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LETTER

Does black carbon abatement hamper CO_2 abatement? A letter

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Abstract Concerns have been raised that near-term black carbon abatement strategies for global warming mitigation would interfere with the longer-term CO_2 abatement efforts. In response, we put forward a "combined target and metric approach", a theoretical framework, in which the time horizon of the metric is linked to the specific target of the climate policy. In this approach, a shorter time horizon for the metric is justified only when the overall climate policy is tightened; the lower the target level of the climate policy, the earlier the year of the target. Employing a consistent time perspective for the metric and target means that enhanced near-term reduction of short-lived climate forcers does not reduce the importance of the CO_2 abatement, since the overall climate target is stricter.

1 Introduction

The Copenhagen Accord in December 2009 recognizes the importance of keeping the global warming below 2°C since pre-industrial times. The United Nation Framework Convention on Climate Change (UNFCCC) (Article 3.3, 1994) states that the climate strategy should include all relevant species. Given the enhanced interest from policymakers in the abatement of short-lived climate forcers (SLCFs), in particular black carbon aerosols (BC), an urgent challenge is to determine the relative weights for emissions of different species operating on a wide range of timescales (e.g. Penner et al. 2010).

On one hand, drastic emission cuts of SLCFs such as BC and/or CH_4 provide a near-immediate benefit to slow the global warming and also avoids adverse health

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impacts (Grieshop et al. 2009). Increased efforts to mitigate BC are supported by a recent study (Ramanathan and Carmichael 2008) that suggests that the BC radiative forcing could be significantly higher than given by the IPCC (Forster et al. 2007). On the other hand, the main cause of the anthropogenic global climate change is the emission of CO_2, a long-lived forcing agent (Archer et al. 2009; CLRTAP 2009). There has been some concern (e.g. Quinn et al. 2008) that an increased emphasis on the abatement of SLCFs will lead to insufficient abatement of CO_2 in the long-term due to (the implied) overall financial budget constraints.

This paper puts forward a unifying framework that we believe is useful to keep abreast of such multi-faceted challenges. The overarching framework seeks to help to strike a balance between the emission cuts of short-lived and long-lived forcing agents from the perspective of the overall temperature target. We discuss what significant near-term abatement of SLCFs means under such a framework: does it lead to less CO_2 abatement that could cause problems down the road?

2 Concept

A multi-component climate policy places an overall *target* in terms of temperature change or CO_2-equivalent concentration; the reductions of individual agents to meet such a target are guided by the emission *metrics*, which aim to compare emissions of long-term and short-term agents on a common scale (Fuglestvedt et al. 2003; Forster et al. 2007; IPCC 2009). However, a shortcoming of current climate policies lies in the fact that the two policy tools—*target* and *metric*—have not yet been simultaneously considered (note that this paper does not discuss the inter-temporal optimization approach which minimizes the cost of emission abatement for all agents simultaneously without using metrics (e.g. Johansson et al. 2008; Kopp and Mauzerall 2010).

We analyse the role of SLCF versus CO_2 by applying a *combined target and metric approach*. The basic concept is the following: the *target* and *metric* share a common time perspective. In other words, the time horizon of a metric (TH) is set at the period until an anticipated target year ($\tilde{x}$) (Manne and Richels 2001; Aaheim et al. 2006; Shine et al. 2007; Tanaka et al. 2009)—i.e. $TH = \tilde{x} - t$, where t denotes the present year.

The combined target and metric approach is radically different from the criticized approach adopted in the Kyoto Protocol in the following two regards (Fuglestvedt et al. 2003; O'Neill 2003; Shine 2009). First, the metric's time horizon that we apply is *the proximity to the target year* (Manne and Richels 2001; Aaheim et al. 2006; Shine et al. 2007; Tanaka et al. 2009) and is thus relevant to the time scale of the climate policy considered (TH depends on $\tilde{x}$). On the contrary, a 100-year time horizon in the Protocol is just one of the three representative time horizons (20, 100, and 500 years) used by the IPCC (1990). Second, in our approach, the metric time horizon will be adjusted as we march into the future (TH depends on t)—such a time-dependent approach to metrics (Wigley 1998; Manne and Richels 2001; Shine et al. 2007; Tanaka et al. 2009) is in contrast to the fixed approach in the Kyoto Protocol. Our argument that follows mainly deals with the first point. Discussion on how the second point can be implemented in a climate agreement is beyond the scope of our analysis. Note that the choice of the metric depends on the target in the climate

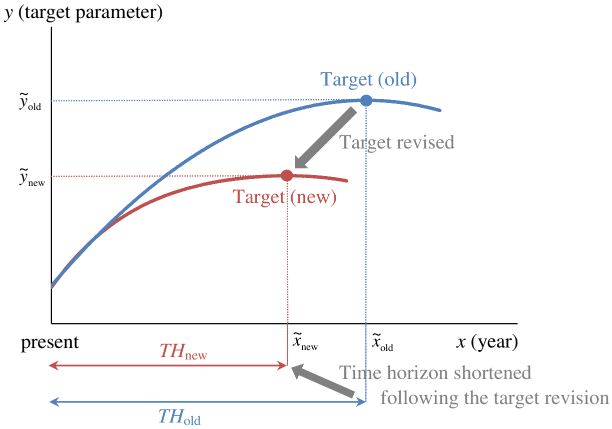

Fig. 1 Schematics illustration of the combined target and metric approach (Manne and Richels 2001; Aaheim et al. 2006; Shine et al. 2007; Tanaka et al. 2009) and its dynamic component. $\tilde{x}$, $\tilde{y}$, and TH denote target year, target level (e.g. global-mean temperature change), and metric time horizon, respectively. When the target level is lowered ($\tilde{y}_{old} \rightarrow \tilde{y}_{new}$), the target can be achieved earlier ($\tilde{x}_{old} \rightarrow \tilde{x}_{new}$). This results in a shorter time horizon for the emission metric ($TH_{old} \rightarrow TH_{new}$)

policy—for a more general target such as the integrated radiative forcing used in the Kyoto Protocol the Global Warming Potential (GWP) is an appropriate metric, while for a climate target based on a specific temperature constraint (e.g. the Copenhagen Accord) the Global Temperature change Potential (GTP) (Shine et al. 2007) is more suitable.

A dynamic component to the combined target and metric approach has not been emphasized before: if a more ambitious temperature target is set, the metric time horizon becomes accordingly shorter because the target must be achieved earlier (Fig. 1). This argument is based on the premise that, *when the target temperature level is lowered, the target year becomes earlier*. In mitigation scenarios, it is generally valid that global emissions levels must peak earlier for a more stringent temperature target (Fisher et al. 2007; Moss et al. 2010) although a unique relationship between the target level and the target year has not been derived in the existing literature. It could be also intuitively understood that a lower target must be achieved earlier as the temperature must deviate from the baseline path earlier. When the target is substantially lowered to a level that can be achieved only after an initial overshoot (Meinshausen et al. 2006; den Elzen and van Vuuren 2007), this relationship appears to hold for the time period before the target level is initially exceeded.

We argue that such a dynamic nature of target and metric provides a fresh look into the hotly debated BC strategies. Advocates of strong reductions in SLCFs open for the possibility of using GWPs with a 20-year time horizon (instead of the current 100-year time horizon) (Bond and Sun 2005; Grieshop et al. 2009; Moore and MacCracken 2009), which leads to larger metric values for SLCFs (Forster et al. 2007; Tanaka et al. 2009; Fuglestvedt et al. 2010). When one looks only at metrics, an obvious side effect of a shorter time horizon is that less emphasis is put on CO_2 abatement (Quinn et al. 2008). In other words, a short time horizon may appear to conflict with a strategy to tackle the long-term climate change, assuming a certain financial allowance. Choosing a metric time horizon that is accordance with the overall mitigation goal (Manne and Richels 2001; Aaheim et al. 2006; Shine et al. 2007) is a useful means of avoiding this conflict. The metric time horizon can be shortened only when the overall temperature target level is lowered, which in turn demands a stronger cap on the total CO_2-equivalent emissions. Note that the target determines the metric and not the other way around; one should first define the target, and then choose an appropriate metric and a consistent time horizon.

3 Numerical experiment

The combined target and metric approach is illustrated in the numerical experiment below (Fig. 2). In these experiments we apply temperature caps following the Copenhagen Accord. Specifically, we create a set of three simple mitigation scenarios (Scenario H, L, and L') to demonstrate that:

(i) a more stringent target level means that the peak or stabilization of the target parameter occurs in an earlier year, and that
(ii) when the metrics are derived from the overall target as we propose, stronger abatement of SLCFs will go hand in hand with stronger abatement of CO_2.

The first scenario (Scenario H) is a reference scenario to cap the warming at 2.0°C above pre-industrial levels. Scenario H adopts the historical emissions up until 2010. Beyond 2010, the emission of an individual gas or aerosols is expressed as a baseline trend (linear extrapolation from the historical trend) multiplied by a mitigation factor: a S-shaped function (Gompertz curve, see d'Onofrio 2005) to mathematically model an initial technological inertia and eventual leveling off of the emission reductions. The separation of baseline and mitigation is under debate (Pielke et al. 2008) and our approach serves merely as an illustration. We use a simple analytical two-box climate model (Schneider and Thompson 1981; Berntsen and Fuglestvedt 2008) to calculate the projection of global mean temperature change. The mitigation rate in the S-shaped function, which is common to all the forcing

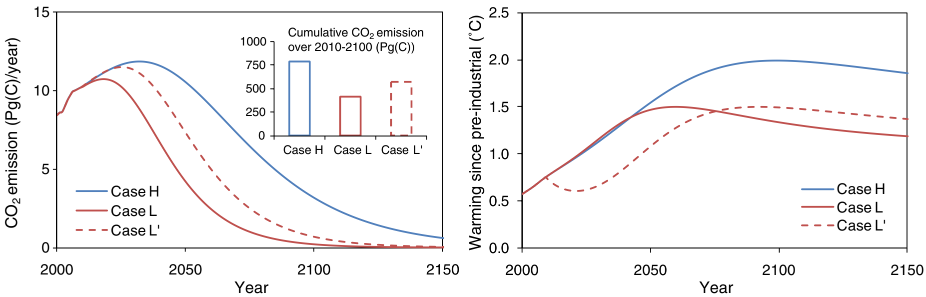

Fig. 2 Annual CO_2 emissions (*left*) and temperature change (*right*) relative to pre-industrial times (including all components) for the three scenarios H, L, and L′. The *insert* of the left panel shows the cumulative CO_2 emissions under the three scenarios. The model includes the long-lived greenhouse gases CO_2 and N_2O, CH_4, and aerosols BC, OC, and sulphate. We use a radiative efficiency for BC corresponding to a current radiative forcing for BC of 0.45 Wm^{-2} (Forster et al. 2007). The model assumes a climate sensitivity of 2.7°C and reproduces the observed warming of 0.75°C since 1860. See text for further discussion

agents, is optimized such that the warming is kept just below the 2.0°C cap. The calculated temperature peaks in 2099 and the cumulative CO_2 emissions between 2010 and 2100 are 790 Pg(C).

The second scenario (Scenario L) has the same setup, except that the warming is capped at a lower level of 1.5°C. Now the temperature peaks in 2060 and the cumulative CO_2 emissions between 2010 and 2100 are 420 Pg(C). This is in line with the point (i).

The third scenario (Scenario L') is a sensitivity case to demonstrate the point (ii) above. The overall target is 1.5°C as in Scenario L. To illustrate clearly the influence of the shorter time horizon in Scenario L and thus high metric values for the SLFCs, we make an extreme assumption in Scenario L' that all anthropogenic BC and methane emissions (not sulphate emission) are removed immediately in year 2010 due to their higher metric values. The emission shutdown causes an initial cooling, temperature then peaks in 2092 and the cumulative CO_2 emissions between 2010 and 2100 are 570 Pg(C). Although the cumulative CO_2 emissions increase compared with Scenario L, they are still far lower than for Scenario H (insert in left panel of Fig. 2). This finding confirms the point (ii)—even if the use of higher metric values of SLCFs lead to a complete removal of BC and CH_4 emissions, there would still be an increase in the total abatement of CO_2 required due to the dominant role of CO_2 as the cause of warming. Note that we do not claim that the shorter time horizon imposed by the 1.5°C constraint would drive the metric values of BC and CH_4 to warrant a shutdown of their emissions; Scenario L' serves merely as a conceivable upper limit to show how sensitive CO_2 mitigation may be to large BC and CH_4 metric values.

The conclusions drawn from the calculations discussed above could be influenced by the assumptions about the strength of the BC radiative forcing. To test the robustness a sensitivity analysis was carried out by using the higher estimate of the direct radiative forcing by Ramanathan and Carmichael (2008). Although this reduces the difference between Scenarios H and L', the cumulative CO_2 emissions in Scenario L' are still lower than in scenario H, confirming the robustness of the point (ii) above.

4 Concluding remarks

Our unifying perspective of target and metric sheds light on the current debate on BC emissions reduction strategies. When SLCF abatement is considered as a part of an overall multi-component climate strategy with one long term target, the increased relative weight of SLCFs can be drawn only from a stricter and thus earlier target. Thus, enhanced near-term reduction of SLCFs based on this approach does not reduce the importance of the CO_2 abatement, since the overall climate target is stricter (the blue line in Fig. 2 is above the red lines). The current ad-hoc proposal of shortening the time horizon alone (Bond and Sun 2005; Grieshop et al. 2009; Moore and MacCracken 2009) is not a good way forward; the BC abatement needs to be addressed in concert with the overall goal.

Our discussion assumes a climate policy with one long-term target. It has been suggested that an additional short-term (Fuglestvedt et al. 2000; Rypdal et al. 2005; Jackson 2009) or mid-term target (O'Neill et al. 2010) can be introduced to the climate policy as an interim goal leading toward the long-term target. The motivation to set up such an interim target may also be as a means to avoid crossing the tipping elements (Lenton et al. 2008) or to curb environmental side-effects (e.g. adverse human impacts of BC emissions). When such an additional target is introduced, a possibility to develop strategies and policies that could in a consistent manner employ different timescales for metric calculations opens up. However, a detailed analysis of how metrics, commitments and timetables should be designed to be effective and consistent under a two-target strategy is beyond the scope of this study.

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