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Methodological and Ideological Options

Requirements to metrics of greenhouse gas emissions, given a cap on temperature

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ABSTRACT

The literature on metrics to measure contributions to climate change from emissions of different greenhouse gases divides into studies that highlight physical aspects and studies that show the importance of economic factors. This paper distinguishes the physical aspects and implications of economic factors by asking what is demanded from physically based metrics if used for a specific policy objective. We study the aim of maximizing the welfare of emissions generated by consumption when there is a limit to the increase in global mean temperature. In that case, metrics ought to change over time, with increasing weight on short-living gases before the temperature limit is met. Metrics for short-living gases increase also with increasing uncertainty. Adjustments to new information spur higher metrics for short-living gases if it reduces the expected allowable emissions before the target is met, and lower metrics in the opposite case. Under a binding target, metrics refer to the instantaneous impact on radiative forcing multiplied by the lifetime of the respective gases, and adjusted by the attitude to risk.

1. Introduction

Climate policy is based on uncertain knowledge about a very complex earth system. Despite the uncertainty, strong measures are needed today to avoid the risk of severe consequences in the future, even though the outcome of the policy may not be observable for decades. This puts strong requirements to the dissemination of knowledge. It has to be simplified and presented in a way that helps policy makers intuitively select measures that support their intentions.

Simplification implies that the same knowledge can be presented in different ways, meaning that the choice of policy will depend on how the knowledge is simplified. This can be illustrated by the way the climate impact of emissions of different greenhouse gases is calculated. Currently, the UN Framework Convention of Climate Change (UNFCCC) uses Global Warming Potentials (GWPs) for this purpose. GWP transforms emissions of the various gases to a common scale, called CO_2-equivalents. This is a metric for the cumulative radiative forcing in W/m^2 of one unit mass of emissions over the coming 100 years, assuming constant background level, relative to a corresponding forcing of the same unit mass of emission of CO_2 (Houghton et al., 1995).

Hence, the GWP of CO_2 is 1 by definition. Myhre et al. (2013) report GWPs for the other gases. For methane (CH_4) it is 34 when the indirect effects are included. The corresponding GWP of the third main gas, nitrous oxide (N_2O) is 298. Using these metrics, emissions of CO_2 contribute >65% of the total radiative forcing from global emissions of greenhouse gases. CH_4 emissions contribute nearly 25% and N_2O >8%. Approximately 1% stems from other greenhouse gases.

The metrics decide the priority of measures to mitigate climate change, for example, how much emphasis should be placed on reducing emissions of CH_4 relative to cuts in CO_2 emissions. It is, however, unclear how well they motivate adequate composites of cuts given the objective of climate policy. Policy is motivated by concerns about the increase in temperature, other climatic changes or their impacts. Radiative forcing over the next 100 years is an imperfect indicator of these changes. This is evident from the speed at which the concentration from one unit mass of the different gases declines. For CO_2, a part of the emission is absorbed after a few years, while other parts remain in the atmosphere for thousands of years (Archer et al., 2009). The climate impact of a unit emission of CH_4 is reduced by nearly 2/3 (to $1/e$) after 12.4 years. For N_2O, the corresponding lifetime is 121 years, while CF_4, for example, has a lifetime of 50,000 years. Therefore, GWP will change significantly depending on the choice of period over which radiative forcing is calculated, and there are no apparent reasons for the chosen 100 years (Fuglestvedt et al., 2003; Shine, 2009).

The choice of period is one of many problems in providing a metric for emissions of different greenhouse gases. Climate science therefore suggests a range of alternatives that emphasize different

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characteristics of the earth system, which are important for the choice of metric (Myhre et al., 2013). There are also suggestions to metrics that reflect differences in abatement costs, damage of climate change and the timing of costs and related benefits to reflect economic factors (Kolstad et al., 2014). They all contribute to a menu of alternatives that policy makers can choose from, depending on their policy objective.

This choice is by no means simple, and it tends to become more complicated as the number of suggested metrics increases. However, if the objective of climate policy is clearly stated, the chosen metric needs to meet certain criteria. While several previous studies show how metrics depend on the policy objective, it is still unclear which criteria to put on a metric used for a given policy objective. This paper aims to develop and clarify these criteria. We consider the objective of maximizing global welfare under a pathway towards a stabilized global mean temperature, similar to the + 1.5 °C to + 2.0 °C target in the Paris agreement from 2015. The criteria are based on a strictly simplified relationship between emissions and radiative forcing, and with uncertainty about the temperature response to a given change in radiative forcing, or climate sensitivity. The next section gives a brief overview of the discussions on metrics in order to put the contributions of this paper in context. The model is presented in Section 3, and optimality criteria are developed in Section 4. Section 5 concludes.

2. The Supply of Metrics for Emissions of Different Greenhouse Gases

The complexities related to the assessment of impacts on the climate from a given pathway for emissions until 2100 are illustrated by the fact that climate and earth system models need three to six months to project the resulting climatic changes. GWP delineates the effect to a so-called pulse, which assumes an increase of emissions by one unit in a single year from a given emission level under a stable climate. Next year, emissions are back to its initial level, and stay there forever. Under a changing climate, the relative forcing of gases would change. Reisinger et al. (2011) study GWP under four representative concentration pathways (van Vuuren et al., 2011), and show that they increase for both CH_4 and N_2O towards 2100 in all of them. This is mainly due to a decline in the absolute radiative forcing for CO_2 under increasing emissions, and alternative metrics have been suggested. Wigley (1998) proposed metrics that refer to an expected pathway for radiative forcing. Lauder et al. (2013) define metrics by the quantity of an emitted gas needed to replace radiative forcing of a ton of CO_2 withdrawn forever along a constant emission level. Both limit the updates needed to concur with adjustment of pathways, but the dependency on the choice of time horizon remains problematic.

An argument for using radiative forcing as the point of reference is that emissions of different greenhouse gases are thereby transformed to the main single driver of climate change. If relating metrics to a more policy relevant measure, such as the increase in temperature, the uncertainties will increase substantially. On the other hand, some of the difficulties in framing the choice of a metric, illustrated by the choice of time horizon for GWP, may become less if the metrics refer more directly to a policy objective. Shine et al. (2005) and Shine et al. (2007) therefore use the temperature change at the end of a chosen time horizon, called Global Temperature change Potential (GTP), as the reference for metrics. These are also based on a pulse emission of a greenhouse gas, and divided by the temperature change from a corresponding pulse of CO_2. The reference to temperature on a fixed, future point in time makes GTP more relevant for planning purposes than GWP. On the other hand, it is based on runs by climate models, and therefore more uncertain than GWP (Reisinger et al., 2010). The reference to a pulse also means that there are similar problems related to the background level for radiative forcing.

Alternatives to GTP have therefore been suggested. Peters et al. (2011) show that uncertainties that can be traced to the choice of climate model can be reduced by considering a mean temperature change (Gillett and Matthews, 2010) or an integrated temperature change (Peters et al., 2011) over a given period instead of a pulse. Tanaka et al. (2009) addresses the problem of changing background levels by proposing a metric that expresses the emissions of one gas needed to replace another gas in order to remain on the same temperature path, the temperature proxy index. Still, adjustments are needed to update temperature paths.

It has been emphasized that the choice of metric depends on which aspects of climate change are considered most important and what the objectives of climate policy are (Plattner et al., 2009; Tol et al., 2012). Myhre et al. (2013) state that considerations related to this choice are beyond the scope of the physical sciences. The socioeconomic aspects of alternative metrics are addressed in several studies with engineering or economic points of departure, however. Kandlikar (1996) suggests that metrics should refer to the damages of climate change instead of the impacts on the climate system. Manne and Richels (2001) show that abatement costs are at least as important for the composite of abatement over different greenhouse gases as the physical properties. They thereby indicate that abatement costs should be taken into account in the metrics. Johansson (2012) suggests a discounted global temperature potential to include the concerns to when the climate is impacted by emissions of the different gases.

Further studies provide numerical estimates on how economic factors make a difference to the priority of which greenhouse gas to abate. Tol (2006) shows that the willingness to pay for cutting CH_4 is low if aiming at a temperature target which is far ahead, because early cuts have a limited effect on the target. Aaheim et al. (2006) find, however, that the costs of using fixed instead of time variant metrics are likely to be moderate, except perhaps to some countries. Johansson et al. (2008) and Ekholm (2013) analyze how uncertainty and learning affect the composite of greenhouse gases in a strategy for abatement towards a temperature target. They show that increasing uncertainty gives more abatement with heavier emphasis on short-living gases if policy aims at achieving a future temperature target. These studies show, in general, how the choice of metric depends on the policy objective. The inadequacy of GWP is shown by Marten and Newbold (2012), who test six criteria that need to be met to support a unique definition of the social unit cost of abatement. They find reasons to question all six.

As the attention to the various aspects of the contributions to global warming from different greenhouse gases increases, it becomes increasingly difficult to make a choice of metric. The physical sciences point at uncertainties that arise when climatic responses to emissions are simplified in order provide a metric that links the causes, i.e. emissions of different greenhouse gases, to the concerns about temperature change. The menu of metrics from the physical sciences shows the need to specify these concerns further before a choice is made.

Economic and engineering studies have identified additional factors that ought to be taken into account in the choice of metric, such as abatement technologies and costs, benefits of mitigation and discounting, and some suggest how these factors can be included in the metric. Although this may be helpful, it also makes the distinction between value judgements and physical properties unclear, as metrics are supposed to reflect the physical properties that matter for the choice of policy. These suggestions are also presented a menu from which policy makers can pick a choice. They thereby add to the difficulties of making this choice.

In this paper, we take instead the policy as our point of departure to establish criteria for metrics applicable to a given policy objective. We thereby provide a reference to test the adequacy of suggested metrics and check if there are properties that are not covered by any of them. We will assume that the aim of the policy is to get as much as possible out of emissions of two greenhouse gases when there is a cap on future temperature and uncertainty about climate sensitivity. We ask what properties are required for such a metric, and if or which value judgements are needed to make this choice.