POLES-Macro: using the GEM-E3 world model to account for the macroeconomic feedback of climate policies in the POLES model [*]

Juan Carlos Ciscar, László Szabó, and Peter Russ
IPTS

First version: 12 November 2004
This version: 29 April 2005

Draft version, please do not quote

Abstract

The partial equilibrium energy model POLES has exogenous regional GDP paths. The absence of a GDP or macroeconomic feedback in the model can lead to a certain overestimation of the mitigation costs of climate policies. The aim of this article is to measure the importance of accounting for the macro-economic feedback in the POLES model. The GEM-E3 model is used to assess that feedback for a concrete climate policy scenario in the 2030 time horizon. The preliminary results indicate that the overestimation of marginal costs and total abatement costs in POLES is not very significant. Further work is required to check the robustness of this result to more general carbon constraint policies.

---

[*] Previous versions of this work have been presented at the CentrA/Fundación Ramón Areces Workshop on Public Economics and the Environment, Sevilla (Spain), 12th-13th November 2004, and at ZEW and IPTS internal seminars. We have benefited from the comments from the workshop and seminars participants, and especially from C. Böhringer (ZEW), N. Kouvaritakis (NTUA), D. van Regemorter (KUL), K. Ruffing (OECD), and A. Soria (IPTS). The opinions expressed in the article are those of the authors and do not necessarily correspond to those of the European Commission.

1 Introduction

The POLES model is a large-scale world model for the energy sector. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world regions. POLES has been used for policy analyses by EU-DGs Research, Environment, and Transport. Recent assessments of climate policies include the Greenhouse gas Emission Control Strategies (GECS, Criqui, 2002) and Greenhouse gas Reduction Pathways in the UNFCCC process up to 2025 (GRP, IEPE *et al.*, 2003) projects.

The partial equilibrium approach of the POLES model does not fully capture the consequences of policies on the rest of the economy, and in particular assumes a constant GDP in the policy scenarios, even *e.g.* for stringent carbon emission targets. That assumption can be unrealistic for some policies with the potential of leading to non-negligible effects in the entire economy. For the case of climate policies, translated in the model into a certain carbon value, the POLES model considers the substitution effects taking place due to the carbon constraint, ignoring the income effect. POLES accounts for the adjustments occurring within the energy sector through the substitution of fuels and technologies. Yet the order of magnitude of the income effect can be significant, leading to an overestimation of the adjustments taken place in the energy sector. The contribution of the other sectors of the economy to attain the emission target can be relatively significant.

One solution to the problem is to construct a macroeconomic sub-module providing an estimate of the feedback effect on the whole economy. This solution is already applied in some partial equilibrium energy models (*e.g.* Markal-Macro), but implies the difficulty to build up a complete macro-economic module. These modules are usually limited feature models - either by size (sectors considered), or significantly increase the running time of the models - as the final outcome is usually a result of an iterative process between the energy and the macro modules.

Another solution is to measure with a computable general equilibrium (CGE) model the macroeconomic feedback of the particular policy scenario of interest, and then introduce it in the energy model. This requires running in tandem the energy and CGE models for each policy scenario. This is the option followed in this paper making use of the general equilibrium model GEM-E3. The main purpose of the work described hereafter is therefore to illustrate and analyse for a particular climate policy such coupling between the POLES and the GEM-E3 models.

One result of the analysis will be an empirical evaluation of the order of magnitude of the income effects at play, relative to the substitution or price effects, for the particular case of the POLES model and for the selected climate policy scenario. Put it in other words: to check (to some extent) the legitimacy of using a partial equilibrium approach in the evaluation of climate policies, versus the general equilibrium approach. Each approach has its advantages and disadvantages. Bottom-up models have a very rich representation of energy technologies, and the various energy sub-sectors, a degree of detail absent in general equilibrium models, but normally do not integrate any macro-economic closure, whereas top-down models often lack of an accurate description of technological options.

The literature has paid some attention to the subject of this article. The MARKAL model (see Messner and Scharattenholzer, 2000) justifies the use of the partial equilibrium approach, however without providing the order of magnitude of the role of the income effect.

Consistency between the baseline scenarios of the two models, POLES and GEM-E3, is crucial, particularly regarding the GDP and emission projections. The constrained emissions scenario should *e.g.* lead to similar shadow price of the emission constraint (the carbon value) in both models. The IMACLIM model (Ghersi., 2004) follows this approach by fully incorporating the energy sector of the POLES model into a general equilibrium model. This full integration is very costly in terms of model design, and that approach will not be followed here.

The article is organised as follows. Section 2 briefly presents the main features of the models. Section 3 explains the implementation framework. Section 4 discusses the results, and section 5 concludes.

2 Models

2.1 POLES Model

The POLES model[1] follows a distinct approach in energy demand modelling compared to the majority of other partial equilibrium energy models. While other energy models (*e.g.* PRIMES, NEMS, MARKAL) are usually classified as optimisation models (usually linear programming (LP) optimiser models), POLES is a behavioural model based on a system dynamics architecture or approach. Agents in the model pursue a closely determined trend in their energy consumption and deviate from this 'equilibrium' path according to the modifications in endogenous and exogenous model variables (*e.g.* price changes, income changes, and technological breakthroughs). Behavioural model equations are characterised by the intensive use of lagged and autonomous trend variables.

Other interactions outside the energy sector, such as the energy sector impact on the whole economy (*e.g.* contribution to total value added) are modelled in less detail, which is justified by the relatively minor share of the energy intensive sectors in the total values added. Table 1 shows the sectoral breakdown of world GDP between the energy sectors and the rest of the economy for the period 2005-2030 according to the baseline scenario of the GEM-E3 world model. The energy sectors include the primary fuels, electricity, and the energy intensive sectors, such as steelmaking, cement and pulp and paper. The energy sectors share is around 13% at world level. This indicates that even a strong negative shock on the energy sector would have a relatively moderate direct influence in the total economy (*e.g.* a 15% reduction in the value-added of the energy sector would have a direct economy-wide impact of around 2% on GDP). From the energy modelling point of view this was the justification to pay relatively less attention to the interaction between the energy sector and other sectors of the economy.

---

[1] For references related to the POLES model see http://web.upmf-grenoble.fr/iepe/Publications/publicRech5.html.

Table 1: Sectoral Value Added Shares in Baseline Scenario (World, GEM-E3 model)

	2005	2010	2015	2020	2025	2030
Energy Sectors	**13%**	**13%**	**13%**	**13%**	**12%**	**12%**
energy intensive	8%	8%	8%	8%	8%	8%
coal	0%	0%	0%	0%	0%	0%
oil	2%	2%	2%	2%	2%	2%
natural gas	1%	1%	1%	1%	1%	1%
electricity	2%	2%	2%	2%	2%	2%
Rest of the Economy	**87%**	**87%**	**87%**	**87%**	**88%**	**88%**

Source: Baseline projection of GEM-E3 world model

The standard demand equation of POLES gives the final energy consumption of the different agents as a function of the following variables:

- the lagged final energy consumption variable;

- a short-term variation of the corresponding price or average price, affected by the short term price elasticity and weighting factor;

- a long-term price elasticity, with an asymmetry factor, and a distributed lag corresponding to the depth or duration of the price effect;

- a variation of the corresponding income or activity variable, affected by an income elasticity;

This standard equation is used to calculate both the total energy demand of each sector and the demand for each individual fuel in the sector. This provides with a flexible way to model the inter-fuel substitution process (similar to the ‘putty–clay‘ energy demand functions). For each period the current demand for each individual fuel is reduced according to a “scrapping factor” corresponding to the phasing out rate of existing energy consuming equipment.

The commented demand equation reveals that modelling the energy demand for the different sectors is rather detailed concerning the price effects. Both the short and long term impacts are considered, including an asymmetry effect in the agents behavioural to differentiate price increase or decrease. In addition, POLES - being a global model covering all energy consuming and supplying regions - derives the international energy prices endogenously for the main energy carriers (oil, gas, coal).

The income effect is included in less detail, following a simple isoelastic formulation. Whereas the sectoral distribution of the value added follows a pre-determined pattern following the *per capita* GDP development of the given region, the level of GDP is exogenous to the model. Both the GDP level and the *per capita* GDP (consequently the population level) are the key driving forces of the model. The population outlook used in POLES is based on the UN population prospects. The economic outlook has been prepared by CEPII[2] and is based on a simple growth model that takes into account the accumulation of physical and human capital in the different regions considered. At the same time the projected GDP path is determined until 2030, implying that the different scenarios have no feedback to the GDP level, even in the most extreme cases.

2.2 GEM-E3 Model

GEM-E3 World model is a multi-region applied general equilibrium model of the world economy providing detailed results on macroeconomic variables, sectoral activity, trade and their interaction with the environment[3]. It is an empirical, large-scale model, calibrated to a base year[4] using the Global Trade Analysis Project (GTAP) v.4 database. The model is not stochastic[5].

The model aggregates the national economies of the world into twenty-one regions, among which four EU regions, and links them through endogenous trade of goods and services. GEM-E3 includes twenty sectors and various economic agents, for which it formulates their individual economic behaviour and their interactions as demanders and suppliers of goods and services. The model covers the major aspects of public finance, including all substantial taxes, social policy subsidies, public expenditures and deficit financing.

The model determines the equilibrium prices and quantities that simultaneously clear all markets, taking into account the optimising behaviour of economic agents. The results of GEM-E3 include detailed input-output tables by region, national accounts, employment, balance of payments, public finance, household consumption, and energy use and supply, among other endogenous variables. The computation of the

---

[2] See http://www.cepii.fr/.

[3] See Capros *et al.* (1997) for a model description, and visit the GEM-E3 pages: http://www.gem-e3.net/index.htm, http://gem-e3.zew.de/ref.html.

[4] The base year of the current version of the model is 1995.

[5] Sensitivity analyses in order to assess the robustness of some outputs are of course possible. Applying Monte-Carlo techniques for this purpose, however, is almost impossible due to the model size.

equilibrium is simultaneous for all domestic markets and their interaction through flexible bilateral trade flows.

2.3 Some of Models' features of relevance

The POLES and GEM-E3 models have radically different characteristics, and some of them are of particular relevance for the kind of application foreseen in this article. First of all, while POLES is a simulation model, GEM-E3 is an optimisation model. POLES is written in a software based in system dynamics. POLES is a dynamic model that requires lag structures in many of its equations. In particular, the demand of the various primary fuels for instance reacts to past prices, *i.e.* with a dynamic structure of several periods. Thus an emission target in a certain future period *t* can be attained with the introduction of a carbon value in time *t*, but this would overestimate the marginal cost of attaining the emission target, since a policy implementing carbon values in the previous periods would achieve the target at *t* at a lower marginal cost.

The myopic characteristic of POLES reinforces the noted overestimation. The capacity planning decisions do take into account the historical (past) demand, without looking into the future, and notably ignoring the emission reduction targets of future periods. This can create an overshooting of the computed carbon values. In order to avoid or at least minimise these limitations, a smooth emission profile is imposed in the model in order to attain a certain emission target in the future. According to this, the energy system is prescribed to start to reduce emissions before the emission constraint takes place. Given that the carbon value computation is the meaningful application of the POLES model, correcting these problems is essential. On the contrary, GEM-E3 is not specifically designed for computing carbon values, but for welfare and activity analyses.

The architecture of GEM-E3 model is soundly based in neoclassical economics, therefore assuming full flexibility of markets. Reducing emissions by a certain amount is made without taking into account market imperfections or adjustment costs, features that are on the contrary considered by the POLES model.

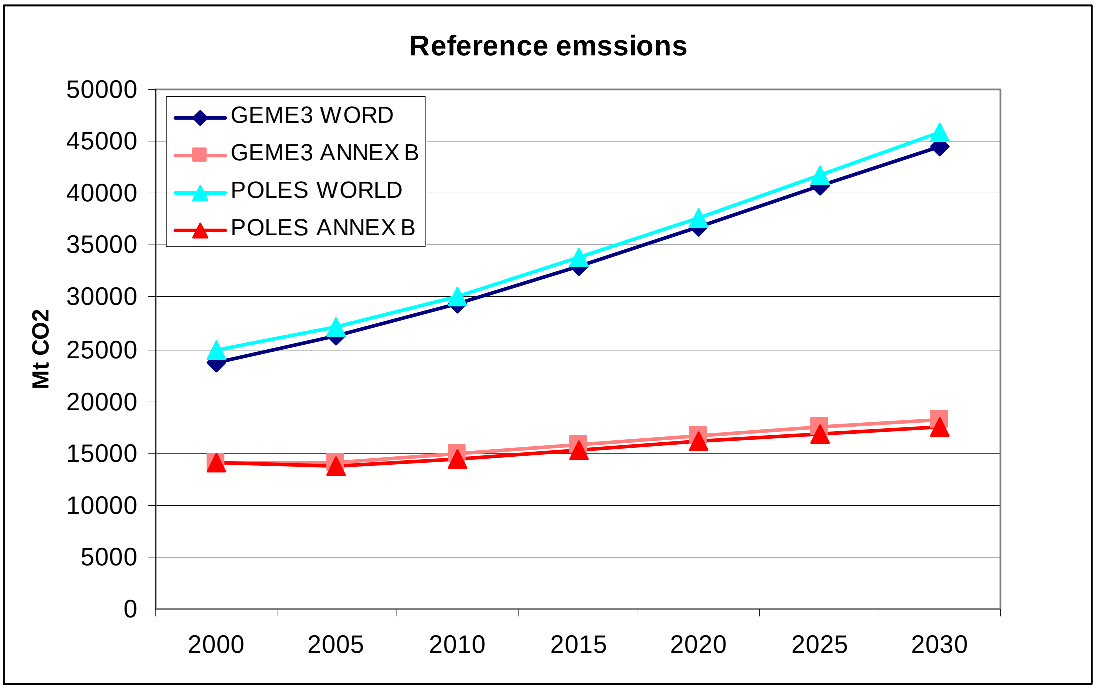
For running a carbon constraint scenario, GEM-E3 requires the allocation of emission permits by regions. This is irrelevant in the partial equilibrium setup of POLES since the financial transfers due to emission trading do not affect the model results. In GEM-E3 those transfers play a crucial role in the results, in particular affecting the welfare and activity (GDP and sectoral value added) levels. GEM-E3 also requires a recycling rule for the permit revenues, in other words, the use that governments make of the financial resources issued by the environmental levies has to be clearly prescribed . The usual assumption in similar policy applications is that revenues are transferred back to firms, as will be assumed here.

3 Implementation Framework

3.1 Consistency of Baseline Scenarios

During the baseline calibration of the GEM-E3 model, an effort was made in order to achieve consistency between the baseline scenarios of the two models. This consistency was obtained not only on the global CO_2 level, but also on the main regional levels of the two models. Figure 1 illustrates this for the global and for the Annex B CO_2 emissions.

Figure 1: Comparison between POLES and GEM-E3 CO_2 emission in the reference case



3.2 Definition of Climate Policy Scenario

In the modelling exercise, a carbon mitigation scenario belonging to the IPPC B1 scenario family was chosen to test the GDP feedback effect on POLES. This scenario, called “soft landing”, has an emission path that allows stabilisation of CO_2 concentration in the atmosphere at around 550 ppm, and a global temperature increase of no more than 2°C relative to the 1990 observations. This path implies carbon constraints in the 2000-2030 period for most of the world regions. From the B1 scenario family, the B1 IMAGE scenario of the IPCC (IPCC, 2000) was chosen. This scenario determines the carbon concentration for the long term (over 2100), from which the applied 2000-2030 carbon emission paths for the modelling regions were derived.

There are further assumptions in order to define the participation scheme in the policy scenario. First, for the period 2008-2012 it is assumed that the Kyoto targets and participation scheme is fulfilled. The USA does not participate in the scheme with a fixed emission target in the first Kyoto period, but it follows the so-called ‘Bush plan’, which calls for a 18% reduction in energy intensity for the 2002-2012 period. An additional assumption is that Eastern European countries and the Former Soviet Union (FSU) follow their baseline emissions without trading their ‘hot’ air on the global trading market.

Second, for the post-Kyoto period a widening participation scheme is assumed, according to the so-called ‘soft landing’ scenario hypotheses. Non-annex B countries take up carbon targets according to their economic development, *e.g.* if they reach certain *per capita* GDP levels[6]. This assumption translates to the following regional targets:

- OECD: 15% reduction of emission by 2030 with respect to the 2010 emissions.
- Eastern Europe and FSU: stabilization of emissions by 2030, relative to the 2010 emissions.
- Non-Annex B with *per capita* GDP above 60% (Category 2): stabilization of emission levels by 2030 to the 2015 emission levels.
- Non-Annex B with *per capita* GDP between 15-60% (Category 3): Stabilization of emissions at the 2030 level.
- Non-Annex B with *per capita* GDP under 15% (Category 4): Stabilization of emissions at the 2045 level.

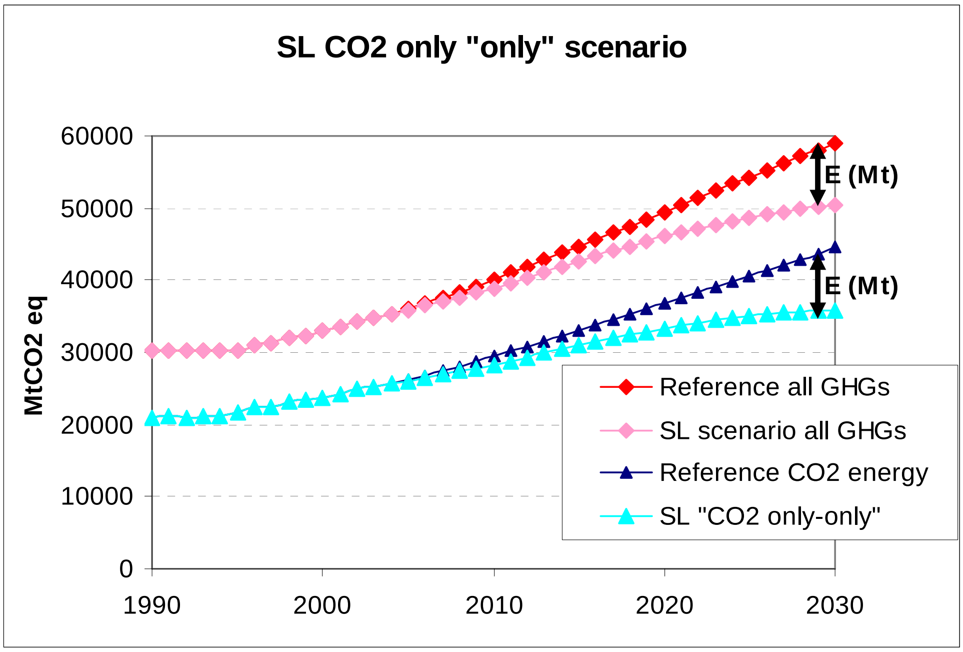
---

[6] This level is set as 15-60% of the OECD *per capita* GDP in 2010. Category 2: GDP is above 60% of the OECD figure; Category 3: between 15-60%; Category 4: under 15%.

This means, that countries belonging to the last two categories (3 and 4) do not pursue emission constraint during the modeling period (2000-2030).

Third, in the scenario energy-related CO_2 emissions bear all the reduction effort, and therefore reductions in the other greenhouse gases were not considered (this scenario is called CO_2 'only only' scenario). Figure 2 illustrates the differences between the emissions in the reference and soft-landing (SL) scenarios, for both cases: when all GHGs and 'only' the CO_2 emissions are considered.

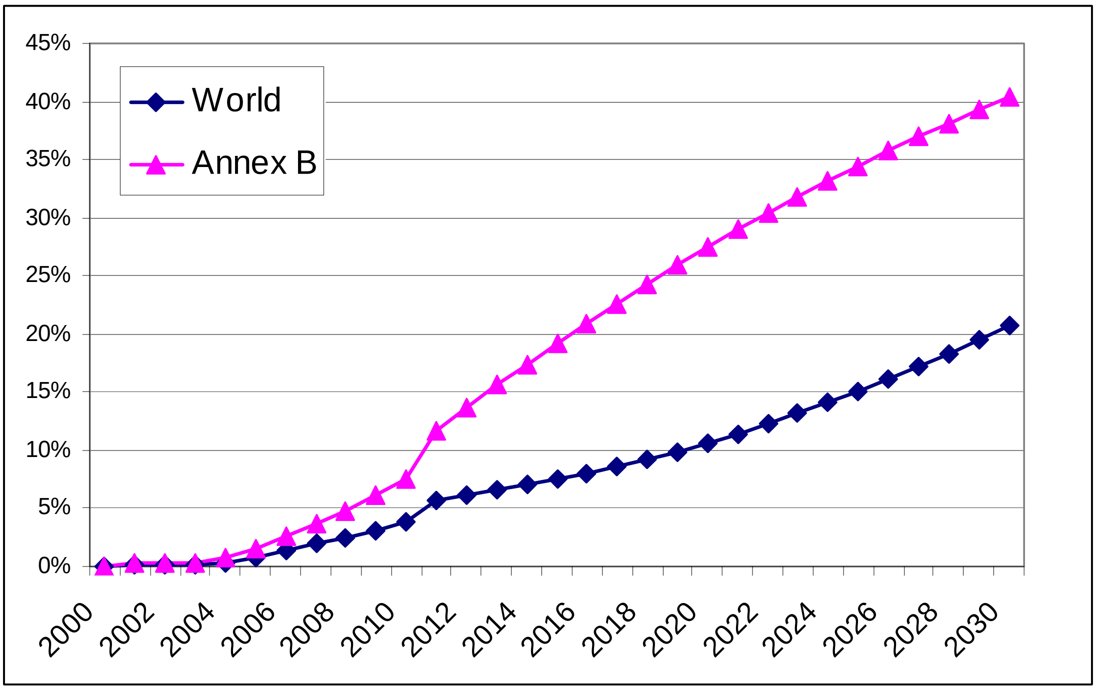
Figure 2: The energy CO_2 profile for the CO_2 'only only' scenario



Source: GECS study, Criqui (2002).

Figure 2 shows the differences amongst the soft-landing scenarios in absolute terms. However, more insights could be gained if the reduction targets are reflected in relative terms. Figure 3 illustrates the relative effort rates compared to the reference scenario. It shows the steadily increasing reduction level on global scale to 20% by 2030, but most importantly it shows the even sharper increase in the effort rate for the Annex B. In this latter case the reduction target rises above 40% compared to the baseline. This explains the steeply rising carbon value in Figure 4.

Figure 3: Relative emission reductions in the carbon constraint scenario (CO_2 'only only' scenario, in % compared to reference scenario)



Once the main structure of the scenario is defined, the assumptions have to be implemented in the model(s) code. In the POLES model this implementation follows the next steps. The global emission target is translated to regionally differentiated *carbon reduction targets* according to the above-described scheme. The model then calculates the equilibrium *carbon value*, assuming global trading amongst the participating regions. This is achieved by a stepwise iterative process: by introducing an increasing 'carbon tax' the model predicts less carbon emission due to the multiple market mechanisms foreseen in the model (energy demand contraction, de-carbonisation of primary fuel mix, energy efficiency increase, etc). This stepwise approach builds up the Marginal Abatement Cost (MAC) curve of the model, which can be plotted as well (see Figure 6). Once the overall level of carbon emissions reach the targeted level in the whole 'bubble' (aggregated participating regions), the process finishes. At this point the carbon emission market is cleared, as the demand for carbon permits equals the available supply. It must be emphasized, that in this process the general equilibrium effects are absent. Additionally, the pre-defined emission reduction path is smoothed with a quadratic function, in order to avoid overshooting in the adjustment process.

The scenario implementation in the GEM-E3 model involves similar elements as in the POLES case, with some additional assumptions necessary for a general equilibrium model. Identical regionally differentiated *carbon reduction targets* are also fed into the GEM-E3 model, which leads to the optimal *carbon value*, which is the shadow price of the given emission constraint assuming global trading (optimal least-cost allocation of reduction efforts to countries and regions). The Joint Implementation (JI) and Clean Development Mechanisms (CDM) can also be taken into consideration. The model requires two further assumptions. The permits are allocated to emitters in these scenarios by grandfathering, following the allocation principle of the European emission trading scheme. Second, the recycling rule for permit revenues is to give it to the firms, which means in the model to indirectly increase the household disposable income (through the factors' ownership). The adjustment process in the general equilibrium model is more complex than in the energy model. Agents modify their optimal behavior to meet the carbon constraint reaching the new equilibrium in all the markets (factors, goods and services) after trade adjustments have taken place (reduction in production level and input mix - fuels) and considering transfers due to global emission trading.

3.3 Linkages between the models

A key element of the analysis presented in this paper is the link made between the two models. Policy shocks modelled with the partial equilibrium POLES model are asymmetrical ones, *i.e.* the shock do only affect the behaviour of agents in the energy sector, but this change has no effect on the overall GDP level. Changes in GDP levels would further modify the behaviour of agents, intensifying or weakening the response to the shock. In economic terms these effects are known as the income effects amongst the different sectors and products. Agents, in addition to substitute away from products (sectors) characterised by high carbon content, would cut their overall consumption if a negative shock affects them. The introduction of this missing mechanism is the objective of the present modelling exercise.

By ensuring the compatibility between the two models through the baseline calibration, the GEM-E3 model gives the adjusted size and the sign of the income effect for the various regions of the models.

The GDP feedback can be introduced at two different levels. First, it can be considered at the aggregated GDP level, by changing only the overall GDP growth rate in the model for all the modelling regions. Alternatively, one could adjust not only the GDP level, but also the distribution of the total GDP amongst the different sectors. This more detailed approach would not only capture the income effect, but also part of the substitution effect (*i.e.* the intersectoral income substitution). The more detailed the sectoral breakdown, the more one can capture this effect. Unfortunately, the sectoral definition of POLES and GEM-E3 are not fully compatible. Table 2 gives an overview of the sectoral details of the two models.

Table 2: Sectoral breakdown of the GEM-E3 and POLES models

GEM E3		POLES	
Energy transformation	Electricity. Petroleum Refineries.	Energy transformation	Electricity Refinary
Fuel extraction	Coal. Crude Petroleum. Natural Gas Production. Distribution of Gasseous Fuels - Manufacture of Gas.	Fuel extraction	Coal Oil Natural Gas
Industry	Ferrous and non ferrous metals. Chemical Products. Other energy intensive. Electronic Equipment. Transport equipment. Other Equipment Goods. Other Manufacturing products. Construction. Food Industry. Textile Industry.	Industry	Steel industry Chemical industry (+ feedstock) Non metallic minerals industry Other industry (+non energy use)
Transport	Trade and Transport.	Transport	Road transport Rail transport Air transport Other transport
RAS	Other Market Services. Non Market Services. Housholds energy use* Agriculture.	RAS	Residential Service sector Agriculture

The GEM-E3 model has more detailed sectoral breakdown in both category of industries and services. Some sectors (*e.g.* transport) are more detailed in POLES, whereas some other sectors are aggregated to different classes (*e.g.* non metallic minerals) in POLES and GEM-E3, so it is difficult to match them. Additionally, important sectors, such as residential and households are different by definition due to the modelling approach. This prevents to reach a full sectoral compatibility between the two models. In order to circumvent this difficulty, it has been decided to perform the sectoral feedback effect only at a more aggregated level. Accordingly, relative changes in the value added at the level of Agriculture, Industry and Services are calculated from the GEM-E3 results, and then these changes are introduced in the POLES model runs.

4 Results

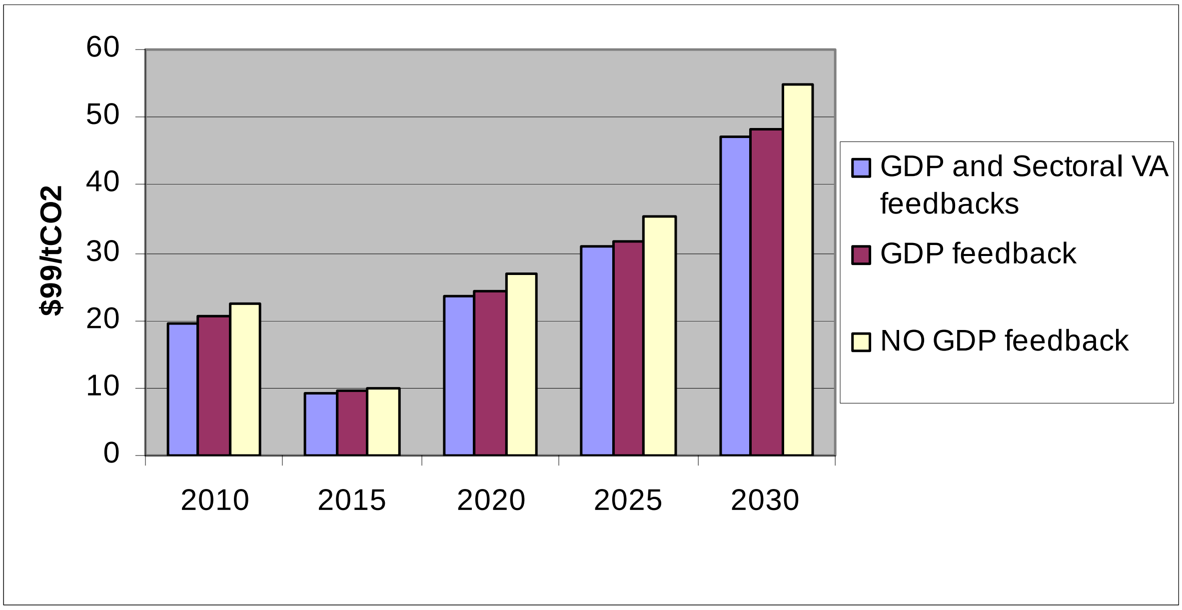
In order to present results several significant variables have been selected. There are various indicators of the aggregate effects of climate policies. In the case of the linear programming (LP) type of energy models this indicator is usually the total system cost. CGE models can compute the changes in welfare and activity levels. The POLES model does not compute the welfare changes, and the GDP is exogenously prescribed. POLES computes the marginal abatement cost (also known as 'carbon value') of the mitigation targets, as well as the total abatement costs, which are commented in the following.

4.1 Carbon Value (CV)

The MAC curve represents the functional relationship between the emission reduction (either in % reduction or in absolute terms) and its marginal cost. The carbon value (CV) can be interpreted within a partial equilibrium context as the 'tax' level that clears the market for carbon emission permits. In POLES the CV is endogenously calculated. A routine determines the level of the optimal (minimal) carbon value in each year to maintain the given region on the desired carbon reduction path (see Russ, 2001).

Figure 4 shows the marginal abatement cost for the different ways of implementing GDP feedback of the model. The figure illustrates the important differences amongst the three cases. The marginal cost is approximately 10% lower with GDP feedback, and 12% lower if both the GDP and sectoral feedback are taken into account. This indicates the importance of the falling GDP when more stringent carbon reduction scenarios are considered. This effect is mainly captured through the change in the overall GDP level, while the further contribution of changing the shares of sectoral value added seems to have a rather minor impact.

Figure 4: The marginal abatement costs (Carbon Value)

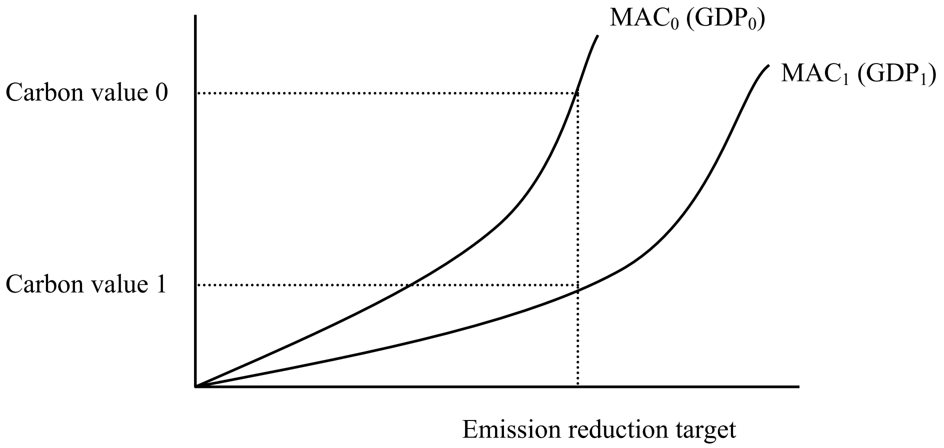


The carbon values show an increasing trend, with a drop in 2015. The specific scenario set-up produces this fall in the evolution of the CV path. While in the first Kyoto period the Annex B countries fulfil their obligation alone, following 2012 some developing countries undertake carbon reduction commitments reaching certain thresholds in their *per capita* GDP development (according to the 'soft-landing' scenario definition).

4.2 MAC curve comparison

From a theoretical point of view, the required carbon value to meet a given emission reduction target when accounting for the GDP feedback would be lower than in the non-feedback case, since the reduction in overall economic activity contributes to part of the necessary adjustment to the environmental target. Figure 2 illustrates this point. Indeed, the marginal abatement cost (MAC) curve is expected to shift to the right when the GDP feedback is considered.

Figure 5: Marginal Abatement Cost Curves

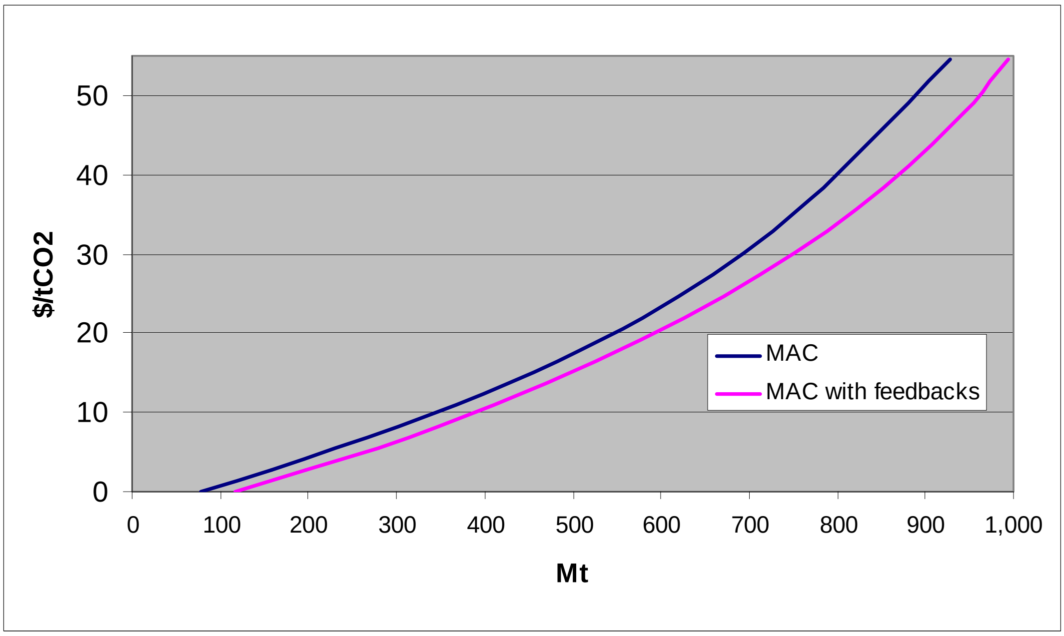


Note: GDP$_0$ > GDP$_1$

However, from the general equilibrium point of view this adjustment is not that straightforward, as more impacts will determine the shape of the MAC curves. The first (and apparently more important one) is the income effect. The decreasing GDP reduces carbon emissions (as the units of GDP not produced do not require emissions), but as a secondary effect also influences world energy prices. This price effect modifies the relative prices of the energy carriers, making the less carbon intensive fuels more expensive, consequently pushing the MAC curve upwards. Apparently this latter effect is the weaker one, and the typical assumption on the GDP effect seems valid. (See Figure 6) There is a third effect involved in the process through the international trade mechanisms. Although this effect does not influence the MAC curve of the individual regions, it does have a real effect on the total GHG emissions of the carbon constraint policy. As the demand for different energy carriers will fall, driving the energy prices of the carbon intensive fuels down (*e.g.* coal, lignite), some regions not covered by the emission reduction scheme (*e.g.* developing regions like China, India) could even increase their energy use and so carbon emissions (the so-called "carbon leakage" effect).

The actual impact of the GDP feedback on the MAC at world level is shown in Figure 6, which represents the actual curves obtained with POLES for two policy cases for the year 2010.

Figure 6: 2010 World Marginal Abatement Cost Curve (MAC)[7]



An additional issue arises from the dynamic feature of the POLES model. Being a year by year recursive simulation model, the dynamic path of the carbon values plays a crucial role in the estimation of costs associated to a given target year. Strictly speaking, a MAC curve can be set up for each year of the modelling period. The CVs applied in earlier periods have an effect on the shape and position of the MAC curve of the given year. Figure 6 illustrates this point. First, the initial point of the MAC is not in the origin. As the horizontal axis in the figure measures the reduction compared to the reference or 'business as usual' (BAU) scenario emissions, the CV values imposed in earlier periods will shift the MAC away from the origin to the right. Even at a CV of 0 Euro/tCO_2 of the given year, emissions are under the original BAU emissions as a consequence of the preceding reductions. The distance between the origin and the starting point of the MAC incorporates this "early action". Second, not only the starting point, but also the shape of the MAC is influenced by the CVs of the earlier periods. The CVs applied in the earlier period will shift the MAC curves to the right. At a first glance it might seem contradictive, as the options used in earlier

---

[7] In order to make the differences more clear, the MAC in the figure shows the MAC where all regions participate in the carbon reduction scheme.

periods would reduce the number of alternatives available to mitigate in the given period. However, as the MACs are not static ones, the investments induced by the CVs in the earlier periods (*e.g.* into less carbon intensive power plants, more efficient boilers) give higher freedom in the subsequent periods to reduce carbon emissions through the faster accumulation of cleaner, more efficient capacities.

4.3 Total Abatement Cost

In addition to the marginal abatement cost, policy makers are also interested in other indicators, such as the total abatement costs (TAC) as a share of GDP. This indicator has two advantages. First, it gives the order of magnitude of the overall impact of the policy compared to a generally established scale (GDP), making it more understandable for non-specialists. Second, with the help of this indicator the cost-effectiveness of the policy instrument could be scaled against other measures (*e.g.* carbon intensity targets, efficiency standards). Usually the CV has no equivalent counterpart if other policy instruments are used, which makes the comparison more difficult.

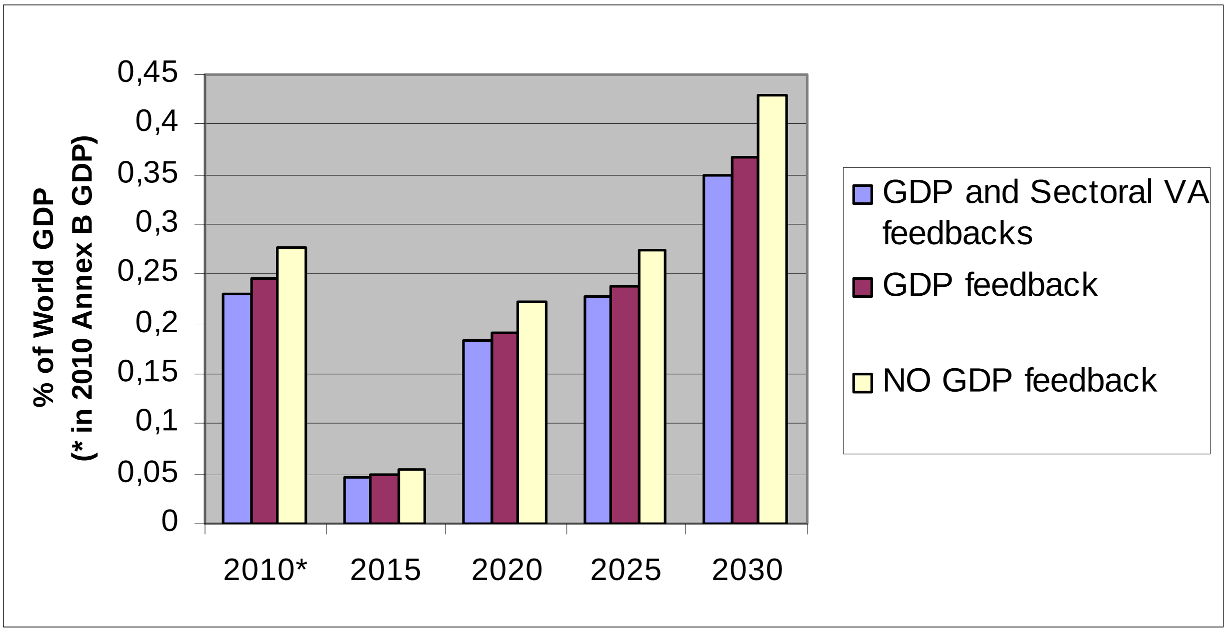
In POLES the same subroutine finding the equilibrium CV calculates the integral of the MAC curve and therefore computes the total abatement cost (in terms of ‘opportunity cost”) for each modelling year. Summing up the TAC on a year by year basis[8] the total cost of the policy over the full time period may be obtained.

Figure 7 shows the world total abatement cost compared to the GDP level in the 2010-2030 period. The TAC shows steep increase during the modelling period. It is around 14% lower with the GDP feedback, and 17% lower if both the GDP and sectoral share feedback is applied in 2030. Note that these relative differences are higher than those found for the carbon value due to the shape of the MAC curve. The substantial difference between the years 2010 and 2015 illustrates the significant impact of the increasing participation in the climate policy.

---

[8] As usually a long time period is involved, discounting should be applied to the costs (in this case a 5% annual rate)

Figure 7: Total Abatement Cost (not cumulated)



4.4 *Interpretation of the overestimation effect with the POLES model*

From the previous results it seems that the size of the overestimation is of around 12% for marginal cost (carbon value), and around 15% for total abatement costs. These results reinforce somehow the validity of partial equilibrium approach of the POLES model. However, the overestimation seems to increase with more stringent carbon constraints (and increasing CV). The relative size of the income effect becomes higher, and then accounting for the GDP feedbacks in POLES seems more necessary.

Another issue is the consistency of these results with the sectoral composition of GDP. The idea is the following. One would expect that given the POLES seems to capture most of the necessary adjustment while being an energy model, then the contribution of the fall in the energy sector to the overall GDP fall would be quite significant. Put it in other words: most of the GDP adjustment takes place in energy-related sectors. The GEM-E3 model can be used to compute the sectoral breakdown of the GDP adjustment. Table 3 presents the sectoral shares in the overall GDP fall, including the energy intensive industries (steel, chemical products, other energy intensive), the primary fuels sectors (coal, oil, and gas), and electricity.

Table 3: Sectoral Value Added Share in GDP fall (World, GEM-E3)

	2005	*2010*	*2015*	*2020*	*2025*	*2030*
Energy Sectors	***43%***	***48%***	***73%***	***68%***	***74%***	***76%***
energy intensive	14%	17%	26%	26%	29%	32%
coal	7%	5%	13%	10%	9%	8%
oil	18%	19%	25%	23%	24%	23%
natural gas	-3%	-2%	-2%	-2%	-1%	-1%
electricity	6%	9%	11%	11%	13%	14%
Rest of the Economy	***57%***	***52%***	***27%***	***32%***	***26%***	***24%***
agriculture	2%	1%	-16%	-15%	-18%	-20%
rest industry	18%	16%	14%	18%	18%	21%
services	37%	34%	28%	29%	26%	23%

The first and most important characteristic is the burden undertaken by the energy sectors. In the early periods (2005-2010) the energy sectors are responsible for half of the GDP fall, and that share increases to more than two thirds in the later periods (2015-2030). There could be two explanations to the sudden change taking place between 2010 -2015. First, the sudden change can be attributed to the increasing level of mitigation efforts. As carbon reduction efforts increase, it might be the energy sector, which would accommodate major restructuring, taking higher burden of the total.

Second, the figures suggest that the change in the participation regime has a significant impact on the energy sector. If the carbon constraint policy is limited to the Annex B countries, the impact is more evenly distributed amongst the sectors. Starting a wider participation entails more concentrated impacts on the energy sectors itself. It is then a sign that developing regions have more available (and relatively cheaper) options to reduce their carbon emissions in their energy sectors, while the developed world already used a significant part of these options (*e.g.* a major part of the energy transformation facilities are already at the edge of the technology frontier).

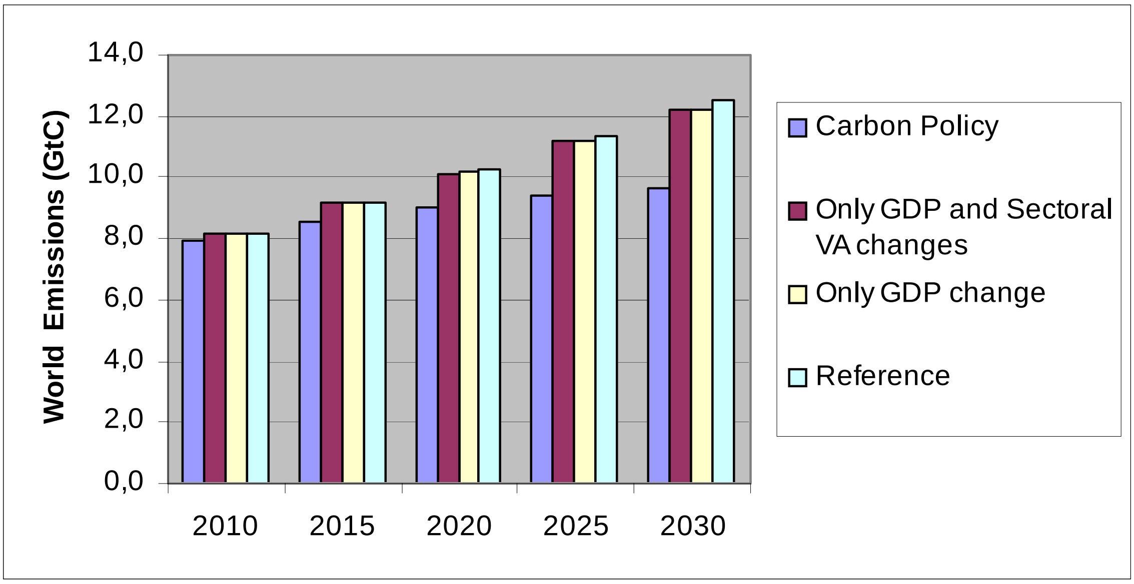
An additional remarkable point is the relatively small reduction of the coal sector value added. Although, this is the sector most affected by any carbon value or tax, the low level BAU value added makes its contribution less important in contrast to the other energy sector. In addition, a major part of coal consumption is taking place in the electricity transformation sectors, therefore a considerable part of its reduction is captured there.

Third, natural gas is the only energy sector able to gain from the policy, although its share in the changing value added is relatively minor. The clear winner of the policy seems to be the agriculture, but these numbers must be handled cautiously, as the GEM-E3 model does not include any damage function yet.

The message from the table is rather ambiguous. The first two periods (2005-2010) would clearly suggest that applying the GDP feedback is crucial. Without it, half of the GDP effect would not be captured, imposing significant bias in the model results. On the other hand, the later values of 2015-2030 suggest, that most part (as high as 68-76%) of these changes are captured within the energy sectors, even with stringent climate policies in place. Consequently, disregarding this part would be less critical, mainly if less stringent climate scenarios are evaluated.

Another way of checking the consistency of the results in this paper is to look at the share of the emission reduction due only to the income effect, *i.e.* ignoring the substitution effects of the POLES model. Figure 8 shows the carbon emissions in the reference scenario, the carbon policy scenario (with the POLES model), and the policy scenarios when only the GDP effect is computed in POLES, without accounting for the carbon constraint. There are two cases in this last situation: either only the aggregated GDP change, or both the aggregated GDP change and the sectoral value added changes. If only the GDP-related effects are taken into account, the emissions are very similar to those of the reference scenario. The GDP feedback (income effect) explains around 10% of the emissions reduction, which seems to be consistent with the results seen in terms of marginal cost and total abatement costs.

Figure 8: Share of GDP feedbacks in fall in Carbon emissions



5 Conclusions

The POLES model assumes that the regional GDP temporal paths are exogenous, and then do not change as a result of a carbon constraint on the economy. This can lead to an overestimation of the costs of climate policies as all the adjustment will have to be made through price changes, without modifications in regional GDP or sectoral activity levels. The GEM-E3 general equilibrium model has been used to compute the GDP or macroeconomic feedback of a particular climate policy in the 2030 time horizon, and that feedback has been introduced into the POLES model.

The preliminary results suggest that the overestimation for the marginal cost (carbon value) is around 12%, and that of the total abatement costs around 15%. Those results seem consistent with the fact that the GEM-E3 model estimates that around 70% of the overall GDP adjustment takes place in the energy-related sectors. Therefore, this preliminary analysis seems to justify to some extent the use of POLES without accounting for the macroeconomic feedback.

However, it should be noted that with increasing carbon constraints (and therefore increasing carbon values), the income effect becomes more significant, and then not considering the macroeconomic feedback leads to a certain overestimation of costs.

There are several caveats that should be taken into account. First, the results of this article are subject to the use of a particular climate policy scenario and implementation scheme. Other cases should be tested to have a broader perspective of the potential role played by the GDP feedback. Secondly, the consistency between the baseline scenarios of POLES and GEM-E3 models should be further explored.

References

Capros P. *et al.* (1997). “The GEM-E3 model: Reference Manual. The GEM-E3 Model for the European Union”. National Technical University of Athens. Available at http://www.e3mlab.ntua.gr.

Criqui P. (ed) (2002), “GECS, Greenhouse gas Emission Control Strategies”, EU research project.

Ghersi F. (2004), “IMACLIM-POLES. Enjeux de l’articulation bottom-up/top-down dans la modélisation de politiques climatiques”, Document de travail Centre International de Recherche sur l’Environment et le Développment (CIRED).

IEPE, RIVM, KUL and NTUA (2003), “Greenhouse gas Reduction Pathways in the UNFCCC process up to 2025”, EU research project, available at http://europa.eu.int/comm/environment/climat/pdf/pm_techreport2025.pdf

IPCC (2000), *IPCC Special Report on Emissions Scenarios*, available at http://www.grida.no/climate/ipcc/emission/index.htm.

Messner S., and . Scharattenholzer (2000), “MESSAGE-MACRO: linking an energy supply model with a macroeconomic module and solving it iteratively”, *Energy* (25), 267-282.

Russ, P. (2001), “Dynamic Carbon Emission Permit Prices and Emission Trade”, paper presented at the 2001 EcoMod Conference, available at http://www.ecomod.net/conferences/ecomod2001/papers_web/Russ_endopap2.pdf.