International Journal of Greenhouse Gas Control 12 (2013) 419–429

Contents lists available at SciVerse ScienceDirect

International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Offsetting methane emissions — An alternative to emission equivalence metrics

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ARTICLE INFO

Article history:
Received 13 July 2012
Received in revised form
27 November 2012
Accepted 28 November 2012
Available online 31 December 2012

Keywords:
CO_2-equivalence
Methane
Offsets
Agricultural emissions
Rangeland grazing

ABSTRACT

It is widely recognised that defining trade-offs between greenhouse gas emissions using 'emission equivalence' based on global warming potentials (GWPs) referenced to carbon dioxide produces anomalous results when applied to methane. The short atmospheric lifetime of methane, compared to the timescales of CO_2 uptake, leads to the greenhouse warming depending strongly on the temporal pattern of emission substitution.

We argue that a more appropriate way to consider the relationship between the warming effects of methane and carbon dioxide is to define a 'mixed metric' that compares ongoing methane emissions (or reductions) to one-off emissions (or reductions) of carbon dioxide. Quantifying this approach, we propose that a one-off sequestration of 1 t of carbon would offset an ongoing methane emission in the range 0.90–1.05 kg CH_4 per year. We present an example of how our approach would apply to rangeland cattle production, and consider the broader context of mitigation of climate change, noting the reverse trade-off would raise significant challenges in managing the risk of non-compliance.

Our analysis is consistent with other approaches to addressing the criticisms of GWP-based emission equivalence, but provides a simpler and more robust approach while still achieving close equivalence of climate mitigation outcomes ranging over decadal to multi-century timescales.

1. Introduction

Methane is the second most important of the anthropogenic greenhouse gases, after carbon dioxide. Efforts to mitigate anthropogenic climate change need to be able to assess the relative effectiveness of measures addressing the different greenhouse gases. To this end, various metrics of climate influence have been devised (see Fuglestvedt et al., 2003; Forster et al., 2007, and Appendix A). Most notable are instantaneous 'radiative forcing' which leads to 'concentration equivalence' and global warming potential (GWP) which leads to defining 'emission equivalence'. 'Concentration equivalence' gives an instantaneous metric, based on the actual amounts of the gases in the atmosphere. In contrast, 'emission equivalence' gives an integrated metric, taking into account the different amounts of time that gases remain in the atmosphere after emission (Solomon et al., 2007, Glossary). The need for a relation between emissions comes from the policy framework of mitigation. In markets where alternative goods can be substituted, the relative prices reflect a balance between relative supply costs and relative demand. However markets for greenhouse gas mitigation are created by regulation and agreement, and so, as noted in Appendix A, there is a need to specify the relative 'demand' so that the mix of mitigation activities to 'supply' this demand can be chosen on the basis of the lowest cost.

The main complicating feature in considering trade-offs between methane and most other greenhouse gases is the short atmospheric lifetime, compared to the timescales that dominate the response of carbon dioxide. As we discuss below, this disparity in timescales can necessitate intertemporal trade-offs.

Analysis of methane entails addressing a number of complicating factors: a poorly known budget, the concept of an effective lifetime, and the poorly-understood plateau in methane concentrations over the period 1999–2006. The atmospheric budget of methane is subject to considerable uncertainties (Dlugokencky et al., 2011) with a recent re-evaluation by Prather et al. (2012). The atmospheric content, M_{CH_4}, is well-known from direct measurement. The loss rate is less well-determined. There is a small loss from oxidation by soils, but the main loss is through oxidation in

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http://dx.doi.org/10.1016/j.ijggc.2012.11.028

the free atmosphere by processes involving the OH radical. This rate is determined indirectly from loss rates of other species (where the sources are better known). Laboratory measurements of reaction rates are used to relate the atmospheric loss rates of different gases. Observations of methyl chloroform (CH_3CCl_3) have played the main role in such determinations of the methane loss rate. Once the loss rate is determined, the source is determined from the relation

$$\text{Growth rate} = \text{sources} - \text{loss rate} \tag{1.1}$$

This means that the total of sources is relatively tightly constrained (Dlugokencky et al. (2011) indicate ±15%) while contributions from particular classes of source are much more poorly known, with some components uncertain by a factor of 2 (Dlugokencky et al., 2011). However methane emissions from enteric fermentation in ruminants are known to make an important contribution to both the natural methane budget and to the human perturbation that has led to a 150% increase in atmospheric methane concentrations since pre-industrial times. The role of methane from livestock has recently been reviewed by Lassey (2008). A minor issue is that for ruminant methane emissions, the carbon originally comes from atmospheric CO_2 through photosynthesis and so there is no extra radiative forcing when the CH_4 is oxidised to CO_2. If methane is offset by terrestrial carbon sequestration rather than reductions of emissions of fossil carbon, then the issue of consequent changes in aerosol forcing (Wigley, 1991; Hansen et al., 2000) is largely absent.

Where the loss processes for a gas are unaffected by the gas itself, loss from a pulse follows an exponential decay whose timescale is the atmospheric turnover time. For CO_2 this is not the case, and the pulse response needs to be expressed in a more complicated manner — commonly as a sum of exponentials. As discussed by Prather (1994, 1996), methane is an intermediate case, where a single exponential gives a good representation of the pulse response, but the timescale, termed the 'effective lifetime', is longer than the bulk turnover time. This indirect effect of methane through changes in atmospheric hydroxyl (OH) is characterised by Eqs. (2.5)–(2.7).

The limitations of the concept of CO_2-equivalent emissions defined by the 100-year GWP, as applied in the Kyoto Protocol, have been widely noted. The problems are particularly serious when considering stabilisation of atmospheric concentrations of greenhouse gases. For example Reilly et al. (1999) give an example (cases 2′ and 3′ in their Fig. 3a) where Kyoto-equivalent emission pathways give a 1990–2100 warming of 0.5 °C for multi-gas reductions, but 1.2 °C for 'equivalent' CO_2-only reductions. Manning and Reisinger (2011) give a more recent example of a study that explores the limitations of emission-equivalence based on GWPs in the context of stabilisation.

A number of studies have explicitly considered the role of CH_4 in climate mitigation. The general conclusion (Brook and Russell, 2007, for example) is that CH_4 reductions can play a useful role in the context of large reductions (or at least stabilisation) of CO_2 emissions. A more detailed study (Kheshgi et al., 1999) notes that projections to 2100 give a 3 W m^{-2} radiative forcing from CO_2 even with stabilisation at 450 ppm (the WRE450 scenario from Wigley et al., 1996), while methane only contributes 1 W m^{-2} even under the modified business as usual (IS92a) scenario. These authors also note the possibility of reducing methane concentrations by reducing emissions of other gases (CO, NO_x) that reduce atmospheric OH levels. The 'alternative scenario' proposed by Hansen et al. (2000) attracted great attention by proposing that reductions in methane emissions were preferable to reductions in CO_2 emissions. In part this was because, as noted by Wigley (1991), many CO_2 emission activities also produce aerosols that cause cooling. It is however, important to note that while the 'alternative scenario' proposed delaying CO_2 emission reductions for several decades, it did assume no increase in CO_2 emissions above the level in the year 2000.

As a way of reducing the need for the inter-temporal trade-offs that are necessitated by the use of GWPs, we propose a 'mixed metric' in which methane offsets are based on comparing on-going methane emissions to one-off removals of CO_2. This is because the concentration of methane (a short-lived gas) is determined by current and recent emissions, whereas the concentration of CO_2 is determined by prior emissions over a much longer time frame. In particular we propose a level of one-off carbon sequestration that will offset ongoing methane emissions when considered over several centuries, and more than compensate for ongoing methane emissions over the decadal scale if the pool accumulates rapidly. If the sequestered carbon pool is built up gradually, then a closer equivalence is achieved over the decadal and multi-decadal timescales. This modified form, with progressively increasing sequestration, can be regarded as an integrated form of an approximate solution of the inverse problem (Wigley, 1998) whose solution gives the time-varying release of methane that has, at all times, equivalent radiative forcing to a pulse release of carbon dioxide. This was expressed in terms of a 'forcing equivalent index' (FEI). Manning and Reisinger (2011), discussed in more detail below, have shown an example of a particular case of such CO_2:CH_4 equivalence in the specific calculation of stabilisation of radiative forcing.

As we discuss below, one of the conceptual bases of our approach comes from considering greenhouse gas stabilisation. Stabilising the atmospheric concentration of methane requires capping the ongoing emissions, while a number of recent studies (Matthews and Caldeira, 2008; Matthews et al., 2009; Allen et al., 2009) describe CO_2 stabilisation in terms of a 'carbon budget' — a cap on integrated CO_2 emissions. In these terms our approach to methane offsets represents a trade-off between the two different types of 'cap'. Recently, Smith et al. (2012) have discussed such a 'mixed metric' for stabilisation covering, at the expense of a degree of approximation, a wide range of gases. This work is discussed in more detail below.

The layout of the remainder of this paper is as follows. Section 2, which is primarily a review of earlier studies, describes the GWP as a metric for emission equivalence, noting the impossibility of having a single metric that captures all aspects of human influence on climate. Section 3 presents our proposal for an alternative to emission equivalence metrics: that methane offsets should be based on comparing on-going methane emissions (or reductions) to one-off emissions (or reductions) of CO_2. We suggest that this avoids a number of the problems that have been identified with GWPs and that it can be regarded as a refinement and clarification of earlier ideas. Section 4 discusses our proposal from the perspective of offsetting methane emissions from rangeland cattle production. Our concluding section looks at the broader implications of our analysis within national and global efforts to mitigate anthropogenic global warming. Appendix A summarises a range of different metrics that have been proposed for comparing greenhouse gases.

2. Metrics for emissions

The various factors that induce climate change are often quantified in terms of radiative forcing. While a range of definitions exist (Hansen et al., 1997), the common aspect is the perturbation in the earth's energy balance (generally expressed in W m^{-2}), most commonly defined at the tropopause. In general circulation models (GCMs), radiative forcing is a diagnostic quantity — a 'summary statistic' that characterises the result of processes that the model calculates in more detail. Simple climate models commonly use radiative forcing as a way of making such models emulate the behaviour of GCMs. We denote the incremental forcing per unit