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Analysis of Post-2012 Climate Policy Scenarios with Limited Participation

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Analysis of Post-2012 Climate Policy Scenarios with Limited Participation

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This document presents part of the modelling work conducted by DG JRC/IPTS as a contribution to the DG ENV Communication on post-2012 climate policy analysis. The authors wish to acknowledge the numerous comments and suggestions made by participants of the inter-service European Commission consultation process, particularly P. Zapfel (DG ENV), and of an IPTS seminar, particularly C. Böhringer (ZEW), N. Kouvaritakis (NTUA), D. van Regemorter (KUL), K. Ruffing (OECD), and our colleagues L. Delgado and A. Soria. The ideas expressed in this document are those of the authors and do not necessarily represent views of the European Commission.

Table of Contents

Executive Summary

As a basis for the consideration of medium and longer term emission reduction strategies, the European Council asked the Commission to analyse the costs and the benefits of post-2012 actions to mitigate climate change, taking into account both their environmental and economic consequences. The Commission's Communication on Action on Climate Change Post-2012, "Winning the Battle against Global Climate Change" (European Commission, 2005), was its response to that request, and it drew upon a number of quantitative studies.

The "Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025" report, by Criqui *et al.* (2003), explores possible climate regimes and greenhouse gas (GHG) reduction targets up to the 2025 time horizon, given certain greenhouse gas stabilisation targets. The economic implications of various countries' full or increasing participation in international climate policy architectures is analysed using two partial equilibrium models (POLES and IMAGE-TIMER) and one general equilibrium model (GEM-E3).

DG JRC/IPTS has carried out an analysis of additional climate policy scenarios, using the POLES and GEM-E3 models of the Criqui *et al.* (2003) report. These are large-scale numerical models of the global energy and economic systems, respectively. This document presents the analysis of those scenarios.

Methodology

The two models have complementary characteristics. The POLES model is a partial equilibrium model of the global energy system, with a technologically detailed characterisation of the energy transformation sectors and energy intensive industries. GEM-E3 is a world multi-region, multi-sectoral computable general equilibrium model, suitable for the analysis of the interactions between all the sectors in the economy.

In a partial equilibrium energy model a GHG emission constraint leads to a series of adjustments, basically through fuel substitution and changes in energy-related technologies. The direct cost of the carbon reduction policy can be calculated. In a general equilibrium setup an emission constraint triggers adjustment not only through changes in the relative prices of production factors and commodities, but also through changes in business activity or revenues, therefore taking indirect costs into account.

Scenarios

The three scenarios analysed are based on differing hypotheses of limited participation up until 2025. All the scenarios assume that the countries that have ratified the Kyoto Protocol will meet their targets. In the *Annex I freeze* scenario the Annex I countries would keep the absolute Kyoto emission target to the year 2025. This implies that by 2025 the EU reduces emissions to 8% below the 1990 level, *i.e.* maintaining emissions after 2012 at the level set in the Kyoto Protocol. Also the US after 2012 stabilises absolute emissions at the level resulting from compliance with its intensity target in 2012. It is assumed that the project-based flexibility mechanisms of the Kyoto Protocol, JI and CDM, are available beyond 2012.

Under the other two scenarios the EU region is the only region actively controlling emissions beyond 2012, and no other countries take on commitments. In the *EU freeze* scenario the EU reduces emissions as in the *Annex I freeze* scenario. In the *EU reduce* scenario the EU reduces emissions by 2025 to 20% below the 1990 level. In both scenarios two alternative cases are analysed assuming the presence or else the non availability of JI and CDM beyond 2012.

Assumptions

Several assumptions were made in the analysis, following those of the Criqui *et al.* (2003) report. Firstly, the emission permits are initially allocated for free following historical emission levels. Secondly, the JI/CDM instruments are simulated as if there were a global emissions trading market, and it is assumed that there are no transaction costs. Three other assumptions are specific to the general equilibrium model: the revenues arising from emissions trading are recycled into the economy by distributing them (through direct transfers) to disposable income for households; the current account balance of the less developed countries is fixed to the reference case level; and, capital is mobile across sectors within a country, but not between countries.

Results

The marginal and total abatement costs were computed using both models. The results of the POLES model show that the marginal abatement costs are much higher in the scenarios without JI/CDM. In the scenarios with JI/CDM the share of domestic action in the EU is between 35% in the Annex I freeze scenario and 10% in the *EU freeze* and *EU* *reduce* scenarios. For the 2012-2025 period the average abatement costs compared to GDP is in the range of 0.008% to 0.036%. If JI/CDM are not available then the abatement costs are estimated to increase more than twofold.

The results of the GEM-E3 model confirm that the marginal abatement costs rise substantially if the international flexibility mechanisms cannot be used. For the scenarios allowing for JI/CDM the GDP changes in the EU in the year 2025 with respect to the GDP in the baseline of that year are estimated to be in the range of -0.015% to -0.045% of GDP. The action embedded in the scenarios without JI/CDM implies bigger GDP changes. They are estimated to be -0.78% and -1.67% relative to the 2025 baseline scenario GDP, for the *EU freeze* and *EU reduce* scenarios, respectively. Note that the GDP changes are defined with respect to the GDP level in the baseline. The annualised GDP changes during the post-Kyoto period are in the range of -0.001 to -0.002% of GDP in the scenarios with JI/CDM, and -0.039 to -0.084% in the *EU freeze* and *EU reduce* scenarios without international mechanisms, respectively.

The costs of emission reduction targets can also be assessed in welfare terms, as in a general equilibrium modelling framework households are maximising their welfare, which is a function of consumption, leisure and savings. For all the scenarios, the range of welfare change with respect to the baseline level in the year 2025 in the EU is between 0.00 and -0.02%, except for the *EU reduce* scenario without JI/CDM scenario (-0.14%).

The GEM-E3 model also provides the sectoral changes in production levels. The energy sectors (*coal, crude petroleum,* and *petroleum refineries*) play the most important role in the adjustment to the carbon constraint. The electricity sector and the energy intensive industries also contribute to a lesser extent to the adjustment. The order of magnitude of the production changes is higher in the scenarios without access to JI/CDM.

The analyses with the POLES and GEM-E3 models show that the costs of abatement policies, both in marginal terms and total terms, can be significantly reduced if emissions trading and project based mechanisms are used.

1. Introduction

The DG JRC/IPTS has analysed a series of climate policy scenarios for the Commission's Communication on Action on Climate Change Post-2012, "Winning the Battle against Global Climate Change" (European Commission, 2005). As an input to its deliberations on medium and longer term emission reduction strategies, the European Council requested an analysis of the costs and the benefits of post-2012 actions to mitigate climate change, taking into account both their environmental and economic consequences.

The Communication outlines key elements for the EU's future climate change strategy. It highlights the need for broader participation including other major emitting nations, and advocates a widening of the scope of international action to cover all greenhouse gases and sectors. Other elements are enhanced innovation in the energy and transport systems, the continued use of market-based and flexibility mechanisms, as well as adapting to the inevitable impacts of climate change.

The Communication is accompanied by a staff background paper (European Commission, 2005), which summarises the results of various studies. One of these studies, commissioned by DG Environment, is "Greenhouse Gas Reduction Pathways in the UNFCCC Process up to 2025" by Criqui *et al.* (2003). This study, referred to below as the GRP study, explores possible climate regimes and greenhouse gas reduction targets over the 2025 time horizon. The economic implications of full and increasing participation by countries in international climate policy architectures, given certain greenhouse gas stabilisation targets, are analysed here using two partial equilibrium models (POLES and IMAGE-TIMER), and one general equilibrium model (GEM-E3).

The GRP study was supplemented with the analysis of a series of additional scenarios based on several hypotheses of limited participation in the time horizon up to 2025. This document analyses those scenarios, which are included in subsection 4.2.2.2 of the background paper of the Communication. In the scenarios participation is limited to Annex I Parties[1], or only to the EU Member States. These participation schemes are

[1] Annex I of the United Nations Framework Convention on Climate Change (UNFCCC, 1992). Annex I Parties include the industrialised countries that were members of the OECD (Organisation for Economic

much less stringent in terms of global emission reductions than those of the GRP study, and therefore their environmental effectiveness is lower.

The assessments presented here are based on the same versions of the POLES and GEM-E3[2] models that were used for the GRP study. The two models have complementary characteristics. The GEM-E3 model is a world multi-region, multi-sectoral computable general equilibrium model, most suitable for the analysis of the interactions between all the sectors in the economy[3]. The POLES model is a partial equilibrium model of the energy system, with a technologically detailed characterisation of the energy transformation sectors and energy intensive industries[4].

The remainder of this report is structured as follows: Section 2 characterises the three scenarios of interest. The subsequent two sections present the results in the year 2025. Section 3 presents the POLES model results, and Section 4 the GEM-E3 model results. Finally, Section 5 concludes.

2. The Limited Participation Scenarios

Three scenarios have been analysed. All the scenarios assume that the Kyoto Protocol targets are met in the countries having ratified the protocol[5].

(1) "Annex I freeze"

Under this scenario the Annex I countries would keep the absolute Kyoto target to the year 2025. This implies that the EU would reduce emissions by 2025 to 8% below 1990 levels *i.e.* maintaining emission at a constant level after meeting the target set in the Kyoto Protocol for 2012. The US, by 2025, would stabilise absolute emissions at the 2012 level through compliance with its intensity target. It is assumed that the project-based flexibility mechanisms of the Kyoto Protocol, Joint Implementation (JI) and Clean Development Mechanism (CDM), are available beyond 2012. This scenario is referred to in the rest of this document as scenario *1a*.

Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States.

[2] The GEM-E3 World version of E3M-Lab was used both in the original GRP study and in the IPTS analysis.

[3] See Appendix I for a brief description of the model.

[4] See Appendix II for a brief description of the model.

[5] Furthermore, the modelled emission reduction policies are multi-gas, *i.e.* exploit the cost advantages of combining abatement of the different greenhouse gases.

(2) “EU freeze”

According to this scenario the EU reduces emissions by 2025 to 8% below 1990 levels, and no other countries take on commitments beyond 2012. Two cases are analysed assuming the presence and the non availability of JI and CDM beyond 2012, respectively. Scenario *2a* refers to the case with international flexibility mechanisms, and the scenario *2b* to the case without them.

(3) “EU reduce”

In this scenario the EU reduces emissions by 2025 to 20% below 1990 levels, and no other countries take on commitments beyond 2012. Again two cases are analysed looking at the presence or else the non availability of JI and CDM beyond 2012. The scenario *3a* refers to the case with international flexibility mechanisms, and the scenario *3b* to the case without them.

3. The POLES model results

3.1. Methodology

Using a year-by-year iterative process the POLES model enables the calculation of the carbon value (*i.e.* marginal abatement cost) that would allow compliance with the quantitative emissions targets of any set of participating countries, assuming emissions trading. The basic assumptions of the model, and in particular the reference scenario, are the same as in the GRP study.

For the period up to 2012, the ‘bubble’ subject to the emission constraints is limited to the participating Annex I parties[6]. The Kyoto targets are supposed to be met in 2012. Although it complies with their national intensity target, the USA is assumed not to participate in the emissions trading regime. The Former Soviet Union is assumed to sell 40% of its available emissions surplus, while the Eastern and Central European countries do not use any of their surplus.

In the scenarios including the international project-based instruments of the Kyoto Protocol, JI and CDM, are modelled as if there were globally accessible and that there were no transaction costs in the emissions trading market.

[6]The Kyoto targets are assumed to be reached without the use of CDM credits.

3.2. Carbon values (marginal cost of abatement)

The emission constraint leads to a series of adjustments in the model, basically through fuel substitution and changes in the technology of the energy sectors. The emission reduction target is achieved thanks to the introduction of an implicit carbon tax in the energy system (the way the endogenous carbon value is computed in POLES is explained in Appendix II). That carbon tax can be interpreted as the marginal cost of abatement, and is known in the literature as 'carbon value'.

Table 1 shows the carbon values in the different scenarios. Of the scenarios in which global trading is assumed, the *1a* scenario has a carbon value of 7.22 $Euro_{1999}$ t/CO_2-eq, much higher than that of *2a* (1.39 $Euro_{1999}$ t/CO_2-eq) and *3a* (2 $Euro_{1999}$ t/CO_2-eq) because the global reduction target is stricter in the first scenario. The global reduction in emissions is 7.3% in the first scenario, compared to the reference or baseline scenario, and 3.3% and 3.9% in the second and third scenarios, respectively. The minor difference between the carbon values of the *2a* and *3a* scenarios indicates that even a significant increase in the EU's target (from a 8% reduction in emissions to a 20% reduction, with respect to the 1990 emissions) has only a small impact on the marginal cost, provided there is full access to the international flexibility mechanisms. If the marginal costs of the scenarios without JI/CDM are compared to those with JI/CDM, the carbon values are much higher in the first case, as the relatively cheaper mitigation options of the non-Annex I countries are not available.

Table 1: Carbon Values (2025)

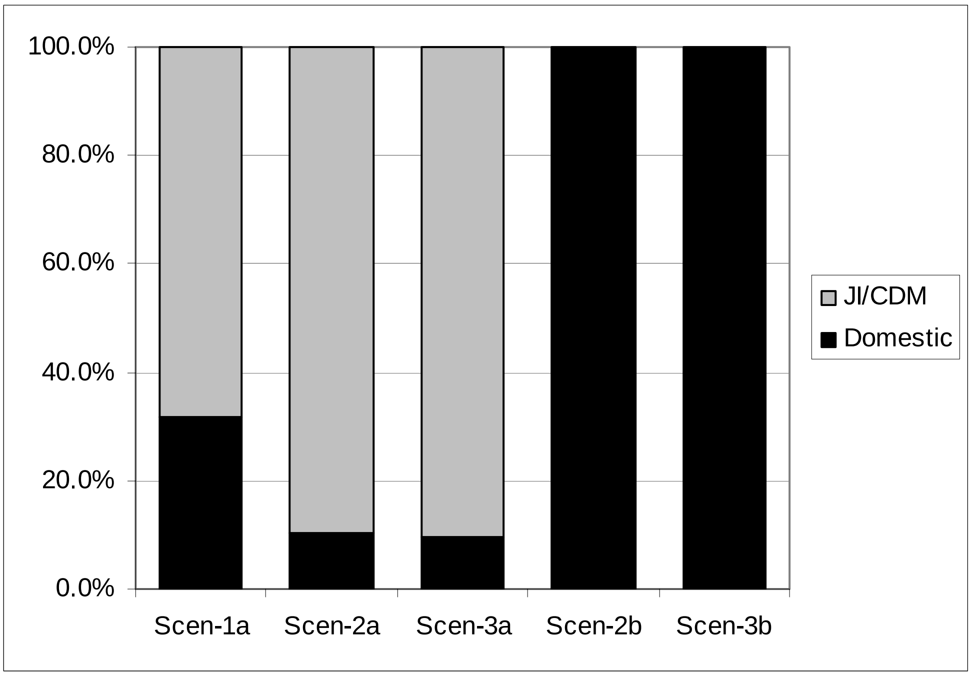
	Carbon Value
Scen-1a	7.22
Scen-2a	1.39
Scen-3a	2.00
Scen-2b	23.08
Scen-3b	54.43

Units: Euro 1999 t/CO_2-eq.

The POLES model provides a breakdown between domestic action and emission reduction abroad, which can illustrate the importance of the international cooperation. Figure 1 represents that split for the EU region in 2025 in the various scenarios.

Considerable use is made of flexibility mechanisms, allowing the EU to significantly reduce the overall costs of the policy (see next subsection). If the Annex I countries have emission targets in 2025 in line with the Kyoto Protocol (*1a* scenario) the share of the domestic actions is around 35% for the whole of the EU. This ratio descends to around 10% in the scenarios where only the EU reduces emissions (*2a*, and *3a* scenarios)[7].

Figure 1: Shares of domestic action and flexibility mechanisms (in 2025)



3.3. Abatement Costs

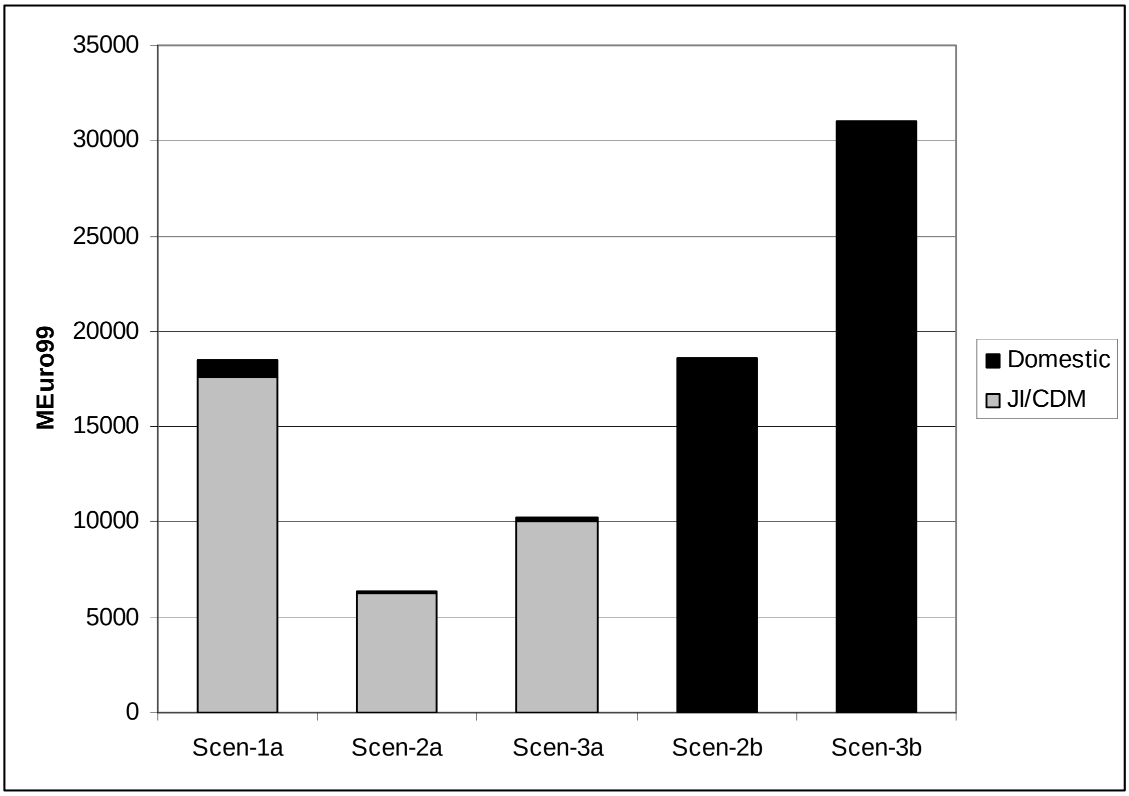
The POLES model – being a partial equilibrium model – calculates the direct cost of the carbon policy and does not give an indication of welfare changes or GDP impacts. In this study the abatement cost of a region is defined as the direct cost, computed as the integral of the marginal abatement cost (MAC) curve for the specific region, plus the amount paid or received as a result of the transfers on the international emissions trading market.

Figure 2 shows the cumulated abatement costs of the scenarios for the EU region over the 2012-2025 period. The costs are discounted to the year 2000 with at a discount rate

[7] Scenario runs were performed on two other cases where JI/CDM was restricted to the power sector. In theses cases domestic action reached almost 40% of the overall abatement. Those results are not reported here.

of 5%, as in the GRP study. The differences between the *a* and *b* scenario families gives an indication of the cost savings for the EU arising from the possibilities of JI/CDM.

Figure 2: Cumulated abatement costs for the EU (2012-2025)



The abatement costs can be compared to the GDP level of the baseline scenario, computing what is called "effort rate" in the GRP study. Table 2 presents the average effort rates for the 2012-2025 period in the EU. The figures in the table confirm that the more stringent the emission constraint is the more the EU saves on using the flexibility mechanisms. This finding emerges from the general feature of the MAC curve: as its shape is convex, the unit emission reduction cost grows more than proportionally with the stringency of the reduction effort.

Table 2: Average EU effort rates in % of GDP (2012-2025 period)

	Effort rate
Scen-1a	+ 0.023%
Scen-2a	+ 0.008%
Scen-3a	+ 0.013%
Scen-2b	+ 0.020%
Scen-3b	+ 0.036%

The POLES model gives information about the regional burden sharing at the global level. Figure 3 shows the allocation of the cumulated abatement costs in the 2012-2025 period for all the regions in the *1a* scenario. The grey bars indicate the transfers derived from the global emissions trading. Net buyers of permits on this figure are on the right-hand side of the chart, while sellers are on the left-hand side. Positive signs in the chart mean costs, while negative signs are benefits from selling emission rights. The black bars show the direct costs of domestic reduction undertaken by the different regions. The EU, USA, Canada and Oceania are the most important buyers of permits in 2025. They take domestic emission action, but their dominant effort is through JI/CDM measures. All the developing regions receive positive transfer from international emissions trading[8], the most important sellers being the CIS region and China. The biggest reductions are made in the USA, China and the CIS where many reduction options exist at the given permit price[9]. While the unit reduction cost of the domestic action starts from zero and increases according to the MAC curve, trading transactions are closed at the marginal cost - at the cost of the last unit of reduction needed. For this reason the costs of emissions trading (shown by the grey areas in Figure 3) are higher than the cost of domestic actions. There is a considerable redistribution effect caused by the permit trade, which underlines the importance of the general equilibrium analysis.

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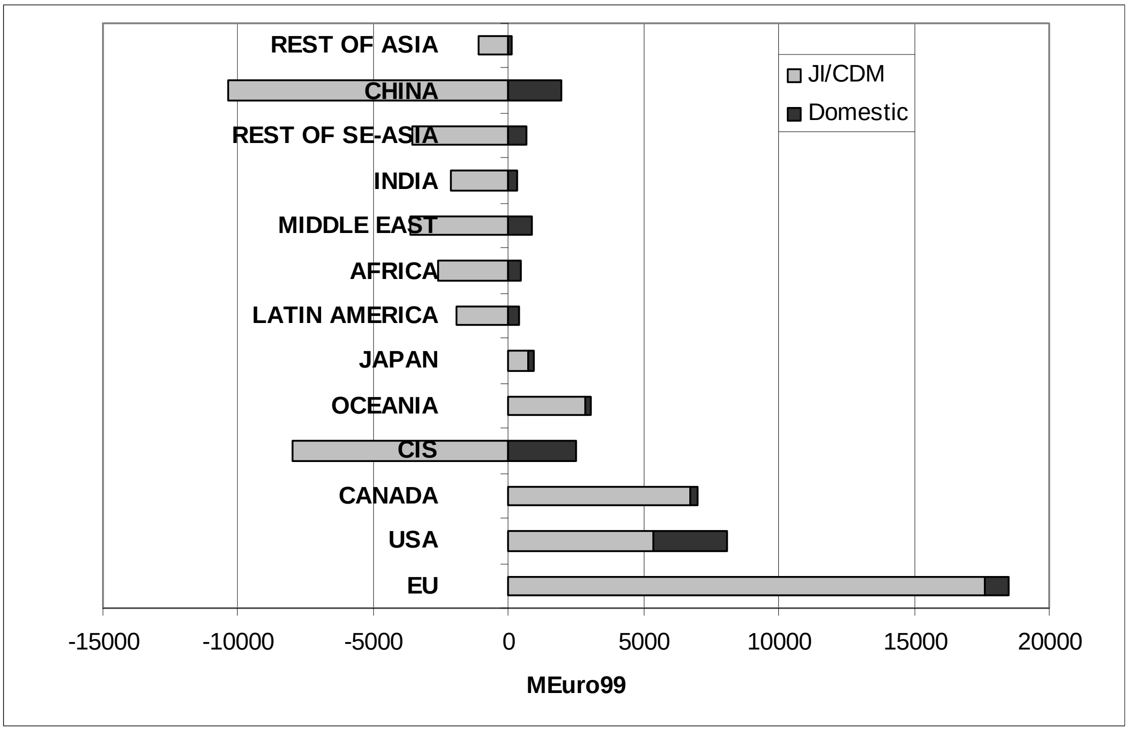
[8] Positive financial transfers are not equal to benefits in POLES model. In a general equilibrium framework regions with positive transfers can be still worse off due to the other effects (*e.g.* terms-of-trade effects could make oil and coal producers worse off).

[9] In the case of the USA this is due to the assumption that the USA will not comply with the Kyoto target and, hence, start from a high emission level.

Figure 3: Regional breakdown of the cumulated abatement costs of the carbon policy (scenario *1a*)



4. The GEM-E3 model results

4.1. Methodology

The GEM-E3 model world version of the GRP study was run for all the scenarios. The model assumptions are the same as in the GRP study. Firstly, in the emission permit allocation the grandfathering principle[10] is applied. Secondly, the revenues arising from emissions trading are recycled into the economy by distributing them to disposable income for households through direct transfers. Thirdly, the JI/CDM instruments are simulated in the same way as in the POLES runs, and it is assumed that there are no transaction costs in the emissions trading market. Fourthly, the current account balance of the less developed countries is fixed to the reference case level. Finally, capital is mobile across sectors within one country, but not between countries.

4.2. Carbon values

The main difference between the POLES model and the GEM-E3 model is that GEM is a multi-sector general equilibrium model, whereas POLES is a partial equilibrium model

[10] Permits are initially allocated for free following historical emission levels.

of the energy system. In a general equilibrium setup an emission constraint triggers adjustment not only through changes in the relative prices of production factors and commodities, but also through activity or income changes. Thus under GEM-E3 the emission constraint is met through a process of substitution of production factors and commodities, and changes in the sectoral activity levels.

Table 3 presents the carbon values for all the scenarios[11]. The family of scenarios with JI/CDM (scenarios *1a*, *2a* and *3a*) exhibit very low carbon values. Scenario *1a* has a carbon value below 2 $Euro_{1999}$ t/CO_2-eq. Scenario *2a* implies a lower carbon value because only the EU region is mitigating emissions worldwide. The overall emission reduction target is less stringent, and therefore it is relatively less costly to meet. The slight absolute increase in Scenario *3a* comes because of the relatively stringent target for the EU region, as compared to that of scenario *2a*.

Table 3: Carbon Value Results

	Carbon Value
Scen-1a	1.79
Scen-2a	0.35
Scen-3a	0.70
Scen-2b	33.60
Scen-3b	91.16

Units: Euro 1999 t/CO_2-eq.

Both of the scenarios excluding JI/CDM (scenarios *2b* and *3b*) entail considerably higher carbon values than those of the scenarios with JI/CDM. Indeed, the very significant increase in the marginal abatement cost comes from the –assumed– impossibility -by assumption- of exploiting the low cost abatement possibilities of the developing countries. The message is that the marginal abatement costs of emission reduction targets rises substantially when global emissions trading (broadly defined, *i.e.* including JI/CDM) is not allowed.

[11] In the general equilibrium framework absolute prices cannot be computed, only relative ones. Prices are measured in terms of a base year ‘numeraire’. In a growing economy prices tend to decrease due to the productivity improvements. From this perspective, under a general equilibrium framework a constant carbon value may be equivalent to an increasing one under a partial equilibrium context, such as that of the POLES model.

4.3. Welfare changes

The welfare index of the GEM-E3 model is linked to the utility function of the representative consumer. This is the function households are assumed to maximise and incorporates consumption, leisure and the value of savings in terms of discounted future consumption. This feature makes the welfare index more suitable than GDP as a means of evaluating the consequences of a carbon constraint. The value of the international transfers arising from the global emissions trading, depending directly on the carbon value or equilibrium price of the international permit market, for each region imply a first order impact on households' consumption possibilities. In general, consumers in regions buying permits will see a deterioration in their welfare, while consumers in regions exporting permits will improve their welfare levels. The revenues from emissions trading will lead to additional consumption, encouraging both domestic production and imports from the rest of the world. The rise in imports may result in a loss of GDP, although this cannot be interpreted as a negative impact in terms of households' welfare as they can consume more.

Table 4 presents the welfare losses in the EU region for the various scenarios with respect to the baseline scenario in the year 2025. Starting with the scenarios allowing for JI/CDM (scenarios *1a*, *2a* and *3a*), all of them lead to very low welfare changes, in the range of 0.00% to -0.02%. These figures are consistent with the discussed results on carbon values.

Table 4: EU Welfare Change Results

Scen-1a	-0.02%
Scen-2a	0.00%
Scen-3a	-0.01%
Scen-2b	-0.02%
Scen-3b	-0.14%

The scenarios without JI/CDM imply rather bigger welfare losses for the EU region. The action embedded in scenario *3b* entails the highest welfare loss amongst the scenarios, estimated to be -0.14%.

4.4. GDP changes

Table 5 presents the GDP changes in the EU region for the various scenarios, with respect to the baseline scenario. Starting with the scenarios allowing for JI/CDM (scenarios *1a*, *2a* and *3a*), all of them lead to losses of output in the range of 0.015% to 0.045% of GDP. These figures are consistent with the discussed results on carbon values.

Table 5: GDP Change Results[12]

	% relative to 2025 baseline	*annualised over the post-Kyoto period*
Scen-1a	-0.045%	-0.002%
Scen-2a	-0.015%	-0.001%
Scen-3a	-0.023%	-0.001%
Scen-2b	-0.780%	-0.039%
Scen-3b	-1.672%	-0.084%

The scenarios without JI/CDM imply rather higher production changes. The action embedded in scenarios *2b* and *3b* implies the highest GDP changes, estimated to be 0.78% and 1.67% relative to the 2025 baseline scenario GDP, respectively. Note that the GDP change reported in the first column are changes with respect to the GDP value in the reference scenario in the year 2025. Looking at the annualised GDP changes over the post-Kyoto period, for the *2b* scenario for instance the annual GDP change is -0.039%.

4.5. Sectoral activity changes

The economic adjustment to meet the carbon emission constraints involves substitution away from commodities whose production processes generate greenhouse gas emissions. These are usually commodities characterised by relatively high energy content. By contrast, production factors other than energy (labour, capital) and commodities with lower energy content are in a relatively more favourable situation, which entails higher relative demand for these goods and factors. Since there are adjustment costs - given the technical production possibilities - scenarios with carbon constraints are usually

[12] As the reduction effort is the highest in this last year of the modelling period, the GDP loss is also at the maximum. The average GDP loss over the post-Kyoto period is lower.

characterised by higher overall costs and decreasing production levels, as seen in the previous sub-sections.

As Table 6 shows the energy sectors playing the most important role in this adjustment process. The table represents the sectoral production changes in 2025 with respect to the baseline levels in that year, therefore without annualising the changes. Most of the sectoral impacts are relatively small in the scenario family with JI/CDM (*1a*, *2a* and *3a* scenarios). The *Coal*, and *Petroleum refinery* sectors are significantly affected in these scenarios, and to a less extent the *Chemical products* and *Electricity generation* sectors. Scenario *1*a in general induces relatively higher sectoral production losses than scenarios *2a* and *3a*, due to the implicit higher carbon value of scenario *1a*.

Table 6: Sectoral production changes in the EU

Sectoral Production change - EU (2025)	1a	2a	3a	2b	3b
01 Agriculture.	0.06%	0.01%	0.01%	-0.82%	-2.63%
02 Coal.	-2.97%	-0.66%	-1.27%	-22.70%	-35.01%
03 Petroleum Refineries.	-0.96%	-0.20%	-0.39%	-11.03%	-20.76%
04 Distribution of Gasseous Fuels - Manufacture of Gas.	0.12%	0.02%	0.04%	0.70%	-0.54%
05 Electricity.	-0.41%	-0.09%	-0.17%	-6.10%	-12.62%
06 Ferrous and non ferrous metals.	-0.04%	-0.01%	0.00%	-1.85%	-4.00%
07 Chemical Products.	-0.27%	-0.06%	-0.11%	-3.50%	-7.14%
08 Other energy intensive.	0.08%	0.02%	0.04%	-1.43%	-3.18%
09 Electronic Equipment.	0.02%	-0.01%	0.00%	-0.53%	-0.95%
10 Transport equipment.	-0.05%	-0.02%	-0.02%	-0.23%	-0.29%
11 Other Equipment Goods.	0.03%	0.00%	0.01%	-0.89%	-1.68%
12 Other Manufacturing products.	0.09%	0.01%	0.03%	-0.38%	-0.90%
13 Construction.	-0.05%	-0.01%	-0.02%	-0.65%	-1.45%
14 Food Industry.	-0.03%	-0.02%	-0.03%	-0.13%	-0.64%
15 Trade and Transport.	-0.03%	-0.01%	-0.02%	-0.34%	-0.80%
16 Textile Industry.	-0.01%	-0.01%	-0.02%	-0.15%	-0.61%
17 Other Market Services.	-0.06%	-0.02%	-0.03%	-0.67%	-1.41%
18 Non Market Services.	0.00%	0.00%	0.00%	-0.06%	-0.17%

In the *2b* and *3b* scenarios - when the Annex I or EU acts alone without JI/CDM measures - the impacts are higher. The energy sectors (*Coal*, *Petroleum*, and *Electricity*) are the most affected, with the exception of *Natural gas production* and *distribution*. Energy intensive industries are also involved in the adjustment process (*Chemical products*, *Ferrous* and *non ferrous metals*, *Other energy intensive*), however, to a lesser extent. The non-energy sectors are less affected, being the changes under 1.5 % in 2025, with the exception of *Agriculture* (in case *3b*).

4.6. External trade effects

Tables 7 and 8 represent the changes in sectoral imports and exports in the year 2025 relative to the baseline figures. The patterns of change are fairly similar to those estimated on the production side. The *b* family scenarios put significantly higher burden on the energy and energy intensive sectors entailing substantial reductions in both their export and import levels. In the non-energy intensive sectors these effects are less significant, and generally the changes are under 2%.

Table 7: Sectoral Imports changes in the EU

Sectoral Imports change - EU (2025)	1a	2a	3a	2b	3b
01 Agriculture.	-0.47%	-0.10%	-0.19%	0.57%	2.29%
02 Coal.	-3.41%	-0.75%	-1.44%	-25.13%	-37.04%
03 Petroleum Refineries.	-0.73%	-0.17%	-0.32%	-10.15%	-19.67%
04 Distribution of Gasseous Fuels - Manufacture of Gas.	na	na	na	na	na
05 Electricity.	-0.35%	-0.08%	-0.15%	-5.60%	-11.95%
06 Ferrous and non ferrous metals.	-0.15%	-0.04%	-0.07%	-1.68%	-3.77%
07 Chemical Products.	-0.23%	-0.05%	-0.10%	-3.39%	-7.09%
08 Other energy intensive.	-0.30%	-0.07%	-0.13%	-0.46%	-0.14%
09 Electronic Equipment.	-0.13%	-0.02%	-0.04%	-0.42%	-0.12%
10 Transport equipment.	-0.10%	-0.03%	-0.04%	-0.82%	-0.94%
11 Other Equipment Goods.	-0.17%	-0.04%	-0.07%	-1.37%	-2.64%
12 Other Manufacturing products.	-0.34%	-0.06%	-0.13%	-1.20%	-1.90%
13 Construction.	-0.04%	-0.01%	-0.02%	-0.53%	-1.18%
14 Food Industry.	-0.23%	-0.05%	-0.09%	-0.70%	-0.17%
15 Trade and Transport.	-0.03%	-0.01%	-0.01%	-0.33%	-0.75%
16 Textile Industry.	-0.16%	-0.03%	-0.06%	-0.76%	-1.46%
17 Other Market Services.	-0.01%	-0.01%	-0.01%	-1.70%	-2.61%
18 Non Market Services.	-0.01%	0.00%	0.00%	-0.09%	-0.26%

Table 8: Sectoral Exports changes in the EU

Sectoral Exports change - EU (2025)	1a	2a	3a	2b	3b
01 Agriculture.	0.29%	0.05%	0.12%	-1.62%	-3.92%
02 Coal.	-4.33%	-0.99%	-1.85%	-17.05%	-26.05%
03 Petroleum Refineries.	-1.34%	-0.28%	-0.53%	-6.88%	-13.46%
04 Distribution of Gasseous Fuels - Manufacture of Gas.	na	na	na	na	na
05 Electricity.	-0.37%	-0.08%	-0.15%	-5.43%	-10.72%
06 Ferrous and non ferrous metals.	-0.02%	0.00%	0.01%	-2.03%	-4.42%
07 Chemical Products.	-0.29%	-0.06%	-0.12%	-2.83%	-5.71%
08 Other energy intensive.	0.39%	0.08%	0.18%	-1.29%	-2.13%
09 Electronic Equipment.	0.05%	-0.01%	0.01%	-0.55%	-0.17%
10 Transport equipment.	-0.06%	-0.02%	-0.01%	-0.17%	0.65%
11 Other Equipment Goods.	0.08%	0.01%	0.04%	-0.50%	-0.22%
12 Other Manufacturing products.	0.27%	0.04%	0.12%	-0.39%	0.20%
13 Construction.	-0.03%	0.00%	0.05%	-1.36%	-2.24%
14 Food Industry.	0.10%	0.01%	0.05%	0.25%	1.28%
15 Trade and Transport.	-0.08%	-0.03%	-0.03%	-0.52%	-0.85%
16 Textile Industry.	0.11%	0.00%	0.03%	-0.15%	-0.34%
17 Other Market Services.	-0.19%	-0.04%	-0.05%	1.12%	2.70%
18 Non Market Services.	0.15%	0.01%	0.05%	0.31%	1.43%

5. Conclusions

The analyses with the POLES and GEM-E3 models show that the costs of abatement policies, both in marginal and total terms, can be significantly reduced making use of the market-based mechanisms of the Kyoto Protocol. Indeed, even in the absence of global participation, international flexibility mechanisms would lead to relatively low carbon values.

Although the models, taking into account the state-of-the-art of the related theoretical literature and the available statistical data, intend to capture the most relevant aspects of the economic consequences of emission constraints, and in particular assess the abatement costs, they still represent a crude approximation to the real world. Therefore, caution against too literal interpretations of the numerical results is advised. The ultimate goal of these quantitative analyses has been to have indications potential economic effects and the order of magnitude of the abatement costs for the considered limited participation scenarios, which might offer some useful insights for the post-2012 climate policy debate.

Appendix I. Brief description of the GEM-E3 Model[13]

The ***GEM-E3*** ***G**eneral* ***E**quilibrium* ***M**odel* for ***E**nergy-**E**conomy-**E**nvironment* interactions model has been developed as a multinational collaboration project, partly funded by the Commission of the European Communities, DG Research, 5th Framework programme (Capros *et al.*, 1997) and by national authorities, and further developments are continuously under way. Applications of the model have been carried out for several Directorate Generals of the European Commission (*e.g.* economic affairs, competition, environment, taxation, research) and for national authorities.

The GEM-E3 (World and Europe) model is an applied general equilibrium model, simultaneously representing 21 World regions/15 European countries, linked through endogenous bilateral trade. The European model is being extended to include the associated countries and Switzerland. GEM-E3 aims to cover the interactions between the economy, the energy system and the environment. The model computes simultaneously the competitive market equilibrium under the Walras law and determines the optimum balance for energy demand/supply and emission/abatement.

The model has the following general features:

1. Its scope is general in two senses: it includes all simultaneously interrelated markets and, furthermore, represents the system at the appropriate level with respect to geography, the sub-systems (energy, environment, economy) and the dynamic mechanisms of agent's behaviour.

2. It formulates separately the supply or demand behaviour of the economic agents which are considered to optimise individually their objective while market derived prices guarantee global equilibrium.

3. It considers explicitly the market clearing mechanism and the related price formation in the energy, environment and economy markets: prices are computed by the model as a result of supply and demand interactions in the markets and different market clearing mechanisms, in addition to perfect competition, are allowed.

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[13] This brief description is taken from http://www.gem-e3.net

4. The model is simultaneously multinational (for the EU or the World) and specific for each country/region; appropriate markets clear European/World wide, while country/region-specific policies and distributional analysis are supported
5. Although global, the model exhibits a sufficient degree of disaggregation concerning sectors, structural features of energy/environment and policy-oriented instruments (*e.g.* taxation). The model formulates production technologies in an endogenous manner allowing for price-driven derivation of all intermediate consumption and the services from capital and labour. In the electricity sector, the choice of production factors can be based on the explicit modelling of technologies. For the demand-side the model formulates consumer behaviour and distinguishes between durable (equipment) and consumable goods and services.
6. The model is dynamic, recursive over time, driven by the accumulation of capital and equipment. Technological progress (either exogenous or endogenous) is explicitly represented in the production function, depending on R&D expenditure by private and public sector and taking into account spill-over effects.
7. The model formulates pollution permits for atmospheric pollutants and flexibility instruments allowing for a variety options, including: allocation (grandfathering, auctioneering, etc.), user-defined bubbles for traders, various systems of exemptions, various systems for revenue recycling, etc.

The following links provide detailed information about the GEM-E3 model, including the reference manual:

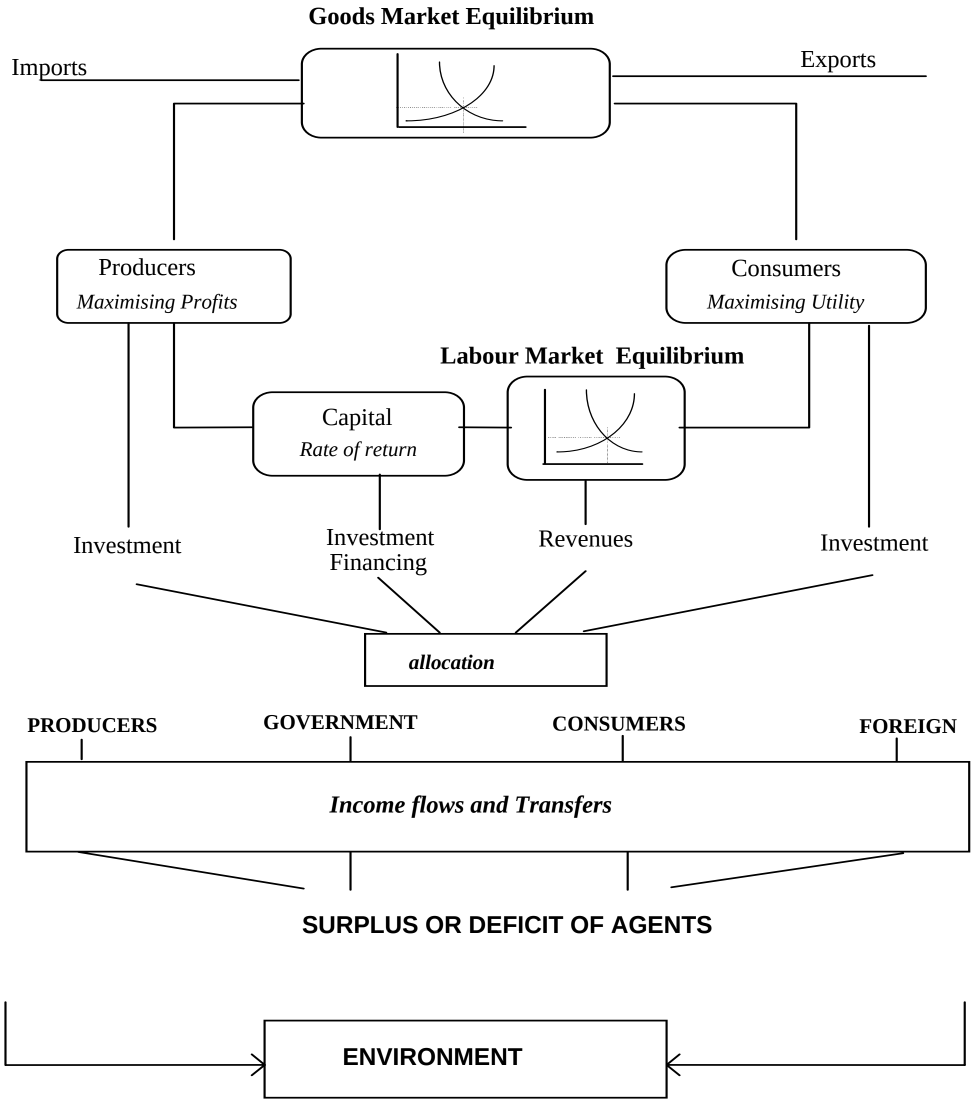
http://www.e3mlab.ntua.gr/

http://www.gem-e3.net/index.htm

http://gem-e3.zew.de/ref.html

See Figure 4 for a model overview.

Figure 4: The basic scheme of the GEM-E3 model



Appendix II. Brief description of the POLES Model

POLES (Prospective Outlook for the Long-term Energy System) is a global sectoral simulation model for the development of long-term (2030) energy supply and demand scenarios. With 38 regions it is one of the most detailed world energy models available. The model structure corresponds to a hierarchical system of inter-connected modules and involves three levels of analysis:

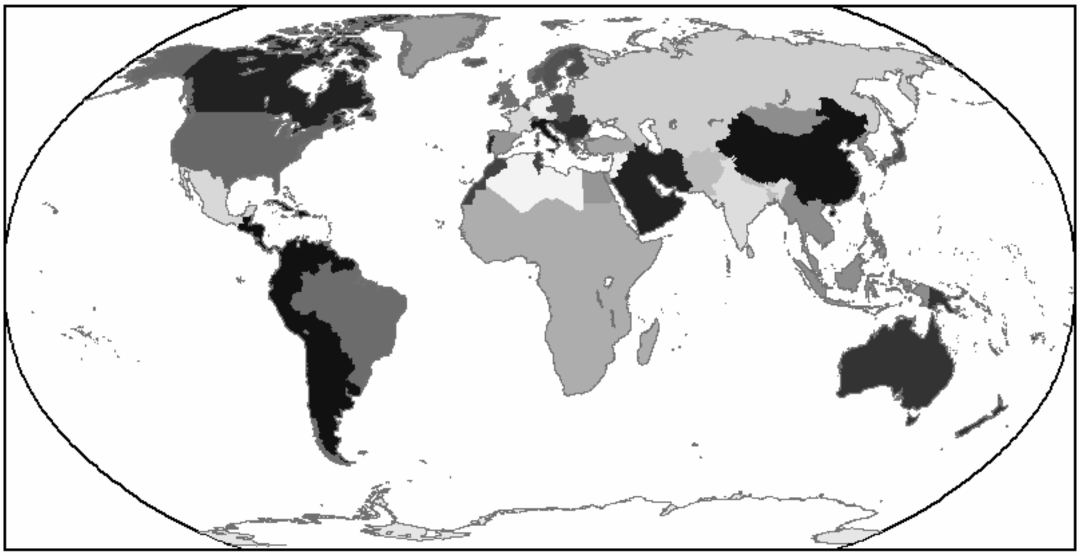
- International energy markets;
- Regional energy balances;
- National models on energy demand, new technologies and renewable energy, power generation, primary energy supply and CO_2 emissions.

The dynamics of the model are based upon a recursive simulation process, in which energy demand and supply in each national or regional module respond (with different lag structures) to international price variations in the preceding periods. In each module, behavioural equations take into account the combination of price effects, techno-economic constraints and trends.

There are fifteen final energy demand sectors (covering the main industrial branches, transport modes, the residential and service sectors), twelve large-scale power generation technologies and twelve new and renewable energy technologies.

Oil and gas supply profiles in the largest world producing countries are dealt with a discovery process model in which oil and gas production depends on the dynamics of the drilling activity and discovery of new reserves, given the existing resources and the cumulative production. Coal supply is essentially demand driven.

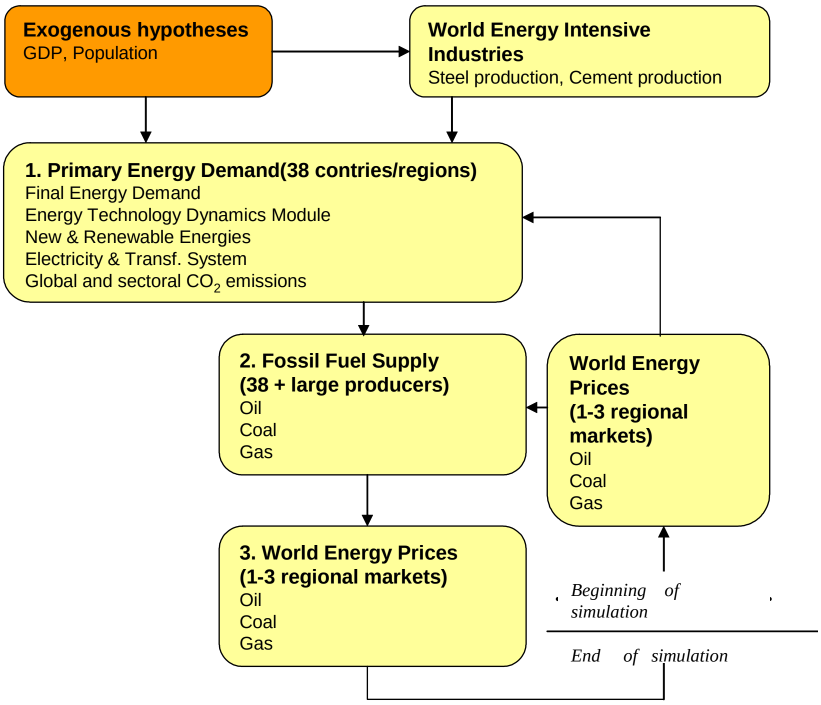
Figure 5: Regional breakdown of the POLES model in 38 regions



The international energy market module integrates import demand and export capacities of the different regions, and it also balances the international energy flows. The market for oil is considered to be a single worldwide market (the ‘one great pool’ concept), while three regional markets (America, Europe/Africa, and Asia) are differentiated for gas and coal to account for regional differences in cost and market structures. The changes in international prices of oil, gas and coal are determined endogenously in this module. The international price equations take into account the relevant variables associated with short-term adjustments in price levels, such as the Gulf capacity utilisation rate for oil, and to medium and long-term variables such as the Reserve on Production ratio for oil and gas, or the trend in productivity and production costs for coal.

The energy balance data for the POLES model are extracted from an international energy database. This database also includes international macro-economic data concerning GDP, the structure of economic activity, deflators and exchange rates. Techno-economic data (energy prices, equipment rates, costs of energy technologies, etc.) are gathered both from international and national statistics.

Figure 6: Simulation scheme of the POLES model



POLES is used for various studies mainly for the European Commission. For a World Energy Outlook, the model provides endogenous international energy prices and all information on energy flows for each country/region (see European Commission, 2003).

A major part of recent applications has been dedicated to Costing studies for CO_2 abatement policies (see *e. g.* Gusbin *et al.*, 1999, IPTS, 2000, Criqui *et al.*, 2003).

A technical description of the model version used for this analysis is under preparation. Please see http://energy.jrc.es for new releases. An older model version is described in POLES 2.2 manual (European Commission, 1996). The following section describes an important feature used for this analysis, namely the endogenous calculation of carbon values.

The endogenous carbon value in the POLES model

The evaluation of the cost of reduction for the different region and the resulting emission permit prices is a typical model application. The usual approach to analysing emissions trading has been to obtain marginal emission reduction cost curves from the energy models and subsequently carry out a static, ex-post analysis of emissions trading based on these cost curves. This "comparative statics" approach can be described as follows:

- entitlements are exogenously given for one benchmark year (e.g. 2010 for the analysis of Kyoto protocol);
- Marginal abatement cost (MAC) curves for the countries under concern are derived by the introduction of different levels of a shadow carbon tax or carbon value, introduced at the beginning of the solution period with emissions obtained as an output;
- finally the impacts of flexibility systems are analysed outside of the model as trade opportunities arising from differences in marginal abatement costs. The 'market clearance' is done for the defined target year (usually 2010 for Kyoto analyses).

Since the analysis of the trade using this approach is done outside of the model, effects resulting from the introduction of different carbon constraints for different regions (change in prices, demands, etc) are not taken into account.

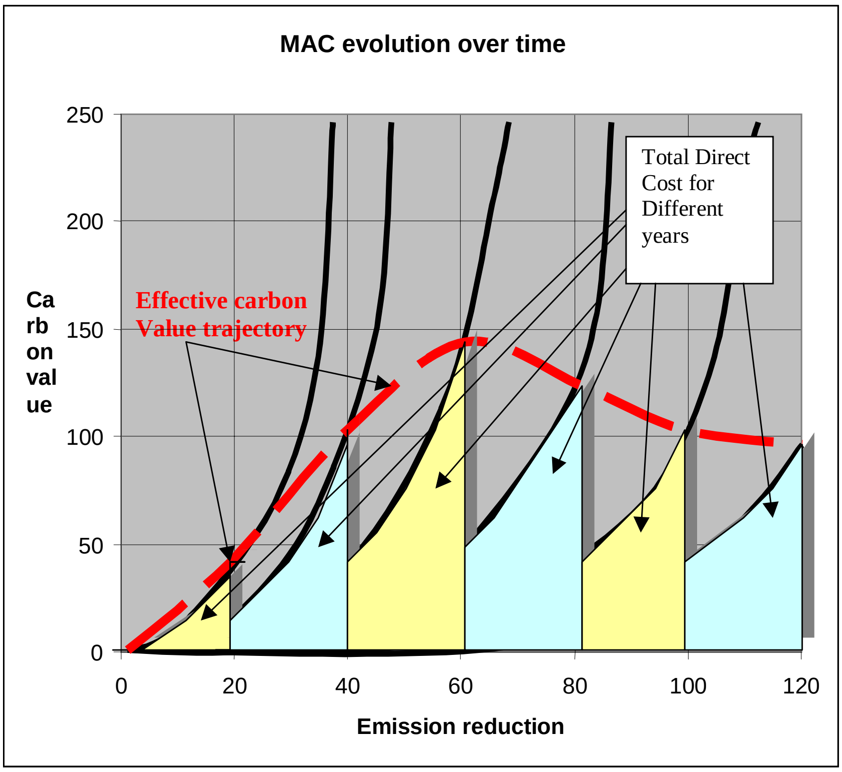
The analyses described in this report use scenario definitions that lead (on a global scale) to carbon prices that are very different across the globe (depending on the scenario definition the EU has a significant carbon value whereas the rest of the world has no carbon value). To analyse this type of scenario marginal abatement cost curves based on the carbon values that are constant across the countries should not be used because the prices and flows assumed to derive the carbon values are very different from the situation defined by the scenarios.

To overcome this problem a method has been developed in the last years for the POLES model that gives the exact solution and was applied for this analysis.

"Endogenous" carbon values

The latest POLES model version endogenises the calculation of the carbon values (Russ, 2001). This version allows inter-temporal pathways to be calculated for carbon values corresponding to year-by-year emission targets. For a set of given targets the corresponding set of prices, energy demand, etc is calculated for as many countries or trading bubbles as wanted. Since the calculation is carried out inside the model all price effects caused by the emission reduction are taken into account. The solution is reached applying an iterative procedure within the model. The carbon values are changed and the reaction of the energy system in the different region (demands and prices) is recalculated until the emission targets are simultaneously met for all regions. Since the solution can be found for as many points in time as wanted intertemporal effects (*e.g.* age structure of existing power plants) are taken into account.

Figure 7: The trajectory of the (dynamic) permit price[14]



[14] The trajectory of the (dynamic) permit price is the result of the MAC calculation for each time step. The area under the MAC curve corresponds to the total direct cost for each year.

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List of Abbreviations

CDM	Clean Development Mechanism, a "Kyoto Mechanism" (UNFCCC 1997)
CIS	Commonwealth of Independent States
EU	European Union
GDP	Gross Domestic Product
GRP	Greenhouse gas reduction pathways in the UNFCCC process up to 2025, Study by Criqui *et al.* (2003)
JI	Joint Implementation, a "Kyoto Mechanism" (UNFCCC 1997)
MAC	Marginal Abatement Cost curve
UNFCCC	United Nations Framework Convention on Climatic Change, see (UNFCCC, 1992)