Contribution of CH_4 to Multi-Gas Reduction Targets

The Impact of Atmospheric Chemistry on GWPs

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Abstract: Weighting indices can be used to express emissions of different greenhouse gases (GHGs) in CO_2-equivalent terms. The choice of a specific weighting index is often thought to determine the emphasis on non-CO_2 GHGs in a multi-gas target. Although the choice of a 100-year Global Warming Potential (GWP) for the Kyoto Protocol narrows the range of possible index values, we use the example of CH_4 to show that this choice does not constrain the GWP to a single number. Projected changes in atmospheric CH_4 concentrations due to interactions with CO, NO_x, and OH produce direct GWPs ranging from 12.5-15.5. This increases to 14-24 when the range of uncertainty in indirect effects due to tropospheric ozone (O_3) and stratospheric water vapour is included. We examine the impact of the calculated range in GWPs on the optimal contribution of CH_4 to U.S. emission reductions up to 1.0 GtC_{eq}. Our results show that for a 100-year GWP there is still significant variation in effective CH_4 reductions for a multi-gas target. This has implications for the overall contribution of CH_4 and other non-CO_2 GHGs to both short-term and long-term strategies focussed on the mitigation of climate change impacts.

1. INTRODUCTION

Abatement of non-CO_2 GHG emissions can increase flexibility and lower the costs of meeting emission targets relative to CO_2 abatement alone. For a multi-gas target, other gases are often expressed in terms of CO_2 equivalence

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through weighting indices. These indices are the primary way to avoid lengthy model calculations when determining the mix of GHG reductions required to meet a target such as that set by the Kyoto Protocol. However, it is widely recognised that weighting indices may misrepresent the contribution of non-CO_2 GHGs to reduction strategies, particularly when considering the impact of climate change, atmospheric chemistry, and trace gas emissions on methane (CH_4).

Methane is the second most important anthropogenic greenhouse gas, responsible for almost 20% of the increase in forcing since pre-industrial times (IPCC, 1996). The atmospheric lifetime of CH_4 is highly sensitive to emissions of trace gases such as CO, NO_x and NMHCs. In the future, CH_4 lifetime may also be affected by climate-change-induced increases in atmospheric temperature and water vapour that affect the production rate of OH, the primary sink of atmospheric CH_4 (Wuebbles *et al*. 1999).

CO_2-equivalent weighting indices for CH_4 are highly dependent on time horizon, due to the order-of-magnitude difference between CH_4 and CO_2 lifetimes. This produces a wide selection of weighting indices (Table 1), ranging from 65 for a time horizon of 20 years, down to <1 for an infinite time horizon over which biogenic CH_4 is completely removed and fossil CH_4 oxidised to CO_2. Attempts to consider this full range will obviously produce a large variation in the potential contribution of CH_4 to GHG reduction strategies. For this reason, policies select a specific type of weighting index and appropriate assumptions on which to base that factor, taking into account the type of issues addressed by that policy. For example, the Kyoto Protocol chose a 100-year GWP to calculate the CO_2-equivalence of non-CO_2 GHG emissions (UN, 1997). This subjective choice narrows the range of possible values for weighting indices, and constrains potential CH_4 contributions to emission targets. However, a recent revision in the radiative forcing of CO_2 (WMO, 1999) has raised the 100-year GWP for CH_4 from its value of 21 at the time of the Protocol up to 24. This revision illustrates the fact that GWPs are highly dependent on current scientific uncertainties, as well as on future projections of trace gas emissions and climate change.

Table 1. CH_4 weighting indices (direct effects only).

WEIGHTING INDEX			VALUE	REFERENCE(S)
Global Warming Potential	GWP pulse	20 years	37-53	IPCC 1995, 1996; Bruhl, 1993; Lelieveld *et al*. 1993; 1998
		100 years	12-21	
		500 years	4-7	
	GWP sustained		6-35	Fuglestvedt *et al*. 1996
Economic Damage Index	EDI		3-50	Hammitt *et al*. 1996
Scenario-Based Index	SBI		6-30	Kandlikar 1995
Forcing Equivalence Index	FEI	20 years	39-45	Wigley 1998
		100 years	20-28	

Ignorance of the fact that the choice of one value for a given weighting index and time horizon may reflect neither scientific uncertainties, nor its dependence on future atmospheric conditions, tends to produce a false sense of certainty. In this study we illustrate the extent to which the choice of one weighting index, particularly one as dependent on future conditions and current uncertainties as a GWP, still allows for a significant range in values. We then assess the impact of this range on the effective contribution of CH_4 to a range of GHG emission reductions in 2010.

2. GWPS: RELATING CH_4 TO CO_2-EQ. EMISSIONS

Global warming potentials for CH_4 emissions are determined by the relationships between CH_4 and CO_2 concentrations and radiative forcing. Each of these relationships in turn is affected by a number of scientific uncertainties and time-dependent factors (*Fig.* 1). Relating CH_4 emissions to radiative forcing, then to CO_2-equivalent emissions, depends on factors such as the impact of trace gas emissions and climate change on the lifetime of CH_4; absorption efficiency; the magnitude of indirect radiative effects from tropospheric O_3, CO_2, and stratospheric water vapour formation; spatial and temporal forcing distributions; and our understanding of the carbon cycle.

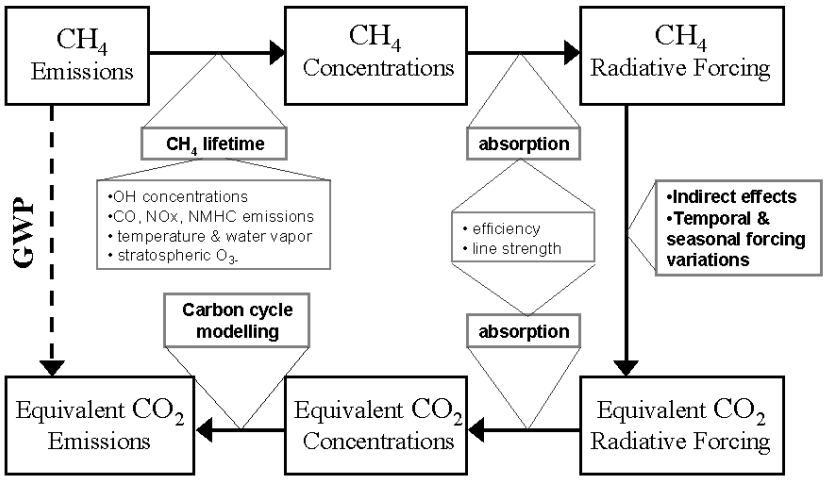

Figure 1. Primary variables affecting the chain of relationships in converting CH_4 emissions to their CO_2 equivalents. In actual GWP calculations, CH_4 radiative forcing is converted directly to CO_2-equivalent concentrations using the forcing relationship given in IPCC (1990).

Changes in each of these relationships arise from two sources: improvements in scientific understanding, and time-dependent changes in atmospheric temperature and composition. Limits to scientific understanding are addressed by incorporating reasonable uncertainty ranges, recognising that certainty may improve over time. This is crucial for model-dependent factors such as the indirect effects of CH_4 on tropospheric O_3 (IPCC, 1995). However, the recent 15% decrease in CO_2 radiative forcing reported by WMO (1999) highlights the need to consider uncertainty in *all* factors.

When relating CH_4 emissions to radiative forcing, the lifetime of CH_4 is the factor most sensitive to time-dependent changes. CH_4 lifetime is mainly determined by atmospheric OH levels. OH is removed by CH_4 and its oxidation product, CO. In the CH_4-OH-CO cycle, increasing methane emissions also increase atmospheric CO, enhancing OH removal, slowing down CH_4 oxidation, and allowing CH_4 concentrations to build up in the atmosphere (Wuebbles *et al*. 1999). Due to this cycle, methane is removed by OH on an 'adjustment' time scale that exceeds the chemical lifetime by approximately three years (e.g., Prather, 1994; IPCC, 1996).

OH production and consumption is also affected by NO_x and NMHCs emissions, stratospheric O_3 concentrations, atmospheric temperature, and water vapour levels. Although current changes in OH production appear to be balanced by consumption at this time (Prinn *et al*. 1995), increasing trace gas emissions are expected to decrease OH levels in the future (e.g., Thompson, 1992; Brasseur *et al*. 1998; Lelieveld *et al*. 1998).

Comparison of the radiative forcing produced by CH_4 emissions with that of CO_2 is additionally uncertain because of indirect forcing effects that result from the production of tropospheric O_3, stratospheric water vapour and CO_2 through the oxidation of CH_4. Estimates of the first two indirect effects range from 10-30% of the total GWP for CH_4 (e.g., IPCC, 1995; Bruhl, 1993; Lelieveld *et al*. 1993, 1998; Fuglestvedt *et al*. 1996).

In the next sections, we explore the dependence of the 100-year GWP for CH_4 on atmospheric chemistry. We then evaluate the impact of the uncertainty induced by future projections of trace gas emissions and indirect effects on the optimal contribution of CH_4 to GHG emission reductions, and the cost reduction obtained by including CH_4 in a CO_2 reduction strategy.

3. IMPACT OF TRACE GAS EMISSIONS ON GWPS

We use the Integrated Science Assessment Model (Jain *et al.* 1994, 1999) to calculate the direct GWP of CH_4, taking into account the CH_4-OH-CO cycle and the impact of changes in trace gas emissions on CH_4 lifetime. Indirect effects are assumed to be 30% of the direct GWP (IPCC, 1995).

GWPs corresponding to six scenarios are shown in Table 2. Trace gas emissions are based on the IS92a 'business-as-usual' emission projections (IPCC, 1999), while CO_2 is held constant at 1990 levels.

NO_x emissions have already been identified as a key factor affecting the relationship between CH_4 emissions and concentrations (Kheshgi *et al*. 1999). Comparison of GWPs for scenarios 2 and 6 extends this conclusion to show that changes in OH production are the most crucial factor in determining the sensitivity of the GWP of CH_4 to atmospheric composition for the scenarios examined. Although NO_x emissions are mainly responsible for the OH changes, OH may also be affected by climate change impacts unresolved by our model. The range in GWPs shown in Table 2 is likely to increase for a greater variety of emission and climate change scenarios.

Table 2. Impact of trace gas emission scenarios on the 100-year GWP for CH_4. Indirect effects are 30% of the direct GWP. Projections are given by the IS92a scenario (IPCC, 1999).

SCENARIO	GWP	
	Direct	Total
1. Constant CH_4 concentrations (1990 levels)	14.6	19.0 (16-23)
2. Changing CH_4 and CO emissions, constant NO_x emissions (1990)	12.5	16.3 (14-19)
3. Changing CH_4 emissions, constant CO and NO_x emissions (1990)	12.9	16.8 (15-20)
4. Changing CH_4 concentrations (regardless of other emissions)	13.5	17.5 (15-21)
5. Changing CH_4 and NO_x emissions, constant CO emissions (1990)	14.3	18.6 (16-22)
6. Changing CH_4, CO and NO_x emissions + additional 10% increase in OH production due to increasing temperatures and water vapour	15.5	20.1 (17-24)

4. IMPACT OF GWPS ON CH_4 ABATEMENT

Future projections of trace gas emissions examined in these 6 scenarios produce a total (direct + indirect) 100-year GWP of CH_4 ranging from 16.3 to 20.1. When the uncertainty in indirect effects is taken into account, this range increases to 14-24, implying that uncertainties in the indirect effect are more likely to increase than decrease the importance of CH_4 relative to CO_2.

We evaluate the impact of these ranges in terms of two measures of the potential for CH_4 to alleviate CO_2 reductions: (1) optimal CH_4 emission reductions (*Fig.* 2), and (2) the cost savings achieved by including CH_4 (*Fig.* 3). CH_4 mitigation cost estimates are those given by the U.S. EPA (1999) for reductions from coal mining, natural gas, landfills, and animal manure for the U.S. in 2010. CO_2 abatement costs for the U.S. are calculated by the SGM, a computable general equilibrium model designed to address issues associated with global change (Edmonds *et al*. 1998). Optimal partitioning between CH_4 and CO_2 reductions is calculated by equating marginal abatement costs (Hayhoe *et al*. 1999).

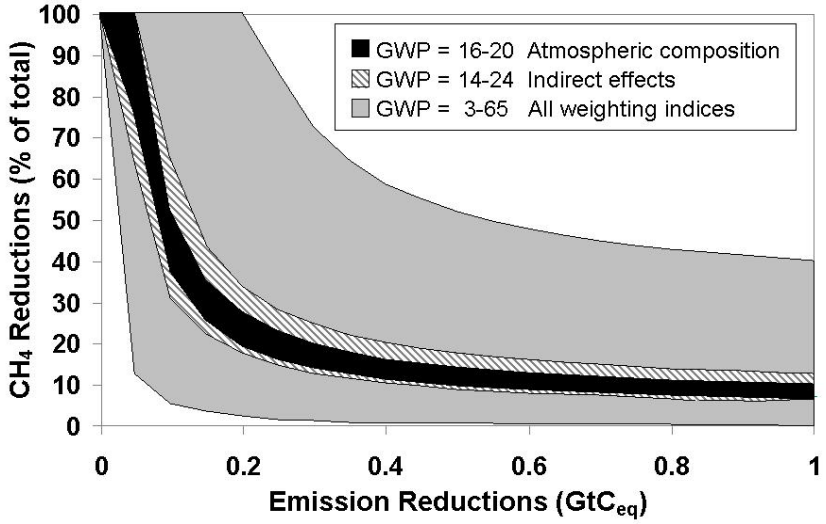

Figure 2. Optimal contribution of CH_4 to CO_2+CH_4 emission reductions, expressed as % of total CO_2 and CH_4 reductions. Costs are for U.S. emission reductions ranging from 0 to 1.0 GtC_{eq} in 2010. Three areas correspond to ranges in: (1) 100-year CH_4 GWP due to changes in atmospheric composition (black), (2) 100-year GWP due to uncertainties in indirect effects (striped), and (3) all weighting indices over time horizons from 20 to 500 years (grey).

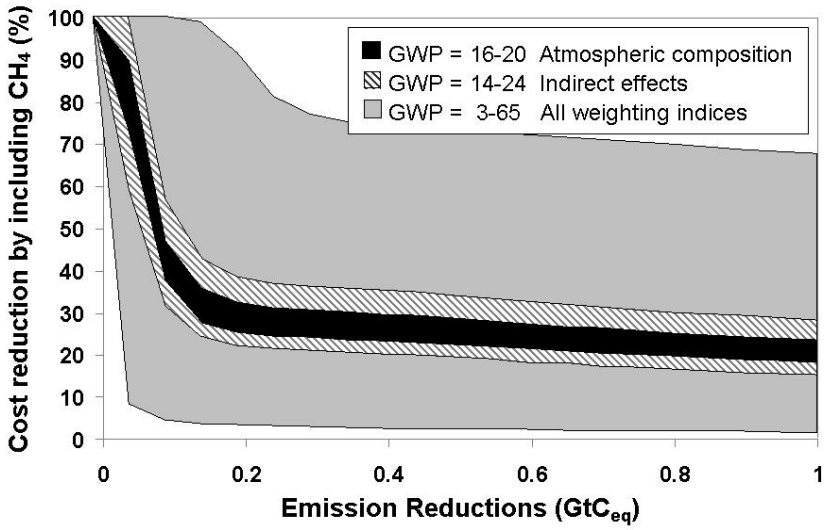

Figure 3. Cost saving achieved by including CH_4 in a CO_2-only reduction strategy, expressed as % relative to CO_2-only costs. Costs and coloured areas are as described in *Fig. 2*.

5. CONCLUSIONS

Weighting indices used to compare CO_2 with other GHG emissions are sensitive to a number of conditions that affect the emphasis on CH_4 and other non-CO_2 GHGs in multi-gas targets. Selection of a GWP with a time horizon of 100 years can eliminate approximately three-quarters of the sensitivity for CH_4. However, these results show that even with a specified time horizon, there is still a significant variation in GWP values.

Many factors affect the long chain of relationships between CH_4 and CO_2-equivalent emissions. We found that two of these factors, future changes in atmospheric composition and uncertainties in indirect radiative effects, can vary the optimal contribution of CH_4 to a joint CO_2/CH_4 target by at least 4-7%. The effect on the cost savings achieved by incorporating CH_4 into a CO_2 reduction scheme is even larger, ranging from 5-13%.

The impact of trace gas emissions on GWPs suggests that the choice of a specific GWP for CH_4 emission reductions is quite sensitive to projections of NO_x, CO, and other gases. Current understanding of tropospheric chemistry limits our ability to model CH_4, OH, and other chemically active gases, and hence our ability to determine weighting indices that capture the full effects of CH_4 on climate (Wuebbles, 1996).

The Kyoto Protocol does not include emission reductions for non-GHG gases that clearly affect the relationship between CH_4 emissions, concentrations and GWPs. As it is likely that emissions of these gases will be affected by controls on sources shared with CO_2 and other GHGs, non-GHG trace gases should be considered in future control strategies.

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