

# **INTEGRATED ASSESSMENT OF THE ECONOMIC TRADE-OFF BETWEEN CO<sub>2</sub>, CH<sub>4</sub> AND N<sub>2</sub>O ABATEMENT – EFFICIENCY LOSSES FROM USING STATIC GWP'S**

Persson U. M., Chalmers University of Technology  
Johansson D. J. A., Chalmers University of Technology  
Azar C., Chalmers University of Technology

Several studies have highlighted the cost-effectiveness of including CH<sub>4</sub> and other non-CO<sub>2</sub> greenhouse gases in a climate strategy compared to a CO<sub>2</sub> only strategy. On the other hand the current GWP formulation, governing the trade off between greenhouse gases in the Kyoto protocol, has received critique from natural scientists as well as economists. This paper focuses on the economic critique of the GWPs and estimates the economic losses from using the 'wrong' metric, i.e. today's GWPs.

For this study an integrated assessment model, encompassing global CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O emissions, has been developed as a tool for studying the economic trade-off between these three greenhouse gases. The climate model consists of a five box, linear pulse representation of the carbon cycle and a standard global-mean mass-balance equations for CH<sub>4</sub> and N<sub>2</sub>O, where the positive feedback of OH on the life-time of CH<sub>4</sub> is accounted for. The tradeoff between reductions of the two gases is examined in a cost-benefit analysis and a cost-effectiveness analysis with constraint on the absolute temperature change.

Although the shadow price ratios between CH<sub>4</sub>, N<sub>2</sub>O respectively and CO<sub>2</sub> deviate to quite a large extent from their GWP indices, the results indicate that the economic losses from using static GWPs are relatively minor, 0.5 per cent of overall abatement and damage costs in the cost-benefit case and 1.5 per cent of overall abatement costs in the cost-effectiveness case. A sensitivity analysis shows that these results are relatively robust, economic losses not exceeding 0.5 per cent in the cost-benefit case or 4 per cent in the cost-effectiveness case.

Although the choice of metric may have large regional or national impacts it is important to note that the efficiency losses from using the 'wrong' metric seems to be at least an order of magnitude smaller than the efficiency gains from adopting a multi-gas approach to climate change as opposed to a CO<sub>2</sub>-only approach.

## **INTRODUCTION**

When the Kyoto protocol to the Framework Convention on Climate Change was established in 1997 it was agreed upon that the emission targets in the protocol should be met for a basket of greenhouse gases, namely carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), HFC's, PFC's and sulfur hexafluoride (SF<sub>6</sub>). The protocol states, in article 5.3, that the Global Warming Potentials (GWPs) adopted by the IPCC shall be used as a metric to calculate emissions and emission reductions in different gases in carbon dioxide equivalents.

The existence of a metric for comparing emissions of different greenhouse gases, with differing radiative properties and differing atmospheric lifetimes, was crucial in the adoption Kyoto basket approach, which may increase the possibility for the parties to reach their emission targets in a cost efficient way, and it has been argued that it was the adoption GWPs that made the climate change issue negotiable (Skodvin, 1999). In the scientific community, on the other hand, the debate on the accuracy of the current GWP formulations has been intense and the debate still very much ongoing.

The GWP metric was first proposed by Lashof & Ahuja (1990) largely building upon the methodology used in calculating the Ozone Depleting Potentials (ODPs) of the gases controlled in the Montreal Protocol. The idea behind current GWPs is to integrate the radiative forcing of an additional emission of one ton of a greenhouse gas over a time period and compare this with the integrated effect of an additional emission of a reference gas, i.e. CO<sub>2</sub>. The integration time adopted in the Kyoto protocol is chosen rather arbitrary to 100 years.

Several articles has pointed at the limitations of the GWP metric (Reilly et al, 1999; Smith & Wigley, 2000a; Smith & Wigley, 2000b) and alternatives have been proposed, both purely physical based metrics and metrics taking into account both physical and economical aspects (Hammitt et al, 1996; Kandlikar, 1996; Manne & Richels, 2001; Reilly & Richards, 1993) etc. Although, none of the proposed metrics has resulted in scientific consensus or gained political acceptance.

Another scientific and political issue, partly overlapping with the issue on appropriate metrics for comparing the different greenhouse gases, has focused on the substantial economic gains of the multigas approach. Hayhoe et al. (1999) and Reilly et al. (2002) have shown that the cost of meeting the targets in the Kyoto protocol can be substantially reduced (more than 50 %) if a multi-gas approach is used instead of a CO<sub>2</sub> only approach. Other studies have focused on a longer time perspective (Tol et al, 2003; Reilly et al, 1999) and have come to a similar conclusion. However, these studies have not included the monitoring and verification problem of many of these gases, which would likely reduce the economic gains (Johansson & Azar, 2003; Victor, 2001).

So, on the one hand we have the possible substantial economic gains of a multi-gas approach, but on the other hand the critique of the current GWPs from natural scientists as well as economists, which makes the metric issue relevant both for the scientific and the political community. Here a highly relevant question is how large the economic losses from using the 'wrong' metric, i.e. today's GWPs, are compared to the overall costs of abatement.

This study assesses the economic losses from using a static GWP metric case compared with a case where the economic trade-off between CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O is optimal over time. We analyze two different cases; a cost-effectiveness case, with a temperature stabilization target of 2 °C at the year 2100, and a cost-benefit case. Given the uncertainties in parameters, such as climate sensitivity and the discount rate, a sensitivity analysis of the importance of these parameters is also conducted.

## **THE MODEL**

The tool used for studying the above posed questions is an integrated assessment model consisting of a coupled climate and economic growth model. The economic model is a standard Ramsey model of optimal growth. In the cost-benefit case, economic output is hampered by climate change damages, given by the expression from Nordhaus's DICE-99 model (Nordhaus & Boyer, 2000). In both the cost-benefit and cost-effectiveness case costs for greenhouse gas abatement is subtracted in the consumption equation. The expression for CO<sub>2</sub> abatement cost is taken from Ellerman & Decaux (1998) and for CH<sub>4</sub> and N<sub>2</sub>O abatement costs from Reilly et al. (2002).

The baseline emissions in the model are taken from the IPCC IS92a scenario (IPCC, 1992), being a business-as-usual scenario. Based on emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O the model calculates concentrations of the gases and subsequent changes in radiative forcings, atmosphere and ocean temperatures. CO<sub>2</sub> concentrations are modeled by the four box, linear pulse representation of the Bern carbon cycle model used in the IPCC:s Third Assessment Report, (REFERENS), hereafter TAR. CH<sub>4</sub> and N<sub>2</sub>O concentrations are modeled using the global mean mass-balance equations given in TAR (Prather & Ehhalt, 2001), taking into account the feed-back effect CH<sub>4</sub> has on its own atmospheric lifetime. The equations for radiative forcing are the simplified expressions given in TAR (Ramaswamy, 2001, pp. 358), accounting for indirect forcings of CH<sub>4</sub> due to its effect on atmospheric chemistry and the overlapping absorption bands of CH<sub>4</sub> and N<sub>2</sub>O. The temperature is modeled by the simple two box model proposed by Schneider and Thompson (1981), consisting of an atmosphere-upper ocean and a deep ocean reservoir.

In both the cost-benefit and cost-effectiveness case the total discounted utility of consumption is maximized for the period 1990-2250, although the results given below are only for 1990-2150 to avoid boundary problems. In the cost effectiveness case damage costs from climate change are not included but a constraint that the temperature shall be stabilized at a level not exceeding 2°C above pre-industrial level is added. To calculate the economic losses from using static GWPs both cases are run with the constraint that the ratios of the marginal cost of abatement between the gases shall equal today's GWP-indices, i.e. 23 for CH<sub>4</sub> and 296 for N<sub>2</sub>O (Ramaswamy, 2001), and without this constraint to allow for an optimal trade-off between the three gases.

The efficiency losses from using today's GWPs are calculated differently in the two cases. In the cost-benefit case, where a trade-off between damage and abatement costs occurs, the efficiency loss is defined as the increased cost of damage plus abatement, in per cent. In the cost effectiveness case, where a temperature goal is to be reached at the lowest total cost, the efficiency loss is defined as the increased cost of abatement, in per cent.

In the base case the pure rate of time preference,  $\rho$ , is set to 3 per cent per year, giving a discount rate of about 4.3 per cent per year at 2000, and the climate sensitivity parameter,  $\lambda$ , is set to 0.8 (°C/W/m<sup>2</sup>), resulting in an equilibrium temperature rise of 2.97°C for a CO<sub>2</sub> concentration doubling. Apart from the base case a sensitivity analysis is preformed, running the model with a lower discount

rate, setting the pure rate of time preference to zero, and with a high and low level of climate sensitivity,  $\lambda$  being set to 1.1 and 0.5 ( $^{\circ}\text{C}/\text{W}/\text{m}^2$ ) respectively.

## **Results**

Figure 1 displays the shadow price ratios (SPR), i.e. the ratio between the cost of additional abatement of a ton of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  respectively and a ton of  $\text{CO}_2$ , at each point in time, for the optimal trade-off base case and the three sensitivity analysis cases.

The trend of an increasing SPR for both gases in the cost-benefit case is partly an artifact of the finite time horizon in the model, giving no weight to climate effects of  $\text{CO}_2$  emissions that occur outside this time horizon. This is reflected in the fact that the trend for  $\text{CH}_4$ , with a life time much shorter than that of  $\text{CO}_2$ , is stronger than that of  $\text{N}_2\text{O}$ . But this trend may also reflect the nonlinearity of the damage function together with the stronger radiative properties of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  relative to  $\text{CO}_2$ .

The most distinguished effect in the cost effectiveness case is that the SPR of both gases rises as one approaches the 2100 temperature stabilization target. The effect is most pronounced for  $\text{CH}_4$  because of the short atmospheric life-time of this gas, meaning that early abatement of  $\text{CH}_4$  has little effect on the climate at the time when the temperature has to be stabilized. Thus the effect is less evident for  $\text{N}_2\text{O}$  which has a much longer life-time, still the strong radiative properties of  $\text{N}_2\text{O}$  makes abatement of this gas more valuable as we are approaching the point in time when the temperature target is to be reached, as reflected in the stronger effect in the high climate sensitivity case.

The main results in this paper, regarding the efficiency losses from using today's GWP indices as opposed to making an economically efficient trade-off between greenhouse gases, are presented in table 1. As can be seen the economic losses are relatively minor, in the base case about 0.5 per cent in the cost-benefit case and 1.5 per cent in the cost effectiveness case. The sensitivity analysis also shows that these results are quite robust, economic losses not exceeding 0.5 per cent in the cost-benefit case or 4 per cent in the cost effectiveness case.

These small economic losses might come as a surprise given the quite large deviations in the SPR for  $\text{CH}_4$  and  $\text{N}_2\text{O}$  from their respective GWP index, as shown in figure 1. Also, this implies that the efficiency gain from adopting a multi-gas abatement strategy is quite insensitive to how the trade-off between gases within the regime are being made. This may partly be explained by the highly non-linear marginal abatement costs for  $\text{CH}_4$  and  $\text{N}_2\text{O}$ , meaning that quite small changes in the total abatement of these gases can have a large effect on the marginal cost of additional abatement and thereby on their respective SPR. This is also reflected in the fact that the emission paths for the three gases differ only by a few percent between the optimal trade-off and the static GWP cases.

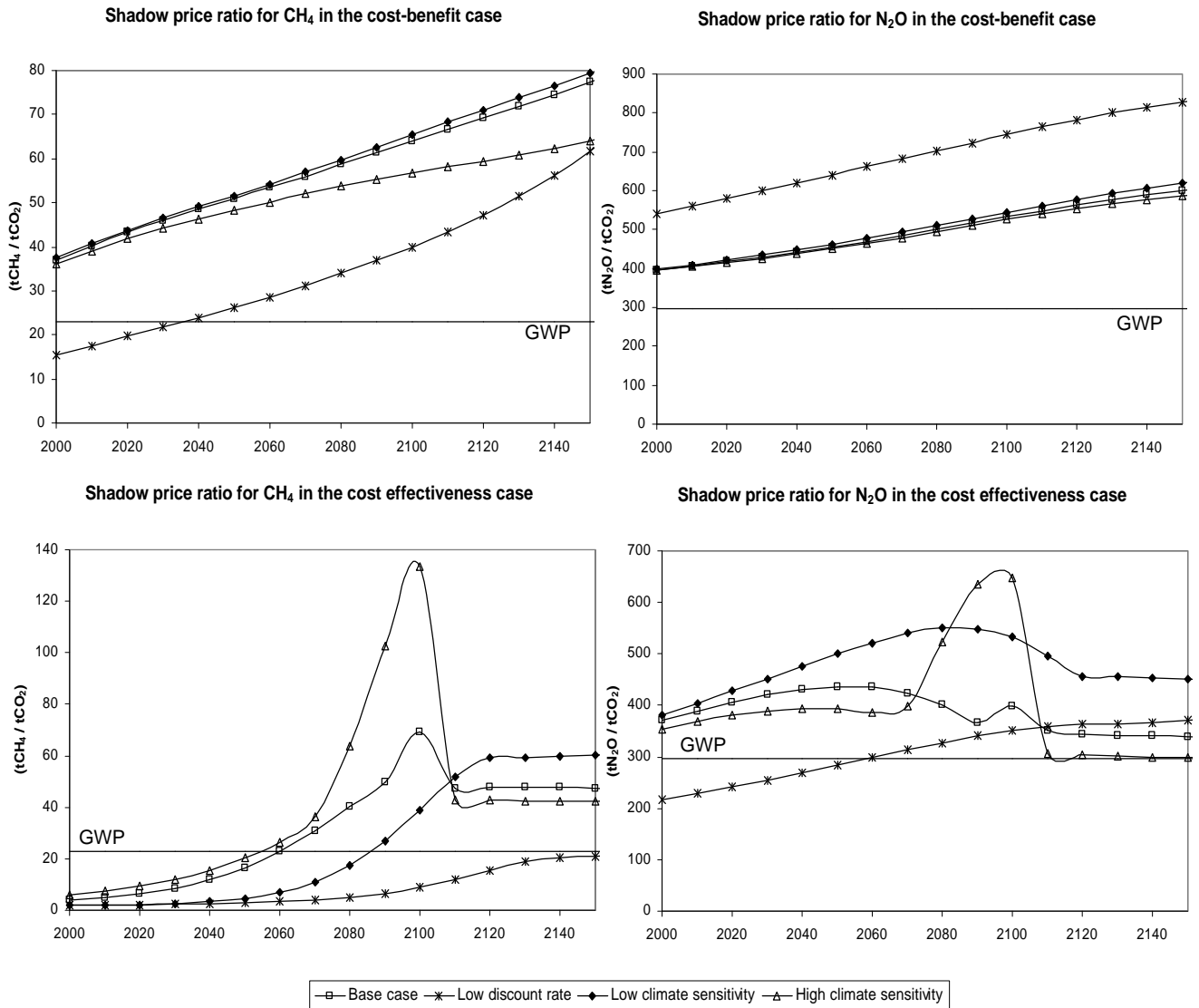


Figure 1: Shadow price ratio between CH<sub>4</sub> (left) and N<sub>2</sub>O (right) in the cost-benefit and cost effectiveness case respectively. Ratios are given for the base case ( $\rho=0.03$  and  $\lambda=0.8$ ), low discount rate case ( $\rho=0$ ) and low and high climate sensitivity cases ( $\lambda=0.5$  and  $\lambda=1.1$  respectively). For comparison the GWP of the gases are also shown as lines.

Table 1: Efficiency losses from using current GWP-indices in (%), see text for explanation.

	Cost Benefit	Cost Effectiveness
Base case	0.499	1.546
Prescriptive discount rate	0.298	0.146
Low climate sensitivity	0.073	3.763
High climate sensitivity	0.353	2.450

## **Discussion**

The evaluation of the current GWP formulation can be pursued from at least two different perspectives, a perspective focusing on the economic shortcomings of the current metric and alternative formulations based on economic indicators, e.g. abatement and damage cost, and a natural science perspective, focusing on the scientific shortcomings of the current metric and calling for alternative measures based on physical indicators and better scientific knowledge. This paper has examined this question from the former point of view and found that the economic losses from using current GWPs seems to be relatively small. Especially, it is important to note that the efficiency losses from using the 'wrong' metric seems to be at least an order of magnitude smaller than the efficiency gains from a adopting a multi-gas approach to climate change as compared to a CO<sub>2</sub>-only approach.

Still, even if the global net losses are small in relative terms the absolute losses are not unsubstantial and the value of the metric is likely to have important national and regional economic consequences, see e.g. Godal & Fuglestad (2002), since the gases are not nationally equally distributed. In general, non CO<sub>2</sub> greenhouse gases often takes a larger share in many developing countries national greenhouse gas budget compared for example to many OECD countries. This might however change over the present century. In any case, these negative aspects of GWP have to be evaluated in relation to the political cost of changing the metric. Choosing an alternative metric, which is not clearly superior to GWP, is likely to lead to political controversies and large transaction cost.

As mentioned above scientific evaluations of the current GWP formulation has revealed shortcomings of the metric. As shown by Reilly et al (1999), the use of GWP's can result in very different climatic effects, even though the reduction targets in CO<sub>2</sub>-equivalents are the same. However, they assume, as we also do, that the GWPs for the different gases will stay constant over the coming century, albeit this is not very likely as the GWPs are being constantly revised based on better scientific understanding and changing background atmosphere, as both lifetime and radiative forcing of many gases depend non-linearly on the concentration.

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