June 2004

Flexible multi-gas climate policies

By

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PRELIMINARY DRAFT

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Abstract

I analyse the costs of policies aimed at stabilising global climate change. I show that abatement of all major greenhouse gases is important to the costs of climate policies and that flexible reduction of methane and other non-CO_2 gases may reduce costs significantly. The non-CO_2 gases offer many low-cost abatement options and this reduces the need for abatement of CO_2 to stabilise climate change. Multi-gas flexibility may be particularly important if climate policies reflect not only long-term stabilisation, but also the rate at which the climate changes, as the latter may require large reductions in emissions in the short-term.

[*]Financial support from DG Environment, European Commission, is gratefully acknowledged. The paper reflects the views of the author. The European Commission is not liable for any use that may be made of the information contained in this paper. Thanks are due to the EMF21 group in general and to Atsushi Kurosawa, Alan Manne, Steven Smith, Detlef Van Vuuren, and Peter Zapfel in particular for discussions and for making data available. Thanks are also due to Kirsten Saward for logistical support and to Dennis Andersen, Gisin Ma and Anna Margrethe Kragh for research assistance. All remaining errors are the responsibility of the author. *Address for correspondence: Jesper Jensen, Copenhagen Economics ApS, Nyropsgade 13[1], 1602 Copenhagen V, Denmark. Tel. +45 7027 0740. Email: jj@copenhageneconomics.com.*

1. Introduction

The concerns for global climate change have many different faces. Some concerns relate to the *rate* of climate change, e.g., how much temperature increases within a decade. Other concerns relate to *absolute* climate change, e.g., how much temperature has increased since the industrial revolution.

I analyse scenarios that reflect the concerns for both the rate of climate change and absolute climate change. The scenarios specifically focus on the importance of flexible abatement of the major gases causing climate change. This flexibility is important as the gases differ widely with respect to their radiative forcing (their effects on warming), their lifetime in the atmosphere, and their abatement potential (in terms of both quantity and costs).

The analysis covers carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the so-called industrial F-gases HFCs, PFCs and SF_6. CO_2 is by-far quantitatively most important, and is therefore the single most important target for climate policies aimed at reducing both climate change and costs. But I show that flexible reductions of all gases may significantly help minimise costs. The non-CO_2 gases offer many low-cost abatement options and this reduces the need for abatement of CO_2 to stabilise climate change.

Methane plays an important role as it has most of the abatement options among the non-CO_2 gases. It also has a stronger warming effect than CO_2, i.e., emissions of one ton of methane increases warming more than emissions of one ton of CO_2. The large set of abatement options and the strong warming effect is important if we want to slow the rate of climate change as methane abatement may substitute CO_2 abatement, reducing the costs of climate policies.

Methane also has a very short lifetime in the atmosphere. If we want to reduce the risks of exceeding a threshold value for absolute climate change, e.g., a 2 degree temperature increase by the year 2100, future methane abatement may substitute short-term CO_2 abatement, as it takes longer for CO_2 to disappear from the atmosphere. This also reduces the costs of climate policies.

These conclusions are based on an analysis with a revised version of the EDGE model.[1] Specifically, this version of the model has been developed for the EMF 21 working group on “Multi-Gas Mitigation and Climate Change” and has been revised with the most recent data on emissions and abatement options for all of the gases mentioned above.[2] I also develop an interface between long-term integrated assessment models of global climate change and the short-term EDGE model to enable analysis of climate change targets in the EDGE model. In short, the interface translates the long-term targets for radiative forcing (or temperature) to 5-year budgets for greenhouse gas emissions. I show that the EDGE model captures some of the long-term climate dynamics, and that comprehensive analysis of the climate impacts requires a full-blown climate model.

The next section presents the EDGE model, which is the computational framework in the paper. I provide an overview the key features of the model and focus particularly on the improved representation of the non-CO_2 gases in the model. The following section outlines the implementation of the EMF 21 scenarios. The paper then presents and interprets the economic and environmental impacts of the scenarios, and it concludes with a discussion of limitations of the analysis and suggestions for extensions.

[1] See Jensen (2004) for model documentation and Jensen and Thelle (2001) for an application of the model.
[2] The analysis thus covers all gases included in the Kyoto Protocol.

2. The EDGE model

This analysis is based on the EDGE model. The following overview focuses on the model features with particular relevance for this analysis. Particular attention is given to the improved representation of the non-CO_2 gases. Full model documentation is provided in Jensen (2004).

The EDGE model: An overview

The EDGE model is a dynamic, multi-region general equilibrium model of emissions, international trade, and energy production and consumption. The model covers the period 2000-2030 in six five-year periods, and the dynamic features include forward-looking investment and savings decisions by households and firms. Specifically, their decisions account for intertemporal linkages via their budget constraints and capital stocks. All decisions therefore account for both current and future climate policies.

Another dynamic feature is the putty-clay description of the capital stock. This feature captures time lags in the responses to changes in energy prices, reflecting that energy consumption is closely linked with long-lived capital stock such as power plants. In other words, as the stock of clay capital depreciates over time, energy demand elasticities increase and CO_2 emissions respond stronger to climate policies.

The model divides the world into 8 regions and each region distinguishes 7 sectors with production of goods and services (see Table 1 for a list of regions and sectors). The regional breakdown represents the major geopolitical regions involved in the climate policy negotiations. The sectoral breakdown reflects two important distinctions: First, CO_2 emissions differ mainly between coal, oil and natural gas. Second, emissions policies will affect energy-intensive industries more than other non-energy producing sectors.

TABLE 1 HERE

Each of the regions has a representative consumer, a government and a production sector for each of the goods and services. Figure 1 gives an overview of the markets, the agents and the flows of goods, services and factors in the model. Firms producing goods and services represent the supply side of the model. All goods and services are being produced with materials, including energy, and primary factors capital and labour. Firms are assumed to maximize profits and there is perfect competition in all markets. A representative agent represents final demand and he finances his consumption with income from sales of capital and labour. A government agent provides public goods financed through taxes. Finally, all regions are connected via international trade in all goods.

FIGURE 1 HERE

The model captures emissions of all greenhouse gases covered by the Kyoto Protocol. CO_2 emissions are directly linked to the use of coal, oil and gas, whereas the modelling of the emissions of the other gases is more complicated (discussed below). Climate policies are linked to the emissions of all gases via emissions allowances. That is, one unit (e.g., a ton) of emissions of a gas require an allowance. Government set the overall cap on emissions and the market then determines the price of allowances.

Climate polices may allow trading of allowances to minimise costs. Generally, trading minimises costs by letting the market price of allowances determine the location of abatement options with the lowest costs. For example, if a firm has abatement options with costs lower than the allowance prices, the firm would gain from reducing emissions and selling the allowances that it would otherwise need to cover the emissions. Conversely, a firm with high cost options would gain from buying allowances instead of reducing emissions.[3]

Policy makers may exploit this flexibility by allowing trading both within their own countries, across countries (international trade), and across gases. The model allows analysis of all these policies. In the case of allowance trading for a single gas (e.g., CO_2), this corresponds to trade with a perfectly homogenous commodity. In the case of trading with a basket of gases, a choice has to be made with respect to how allowances for the different gases may be exchanged. The EDGE model adapts the simple assumption that all gases are converted into CO_2-equivalents using the 100-year global warming potentials from Houghton *et al.* (1996).

Economic analysis of multi-gas abatement

The EDGE model covers emissions of all greenhouse gases covered by the Kyoto Protocol. In the previous version of the model, the quality of the CO_2 data was significantly better than the quality of the data for all the non-CO_2 gases.[4] The model has now been updated and revised to include the most recent data on both emissions and abatement options for CH_4, N_2O, HFCs, PFCs and SF_6, with the latter three being grouped into one composite gas labelled HGW for high global warming potential.[5]

Emissions of non-CO_2 gases constitute a significant share of total greenhouse gas emissions in most countries. Globally, non-CO_2 gases account for around 30% of total emissions, higher in the developing countries and lower in the developed countries. In both groups of countries, CH_4 dominates the non-CO_2 gases. Figure 2 and Figure 3 present an overview for Annex B and non-Annex B countries, respectively.[6] Emissions growth in the developing countries far exceeds growth in the developed countries, and the developing countries will after 2010 account for more than 50% of total greenhouse gas emissions. This directly shows that control of global emissions towards a long-term climate targets necessarily must involve the developing countries not too far from now in order to be effective.

FIGURE 2 HERE

FIGURE 3 HERE

The modelling of emissions and their associated abatement options differ between CO_2 and non-CO_2. Almost all CO_2 emissions are linked directly to the combustion of fossil fuels. Furthermore, each of the main fossil fuels; coal, oil and gas, have their own roughly constant emissions factor, and one abatement option currently dominates: Reduced combustion.[7]

The model captures CO_2 emissions via separate modelling of the three fuel markets. The emissions of a given fuel are then calculated directly as quantity times the emissions factor. The model also captures the potential for substitution between fuels, e.g., away from the emissions intensive coal to the less emissions-intensive oil and gas. This substitution furthermore differs by production sector and region.

[3] See Weyant (1999) for a graphical exposition of these arguments.

[4] See Jensen and Thelle (2001).

[5] This simplifying assumption reduces model complexity significantly without missing important effects in the present analysis. Radiative forcing and atmospheric life-times differ widely across the basket of gases HFCs, PFCs and SF_6, but these gases are not quantitatively important relative to the other greenhouse gases.

[6] Annex B countries refer to the countries listed in Annex B in the Kyoto Protocol. This is also the list of countries that originally committed to emissions targets in the protocol.

[7] Storage and in particular sequestration of CO_2 are also important options. The EDGE model does allow for sequestration (also known as sinks), but this feature is not applied here due to the lack of long-term data for both baseline sequestration and sequestration costs. See Jensen and Thelle (2001) for an analysis of the Kyoto Protocol, which incorporates sinks.

The modelling of non-CO_2 emissions is significantly more challenging. Emissions come from many different sources. For example, CH_4 emissions come from both mining of coal, enteric fermentation, waste management, transportation of gas, and rice production. Proper representation of the emissions thus requires a level of technological detail not present in most economy-wide models, including the EDGE model. Aggregate economic activity in an aggregate economic sector, e.g., agricultural production, may therefore be a misleading emissions driver.

Multiple abatement options complicate the modelling challenge further. In addition to lower use, most of the non-CO_2 gases may both be recovered and recycled. That is, increased use may not necessarily be associated with increased emissions.

Rather than trying to capture all these details in a stylized manner, the EDGE model employs the following simplifying assumptions. First, we assume that emissions of non-CO_2 gases are independent of other policies. For example, there are no interaction effects between CO_2 policies and non-CO_2 emissions. Second, the model employs continuous cost functions to characterise the abatement options. The detailed abatement cost data show the abatement potential and the costs associated with alternative abatement technologies. When ordered by their costs the data points characterise a marginal abatement cost schedule, which can be incorporated in the model.

The cost functions have been estimated assuming that no abatement takes place below 1 \$/TCE and that the cost functions takes exponential form $p=e^{\alpha x}$, where p is the marginal abatement costs in \$/TCE, α is the estimated parameter, and x is the abatement effort measured as the percentage reduction in emissions with reduction potential.[8] Figure 4 illustrates the estimation for methane in 2010 in the EU15, where the points are given by the data set and where the solid line is the estimated function. The appendix contains the detailed estimation results by region.

FIGURE 4 HERE

The model endogenously determines the gas-specific reductions in emissions that minimises costs across gases. That is, the model determines emissions of each gas such that the marginal abatement cost of reducing emissions by one unit is equal across all gases. Finally, the model incorporates the total costs of abatement of non-CO_2 gases by calculating the area below the cost curve for each gas. For simplicity and due to the lack of data, the cost functions are assumed to have fixed coefficients for capital (1/3) and labour (2/3).

Interface with long-term integrated assessment models

The horizon of the EDGE model ends by 2030. Detailed analysis of long-term climate targets requires models with horizons of a century or more, and the EDGE model therefore relies on an interface with long-term models for analysis of long-term climate targets. In short, the interface translates long-term climate targets to 5-year budgets for greenhouse gas emissions. The idea of 5-year budgets reflects the style of targets adopted in the Kyoto Protocol.

The first step from the stabilisation target is to develop least-cost emissions paths. This is output from the long-term models and results in gas-specific emissions paths for both the cases of no climate target (the model reference emissions path) and of alternative climate targets.

[8] The data for N_2O shows that the full abatement potential can be realised at costs below 10 \$/TCE, but the data is not sufficiently detailed to allow estimation of a continuous function. It is therefore assumed that the full abatement potential for N_2O can be realised at 5 \$/TCE.

The second step is the construction of total 5-year greenhouse gas budgets in the EDGE model. The model uses the results from the long-term models to calculate total 5-year emissions using the 100-year global warming potentials. To derive the emissions targets in the EDGE model, the *relative* change in emissions between the reference case and the policy case (both originally from the long-term model) is then applied to the EDGE reference case.[9][10]

3. Policy scenarios and results

We begin with two long-term scenarios with global country participation. They both share the same climate change target: Stabilise radiative forcing at 4.5 Wm^{-2} relative to pre-industrial times by 2150. The key difference between the two scenarios is the set of mitigation options: The multi-gas scenario includes mitigation of all greenhouse gases, whereas the CO_2-only scenario includes mitigation of, yes, CO_2 only. We can then evaluate the significance of multi-gas mitigation by comparing the two scenarios.

Figure 5 summarizes the global emissions profiles for the reference scenario and for three policy scenarios (we will return to the scenario "Decadal target" below). In the reference scenario, emissions increase by more than 50% between 2000 and 2030. [11] This is mainly due strong emissions growth in the developing countries. The multi-gas scenario allows higher emissions than the CO_2-only scenario because of the differences in life-times between CO_2 (varies between 5 and 200 years) and methane (12 years).[12] The longer life-time of CO_2 implies that abatement in the CO_2 only scenario need to start early to meet the long-term stabilisation target. In the multi-gas scenario non-CO_2 abatement reduces the need for CO_2 abatement. Furthermore, the short life-time of methane implies that the abatement needs not to take place before close to target year (2150) to meet the stabilisation target.

FIGURE 5 HERE

The marginal costs of abatement (see Figure 6) reflect the emissions profiles. Two factors help explain the lower costs in the multi-gas scenario: more abatement options and lower abatement requirements. Even as the abatement requirements are only marginally lower in the multi-gas scenario, costs decrease significantly as the non-CO_2 gases offer additional abatement options. The same factors also explain the differences in total costs (measured as changes in GDP in Figure 7).

FIGURE 6 HERE

FIGURE 7 HERE

Limiting the rate of climate change
The final scenario reflects a concern for both the rate of climate change and absolute climate change. The scenario specifically adopts the same long term climate change as above, but also limits the increase in the global mean temperature to an average decadal rate of 0.2 degree C over the period 2000 to 2050 and then again for the period 2051 to 2100. In line with the EMF scenario specifications (and the assumptions underlying the calculation of the long-term emissions profiles in the GRAPE model), the scenario only considers the multi-gas case.

[9] The reference emissions paths generally differ across models and the interface therefore uses relative changes from the reference paths instead of absolute changes.
[10] The Kyoto Protocol is *not* in the reference scenario for the scenarios. This is partly due to the uncertainties about how countries will implement the Kyoto Protocol.
[11] All the long-term emissions profiles are based on output from the GRAPE model.
[12] The lifetime of CO_2 differ across removal processes due to difference in the rate of uptake.

The scenario requires large reductions in emissions in the short run (see Figure 5). In 2020, the reductions are 5% and in 2030 the reductions are above 10%. The large reductions also imply high marginal abatement costs (see Figure 6). The putty-clay formulation of the capital stock implies that energy demand elasticities are increasing over time. The low short-run elasticities make it costly to substitute fuels, e.g., in electricity production. In the long run, retirement of existing capital make is it less costly to substitute fuels, which in turn moderates the costs even as the reduction requirements are large. The large reductions are also costly in terms of lower GDP (see Figure 7). In other words, limiting the rate of climate in addition to limiting long-term climate change may increase costs significantly

The non-CO_2 gases are particularly important in the short run, when the reduction requirements are small. Figure 8 shows the share of total reductions coming from reductions in the non-CO_2 gases. In the long run, when larger reductions in emissions are required, the importance of non-CO_2 gases decreases mainly due to their small share in total emissions. The results are similar for both the scenarios of stabilisation of climate change and of limits on the rate of change.

FIGURE 8 HERE

4. Concluding remarks

Several insights emerge from the analysis. First, the non-CO_2 gases offer many low-cost abatement options and this reduces the need for abatement of CO_2 to stabilise climate change. Flexible multi-gas policies can have a major impact on costs, but does not change the fact that CO_2 is the single most important target for climate policies aimed at reducing both climate change and costs. Second, multi-gas flexibility may be particularly important if climate policies reflect not only long-term stabilisation, but also the rate at which the climate changes, as the latter may require large reductions in emissions in the short-term.

Several issues are not covered by the analysis and call for further analysis. One is that the analysis assumes flexible and competitive markets. In reality, markets do not adjust instantaneously and the cost estimates provided may therefore underestimate the true costs. Also, not all markets are competitive. The international oil markets are of particular relevance for this analysis. An interesting issue is thus the response by the OPEC countries to lower oil demands. Will the OPEC countries restrict supply further and may climate policies affect the stability of the cartel?

Another issue relates to the assumption about efficient policies, i.e., policies that minimise the costs by choosing directly or indirectly the abatement options according to costs. Market based policies, e.g., tradable emissions allowances, have the potential to minimise costs, at least in theory, but these policies may not always be politically and practically feasible. Less efficient policies may therefore in practice increase costs and have lower environmental effectiveness.

The complexity of particularly non-CO_2 emissions suggests that there are significant benefits from developing models with technology details. More detailed models should be able to properly capture that the emissions come from many different sources and that there already exists many different abatement options, including lower use, recovery and recycling.

Appendix

TABLE A.1 AND TABLE A.2 HERE

References

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Table 1. Regions and sectors in the EDGE model

Regions	Sectors
Annex B regions:	Energy:
1. European Union	1. Coal
2. United States	2. Petroleum
3. Japan	3. Crude oil
4. Eastern Europe and Former Soviet Union	4. Natural gas
5. Rest of the OECD	5. Electricity
Non-Annex B regions:	Non-energy:
6. China	6. Energy intensive sectors
7. Major oil exporters	7. All other sectors
8. Rest of the world	

Note: The major data sources for the model include data on economic transactions and CO_2 emissions from the GTAP5 database (Dimaranan (2002)), baseline data from the European Commission (2003), Schaefer et al. (2004) and Scheehle and Kruger (2004).

Table A.1 Estimation results for CH_4

Region in dataset	2010	2020	Model region
Australia & New Zealand	7.0455	7.2936	Rest of the OECD
China	5.9231	5.9538	China Rest of the World
EU-15	11.476	11.841	European Union
Japan	6.0639	6.3646	Japan
OPEC	10.839	10.794	Major oil exporters
Russia	10.853	11.171	Eastern Europe and Former Soviet Union
United States	8.0132	8.3729	United States

Note: The table present estimates of α in the cost function $p=e^{\alpha x}$, where p is the marginal abatement costs in $/TCE, and x is the abatement effort measured as the percentage reduction in emissions with reduction potential. The value in parentheses is R^2.
Source: Estimates based on Schaefer et al. (2004) and Scheehle and Kruger (2004).

Table A.2 Estimation results for HGW

Region in data set	2010	2020	Model region
Canada	10.983	9.795	Rest of the OECD
China	6.935	6.1658	China Rest of the world
EU-15	17.128	10.527	European Union
Japan	15.433	11.221	Japan
OPEC	15.066	7.0659	Major oil exporters
Russian Federation	11.003	8.5361	Eastern Europe and Former Soviet Union
United States	15.644	8.9627	United States

Note: The table present estimates of α in the cost function $p=e^{\alpha x}$, where p is the marginal abatement costs in $/TCE, and x is the abatement effort measured as the percentage reduction in emissions with reduction potential. The value in parentheses is R^2.
Source: Estimates based on data from Schaefer et al. (2004) and Scheehle and Kruger (2004).

Figure 1 Overview of the EDGE model

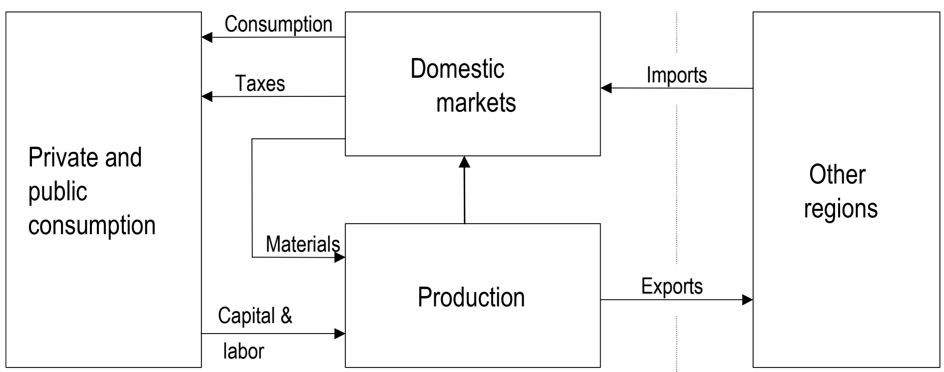
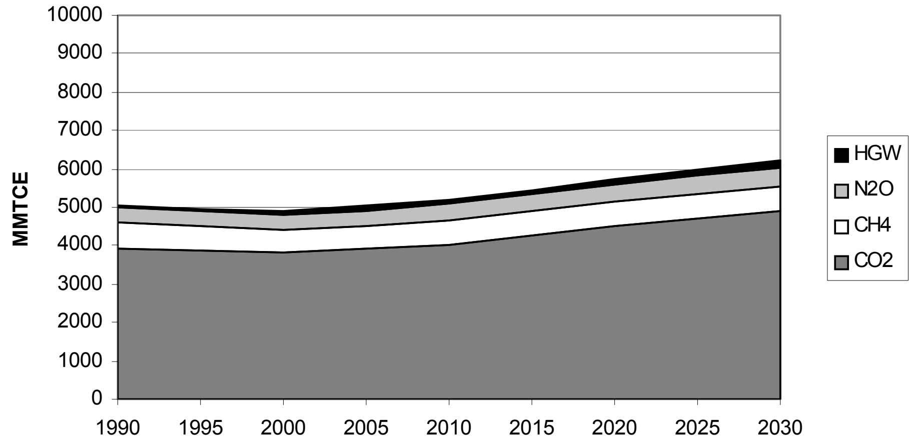
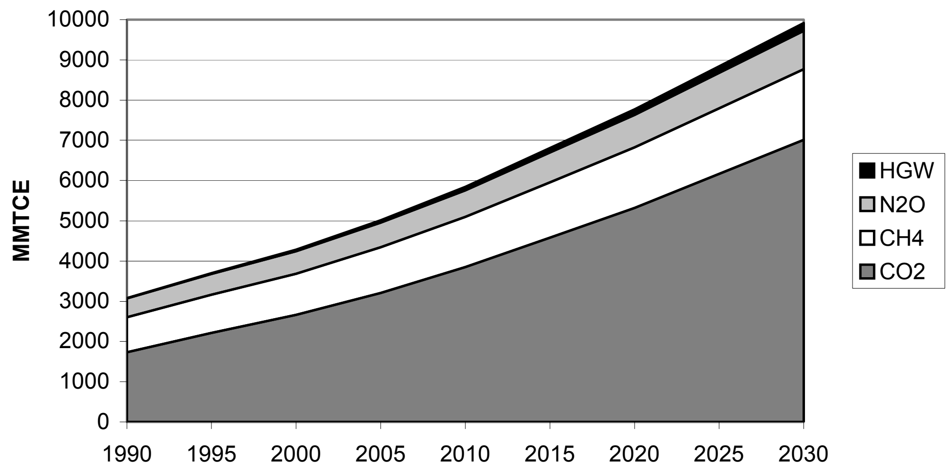


Figure 2 Reference Annex B emissions



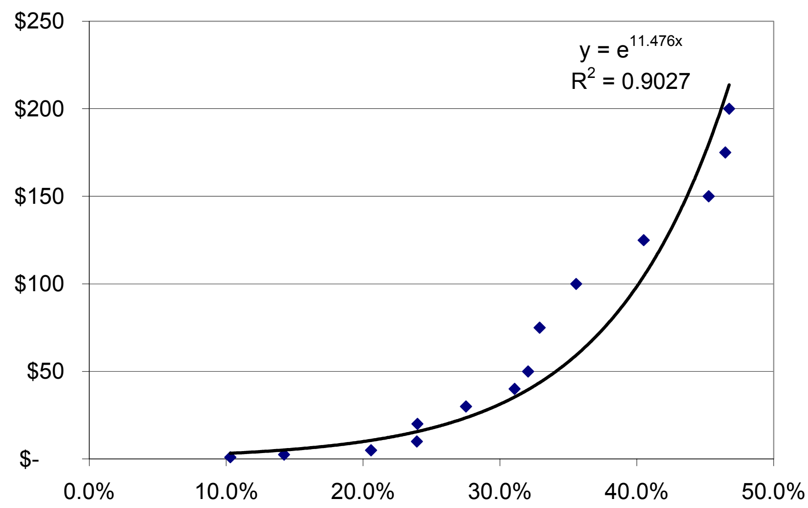
Source: The EDGE model

Figure 3 Reference non-Annex B emissions



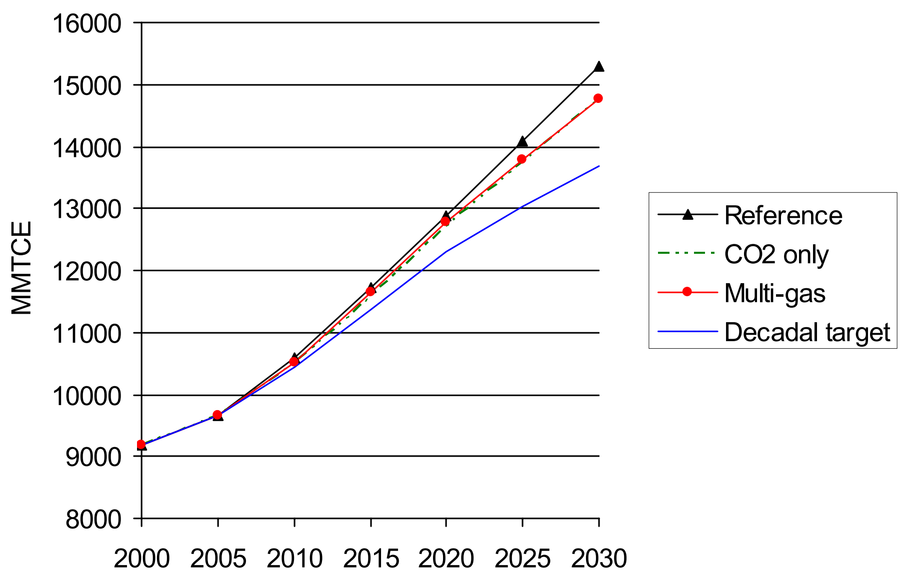
Source: The EDGE model

Figure 4 Estimation of continuous marginal abatement cost functions



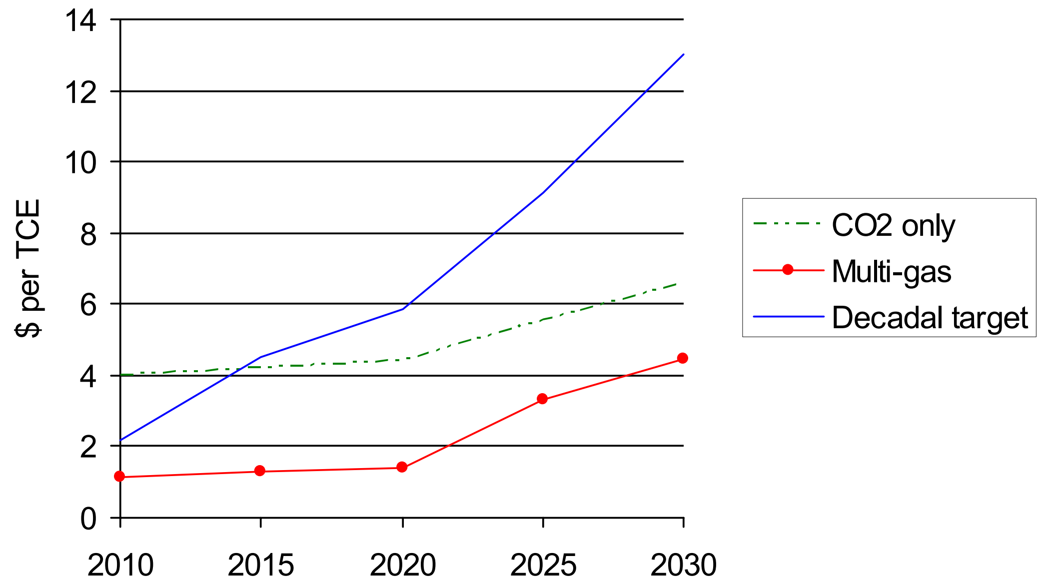
Source: The EDGE model

Figure 5 Global emissions



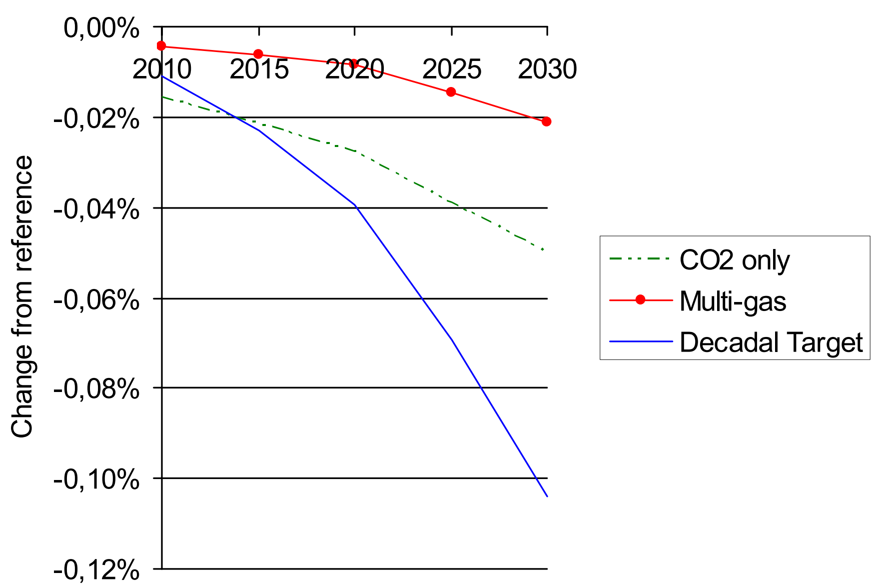
Source: The EDGE model

Figure 6 Marginal abatement costs



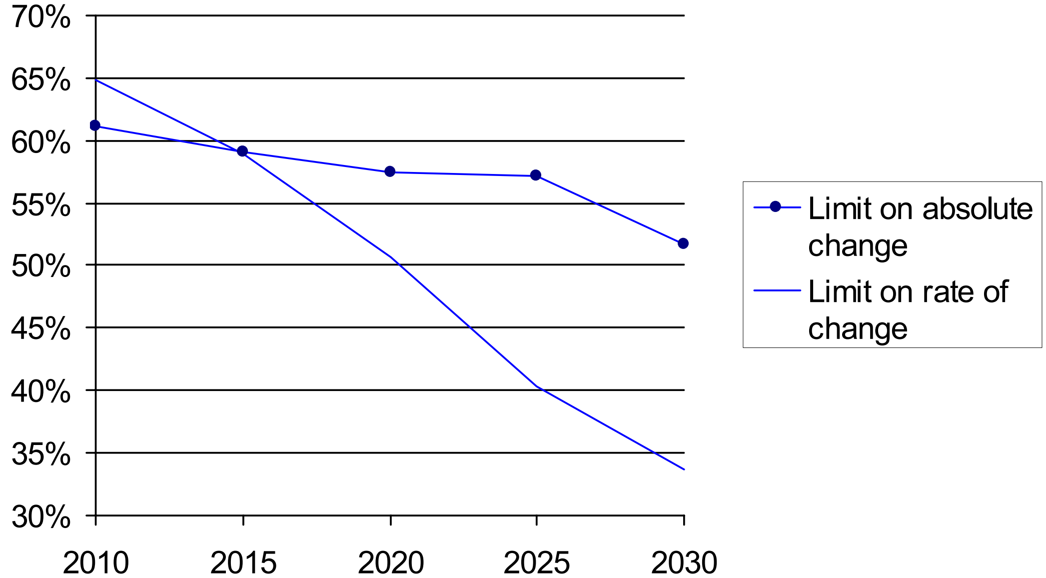
Source: The EDGE model

Figure 7 World GDP



Source: The EDGE model

Figure 8 Share of total reductions from reductions in non-CO_2 gases



Source: The EDGE model