potential and the potential to produce renewable biomass. The calculations show that greenhouse gas emission reduction may well have significant impacts on agriculture and forestry on the long term. MARKAL studies for non-EU countries allow the identification of important strategies and key projects for CDM (Clean Development Mechanism) and JI (Joint Implementation). If all Kyoto mechanisms and all reduction potentials can be used, the global equilibrium price of emission credits can be as low as 3 – 8 EUR/t CO_2 eq. (excluding transaction costs and assuming an ideal market). If non-CO_2 reduction options are excluded the equilibrium price of CO_2 emission credits will be significantly higher, up to 15 EUR/t. The inclusion of non-CO_2 gases will increase the annual global trade in emission credits from 1.4 Gt to 1.9 Gt in the Kyoto period. Non-Annex 1 countries may benefit from important secondary benefits of GHG emission reduction, for example an improvement of the local air quality. However the relevance of such benefits should not be overestimated, given cheap competing end-of-pipe technologies.

New insights regarding carbon leakage and regarding regional economic impacts of GHG policies have been obtained by applying a MARKAL type global sector model for the petrochemical industry. The calculations suggest that despite the significant technological potential to reduce emissions, an ambitious global GHG policy will affect the industry location selection in favour of developing countries. The extent of relocation of Western European industries is approximately twice as high in case non-Annex 1 countries are not included in future GHG policies for this industry sector. Finally the optimal selection of policy instruments has been investigated. Policies aiming for a long term target of 50% emission reduction based on generic pricing instruments can reduce costs for Western Europe by as much as 150 billion EUR per year in 2030, compared to policies with ambitious regulation and exclusion of exposed sectors.

1. Introduction

This paper provides an overview of recent insights from MARKAL modelling activities at ECN. In recent years the models have been extended in order to cover the full spectrum of Kyoto mechanisms. Using varying new analysis approaches, the bottom-up MARKAL type models based on detailed data regarding the techno-economic characteristics of emission reduction potentials provide additional insights regarding optimal policy selection. The goal of this paper is to provide an overview of the methodology and the results. The MARKAL model features are not discussed, see e.g. (ETSAP 2000).

The following issues are discussed from a Western European policy perspective:

- The impact of non-CO_2 greenhouse gases, land use change and afforestation (GHGs);

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- The potential of JI and CDM;
- Emission reduction potentials in exposed sectors;
- The optimal selection of policy instruments.

These topics have emerged from the Kyoto protocol. They are complex issues that extend beyond traditional energy systems modelling. One model is not able to handle all these questions. For this reason, an alternative approach has been selected. The databases and the results from the existing family of MARKAL models have been used as an ‘expert system’, which has been used to build small, dedicated models to answer specific questions. This flexible approach has proven itself by providing new insights relevant for policy makers. Table 1 presents an overview of the issues that are discussed in this paper, the methodological approaches and the main policy conclusions. These issues are elaborated in Sections 2-6.

Table 1: *Overview of studies discussed in this paper*

	Region	Scope	Approach	New insights	Policy recommendation
Post-Kyoto (Gielen et.al. 1998)	W-Europe	All GHGs	Marginal reduction cost curves from national LP models + extensions	Optimal distribution EU targets	Change distribution or add flexibility
Kyoto mechanisms (Sijm et.al., 2000)	Global	All GHGs	Marginal reduction cost curves from national LP models + extensions	Value global emission credits 3-8 EUR/t CO_2 in 2010	Use JI and CDM wisely
BRED (Gielen et.al., 2000)	W-Europe	All GHGs	Extended Western European MARKAL MATTER energy + materials model	Impact of GHG policies on agriculture/land use quantified; consider materials and afforestation	Possibly funds from agricultural policies can be used for GHG policies
Shanghai (Gielen et.al., 2000)	Shanghai	CO_2, SO_2, NO_x, PM_{10}	Common MARKAL model for Shanghai municipality	Secondary benefits GHG policies of minor importance for strategy selection	Keep the discussion focused on GHG benefits
TOG (Gielen and Pieters, 2000)	W-Europe	All GHGs	Western European MARKAL MATTER energy + materials model	Materials options are important, pricing much more efficient and effective than regulation	Use generic pricing instruments; promote materials efficiency
FREAK (Gielen and Yagita, forthcoming)	Global	Energy/CO_2	New regionalised LP model, using MARKAL database for petrochemical products	Impacts of pricing policies and policy scope on global industry location;	Impacts on industry are substantial. If a generic approach is not possible, develop a dedicated approach for each industry sector

2. The relevance of non-CO_2 GHGs, land use change and afforestation

2.1. *Framework of the analysis*

In March 1997, a differentiated greenhouse gas (GHG) emission reduction agreement was reached within the EU, covering three GHGs (CO_2, CH_4 and N_2O). At COP-3 several additional elements were introduced in the Kyoto protocol. Three new GHGs (PFCs, HFCs and SF_6) and land use change related sinks had been added, and in addition the reduction target for the EU as a whole was changed to -8%. Consequently, the differentiation had to be revisited. The emission reduction targets for individual EU countries were set in Luxembourg in the summer of 1998. The consequences of this target for non-CO_2 GHGs and sinks have been analysed (Gielen and Kram, 1998). Western European conclusions cannot be translated directly to other regions because local emission sources, costs and trends may differ significantly. For this reason, a similar global approach has been elaborated (Sijm et.al. 2000).

A separate study, the BRED project (Biomass for greenhouse gas emission REDuction), has focused on the optimal use of Western European biomass for greenhouse gas emission mitigation on the long term. Afforestation, carbon storage in soils, and the production of materials from biomass have been considered on top of bio-energy. Moreover the competing land use for food and fodder production has been considered in detail.

2.2. Methodology

The data for the European and the global post-Kyoto study are taken from various sources. Emission data, projections and abatement costs for CO_2 are derived from MARKAL studies and similar techno-economic models, with some updates and modifications. Emission data and projections for the other GHGs and the sinks are those presented by EU member states in recent EU discussions. Abatement costs for non-CO_2 GHGs are based on a number of different studies. The BRED study is based on the MARKAL MATTER4.2 model for Western Europe. This model has the special feature of covering both energy and the materials life cycle, showing new strategies for GHG emission reduction (see ETSAP, 2000).

2.3. Results

Currently non-CO_2 GHGs represent 21% of total Western European GHG emissions. They are relevant in the framework of the Kyoto protocol for two reasons. Emissions decrease autonomously for the two other major non-CO_2 GHG emissions, CH_4 and N_2O. A significant potential exists for further emission reductions, if the proper policies are introduced.

The contribution of non-CO_2 GHG emissions will gradually decrease to 18% because of autonomous trends such as coal mine closures and waste policies. Trends differ per emission category: while CH_4 and N_2O emissions decrease, HFC emissions will increase significantly. CH_4 and N_2O represent the bulk of the emissions and remain dominant until 2010 in the autonomous trends.

Figure 1 shows that the contribution of non-CO_2 GHGs is 27% to the total emission reduction in Western Europe in 2010. Important emission reductions are introduced for CH_4 from landfill sites, N_2O from the chemical industry, and substitutes for HFCs.

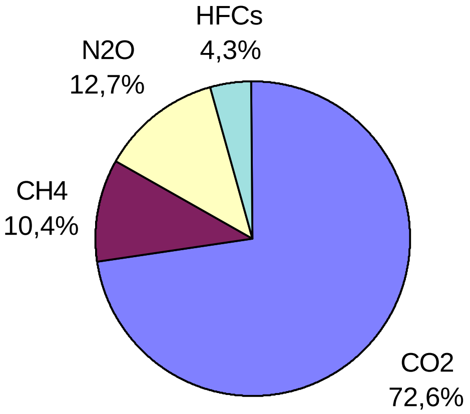

Figure 1: *Contribution of GHGs to 8% emission reduction in 2010, EU-15, based on Luxembourg targets for individual countries (Gielen and Kram, 1998)*

The results show that the inclusion of non-CO_2 GHGs will increase the annual global trade in emission credits from 1.4 Gt to 1.9 Gt CO_2 eq (out of a total emission reduction of 2.4 Gt) (Sijm, 2000). Approximately one quarter of the emission reduction is related to non-CO_2 GHGs in the Western European case, but half of the emission reduction is related to non-CO_2

GHG in the global optimisation case[2]: the relevance of non-energy related GHGs increases. The cost impacts are discussed in Section 3. While absolute cost estimates and projections should be treated with some caution, relative cost levels of the different countries are more robust and comparable with other studies.

The relevance of energy vs. non-energy related emission reduction has been studied in more detail in relation to Western European biomass[3]. The BRED results suggest that up to 30 Mha land can be made available for GHG policies in 2030. However it is cost-effective to use three quarters of this land for afforestation, because sufficient cost-effective biomass applications are lacking. Depending on the GHG policy targets, biomass use ranges from 200 Mt dry matter to 650 Mt dry matter. Biomass is used for transportation fuels and as a feedstock for plastics and other synthetic organic materials. Energy recovery from waste is also relevant. Electricity production from clean biomass is not an attractive strategy because of the large number of cost-effective competing alternatives for emission mitigation in this market. In many cases it is uncertain as of yet which technology will be the best. For this reason it is recommended to apply generic pricing policy instruments instead of regulations that prescribe specific technologies. A clear and reliable long term GHG policy target is recommended in order to facilitate a timely industrial change to appropriate production technologies.

Table 2 shows that the technical potential is significantly higher than the economic potential. The former one is based on bottom-up estimates. The latter one is based on MARKAL MATTER 4.2 calculations. This difference can be attributed to the consideration of competition of land use options, competing emission mitigation options and interactions between emission mitigation options (e.g. increased energy efficiency reduces the potential for emission reduction in energy supply). The results show the importance of taking these factors into account. Neglecting these factors results in an overestimation of the emission reduction potential by a factor three.

Table 2: *The relevance of biomass GHG strategies: techno-economic potentials, 2030*

Strategy	Technological potential[4] [Mt CO_2 eq]	Economic potential[5] [Mt CO_2 eq]
Afforestation/soil carbon	180	150
Carbon storage in products	105	25
Energy substitution	400	100
Materials substitution	500	100
Energy recovery from waste	100	25
Total	1285	400

The economic biomass emission reduction potential of 400 Mt CO_2 eq represents 9% of the 1990 emissions.

3. The relevance of flexible mechanisms

3.1. Framework of the analysis

Given the high cost of GHG emission reduction in Western Europe, there is considerable interest in the use of flexible mechanisms. For example the Dutch government aims for 50% of its targeted emission reduction abroad.

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[2] In case the energy saving options with negative marginal costs are excluded

[3] The bulk of the non-energy related emissions and emission reduction strategies are related to land use, agriculture and forestry

[4] Estimated on the basis of 10 Mha biomass crops, current reference system, not considering costs or interactions

[5] Characterised by the GHG emission mitigation contribution at a permit price of 200 EUR/t CO_2

3.2. Methodology

For the analysis of flexible mechanisms, two approaches have been applied: dedicated MARKAL models for developing countries and regions, and aggregation of such emission abatement curves from such models for global analysis. Detailed bottom-up studies for a number of non-Annex 1 countries. The results that are discussed here focus on a recent study for the municipality of Shanghai (Chen et al., forthcoming).

3.3. Results

The calculations suggest that if all Kyoto mechanisms and all reduction potentials can be used, the equilibrium price of global emission credits will be as low as 3 – 8 EUR/t CO_2 eq. (excluding transaction costs and assuming an ideal market). Consideration of non-CO_2 reduction options decreases the equilibrium price of CO_2 emission credits from 15 to 8 EUR/t (Sijm et.al., 2000).

The case study for the municipality of Shanghai suggests important emission reduction potentials of 39 Mt CO_2 eq in 2010 (a 24% emission reduction), compared to a Dutch national target of 25 Mt foreign emission reduction in 2010 (Gielen and Chen, forthcoming). Reduction of CO_2 emissions can simultaneously reduce local air pollution problems in developing countries. For example SO_2, NO_x and PM_{10} emissions in China are reduced in case energy efficiency is increased or in case natural gas is introduced as a substitute for coal. These reduced emissions can be valued according to the damage reduction (e.g. based on World Bank, 1997). The effects of an introduction of CO_2 credits in Shanghai at a cost level of 15 EUR/t are quantified in Table 3 (this level is in line with the value of emission reduction credits from the global analysis). 42% of the benefits are secondary benefits. If such benefits are accounted for, the emission reduction costs for CO_2 decline significantly. The conclusion can also be reversed: the occurrence of secondary benefits could be used to convince countries such as China that they should accept CDM projects.

Table 3: *Valuation of benefits of CO_2 policies in Shanghai, 2020 (Chen et.al., forthcoming)*

Emission category	Emission reduction [kt/yr]	Relative reduction [%]	Value [EUR/t]	Total benefit [MEUR/yr]	Fraction [%]
CO_2	31,000	16	15	465	58
SO_2	245	24	700	172	21
NO_x	166	15	700	116	14
PM_{10}	20	9	2850	57	7
Total				808	100

However the valuation according to damage reduction is too optimistic. One should account for the fact that comparatively cheap end-of-pipe technologies exist for reduction of SO_2, NO_x and PM_{10} emissions. For example catalytic converters for road vehicles, soot filters for diesel engines, limestone scrubbers for power plants, and selective catalytic reduction for power plants are examples of such technologies which can reduce local air pollutant emissions by more than 90%. The cost level of these technologies is well below the damage cost level. As a consequence, the secondary benefits in Table 3 are somewhat overestimated. MARKAL model calculations for Shanghai suggest that the bulk of local air pollution reduction can be achieved cost-effectively by using end-of-pipe technology. It is recommended to give priority to CO_2 emission reduction benefits in the CDM project evaluation, and to value the reduction of other pollutants at the cost level of end-of-pipe emission reduction technologies.

4. Carbon Leakage

4.1. Framework of the analysis

Carbon leakage is an important argument in the discussion whether certain industries should be exempted from GHG policies. However the discussion of such effects is generally based on economic models using price elasticities (see e.g. Manne and Richels 2000, Bollen and Manders 2000). This approach does not account for the technological options for emission reduction on the long term. In order to analyse if the consideration of such effects is relevant, MARKAL type energy and materials models have been applied. Results from two studies are discussed: one for OECD and another study for MITI, the Japanese Ministry of International Trade and Industry.

4.2. Methodology

The results from the OECD study are based on the Western European MARKAL MATTER3.0 model. This model does not account for changes in foreign trade, but includes a detailed database of technological options for emission mitigation in the life cycle of materials. The FREAK model (FoReign trade Effect Assessment Kit) is a regionalised global model that covers the life cycle of all major petrochemical products ‘from cradle to grave’, including all trade flows between the regions. The FREAK model structure and the technology database have been derived from the MARKAL-MATTER model.

4.3. Results

The model calculations suggest GHG taxes can result in such an increase of production costs that foreign producers not subject to similar policy constraints would outcompete European producers (Gielen and Pieters, 2000). This point is illustrated by the cost increase figures for important commodities in Table 4. The grey areas indicate cost increases in excess of 100 EUR/t product. For 100 EUR/t most commodities can be transported between all continents. Given the increasingly open European markets and the opposition of some developing countries to GHG emission reduction, the threat of carbon leakage is apparent.

Table 4: *Changing prices due to GHG emission taxation, 2030 (Gielen et.al. 2000)*

Product [EURO/t product]	*Base case*	*50 EUR/t*	*100 EUR/t*	*200 EUR/t*
Food				
Beef meat	8385	8610	9380	10050
Chicken meat	2378	2370	2469	2467
Corn	217	210	255	263
Straw	25	25	50	110
Wheat	187	185	229	280
Materials				
Aluminium ingots	2182	2696	3079	3437
Aluminium scrap	1524	1995	2341	2637
Ammonium nitrate	59	73	89	129
Cement	34	71	111	192
Cumene	441	763	989	1353
Soda	111	181	252	311
Steel coils	326	402	436	509
Steel scrap	100	100	118	144
Wood products				
Chemical pulp	550	527	603	801
Demolition wood	-47	-26	-21	64
Energy wood chips	55	63	30	139
Graphic paper	548	604	681	897
Mechanical pulp	147	188	210	234
Particle board	194	227	298	443
Roundwood	59	58	83	110
Sawn timber	149	166	182	297
Waste paper, separately collected	-19	0	5	81

Figure 2 illustrates the effects of GHG policies on the location of the global petrochemical industry. Three cases are shown: no GHG policies, a global taxation and a taxation only in Annex B countries. The model calculations suggest that significant changes in production location can occur, if GHG policies are introduced. Even if the large number of technological options is considered that can be applied for emission reduction, resource availability will affect the location selection, resulting in a decreasing competitive position of Western European producers. Such effects pose a major obstacle for policies that affect materials producing industries. Production in Western Europe could halve, compared to the base case.

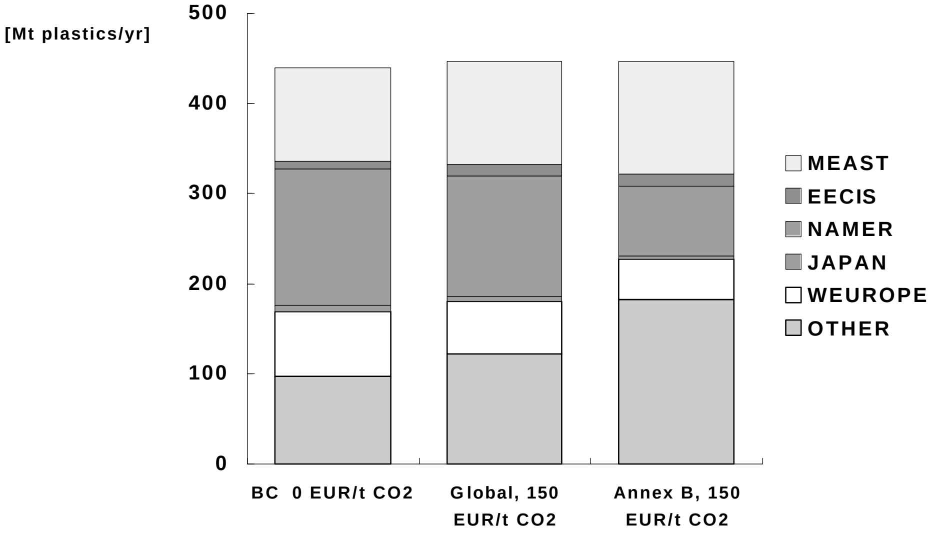

Figure 2: *Changing location of global petrochemical industries caused by GHG emission reduction policies, 2025 (Gielen and Yagita, forthcoming). MEAST=Middle East; EECIS=Eastern Europe and the Community of Independent States; NAMER=North America; WEUROPE=Western Europe.*

Relocation will also affect the CO_2 emission reduction. In case of the global approach, the emission reduction amounts to 564 Mt in 2025. This is an emission reduction of 55% compared to the base case. However in case only the EU, North America and Japan apply the tax, the emission reduction amounts to 179 Mt. An emission reduction of 355 Mt within these countries is balanced by an emission increase of 176 Mt in other region. In case the leakage is defined as the emission increase outside the policy region divided by the emission decrease inside the policy region, the leakage amounts to 179/355*100 = 50%. This result suggests that leakage can be very significant. Off course other factors than costs may decrease leakage rates.

5. Selection of policy instruments

5.1. Framework of the analysis

The OECD TOG study (Technological options for GHG emission mitigation, material flows and policy instruments) explores the potential of many technical options that so far have received little or no attention in policy design and GHG mitigation studies and estimates their possible contribution to GHG emission reductions. In particular many options have been included that relate to the *life cycles of materials* (materials production, use and disposal) as part of the overall set of technical options (Kram, forthcoming). The second important feature of the study is the estimation of the effects of two different policy frameworks on the effectiveness and efficiency of GHG mitigation policies.

5.2. *Methodology*

The MARKAL MATTER 3.0 model has been applied for this analysis. In order to separate out the contribution of the materials options, a distinction has been made between the ‘energy system’ and the ‘materials system’, covering the product life cycle of all energy carriers and all materials respectively. Therefore, the study distinguishes the effects of two ‘policy scopes’. The first is limited to the application of *technical options that belong to the energy system* (E options) *only*. The second includes all technical options, belonging *to either the energy or the materials system* ((E+M) options together).

Under an *‘Ideal-Policy framework’*, it is assumed that policies would lead to equal marginal abatement costs and all technical options are included in the calculations with no additional bounds on the technical options. This policy framework is compared with a *‘Policy-Continuation framework’*. This framework is characterised mainly by avoiding (significant) increases of the costs of products that are traded on world markets (exposed sectors) and the use of some deliberate policy actions to stimulate certain technical options. These policy actions include an increase in renewable energy use to 25% and the reduction of GHG emissions from cars. The condition of no increase in the costs of products of the exposed sectors, mirrors the fears in many countries that these industries would suffer a loss of competitiveness, if they were made subject to the same policies that apply to industries that do not compete on world-markets (sheltered sectors).

The methodology applied in this study — starting from the (chains of) technical options — also allows for the investigation of the interdependencies of GHG emission reduction policies and environmental policies in other areas, such as waste management and resource efficiency. Combining the two different scopes and the two different policy frameworks, four ‘*scenarios’* are compared: E options/ Ideal-Policy framework; (E+M) options/ Ideal-Policy framework (I); E options/ Policy-Continuation framework and (E+M) options/Policy-Continuation framework (C).

5.3. *Results*

The difference in emission reduction between the integrated energy and materials systems calculations (E+M) and the stand-alone energy system calculations (E) can be seen as the contribution of the materials system to emission reduction. In Figure 3, the effects of E and (E+M) options are compared under the Ideal-Policy scenario. Including M technologies results in a significant increase in the effectiveness of GHG emission reduction policies. The effect on costs is even more pronounced, especially for the range of GHG penalties between EUR 50 and EUR 100/tCO_2-equivalent.

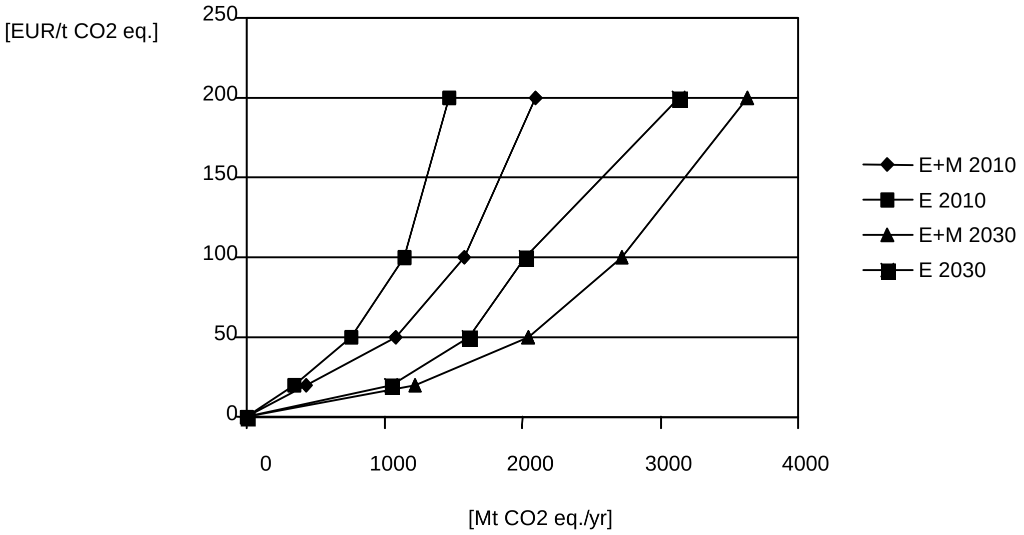

Figure 3: *Marginal cost curves (GHG emission reduction at increasing GHG penalties, 2010 and 2030) for the Ideal-Policy framework, all technical options (I/(E+M)-scenario) and the Ideal-Policy framework, Energy options only (I/(E)-scenario), relative to the base case.*

The study finds very significant gains in effectiveness and efficiency of GHG mitigation policies if policies were to include materials (M) options and ensuring equality of marginal abatement costs. Policies which do so could reduce the total policy costs of achieving the various levels of mitigation that are investigated in this study by roughly 40% (100-150 billion EURO). At lower emission targets, the equalisation of marginal abatement costs causes the bulk of the difference. While at higher emission targets, the policy scope is the main source of cost differences. The GHG penalties (which represent the cost of regulations, or the price of GHG tradable permit, or a tax rate) that are required to achieve the various GHG emission reduction targets vary among the scenarios analysed. The differences between the penalties vary between 25-50% (of the penalty), or 50-100 EUR/tCO_2 equivalent.

Implementing the full range of materials options in the Policy-Continuation framework will generally be extremely difficult because of the pervasive use of most materials (in many different products and processes) and the strong interactions in the materials system, which complicates the selection of optimal options. Competition from foreign materials producers (which may result in changes in the geographical distribution of emissions) complicates the design of any policy that aims at pervasive changes in materials life cycles (see the previous section). It can safely be assumed that M options cannot be brought about under the Policy-Continuation framework, because realising M options implies significant changes in prices, including those of materials traded on world markets. So a Policy-continuation scenario containing (E+M) options (a C/(E+M)-scenario), may *not* be realistic. By contrast, under the assumptions underlying the Ideal-Policy framework, the I/(E)-scenario may not be realistic either, since energy price increases will affect materials prices directly and will provoke substantial GHG emission reduction measures in the materials system. (Note that, in this study, the energy requirements for materials production are part of the materials system.) As a consequence one *could* argue that the real difference between the two policy frameworks, *would best be illustrated by comparing the I/(E+M)-scenario with a C/(E)-scenario*. In Figure 4, the I/(E+M)-scenario is compared with the C1/(E)-scenario. The latter is based on the restrictions of no cost increases in the exposed sectors, minimum share of renewable energy sources in electricity generation, limited land availability for biomass production. It includes transaction cost adders. The gap between these scenarios is very large. Marginal cost for the C/(E) scenario are (more than) twice the marginal cost for the I/(E+M)-scenario (between a reduction of approximately 1500-2700 Mt CO_2 equivalents). In terms of total costs, the effects are still relevant: a difference by as much as 150 billion Euro per year in 2030.

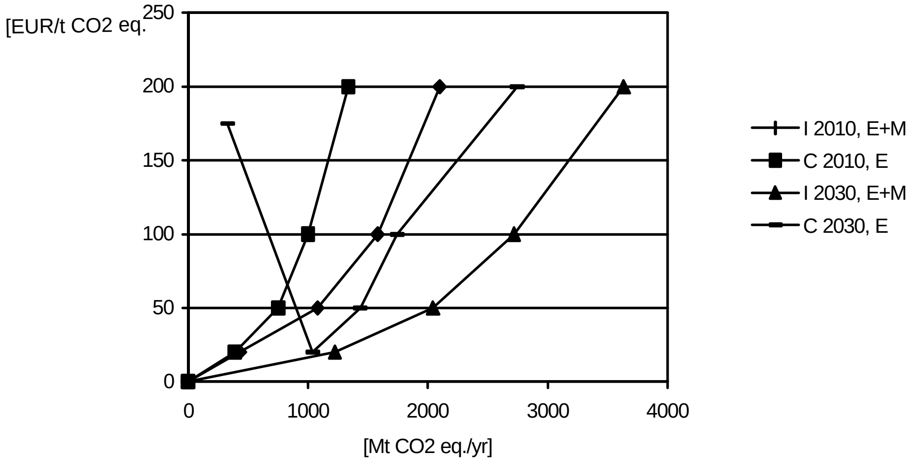

Figure 4: *Marginal cost curves (GHG emission reductions at increasing GHG penalties, 2010,2030) for the Ideal-Policy framework, all technical options (I/(E+M)-scenario) and the Policy-Continuation framework, E-options only (C1/(E)-scenario), relative to the base case*.

The difference between the I/(E+M)/-scenario and the C/(E)-scenario can also be interpreted as mainly the effect of *international co-operation*. After all, international co-operation would allow for relaxing the restriction of 'no price increase for the exposed sector' and would allow for the inclusion of M options —more or less at the same token. The other differences between the I/(E+M)- and C1/(E)-scenarios have a limited effect. The minimum share of renewable energy sources in electricity generation affects the marginal cost curve mainly below a GHG reduction level of less than 1000 Mt CO_2 equivalent, while transaction cost adders have a small effect at all levels

Below reduction levels of approximately 1 000-1 200 Mt CO_2 equivalent/year, the marginal costs of GHG reduction policies for the policy continuation scenario for 2030 exceed by far the level of those for 2010. This because of the high marginal cost of providing 24% of the gross inland energy consumption by using renewable energy sources and reducing the emissions per car kilometre. (Even when assuming steep learning curves as is the case in this study.) These policy objectives are extrapolations of current measures of the European Commission. These measures are assumed to be deployed, regardless of the stringency of the overall GHG emission reduction objective. In (optimal) least cost combinations of technical options they would feature only at high GHG emission reduction targets, much more stringent than the targets set in the Kyoto Protocol. This is not to say that such policies should not be adopted. If in the future, more demanding GHG emission reduction targets prove to be needed, governments should start now to implement all technological options that are needed to meet such a more ambitious objective. Because of the long gestation periods and interdependencies of technical options, starting with least cost combinations of technical options that satisfy low GHG reduction targets, gradually adding more options to satisfy more ambitious targets is a very costly strategy. So the choice is really between the chance that one overshoots (aiming at too ambitious a GHG target), or that one becomes trapped in a costly process of continuously raising GHG reduction targets. Introducing a system of internationally traded GHG-permits might mitigate both types of risks.

6. Conclusions

Substantial improvements in both effectiveness and efficiency of GHG mitigation policies can be achieved if Governments:

1) Take a comprehensive approach in policy application, allowing as many technical options to contribute to GHG emission reductions as possible, including materials options.

2) Set the GHG emission reduction targets to be obtained in the long run, since optimal mixes of (chains of) technical options depend inter alia on the levels of GHG emission reduction targets. This would also give business more time to adjust practices to achieve the long-term targets.

3) Strive for equality of marginal GHG mitigation costs across all sectors of the economy and across countries, including those sectors that produce for world markets. (This may be facilitated through more international co-operation).

4) Strive for integrating GHG mitigation strategies with other environmental policies (notably regarding waste and resource productivity), as well as integrating them with other (non-environmental) policies.

5) Are very prudent in pursuing policies that deliberately stimulate certain technologies (especially if they are relatively costly in terms of money spent per ton of GHG emission reduction), allowing businesses to choose the most cost-effective options to respond to a certain level of GHG penalty instead.

The introduction of GHG taxes will affect the structure and location choice of the global industry significantly. The impacts depend on the scope of the policies and they depend on the emission accounting regime. For example in case of global taxes, impacts on the production structure for polymers and impacts on the global trade in intermediate petrochemicals are limited, and up to 58% emission reduction can be achieved. In case the industrialised countries introduce taxes while no taxes are introduced in the other regions, production shifts to the developing countries and production in industrialised nations declines by 35-40%, despite the significant technological potential to reduce emissions. A 50% leakage rate has been estimated for the petrochemical industry. These results show that global policy co-ordination is essential. In case such co-ordination proves to be infeasible, a detailed dedicated approach per industry sector is recommended on order to avoid major detrimental effects.

The analyses have shown the relevance of non-CO_2 GHGs, land use change and afforestation for the Kyoto protocol and beyond for Western Europe and for the world. Non-CO_2 GHG emission reduction is a key strategy for emission reduction, both in Western Europe and globally. In the Kyoto period it can constitute up to 25% of the total EU emission reduction. Globally the relevance of non-CO_2 GHGs may increase up to 50% of the total emission reduction. The bulk of non-CO_2 emissions is not energy related. Agriculture is the main source of non-CO_2 GHGs. The calculations show that on the longer term, greenhouse gas emission reduction will have significant impacts on agriculture and forestry. European agricultural policies should take such impacts into account. In fact, a lot of the agricultural subsidies could be used for GHG policies.

The calculations suggest that if all flexible mechanisms and all reduction potentials can be used, the equilibrium price of emission credits will be as low as 3 – 8 EUR/t CO_2 eq. (excluding transaction costs and assuming an ideal market). If non-CO_2 reduction options are excluded the equilibrium price of CO_2 emission credits will be significantly higher, up to 15 EUR/t. The inclusion of non-CO_2 gases will increase the trade in emission credits from 1.4 Gt to 1.9 Gt.

This overview shows how the MARKAL type models can be applied in order to provide new insights for policy making. Instead of using one inert model, the MARKAL framework and the databases are used as an expert system, using elements from the input and/or results in order to generate dedicated smaller dedicated models which can be used to answer clearly formulated policy research questions. This has proven to be a successful approach that will be continued.

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